WASHINGTON STATE DEPARTMENT OF
Natural Resources
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Division of Geology and Earth Resources
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Geologic Map of the Elwha and Angeles Point 7.5-minute Quadrangles, Clallam County, Washington

by Michael Polenz, Karl W. Wegmann, and Henry W. Schasse

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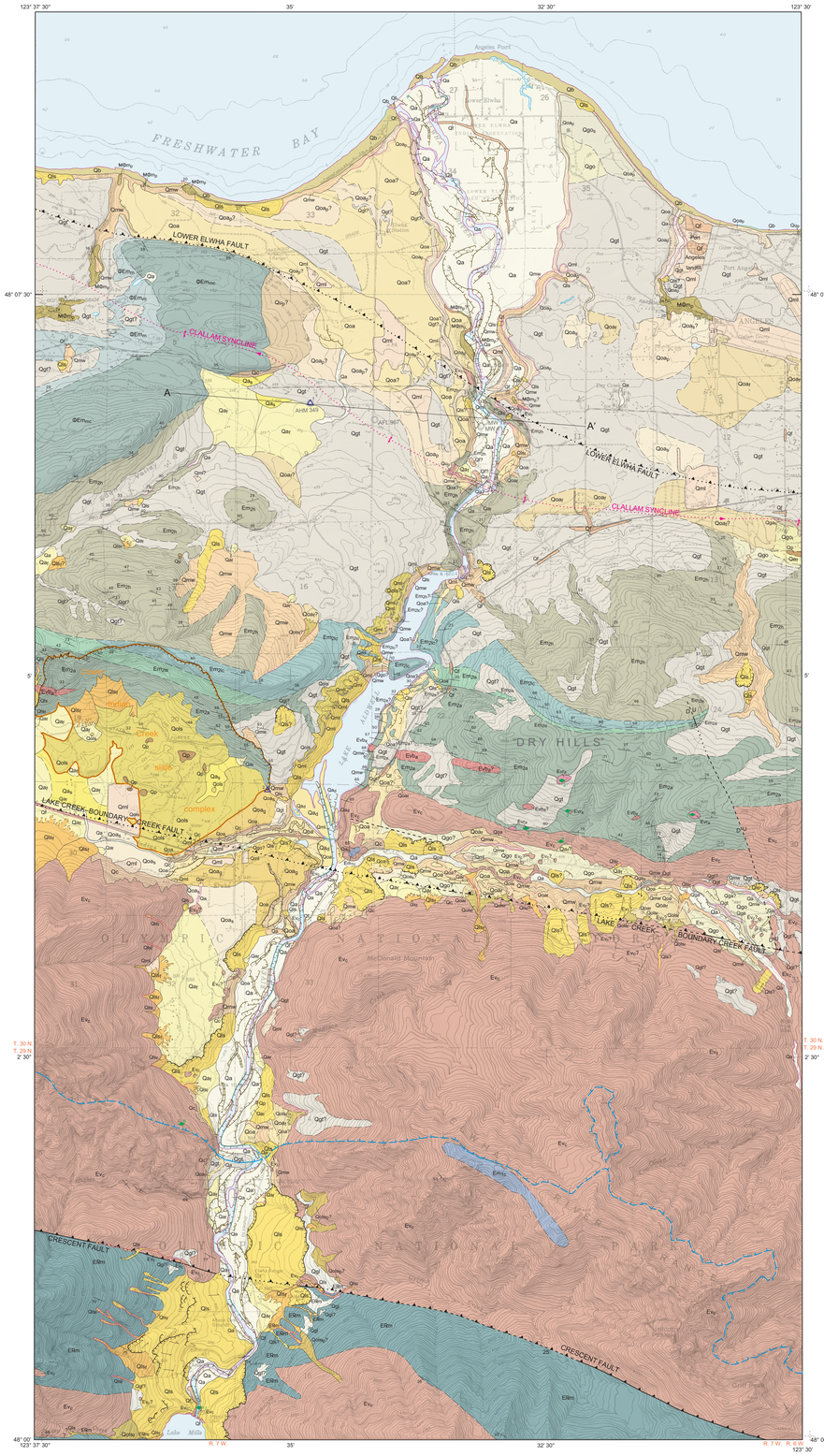
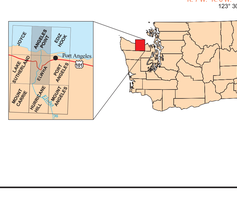


Lambert conformal conic projection
North American Datum of 1927. To place on North American Datum of 1983, move projection lines 24 meters north and 96 meters east as shown by dashed corner ticks
Base map from scanned and rectified U.S. Geological Survey 7.5-minute Elwha and Angeles Point quadrangles, 1950 (photorevised 1985) and 1950 (photorevised 1978) respectively
Digital cartography by J. Eric Schuster, Sandra L. McAuliffe, and Anne C. Heinitz
Editing and production by Jaretta M. Roloff

SCALE 1:24 000

contour interval 20 feet



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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://nsdi.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 ^{14}C$^{\prime}$. 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 (Cannetti, 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 rock units, and we report 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 thrust-faulted 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 (above sea level) and locally thicken in valleys of the ancestral coastal plain (Wash. Dept. of Ecology, 1978; K. L. Ottberg and R. L. Logan, Wash. Div. of Geology and Earth Resources, unpub. field notes, 1977). Sediments from Vancouver Island and the Olympic and 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 constituents. Olympic sediments consist of about 90 percent lithic sandstone. 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 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$_b$) with less than 1 percent northern sediment. Unit Qoa$_b$ is discontinuously covered by till that is rarely underlain by advance outwash. The delta was dissected by Olympic glacis. 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$_b$, coupled with a relative abundance of northern sediment beneath unit Qoa$_b$, 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 ^{14}C ky B.P. and recession at about 14.5 to 14 ^{14}C ky B.P. (Fig. 1; Anderson, 1968; Heusser, 1973; Petersen and others, 1983; Waitt and Thorson, 1983). Blunt and others (1987) give an advance date of "shortly 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 designation).

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 outwash aggradation was prompt from the Elwha valley was coeval with deposition of unit Qoa in the Elwha valley. Such coeval deposition and mixing of units Qoa and Qga are further supported by data of Heusser (1973), who suggests that some JFL ice may not have melted until after 8 ^{14}C ky B.P. (~8.8–9 ka). Deposition of unit Qgo began with locally ice-free conditions some time between 14,460 ±200 and 12,040 ±310 ^{14}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 Qal) 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 Qgm$_a$) 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 ±200 ^{14}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.$^{\prime}$ (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 landslide-damming of the lower Elwha valley could alternatively explain 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 deposition 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 M∂m$_{ps}$) appears most slide-prone, followed by the Quaternary units (especially where glaciolacustrine sediments [unit Qgl] are present), then the Aldwell Formation (unit Eπ_{al}). 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 west side of Indian Creek valley incorporates areas mapped as units Qls, Qols, Qlls; Qls$_a$, Qla$_c$, Qlp, Qm$_{ba}$, Qm$_{ba}$, and Qm$_{ba}$. It spans 1500 ft of relief, has covered at least 1 mi^2 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 Eπ_{ly2}) 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 north-west 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 predates deposition of the upper Eocene Hoko River Formation (Brown and others, 1960).

Three faults roughly parallel the Clallam syncline and appear to include north-side-up reverse slip. The northernmost is located on the north limb of the syncline and was noted by Brown and others (1960), Brown (1970), Tabor and Cady (1978a), Tabor (1983), Dragovich and others (2002), and Schasse (2003), but has not been formally named. We refer to the segment within the field area as the Lower Elwha fault, in keeping with the naming used by Atkins and others (2003). Brown (1970) referred to the same structure as the Freshwater fault. We believe that field relations require the fault to be a post-early Miocene structure. Brown and others (1960) and Brown (1970) showed the south limb of the structure as upthrown, but we agree with Tabor (1983), Dragovich and others (2002), and Schasse (2003) and show the north limb as upthrown.

The second previously mapped fault runs roughly east to west along the Little River and Indian Creek valleys. It was inferred (Tabor and Cady, 1978a; Tabor, 1983; Dragovich and others, 2002; Schasse, 2003) to connect the Lake Creek fault (Brown and others, 1960) to the east and the Boundary Creek fault (Brown and others, 1960) to the west. Brown (1961) speculated on the connection but did not show it on a map. We refer to this fault as the Lake Creek–Boundary Creek fault (**LCBCF**). The lidar-based DEM of the field area reveals surface lineaments and possible scarps along the mapped trend of the LCBCF in Little Creek valley. The queried, near-parallel, dashed lineament 0.2 mi east of the Elwha River and 0.2 mi north of the Little River maps a possible alternate alignment or may locate a fault splay, as could several other, subparallel lineaments (not shown) in the area.

The LCBCF offsets late Eocene and older units, but little is known about the timing of its activity. Until a lidar-based DEM became available, there was no documented evidence for Quaternary movement, except perhaps the landsliding that dammed Lake Crescent a few miles west of the field area (Logan and Schasse, 1991). But scarps on unit Qgo fluvial terraces suggest post-glacial movement.

Whereas some scarps along Little River valley are conspicuous, no scarp has been confidently identified in the younger units exposed west of the Elwha River. Some possible scarps are apparent in and near the LICS, but these are either subtle or not subparallel to the inferred fault trend. This could imply that the fault is inaccurately mapped or that weak splays are scattered across a broader zone or that deposition of the post-Pysht units west of the Elwha River post-dates the latest LCBCF ground rupture. If the latter is correct, the age of these units relative to the age of unit Qgo east of the Elwha River stratigraphically brackets the latest fault motion.

If the fault is located near the southern sidewall of Indian Creek valley (see map), it passes through unit Qoa$_b$. The sediments in this unit remain undated but appear to be roughly correlative with the onset of crustal rebound at the end of RSLM, which apparently occurred about 13.3 ka (Fig. 1; Mathews and others, 1970; Dethier and others 1995; Mosher and Hewitt, 2004). RSLM also marks the inferred likely time of deposition of unit Qgo terraces that appear to contain scarps along Little River, suggesting that if the fault alignment as shown is correct, the fault has not caused geomorphic expression since at least about 13.3 ka.

If the LCBCF enters Indian Creek valley farther north, it traverses the LICS. This slide complex rivals in scale the landsliding to which previous workers (Reagan, 1909; Weaver, 1937; Tabor, 1975; Logan and Schasse, 1991) have ascribed the damming of Lake Crescent a few miles west of the field area. Tabor (1975) and Logan and Schuster (1991) speculated that the sliding at Lake Crescent may have been triggered by seismicity. Seismic triggering would be equally reasonable for the LICS.

A unit Qoa terrace that appears to consist of ancestral Indian Creek gravel is incised into and therefore post-dates deposition of the eastern flank of the LICS. The gravel-clast size on this terrace implies that the terrace and LICS were active before Lake Crescent was dammed; if all major slide events in both locations were seismically triggered by the LCBCF, it implies multiple events between RSLM around 13.3 ka and a slightly lowered sea level that controlled deposition of the ancestral Indian Creek terrace on the east side of the LICS. Because crustal rebound was very rapid, such a slightly lowered sea level would have followed the RSLM by a few hundred years at most (Fig. 1; Mathews and others, 1970; Booth, 1987; Mosher and Hewitt, 2004).

However, a latent(?) disturbance in the area is recorded by an organic clastic dike that intruded (landslide-disturbed?) till (from below?) at the east end of the LICS (^{14}C loc. 2) and indicates either more recent seismicity or major LICS activity coeval with clastic dike formation (but likely prior to formation of the ancestral Indian Creek terrace and to the LICS). Organic sediment from the dike was sampled for radiocarbon dating and yielded a conventional radiocarbon age of 10,190 ±60 ^{14}C yr B.P. (2 σ cal yr B.P. 12,340–11,570; Beta No. 187684); peat from the same sample yielded a conventional radiocarbon age of 10,240 ±60 ^{14}C yr B.P. (2 σ cal yr B.P. 12,360–11,680; Beta No. 188531). Thus the disturbance recorded by the clastic dike appears to date to about 12,360 to 11,570 ka (Fig. 1), somewhat later than the time of least post-LICS emplacement scarps. Similarity in apparent stratigraphic relationships. A more recent event may also be supported by an east–west-trending lineament across the ancestral Indian Creek terrace that cross-cuts the LICS deposits (Ralph Haugerud, written commun., March 2004). Though not aligned with the mapped trend of the LCBCF, this lineament could be a fault scarp.

Aside from the above, the only evidence noted herein for possible LCBCF fault activity after RSLM is severe liquefaction features in sand, silt, and clay (unit Qoa$_b$) near the southern valley sidewall of Indian Creek valley. These reinforce the record of disturbance by seismicity or by the landslide to the north, but they add no stratigraphic constraints to the factors noted above.

The third known fault in the field area is the Crescent fault (Brown and others, 1960; Tabor and Cady, 1978a; Tabor, 1983; Snavely and others, 1993) near the southern map limit, which elevates the rocks on the north over those on the south. It was first suggested by Tabor (1975), who noted well-preserved faceted spurs 8 mi west of our map area. We agree with Snavely (1983) and Tabor (1983), who extended the fault east of the Elwha to the southeastern corner of our map and postulated that it reflects regional, post-early Eocene north–south compression. Dragovich and others (2002) and Schasse (2003) likewise show the fault on both sides of the Elwha.

The fourth known fault is a 2-mile-long, roughly north-trending structure inferred to resolve the apparent justaposition along strike of Aldwell Formation siltstone (unit Eπ_{al}) and Crescent Formation basalt (unit Eπ_c) (Brown and others, 1960; Brown, 1970). Based on bedrock deformation exposed in a road rock quarry, we extended this fault approximately 1500 ft to the north of where Brown (1970) had terminated it.

DESCRIPTIONS OF MAP UNITS

NONGLACIAL DEPOSITS

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

Qmf — **Modified land (Holocene)**—Soil, sediment, or other geologic material locally reworked by excavation and (or) redistribution to modify topography; includes mappable sand and gravel pits excavated mostly into units Qga and Qoa$_b$.

Qb — **Beach deposits (Holocene)**—Sand and cobbles, may include silt, pebbles, and locally boulders; usually a mix with variable proportions of northern and Olympic rocks, but within 1 mi west and 2 mi east of the Elwha River, dominated by Olympic rocks; pebble-size and larger clasts typically well rounded and flat; locally well-sorted; loose, except near Port Angeles landfill, where some of unit is locally cemented by hematite and other minerals.

Qa — **Alluvium (Holocene)**—Gravel, sand, silt, clay, and peat; variably sorted; loose; bedded; deposited in stream beds and estuaries, and on flood plains; may include some lacustrine and beach deposits; mostly of Olympic derivation, but may contain northern clasts (typically <3%); locally grades down into units Qoa or Qgo where drainage is not at grade with MSL (for an example, see Petersen and others, 1983). Subscript 's' indicates mostly sand-size or finer deposits. Subscript '$^{\prime}$' indicates alluvial fan. Alluvial fans generally interfinger at their upper end with debris slide fans (unit Qlls). Subscript 'd' indicates historic debris deposits (propagated into Lake Aldwell).

Qp — **Peat (Holocene)**—Organic and organic-matter-rich mineral sediments deposited in closed depressions; includes peat, muck, silt, and clay in and adjacent to wetlands.

Qc — **Colluvium (Holocene)**—Boulders, gravel, sand, silt, and clay; unsorted mix of mostly Olympic rock types with minor northern rocks; locally stratified along slope-parallel planes; loose; deposited by soil creep and dry raveling along (typically steep) hillslopes; mapped where colluvium was noted in the field and is thought to be at least 5 ft thick.

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

Qls — **Landslide (Holocene)**—Boulders, gravel, sand, silt, and clay in slide body and toe; underlying units in head wall and head scarp area, which is included with landslide areas, except in the LICS, where the scarp and headwall are mapped as bedrock; angular to rounded; unsorted; generally loose, unstratified, broken, and chaotic, but may locally retain primary bedding structure; commonly includes liquefaction features; deposited by mass wasting processes other than soil creep and frost heave; typically in unconformable contact with surrounding units. Unit includes inactive (including 'ancient') slides that cannot be age-correlated to other stratigraphic units. Landslides shown where scale permits. Absence of a mapped landslide does not imply absence of sliding or hazard. Subscript '$^{\prime}$' indicates debris fan, which may include head scarp and slide track. Debris fans interfinger with but are steeper, coarser, and more angular than alluvial fans and reflect a greater hazard from rapid, high-energy deposition.

Qoa — **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 '$^{\prime}$' indicates alluvial fan. Alluvial fans typically interfinger at their upper end with debris slide fans (unit Qolls).

Qols — **Landslide (late Pleistocene)**—Boulders, gravel, sand, silt, and clay in slide body and toe; underlying units in head scarp area; angular to rounded; generally loose; unsorted; generally unstratified, broken, and chaotic, but may locally retain primary bedding structure and include liquefaction features. Includes inactive slides that delineated sediment onto terraces of units Qgo or Qoa during or shortly after their formation; the terraces are now perched up to 200 ft above modern valley floors, and both units are dissected by modern streams. Some slides lack stratigraphic evidence to exclude significant more recent activity and were therefore included with unit Qls. Subscript '$^{\prime}$' indicates fan, which may include head scarp and slide track. Debris fans interfinger with, but are steeper, coarser, and more angular than, alluvial fans (unit Qoa) and reflect a greater hazard from rapid, high-energy deposition.

LATE WISCONSINAN GLACIAL DEPOSITS

Qgo — **Recessional outwash and glaciomarine drift**—Gravel, sand, silt, clay, and locally peat; glaciomarine drift facies includes pebbly silt and clay and discontinuous layers of silty sand; characterized by northern rock types; within 2 mi of Elwha River, however, may locally contain more than 95 percent Olympic sediment; typically well-rounded; loose; generally well-sorted; mostly stratified; glaciomarine drift facies weakly stratified to nonstratified; deposited by melting ice and (or) exposed in modern streams; locally grades up into or interfingers with post-glacial alluvium (units Qoa and Qa). Several subtle topographic steps that roughly parallel the shoreline on the coastal plain east of the Elwha River may include older, higher, post-glacial shoreline berms. Subscript '$^{\prime}$' indicates sand or finer-grained facies. Subscript '$^{\prime}$' indicates outwash interpreted as ice-contact deposits.

Qgl — **Glaciolacustrine sediment**—Sand, silt, or clay, locally with northern dropstones; brown to gray; may be massive, laminated, varved or otherwise stratified; well-sorted; loose to compact; most exposures are stiff; includes JFL advance, full-glacial, and recessional lake deposits; may include deposits from earlier glaciations. Along the Elwha valley sidewalls between about 800 and 1100 ft above MSL south of the JFL ice limit, unit Qgl is interpreted as a veneer over older Olympic sediment, such as units Qoa$_b$ and Qolls$_b$. The older sediments are inferred based on dissected benches and fans perched on the Elwha valley sidewalls. South of the ice limit, below 800 ft, unit Qgl is widely exposed in large landslide complexes along both sides of the valley. North of the ice limit, exposures are below 550 ft and less extensive, and landslides less prevalent. The unit is mostly seen in landslides and in subsurface exposures along stream cutbanks, such that few surfaces are mapped as unit Qgl.

Qgt — **Juan de Fuca Lobe till**—Unsorted and highly compacted mixture of clay, silt, sand, gravel, and (erratic) boulders deposited directly by glacier ice of the Juan de Fuca lobe; gray where fresh, light yellowish brown where oxidized; permeability varies from where fodgment till is well-developed; generally characterized by northern source clasts, but locally dominated by Olympic rock types, especially where Olympic sediments are abundant in the substrate, such as in the Elwha River delta fan area; most commonly matrix supported, but locally clast supported; matrix more angular than water-worked sediments; cobbles and boulders commonly faceted and (or) striated; forms a patchy cover varying across short distances from less than 0.5 to 20 ft thick; thicknesses of 2 to 10 ft are most common; may include outwash clay, sand, silt, and gravel, or loose ablation till that is too thin to substantially mask the underlying till plain; erratic boulders commonly signal that this unit is underfoot, but such boulders may also occur as lag deposits where the underlying deposits have been modified by meltwater; typically, weakly developed modern soil has formed on the cap of loose gravel, but the underlying till is unweathered; local textural features in the till include flow banding, clasts aligned parallel to ice flow, and misfaction of the unit in the Dry Hills. Siltstone is olive-gray to black, thin- to medium-bedded, and well-indurated. Sandstone is greenish gray and weathers to brown and buff-gray. Calcareous beds weather tan. At the type locality on Lake Aldwell, the unit is about 2950 ft thick (Brown and others, 1960). Unit is characterized by lower Narizian foraminifera, indicating a middle Eocene age (Armentrout and others, 1983; Rau, 1964). Divided into:

Qoa$_b$ — **Basaltic rocks (middle Eocene)**—Pillow basalt, breccia, and tuff; consists of pods and tongues up to 350 ft thick and occurring up to 1000 ft above the base of unit Eπ_{ly2} (Brown and others, 1960).

Qoa$_s$ — **Olympic alluvium**—Gravel with less abundant sand and minor silt, clay, and peat; variably sorted; compact; crudely bedded; may locally include lacustrine and beach deposits; likely dominated by outwash from Olympic alpine glaciation(s) (Thackray, 1996), with typically <1% northern clasts; local paleoflow directional indicators suggest northeast to northwest flow of an ancestral Elwha River. Unit Qoa$_b$ is stratigraphically beneath JFL till in the 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-upward northern sediment (unit Qoa$_s$). Unit Qoa$_b$ likely dates to marine oxygen isotope stage 3 (~70–18 ka) or earlier, but could represent an Olympic recessional outwash pulse from the alpine glaciation that preceded the arrival of the JFL ice early in the late Wisconsinan.

Qolls$_b$ — **Debris slides**—Boulders, gravel, sand, silt, and clay in debris slide fan deposits; may include a draping of unit Qgl and expose underlying units in head scarp and slide track areas (included only where distinct); slide material is angular to rounded; unsorted; generally unstratified, broken and chaotic, gravel to boulder clast-supported; likely to interfinger at distal (downslope) end with coeval alluvium (inferred beneath unit Qgl). Unit Qolls$_b$ is mapped on midslope benches along the Elwha valley sidewalls between about 800 and 1100 ft above MSL (~400 ft above the modern valley floor) and south of the apparent JFL ice limit. The benches are locally blanketed with a veneer of unit Qgl. The fans appear to grade to a paleovalley floor at their terminus, and dissection by modern drainages indicates that they are no longer active slide areas. The fans are interpreted as pre-Wisconsinan debris fans on the basis of location, field relations, and geomorphic characteristics.

PLEISTOCENE DEPOSITS OLDER THAN JFL TILL

Qllp — **Undifferentiated sediment**—Gravel, sand, silt, clay, peat, and till; variably sorted; mostly bedded; compact; maximum thickness ~200 ft; contains both northern and Olympic glacial and nonglacial deposits. Shoreline exposures 0.3 to 1 mi east of the map area may literally grade into unit Qoa$_b$, suggesting that an ancestral Elwha River may have carried sediment several miles farther east than the modern Elwha. Analysis of wood fragments obtained from a sand facies (⅜ ft below the surface in a water well (^{14}C loc. 1 on map) yielded a conventional radiocarbon age of 37,800 ±1100 ^{14}C yr B.P. (Beta No. 187683), correlative to marine oxygen isotope stage 3 (~70–18 ka). A peat sample collected near sea level from the shoreline bluff at the west end of Ediz Hook (1 mi east of the map area) yielded a radiocarbon date of ~44,620 ^{14}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 section. We postulate that the nonglacial deposits within unit Qllp are likely dominated by sediments of marine oxygen isotope stage 3. The northern source sediments within the unit are undated but local stratigraphic relations suggest that they are mostly pre-late Wisconsinan (that is, oxygen isotope stage 4 or earlier). Most exposures of Qllp are dominated by Olympic sediment, such that northern sediments are generally too isolated to suggest inference of coherent layers, except in landslide scarps along the shoreline bluffs from the western map edge 2 mi to the east. Northern sediments may locally include late JFL advance outwash.

Qll$_b$ — **Marine sedimentary rocks (middle and lower Eocene)**—Flow breccia, tuff breccia, volcanic conglomerate, and volcaniolithic sandstone; less commonly chert and calcareous argillite; clasts mostly basalt and diabase; lithic, calcareous, and fossiliferous, gray, green, red, or black; well stratified; breccias, tuffs, and sandstones are normally graded; unit occurs as thin tongues and isolated lenses of sedimentary rock within unit Eπ_c. Foraminifera range in age from Penutian to Ulatisian (Rau, 1981, 2000).

Ellm — **Blue Mountain unit of Tabor and Cady (1978a) (Eocene–Paleocene?)**—Lithic sandstone, siltstone, argillite, granule or pebble conglomerate, and siltstone- or slate-clast breccia; gray to black; laminated and rhythmically bedded; believed to be a submarine turbidite fan facies (Einarsen, 1987); sandstone beds locally very thick; contains black plant material concentrated along fine-grained laminations; interfingers and is in fault contact with the Crescent Formation unit Eπ_c; contains foraminiferal assemblages of Ulatisian or older stages (Rau, 2000).

Tertiary Sedimentary and Volcanic Rocks

TWIN RIVER GROUP—Divided into:

M∂m$_{ps}$ — **Pysht Formation (Miocene–Oligocene)**—Mudstone, claystone, and sandy siltstone; also contains 1- to 20-ft-thick beds of calcareous sandstone; unweathered mudstone, claystone, and siltstone are medium gray to dark greenish gray; unit weathers pale yellowish brown to medium brown; massive, poorly indurated; marine mudstone may contain thin beds of calcareous claystone; argillaceous rocks contain sparsely disseminated calcareous concretions; mollusk shell fragments, foraminifera, and carbonized plant material are common in mudstone; graditional with the underlying Makah Formation (unit Eπ_{mp}) (Snavely and others, 1978); approximately 300 ft thick 2 mi west of the Elwha River (Brown and others, 1960). Only the lowest strata in the formation are exposed in the map area. The unit contains lower Saucesian and upper Zemorrian foraminifera (Rau, 1964, 1981, 2000, 2002). Mollusks are indicative of the Juanian Stage (Addicott, 1976, 1981).

Eπ_{mp} — **Makah Formation (Oligocene–Eocene)**—Siltstone, mudstone, and minor thin-bedded sandstone (unit Eπ_{mp}); basal conglomerate facies (unit Eπ_{mp1}) of pebbles and cobbles of varied lithology in a matrix of mostly coarse-grained sandstone; sporadically exposed sedimentary breccia of angular volcanic debris at the base; weathers to grayish orange and yellowish brown; dark gray to black where carbonaceous; massive to thin- and rhythmically bedded; spherical calcareous concretions (often containing fossil shells and plants) and nodules occur throughout; sandstone is angular, very fine to medium grained, subquartzose, and feldspathollitic; conglomerate facies is massive; unit Eπ_{mp} is approximately 1500 ft thick (Brown and others, 1960), unit Eπ_{mpc} approximately 1000 ft thick, and both plunge westward (Brown and others, 1960); crops out about 2 mi west of the Elwha River in a crescent-shaped belt open to the west and spanning both limbs of the Clallam syncline; gradational with the more arenaceous rocks of the underlying Hoko River Formation (unit Eπ_{ly}) (Snavely and others, 1978); contains upper Narizian and Refugian foraminifera (Rau, 1964, 2000, 2002).

Eπ_{ly} — **Hoko River Formation (upper Eocene)**—Lithofeldspathic sandstone and siltstone in equal amounts, with pebble-cobble conglomerate lenses and literally and vertically gradational contacts; thick beds of sandstone and pebble-cobble conglomerate occur locally near base of unit along Elwha River; sandstone is gray to olive-gray, fine to very coarse grained to granular, well bedded, and thin to very thick bedded; siltstone contains thin beds and laminae of very fine-grained sandstone and is well bedded, well indurated, locally cemented with calcium carbonate, and may contain calcareous concretions; 2 mi west of the Elwha River, unit thickness reaches 4800 ft on the south limb of the Clallam syncline; on the north limb the unit thins to 500 ft, probably due to structural highs in older rocks (Brown and others, 1960); conformable with the underlying Lyre Formation (units Eπ_{ly2} and Eπ_{ly1}); contains upper Narizian foraminifera (Snavely and others, 1980; Rau, 2000).

TERTIARY SEDIMENTARY AND VOLCANIC ROCKS OLDER THAN THE TWIN RIVER GROUP

Eπ_{ly2} — **Lyre Formation (middle Eocene)**—Conglomerate and sandstone (unit Eπ_{ly2}) overlies and is interbedded with sandstone and minor thin-bedded, interbedded sandstone and siltstone (unit Eπ_{ly1}). Conglomerate is subdivided into lenticular or channel deposits of well-indurated, well-rounded, thin- to very thick bedded pebble to boulder conglomerate and pebbly sandstone. Conglomerate also contains lenses of fine-grained to granule sandstone. Conglomerate clasts are gray to black argillite, quartzite, chert, metavolcanic rocks, gneiss, quartz, and minor basalt. Sandstone is lithic, phyllitic, and quartzose, light olive-gray, thick bedded, and well indurated. The Lyre Formation is at 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 in the "Dry Hills". It rests conformably upon and interfingers with the upper part of the Aldwell Formation (unit Eπ_{al}) and contains foraminifera assigned to the upper Narizian Stage (Snavely, 1983).

Eπ_{al} — **Aldwell Formation (middle Eocene)**—marine siltstone and sandy siltstone with sparse interbeds of fine- to very fine-grained feldspathollitic sandstone; siltstone contains thin sandy laminations and local thin to medium beds of fine-grained limestone or calcareous very fine-grained sandstone and sporadically distributed lenses of un