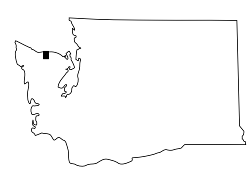
NATURAL RESOURCES

Geologic Map of the Morse Creek 7.5-minute Quadrangle, Clallam County, Washington

by Henry W. Schasse
and Michael Polenz

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Open File Report 2002-8
December 2002



Location of quadrangle

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

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INTRODUCTION

The Morse Creek 7.5-minute quadrangle is located in the lower southeast quarter of the Port Angeles 30- by 60-minute quadrangle (Fig. 1) and is situated on the northeast part of the Olympic Peninsula on a narrow coastal plain at the base of the northern foothills of the Olympic Mountains (Fig. 2). The Olympic Mountains are an accreted subduction complex composed of two geologic terranes: (1) a peripheral belt of oceanic basalt and marine sedimentary rocks, called the Crescent terrane by Babcock and others (1994), that wraps around (2) a core of marine sedimentary rocks and minor volcanogenic rocks that are approximately coeval with the peripheral rocks but everywhere in fault contact with them (Fig. 2). The core rocks were deposited on or near the Juan de Fuca plate and later accreted to the Olympic Peninsula by thrust faulting (Brandon and Calderwood, 1990). The Crescent Formation, in the basal part of the peripheral rocks, is a thick sequence of oceanic pillow basalt, breccia, interbedded volcaniclastic rocks and minor pelagic sedimentary rocks, and rare columnar basalt near the top of the section (Tabor and Cady, 1978b). These volcanogenic rocks probably erupted in a marginal marine basin in which sediments of the Blue Mountain unit were deposited. Deposition of Blue Mountain unit sediments continued throughout the eruptive history of the Crescent volcanic rocks.

Along the north flank of the Olympic Mountains, more than 19,000 ft of marine sedimentary rocks overlie the Crescent Formation (Snavely, 1983). Snavely and others (1980) suggested that these strata were deposited in the Tofino–Juan de Fuca basin, a deep marginal basin whose axis generally paralleled the Clallam syncline (Fig. 2). These fossiliferous rocks are faulted and folded but, in general, are stratigraphically continuous. Fold axes are subparallel to many of the faults, trend eastward, and plunge gently east (Fig. 2).

In the Morse Creek quadrangle, sedimentary rocks of the Aldwell Formation and Twin River Group overlie the Crescent Formation and the Blue Mountain unit. In this study, we correlate Tertiary sedimentary units previously mapped as the upper, middle, and lower members of the Twin River Group in this quadrangle with the Pysht, Makah, and Hoko River Formations respectively (Snavely and others, 1978, 1980). The Aldwell Formation, Twin River Group, Crescent Formation, and Blue Mountain unit all appear to be folded and thrust-faulted together, apparently by a post–early Miocene tectonic event of unknown duration. Cross faulting appears to offset one of the thrust faults and a minor fold.

More than 2,000 ft of unconsolidated Pleistocene sediments, identified in logs of the Standard Oil Dungeness Unit No. 1-54 exploratory well northeast of Sequim, were deposited on the Tertiary sedimentary rocks. The most recent of these deposits were left during the Fraser Glaciation (20–10 ka) from lobes of the Cordilleran ice sheet that advanced southward out of Canada and split east of the study area. The Puget lobe flowed south, covering the area now known as the Puget Lowland, and the Juan de Fuca lobe flowed west through the Strait of Juan de Fuca to a terminal position on the continental shelf. The younger glacial deposits are thickest in the north half of the Morse Creek quadrangle, where they consist of glaciomarine drift, recessional outwash, till, and advance outwash, all exposed at the surface. In the south half of the quadrangle, glacial sediment consists of advance outwash covered by till that thins southward to a veneer on the foothills, forming a patchwork pattern of till (where it fills depressions) and bedrock (where the till was either not deposited or eroded away). Pleistocene strata underlying the Fraser glacial deposits in the Morse Creek quadrangle represent at least one pre-Fraser glacial period and at least one pre-Fraser nonglacial period. Holocene fluvial and mass-wasting processes have locally modified bedrock and glacial deposits.

New or refined information has been developed during the course of this study:

- Through detailed mapping, we have delineated bedrock exposures that were mapped as undivided glacial drift in earlier published maps (Brown and others, 1960; Tabor and Cady, 1978a).
- We provide new foraminiferal data to augment those previously collected from the Tertiary Twin River Group in the Morse Creek quadrangle (Rau, 1964). These data aided us in our assignment of these rocks to the Pysht and Makah Formations.
- We assign rocks that crop out in the quadrangle south of the Lake Creek fault to the Hoko River Formation. These rocks were formerly mapped by Brown and others (1960) as Lyre Formation and Twin River Formation (undifferen-

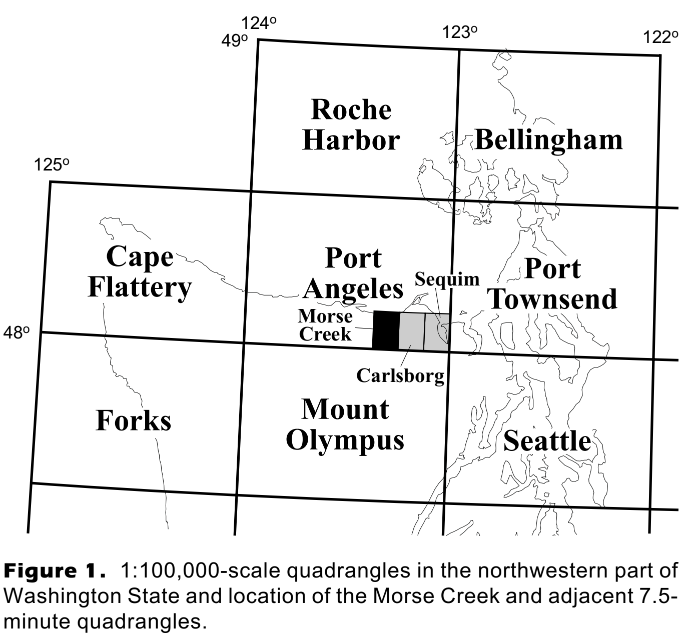

Figure 1. 1:100,000-scale quadrangles in the northwestern part of Washington State and location of the Morse Creek and adjacent 7.5-minute quadrangles.

tiated) and later by Tabor and Cady (1978a) as Twin River Group (undivided)

- We reinterpret the stratigraphic relationships of Fraser and pre-Fraser glacial and nonglacial deposits in sea cliff exposures in the north part of the quadrangle. There we describe possible subglacial flow and (or) glacial outburst flood (jökulhlaup) deposits (Plate 1; cross section D, Plate 2).
- We provide geochemical and petrographic analyses of some basalts and a rare rhyolite of the Crescent Formation.
- We publish five new radiometric ^{14}C age dates in this report (Appendix 2): two imply an Olympia nonglacial in-

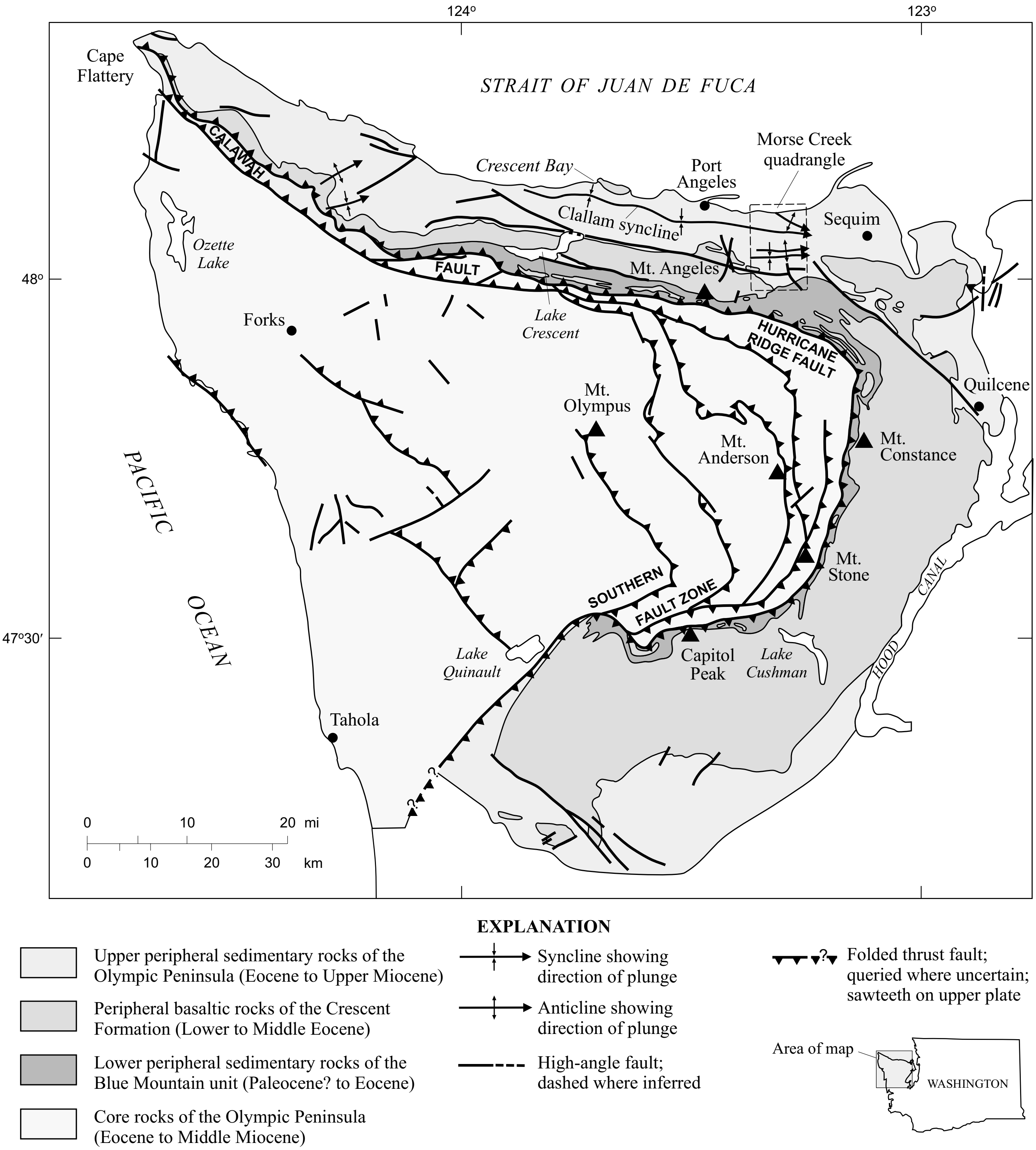

Figure 2. Geologic terranes and major folds and faults of the Olympic Peninsula. Peripheral rocks include the basalt (mostly oceanic) of the Crescent Formation, marine sedimentary rocks of the Blue Mountain unit that underlie and intertongue with the basalts, and overlying marine sedimentary rocks. They form a horseshoe-shaped belt around the mountainous core. Folds in core rocks, the Crescent Formation, and areas of glacial cover over bedrock are not shown. Geology modified from Tabor and Cady (1978b).

terval or older age for peat-bearing clays and silts that crop out in the lower parts of the sea cliffs in the northeast corner of the quadrangle; two others imply an Olympia nonglacial or older age for similar sediments that crop out in the lower stream banks of Siebert Creek; and the fifth establishes a Holocene age for peat deposits nested in Vashon glacial drift at the surface.

METHODS, PREVIOUS WORK, AND RELATED STUDIES

Our mapping and interpretations are based on fieldwork performed in 2000, as well as previous studies in the area. Areas included on previous geologic maps and pertinent topical studies are shown on Figure 3. Our geologic map (Plate 1) incorporates significant amounts of the work of Brown and others (1960), particularly their mapping of the bedrock exposed in the bottoms and banks of the north-trending drainages of Morse and Siebert Creeks and their tributaries. Tabor and Cady's (1978a) geologic map of the Olympic Peninsula includes our study area. Their map, published at a much smaller scale, depicts the upper Eocene marine sedimentary rocks, which we have assigned to the Hoko River Formation, as Tertiary undivided Twin River Formation [Group]. Mapping by K. L. Othberg and R. L. Logan (Washington Division of Geology and Earth Resources, unpub. mapping, 1977) was used to guide us in our mapping of the surficial geology of the Morse Creek quadrangle. Schasse and Wegmann (2000) provided structural interpretations in the Carlsborg 7.5-minute quadrangle to the east that we carried over into the Morse Creek quadrangle. The Washington Department of Ecology (1978) mapped the coastal geology inland for 2,000 ft. Much of the information contained therein was included in our mapping of the upland surficial geology in that area.

Due to the paucity of bedrock exposures, we relied on subsurface information contained in water-well logs for help in interpreting structure and subsurface Quaternary geology. All of the wells used in this study are shown on Plate 1 and are identified using a numbering system used by the U.S. Geological Survey (USGS) (Fig. 4). The USGS assigns water wells in Washington numbers that identify their location in a township, range, and section. For example, well number 30N/04W-16D01 indicates, successively, the township (30N) and range (04W) relative to the Willamette base line and meridian. The first number following the hyphen indicates the section (16) within the township, and the letter following the section number gives the quarter-quarter section (40-acre subdivision). The two-digit number (01) following the letter is the sequence number of the well recorded within the quarter-quarter section. We have rendered this number as a single digit in the cross sections (Plate 2) because of space limitations.

Sixty-one wells, listed in Appendix 1, were selected to construct the cross sections. An abbreviated identifying number, giving the section and alphanumeric well location number within that section, identifies the wells in the cross sections. Referring to the cross section line on Plate 1 will enable one to identify the township and range for that well. Wells that were used to construct the cross sections have depth-drilled values, in feet, associated with the well numbers on Plate 1.

Radiocarbon ages are given in Appendix 2. Paleontological and geochemical analyses for this study are given in Appendices 3 and 4, respectively. Sample sites for radiocarbon and geochemical analyses and foraminiferal assemblages are shown on Plate 1. Results of our petrographic study are incorporated in the unit descriptions in the text.

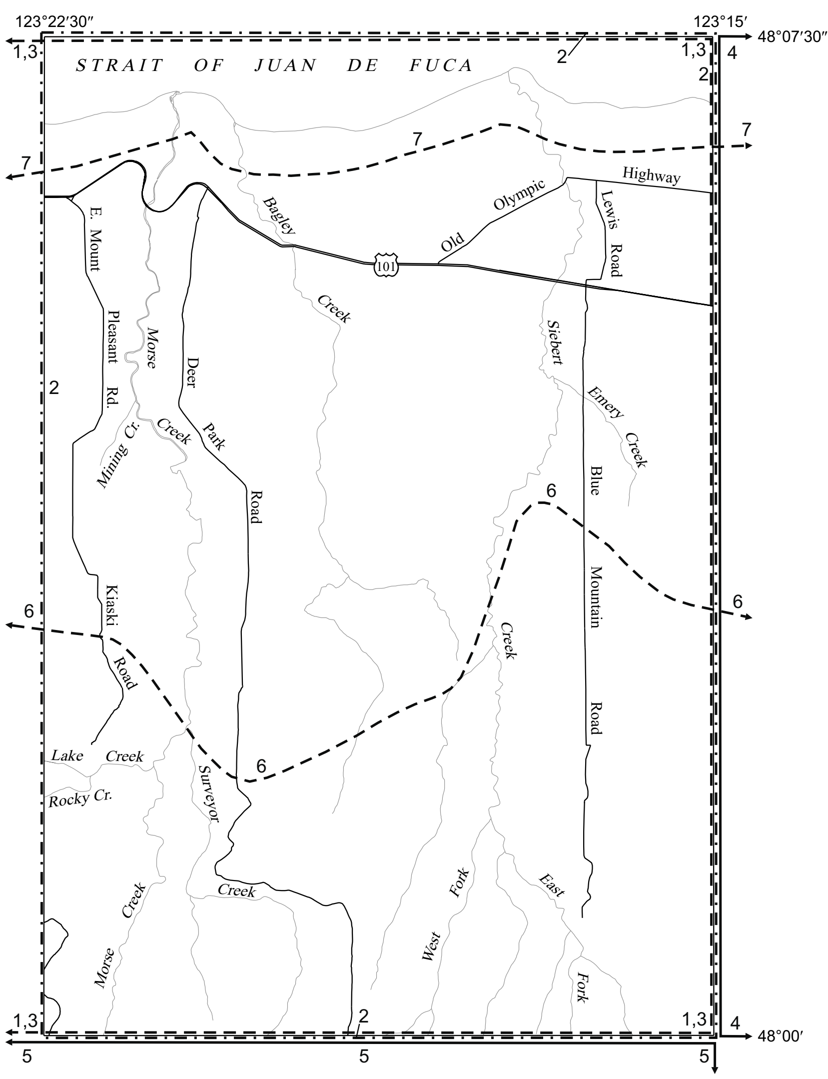

Figure 3. Previous geologic mapping and topical studies within and adjacent to the Morse Creek 7.5-minute quadrangle. **1.** Brown and others (1960), 1:62,500; **2.** Tabor and Cady (1978a), 1:125,000; **3.** K. L. Othberg and R. L. Logan (Washington Division of Geology and Earth Resources, unpub. mapping, 1977), 1:62,500; **4.** Schasse and Wegmann (2000), 1:24,000; **5.** Tabor and others (1972), 1:62,500; **6.** Drost (1986), 1;62,500; **7.** Washington Department of Ecology (1978), 1:24,000.

DESCRIPTIONS OF MAP UNITS

Unit symbols provide information about the age, lithology, and name (if any) of geologic units: upper-case letters indicate age, lower-case letters indicate lithology, and subscripts identify named units. For example, Oligocene to Eocene marine rocks of the Makah Formation are shown with the symbol ΦEm_m. We used the geologic time scale for the Correlation of

Stratigraphic Units of North America (COSUNA) project of the American Association of Petroleum Geologists (Salvador, 1985), with boundary-age modifications of Montanari and others (1985). Some of the 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). Landslides are classified according to Varnes (1978).

Quaternary Sediments

NONGLACIAL DEPOSITS

Qf **Fill and modified land (Holocene)**—Riprap, soil, sediment, rock, and solid waste material that has been added and reworked to modify topography. Fill is used for bridge abutment support where U.S. Highway 101 crosses Siebert Creek, as riprap along the shores of the Strait of Juan de Fuca west of the mouth of Morse Creek, and as modified land at the Clallam County transfer station just west of Blue Mountain Road and south of Emery Creek.

Qb **Beach deposits (Holocene)**—Locally well-sorted deposits of mostly sand and cobbles, but may include silt and pebbles; found within the influence of the surf zone. Most of the larger clasts in coarser deposits are well rounded and flat as a result of wave action.

Qa **Alluvium (Holocene)**—Generally well-stratified and well-sorted deposits of rounded cobble and pebble gravel, sandy gravel, gravelly sand, silt, and clay; brown to gray, depending on composition and weathering; deposited in and along present streams. Grain size varies both laterally and vertically due to stream migration.

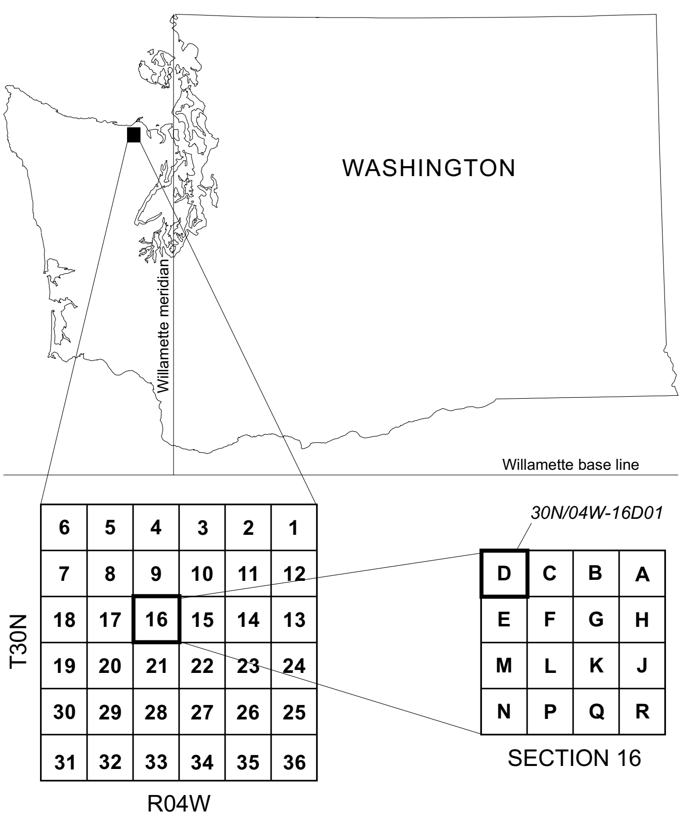

Figure 4. Well numbering system used by the U.S. Geological Survey. The two-digit number (01) following the letter D is the first in a sequence of wells recorded within the quarter-quarter section subdivision.

Qp **Peat and marsh deposits (Holocene)**—Fine sediments and organic matter; dark brown to black; formed by the accumulation and decomposition of organic material in wet depressions and other areas of poor drainage. Identification and delineation of this unit is based largely on interpretation of aerial photographs. These deposits are nested in depressions in glacial drift and till in the north half of the quadrangle. A radiocarbon age of 6,330 ±60 yr B.P. was measured on a peat collected in the flats above the sea cliffs at the north end of the quadrangle (sample site 5, Plate 1; Appendix 2).

Qls **Landslide deposits (Holocene)**—Poorly sorted deposits consisting of angular to rounded boulders, cobbles, and gravel in a sand, silt, and (or) clay matrix; mapped where there is geomorphic expression of active or inactive (including 'ancient') landslides. Landslides mapped in the quadrangle include the entire landform, from headwall to toe, and include both the landslide scarp and debris. Most of the landslides are earth-slump blocks resulting from streams or wave action undercutting the toes of these blocks.

Absence of a mapped landslide polygon on our map does not imply absence of slope instability or landsliding. Many landslide features are too small to show at map scale, and many slopes that appear unstable do not exhibit unambiguous landslide characteristics and therefore are not shown as landslides. However, it is safe to say that the shoreline bluffs and most of the valley sidewalls of Morse and Siebert Creeks and many tributaries are unstable, and the same holds true for numerous other slopes within the quadrangle.

Qaf **Alluvial fan deposits (Holocene to Pleistocene?)**—Thin- to medium-bedded sand and interbedded silt and clayey silt, with lenses of sand and pebbly gravel. Sands are fine to medium grained and well sorted and are light gray to pale yellowish brown and pale brown. Fan surfaces grade to the surface of Vashon glaciomarine drift (unit Qgdm) and Othberg and Palmer (1979a) suggested that unit Qaf may interfinger with unit Qgdm. Unit Qaf is the product of reworking of Fraser-age glacial deposits (units Qgd, Qgo, Qgt, and Qga).

In the Morse Creek quadrangle, sea cliff exposures and water-well data suggest that the unit overlies Vashon recessional outwash (unit Qgo) and glaciomarine drift (unit Qgdm) (cross section A, Plate 2). In the adjacent Carlsborg quadrangle, this unit contains a tephra that was correlated with the Mazama ash dated at 6,730 ±40 ^{14}C yr B.P. (Schasse and Wegmann, 2000).

Qc_o **Sediments of the Olympia(?) nonglacial interval (Pleistocene)**—Poorly bedded to nonbedded, greenish gray to brown, peat-bearing silts and clays with lenses of stratified gray sandy pebbly gravel; west of Siebert Creek, grades laterally to a rusty brown granule to pebble gravel; clasts are well rounded and moderately well sorted. The thickness of the unit is uncertain.

Unit Qc_o is exposed in the lower 20 ft of sea cliffs along the Strait of Juan de Fuca (Plate 1). Sea cliff exposures of the unit extend from the east boundary of the quadrangle westward to about 2,500 ft west of Siebert Creek (see cross section D). Deformed greenish gray to bluish gray silty clay crops out along the stretch of Siebert Creek between the Strait of Juan de Fuca and the vicinity of U.S. Highway 101, suggesting that these clays have been overridden by glacial ice and that they probably belong to unit Qc_o.

We interpreted unit Qc_o from water-well logs as a sequence of relatively thin alternating clays and sands with small amounts of gravel underlying a thicker sequence of water-bearing sands and gravels.

The Olympia nonglacial interval has been dated outside the Morse Creek quadrangle. Radiocarbon dates from the type locality at Fort Lawton in Seattle range from 18.1 to 22.4 ka (Mullineaux and others, 1965), and dates in the central Puget Lowland extend to 28 ka (Hansen and Easterbrook, 1974; Easterbrook, 1976). Other deposits associated with this period are dated as 40.5 ±1.7 ka and perhaps 58.8 +2.9/-2.1 ka (Clague, 1981, p. 5, ^{14}C sample numbers GSC-2167 and Ql-195). In the adjacent Carlsborg quadrangle, wood from nonbedded bluish gray silty clay exposed along sea cliffs west of McDonald Creek produced a ^{14}C age of 34,930 ±850 yr B.P. and a second sample of wood from a peat bed approximately 300 ft from and 10 ft stratigraphically beneath the first sample produced a ^{14}C infinite age of >45,360 yr B.P. (Schasse and Wegmann, 2000).

For our study we collected four samples of wood from nonbedded to poorly bedded, peat-bearing, greenish gray to dark gray silty clay and olive-black to grayish brown clayey silt that are exposed in sea cliffs east of Siebert Creek and in stream banks of Siebert Creek. All four samples produced ^{14}C ages that were radiocarbon infinite (Appendix 2). Although these four samples do not indicate a particular interval, we favor their inclusion in the Olympia nonglacial beds. We base this inclusion on the lateral continuation of peat-bearing silty sediments from the Carlsborg quadrangle, which produced a finite age of approximately 35,000 yr B.P. (Schasse and Wegmann, 2000), into the Morse Creek quadrangle. We indicate uncertainty with this age assignment (and correlation to Olympia nonglacial sediments elsewhere) by querying the unit on Plates 1 and 2.

GLACIAL DEPOSITS

Fraser Glaciation, Vashon Stade

Qgdm **Glaciomarine drift (Pleistocene)**—Poorly sorted, weakly stratified to nonstratified, poorly compacted deposits of pebbly silt and clay and discontinuous layers of silty sand; weathers to a vertically jointed columnar appearance on vertical cliff faces; tan to gray, weathers dark to pale yellowish brown; rare marine fossils. The thickness in the study area is not well documented in water wells; however, it is typically 20 to 25 ft thick in the adjacent Carlsborg quadrangle (Schasse and Wegmann, 2000) and ranges from 5 to 20 ft thick where it is exposed at the top of coastal bluffs in the northeast corner of the Morse Creek quadrangle.

In the Morse Creek quadrangle north of the Old Olympic Highway, the glaciomarine drift forms a subtle terrace at an elevation of >38 m (125 ft), an elevation reported as a local glaciomarine high by Dethier and others (1995, fig. 3).

Dethier and others (1995) report a radiocarbon age of 12,600 ±200 yr B.P. from a shell in glaciomarine drift northeast of the study area (their locality 11, fig. 2), establishing that the glaciomarine drift in the Morse Creek area is roughly coeval with the Everson Interstade of the Fraser Glaciation. Although this unit is lithostratigraphically equivalent to Everson Glaciomarine Drift, it is not clear that the label Everson Glaciomarine Drift should be applied to deposits as far west as the Morse Creek area.

Qgo **Recessional outwash (Pleistocene)**—Stratified, moderately well-sorted sand and well-rounded pebble to cobble gravel, locally grading to sand; thin- to thick-bedded; generally loose; gray, tan, and light brown. The unit consists primarily of sand and gravel meltwater deposits. It may also include alluvial sand and gravel deposited by streams that flowed off the bedrock highs in the southern part of the quadrangle. Streams were active as ice receded in this area (Othberg and Palmer, 1979b), reworking and depositing detritus left by the retreating ice sheet. In the northeast corner of the quadrangle adjacent to Siebert Creek, recessional outwash deposits grade to alluvial fan deposits (unit Qaf). We mapped remnant stream-cut terraces in recessional outwash between Morse and Surveyor Creeks and along the upper east bank of Siebert Creek north of U.S. Highway 101.

Water-well data indicate that the thickness of the recessional outwash ranges from 0 to 90 ft and is most commonly 30 ft. Recessional outwash overlies Vashon till (unit Qgt), or Vashon advance outwash (unit Qga) where till is absent. It may be interbedded locally with glaciolacustrine deposits (unit Qgl) or with undivided glacial drift (unit Qgd) (cross section A, Plate 2).

The age of the recessional outwash is constrained between the time of recession of the Juan de Fuca lobe from its terminal zone, established by a radiocarbon date of 14,460 ±200 yr B.P. near the western margin of the Strait of Juan de Fuca (Heusser, 1973), and a radiocarbon date of 12,100 ±310 yr B.P. from wood collected from sediments 3 cm above Vashon till (unit Qgt) at the Manis Mastodon site in the Sequim quadrangle (Petersen and others, 1983). High outwash terraces along Morse and Siebert Creeks that record reworking and deposition of glacial and glaciofluvial sediments may be as young as early Holocene.

Qgl **Glaciolacustrine deposits (Pleistocene)**—Stratified, well-sorted clay, silt, sandy clay, and sand; displays alternating horizontal beds of silt and clay interrupted by thin beds of sand; brown to gray. This unit is poorly exposed at the surface and is best seen in the upper part of sea cliffs in the northeast corner of the quadrangle (north end of cross section A). The unit is also identified in water wells in the area of the Old Olympic Highway (cross section A), where the unit ranges in thickness from 0 to 60 ft.

We were unable to find datable material in unit Qgl. We correlate this unit with Vashon recessional outwash (unit Qgo) based on its stratigraphic position relative to Vashon till (unit Qgt) as shown in cross section A (Plate 2).

Qgt **Till (Pleistocene)**—Unstratified compact mix of poorly sorted pebbles, clay, sand, and silt with scattered cobbles and sparse boulders; yellowish gray to light gray and tan. This unit may locally include ablation till of varied thickness and generally forms irregular hummocky topography. Lodgment till lies stratigraphically between overlying recessional outwash (unit Qgo) and underlying advance outwash (unit Qga) in much of the subsurface. Locally, it underlies Vashon glaciolacustrine deposits (unit Qgl, cross section A).

Approximately one-half of the surface of the quadrangle is covered by lodgment till (Plate 1). It makes up most of the upland areas, except where bedrock crops out. The unit varies in thickness from 0 ft to possibly 100 ft as indicated in water-well logs. It is thinnest where it underlies the lowlands in the northern part of the quadrangle, where it averages only 10 to 15 ft thick and occurs only intermittently (Plate 2, cross sections A and D) In sea cliff exposures, the till thickness varies from 0 to 10 ft. Much of the till in this area was probably removed by subsequent glaciofluvial erosion during recession of the Vashon ice sheet. Till was mapped where thicker than about 5 ft.

The age of the Vashon till is bracketed by radiocarbon dates from Vashon advance outwash at Port Williams, 9 mi east of the quadrangle, of about 14.5 and 17.5 ka (Blunt and others, 1987) and a radiocarbon date of 14,460 ±200 yr B.P. from a bog on Vashon Drift near the western margin of the Strait of Juan de Fuca (Blunt and others, 1987).

Qga **Advance outwash (Pleistocene)**—Parallel-bedded and locally cross-bedded, well-sorted, sand and sandy pebble to cobble gravel; clasts well-rounded; local silts and clays; gray to grayish brown and grayish orange. This unit was deposited from meltwater directly in front of the advancing Vashon glacier. Advance outwash is generally more compacted than recessional deposits due to the weight of the overriding glacier. It tends to be more stained by iron oxide (and in some places is iron-oxide cemented) and generally contains a larger percentage of silt and clay relative to recessional outwash.

The unit is mapped where its stratigraphic position beneath Vashon till (unit Qgt) can be established. It lies stratigraphically above older (pre-Fraser) Pleistocene sediments (units Qc_o, $Qgpt_p$, and Qgpc) and locally rests on bedrock. In the Morse Creek quadrangle, the unit is exposed at the surface in two road cuts along Blue Mountain Road east of Siebert Creek and in sea cliffs (Plates 1 and 2).

In sea cliffs, the advance outwash consists of well-bedded sands and gravels, up to 40 ft thick, with prominent, crudely west-dipping (20–30° apparent dip) foreset or antidune beds (10–15 ft high). Very large (some 5 ft or more in diameter) angular to rounded boulders occur throughout the unit. The unit may contain till fragments. An apparent till sheet is visible in the cliff exposures near the top of the unit in the northeast corner of the quadrangle. Very large grayish-tan silt rip-up blocks that resemble underlying beds occur throughout the unit and are concentrated near the base of the unit where it is in erosional contact with older glacial and nonglacial units (units Qgpc and Qc_o). The foreset beds and beds with silt rip-up clasts are unique in that they are laterally continuous over a greater distance than any of the overlying or underlying units exposed in the sea cliffs and, wherever the contact is visible, occupy channels that eroded into underlying strata. The beds rise in elevation from the east boundary of the quadrangle to approximately 3,000 ft west of the mouth of Siebert Creek (a distance of about 2.5 mi), where they appear to transition to subhorizontally bedded sediments (cross section D). These beds probably represent a high-energy depositional environment, where one or possibly several glacial outburst flood events (jökulhlaups) or subglacial flows may have occurred during the advance of the Vashon ice sheet. We have queried unit Qga in the sea cliffs because their inaccessibility prevented us from studying the sediments in the unit closely.

We identified advance outwash in water-well logs as the first relatively thick deposits of sand and gravel beneath till. Where till is absent, we inferred a contact between recessional outwash (unit Qgo) and the advance outwash. The thickness of the advance outwash is varied in the subsurface. The advance outwash appears to be relatively thick in the vicinity of Morse and Siebert Creeks (Plate 2), where it has a maximum thickness of 150 ft. Elsewhere, it ranges from 30 to 70 ft thick.

The age of unit Qga in the Morse Creek area is bracketed between radiocarbon ages of 18,265 ±345 yr B.P. and 17,350 ±1,260 yr B.P. reported by Blunt and others (1987) from bluff exposures at Port Williams, 9 miles to the east.

Qgd **Drift, undivided (Pleistocene)**—Glacial deposits of Vashon age consisting of mixtures of sand and gravel, lodgment till, sandy ablation(?) till, and lacustrine(?) silts; commonly characterized by hummocky topography. This unit is used to represent those materials not differentiable as belonging to units Qgo, Qgl, Qgt, or Qga. We mapped remnant stream-cut terraces in unit Qgd near the mouth of Siebert Creek on its upper west banks.

Locally, water-well data did not allow a more detailed subdivision of units. In those instances, we show this undivided unit interbedded with adjacent Vashon glacial deposits (Plate 2).

The age range of unit Qgd is that of the included units (~12–19 ka).

Pre–Fraser Glaciation

$Qgpt_p$ **Possession Drift(?) (Pleistocene)**—Lodgement till, local flow till, and glaciolacustrine or glaciomarine drift; lodgement till consists of an unstratified compact mixture of gray, poorly sorted, sandy, pebbly silt and clay; 15 to 25 ft thick; tentatively mapped as Possession Drift based solely on stratigraphic position, where it underlies Vashon glacial deposits that locally contain till near the top of the sea cliffs (cross section D). In the sea cliff exposure, unit $Qgpt_p$ overlies cobbly to bouldery fluvial and possibly glaciofluvial gravels (unit Qgpc). The postulated Possession till is also present in valley sidewall exposures near the mouth of Bagley Creek and upvalley where lodgement till overlies fluvial or glaciofluvial gravels and underlies flow till. Upvalley, flow till is overlain by undated silt that is in turn overlain by apparent Vashon advance sand. At one location, approximately 20 ft of compact silty clay may represent Possession glaciolacustrine or glaciomarine drift.

Amino-acid analyses of marine shells from sea-cliff exposures of a glaciomarine drift at Port Williams (15 mi to the east) in a geologic setting similar to that at Bagley Creek suggest a mean age of 80 ±22 ka, which correlates with Possession glacial time (Blunt and others, 1987; Easterbrook and Rutter, 1981, 1982).

GLACIAL AND NONGLACIAL DEPOSITS

The units listed below consist of heterogeneous sediments that do not lend themselves to specific lithologic descriptions.

Fraser and pre-Fraser events

Qguc **Glacial and nonglacial deposits, undivided (Pleistocene)**—This unit is found along steep slopes of stream valleys and sea cliffs where exposures are poor and (or) map scale does not allow detailed delineation (Plate 1). We use unit Qguc as a summary unit where glacial and nonglacial units cannot be shown separately at map scale in near-vertical sea cliffs and where stream valleys reveal a complex mosaic of various geologic materials of glacial and nonglacial origin.

Geomorphic features within the valleys include active landslides, dormant (older, inactive) landslides, valley sidewalls that lack unambiguous evidence of landsliding, and river terraces of various ages. Some of the complexity of the exposures within unit Qguc is the result of mass wasting. Although some landslides (unit Qls) are shown in the valley sidewalls separately from unit Qguc, numerous areas within unit Qguc are also disturbed, and some are actively sliding. Landslide depiction is somewhat arbitrary and is restricted by such factors as map scale, size of landslide, degree of landslide activity, extent to which the landslide is apparent in aerial photographs, and accessibility. It is important to note, however, that all of the valley sidewalls are potentially unstable, and a site-specific geotechnical evaluation is advisable before any construction activities are undertaken within or near the valley sidewalls.

Pre-Fraser events

Qgpc **Glacial and nonglacial deposits, undivided (Pleistocene)**—Unit Qgpc is shown only in the cross sections (Plate 2). These sediments are mostly partially cemented, iron-oxide stained, pebbly, cobbly, and bouldery gravels with local, thin, discontinuous interbeds of sand and silt where exposed in sea cliffs. Gravels in the lower part of this unit have west-directed cross bedding as shown schematically in cross section D. This unit includes deposits identified in a limited number of water wells that are older than sediments of both the Olympia(?) nonglacial interval (unit Qc_o) and Possession(?) Drift (unit $Qgpt_p$) (Plate 2, cross sections A and D).

The age of this unit is unknown. Near the mouths of Morse and Bagley Creeks, it underlies what we have tentatively identified (based on stratigraphic position) as Possession Drift (unit $Qgpt_p$). Near the mouth of Siebert Creek it underlies what we have tentatively identified as Olympia-age nonglacial sediments. On that basis, the unit may be as old as or older than the Whidbey Formation (~100–140 ka), which was tentatively identified in the Sequim quadrangle, 15 mi to the east (Schasse and Logan, 1998). It may also be part of the Possession(?) Drift or the Olympia-age(?) nonglacial sediments.

Tertiary Sedimentary and Volcanic Rocks

Tertiary rocks in the Morse Creek quadrangle include the lower Miocene to upper Eocene Twin River Group, the middle Eocene Aldwell Formation, the early to middle Eocene Crescent Formation, and the Eocene to Paleocene(?) Blue Mountain unit. Brown and others (1960) mapped the rocks represented by these units at a scale of 1:62,500. Tabor and Cady (1978a) reinterpreted some of Brown and others' unit assignments in their later map of the Olympic Peninsula at a scale of 1:125,000. Because of limited time and resources, we drew heavily on the bedrock mapping of these previous workers, particularly for the less-accessible rocks that crop out along the canyon bottoms of Morse and Siebert Creeks.

TWIN RIVER GROUP

The Twin River Formation was originally defined by Arnold and Hannibal (1913) and redefined by Brown and Gower (1958). Snavely and others (1978) raised it to group status. Three formations make up the Twin River Group: the Pysht, the Makah, and the Hoko River Formations. All three are exposed in the Morse Creek quadrangle. Prior to the raising to group status, Brown and others (1960), who mapped the geology in the area that includes the Morse Creek quadrangle, referred to these rocks as the upper, middle, and lower members, respectively, of the Twin River Formation.

Pysht Formation

The Pysht Formation (Snavely and others, 1978) is upper Oligocene to lower Miocene (late Zemorrian to early Saucesian; see Plate 2) and gradational with the underlying Makah Formation.

$M\Phi m_{p}$ **Pysht Formation (Miocene to Oligocene)**—Massive poorly indurated mudstone, claystone, and sandy siltstone (lithofeldspathic to feldspatholithic); medium to dark greenish gray and dark gray, pale yellowish brown on weathered surfaces; poorly sorted; mudstone strata locally contain thin beds of calcareous claystone; argillaceous rocks contain sparsely disseminated calcareous concretions that are spherical, cylindrical, or irregular in shape; macrofossils, foraminifera, and carbonized plant material are common (Brown and others, 1960).

In the Morse Creek quadrangle, the unit is restricted to local structural depressions along the Clallam syncline (Plate 1) where the lowest strata in the formation are exposed. The thickness of the unit cannot be precisely determined in the study area because of poor exposure. By projecting structure inferred from exposures along Blue Mountain Road to bedrock penetrated by a limited number of water wells in that area, we infer that the thickness along the axial trace of the Clallam syncline is about 350 ft (cross section A, Plate 2).

Foraminifera from a sandy siltstone were assigned a Zemorrian Stage age by Weldon W. Rau (Appendix 3 and Plate 1, sample site 2). The sample also contained macrofossil fragments, which, together with the foraminiferal age, allowed us to assign the unit to the Pysht Formation.

Makah Formation

The middle formation of the Twin River Group, the Makah Formation, as described by Snavely and others (1980), is late Eocene to Oligocene (late Narizian(?) to late Zemorrian) in age. The contact with the underlying Hoko River Formation is in most places gradational and conformable (Snavely and others, 1978).

In the study area, Brown and others (1960) mapped the Makah Formation (which they referred to as the middle member of the Twin River Formation) at a scale of 1:62,500. They estimated the thickness of the unit on Morse Creek to be about 5,100 ft.

ΦEm_{m} **Makah Formation (Oligocene to Eocene)**—Siltstone and lithofeldspathic to feldspatholithic silty sandstone and sandstone; greenish gray on unweathered surfaces, light yellow-brown on weathered surfaces; mostly fine to medium bedded, locally thick bedded; sandstones are fine to medium grained and angular; unit contains calcareous concretions and nodules ranging in size from about 3 to 12 in. The Makah Formation is in gradational contact with the overlying Pysht Formation.

Foraminifera from the late Narizian(?) and Refugian Stages identified by Weldon W. Rau (this study) indicate that these rocks belong to the Makah Formation. (See Appendix 3 and Plate 1, sample localities 1, 3, 6, and 7).

Hoko River Formation

The lowest formation of the Twin River Group, the Hoko River Formation, is late Eocene (late Narizian) in age (Snavely and others, 1978).

In the Morse Creek area, Brown and others (1960) estimated 2,600 ft of the Hoko River Formation (which they called the lower member of the Twin River Group). They distinguished the unit chiefly by distinct bedding and by the presence of chloritized basaltic debris, which imparts a dark greenish gray color to the rock. They described the unit as consisting of approximately equal amounts of platy to massive fine- to medium-grained sandstone and bedded olive-gray siltstone that grade laterally and vertically and interfinger along strike. Brown and others (1960) also stated that beds of pebbly sandstone and conglomerate occur locally at the base of the unit, including in strata exposed in Morse and Siebert Creeks.

Brown and others (1960) mapped a sequence of sandstone, conglomerate, and siltstone that crops out near Morse Creek, south of the Lake Creek fault, as Lyre and Twin River Formations (undifferentiated). Tabor and Cady (1978a) later mapped those rocks as Twin River Group (undivided). In this study, we assign those rocks to the Hoko River Formation. We base our assignment on a similar sequence of rocks that crops out in McDonald Creek south of the extension of the Lake Creek fault that was mapped as Hoko River Formation in the adjoining Carlsborg quadrangle just east of the study area (Schasse and Wegmann, 2000).

Em_{2h} **Hoko River Formation (late Eocene)**—Interbedded, well-bedded, lithofeldspathic sandstone and siltstone; sandstone is medium to thin bedded (locally thick bedded); medium to very fine grained (locally coarse grained to granule size); gray to greenish gray and olive-gray on unweathered surfaces and light brown and moderate yellow-brown on weathered surfaces. The unit locally contains interbeds of medium- to very thick-bedded conglomeratic sandstone and conglomerate with rounded clasts of chert, basalt, rhyolite(?), and sandstone, angular siltstone rip-up clasts, and rare limestone clasts. The conglomeratic beds occur at Mount Pleasant, Buck Knoll ridge, Siebert and Morse Creeks, and in the vicinity of Lake Creek. Rare limestone beds and spherical to flattened calcareous concretions were noted along Siebert Creek.

The Hoko River Formation conformably grades to the overlying Makah Formation. The unit rests conformably on the underlying Aldwell Formation (unit Em_{2a}). It unconformably onlaps the Crescent Formation basalt (unit Ev_{c}) (cross section C) and apparently similarly onlaps the Blue Mountain unit conglomerate (unit ERm_{c}).

Samples from the unit in this study did not contain foraminifera. However, Rau (1964) identified foraminifera from the unit in the Morse Creek quadrangle and the adjacent Carlsborg quadrangle (Schasse and Wegmann, 2000) as belonging to the upper Narizian Stage of the Eocene.

ALDWELL FORMATION

The Aldwell Formation (Brown and others, 1960) is a sequence of well-indurated marine siltstone that overlies and interfingers with the Crescent Formation. Brown and others show it with an average thickness of 2,000 ft in the south limb of the Clallam syncline in the Morse Creek quadrangle (see cross section C and accompanying map, Plate 2).

Em_{2a} **Aldwell Formation (middle Eocene)**—Thin- to medium-bedded siltstone and sandy siltstone with thin- to medium-bedded, fine- to very fine-grained feldspatholithic sandstone interbeds; siltstone contains thin sandy laminations; thin to medium beds of fine-grained limestone or limey, very fine-grained sandstone occur locally; siltstone and sandy siltstone are shades of olive-gray to gray and black; sandstone is greenish gray and weathers to grayish brown, olive-gray, or moderate brown; limey beds are tan on weathered surfaces. In thin section, the rock consists of varying amounts of angular quartz, chert, plagioclase, volcanic lithic fragments, and alteration products consisting of chlorite, calcite, and limonite.

Exposures of the Aldwell Formation in the Morse Creek quadrangle are generally poor, occurring in road cuts and along the steep lower canyon walls of Morse and Siebert Creeks

None of the five samples collected from the Aldwell Formation in the study area contained foraminifera. In other areas, lower Narizian foraminifera characterize the Aldwell Formation and indicate a middle Eocene age (Armentrout and others, 1983; Rau, 1964). Part of the Ulatisian Stage may also be represented in the Aldwell Formation (Rau, 1964). Schasse and Wegmann (2000) found fauna representative of the lower Narizian and Ulatisian Stages in rocks that they mapped as Aldwell in the adjacent Carlsborg quadrangle.

CRESCENT FORMATION AND THE BLUE MOUNTAIN UNIT

Crescent Formation

The Crescent Formation was originally named by Arnold (1906) for exposures of basalt at Crescent Bay (Fig. 2). Brown and others (1960) redefined the Crescent Formation to include rocks between Lake Crescent and Hurricane Ridge. Cady and others (1972a,b) and Tabor and others (1972) subdivided the Crescent volcanic rocks into an upper subaerial basalt member and a lower submarine member. Pillowed flows with numerous diabase or gabbroic dikes and sills make up most of their lower member. Subordinate interbeds of basaltic breccia, hyaloclastites, basaltic sandstone, chert, and limestone occur throughout that member.

The Crescent basaltic rocks that crop out in the Morse Creek quadrangle belong to the lower submarine unit mapped by Tabor and Cady (1978a), Cady and others (1972a,b), and Tabor and others (1972). The thickness of the unit cannot be determined within the quadrangle. However, Brown and others (1960) mapped more than 10,000 ft (1.9 mi) of submarine basalts of the Crescent Formation near the east end of Lake Crescent, 20 mi west of the study area (Figure 2). Babcock and others (1992) described a measured composite section of 8.4 km (5.2 mi) of predominantly submarine flows in the Dosewallips River area 20 to 25 mi southeast of the Morse Creek quadrangle.

Sedimentary rocks interbedded with Crescent Formation basaltic rocks were mapped at two localities in the southwest part of the quadrangle. These rocks consists of volcanic sandstone and siltstone.

Ev_c **Basalt, basalt breccia, diabase, and rhyolite (early to middle Eocene)**—Aphyric, sparsely jointed basalt, pillow basalt, and lesser basaltic breccia, diabase (or gabbro), and local rhyolite. Basalts are dark gray and dark greenish gray, weathering to brown and dark brown. The basalt typically has a rounded blocky appearance. Basaltic breccia is much less common than the flows and consists of angular clasts of basalt, typically 2 to 4 in. in diameter. Diabase (or gabbro), possibly in the form of sills, is dark gray and white with a graphic texture. Rhyolite is tan and aphanitic, with laths of milky white feldspar phenocrysts.

Basaltic rocks in the Morse Creek quadrangle are typically composed of plagioclase laths and subhedral augite in a cryptocrystalline (altered glass), chloritic, and limonitic groundmass. Plagioclase (andesine or labradorite) is common and occurs as euhedral to subhedral laths, frequently bladed and intergranular with clinopyroxene. Clinopyroxene (probably augite) is abundant and is locally replaced by chlorite. Basalt locally contains amygdules of zeolites and chlorite. Accessories include limonite, calcite, unidentifiable matrix minerals (possibly clays), and unidentified opaque minerals.

Flows and breccias typically have basalt geochemistry (Appendix 4). A poorly exposed basalt flow north of Lake Creek and diabase from a small exposure just west of the quadrangle above Lake Creek both yielded trachybasalt geochemistry (Appendix 4). A small logging road cut north of Lake Creek exposed a rare rhyolite tuff or altered porphyry in proximity to basalt (geochemical locality 1, Appendix 4; also Plate 1). The rhyolite contains euhedral phenocrysts of Carlsbad(?)-twinned feldspar (sanidine?) in crystal cumulates of Carlsbad-, albite- and pericline-twinned feldspars. An occurrence of rhyolite within the Crescent Formation was reported by Schasse and Logan (1998) in the Sequim quadrangle, 12 mi to the east. Tabor and Cady (1978a) describe water-laid rhyolitic to dacitic tuffs on Striped Peak just east of Crescent Bay (Fig. 2) and cite Brown and others (1960) as their source. Brown and others (1960) describe the tuffaceous debris at Striped Peak as more closely related to andesite and dacite, leaving some uncertainty as to the actual existence of rhyolite in that area.

There are no previously published ages for the Crescent Formation in the Morse Creek study area. Foraminifera from sedimentary interbeds in the Crescent Formation elsewhere range in age from Penutian to Ulatisian (lower and lower–middle Eocene; Rau, 1981). Submarine basalts were dated with $^{40}Ar/^{39}Ar$ geochronometry (Babcock and others, 1992) in the Dosewallips section to the southeast and the Lake Crescent–Hurricane Ridge area west of the study area. Ages are: 56.0 ±1.0 Ma near the top at Dosewallips; 52.9 ±4.6 Ma just below the contact with the overlying Aldwell Formation at Crescent Lake; and 45.4 ±0.6 Ma at the base of the flows exposed on the Hurricane Ridge Road just west of the Morse Creek quadrangle. Brown and others (1960) have mapped exposures of basalt at the latter two areas as a contiguous unit. However, the age discrepancies indicate that basalts must be part of separate extrusive centers (Babcock and others, 1994).

Em_{1c} **Marine sedimentary rocks (early to middle Eocene)**—Medium- to thick-bedded, fine-grained, olive-gray, volcaniclastic sandstone with thin laminations of siltstone and coarse-grained sandstone or interbedded thin- to very thin-bedded siltstone and very fine-grained, gray to olive-gray feldspatholithic sandstone.

Three samples from small exposures in the southwest part of the quadrangle were analyzed for foraminiferal assemblages, but they did not contain assemblages sufficient to make an age determination. Sediments interbedded with the basaltic rocks of the Crescent Formation in the adjacent Carlsborg quadrangle contained foraminiferal assemblages that were Ulatisian or older (Schasse and Wegmann, 2000). These dates are consistent with dates provided elsewhere for similar sediments interbedded with the Crescent Formation (Rau, 1964).

Blue Mountain Unit

The Blue Mountain unit is an informal name assigned by Tabor and Cady (1978a) to marine sediments that underlie and interfinger with the Crescent volcanic rocks. The Blue Mountain unit crops out regionally in a basal stratigraphic position between the Hurricane Ridge fault and the overlying and locally interbedded volcanic rocks of the Crescent Formation (Fig. 2). The contact between the Blue Mountain unit and the Crescent volcanic rocks is varied. Cady and others (1972a,b), Tabor and others (1972), and Tabor and Cady (1978a) provide field evidence for a depositional contact along the eastern part of the Olympic Peninsula. Detailed studies by Einarsen (1987) in the northwest and eastern parts of the peninsula show that the contact is both faulted and depositional. Thin-bedded turbidites dominate the Blue Mountain unit, but a few very thick sandstone beds also occur throughout the unit. This unit is believed to be a submarine fan facies (Einarsen, 1987).

In the Morse Creek quadrangle, we infer an unconformable depositional contact between the conglomerate and pebbly sandstone facies of the Blue Mountain unit (unit ERm_{c}) and the overlying Hoko River Formation (unit Em_{2h}). Schasse and Wegmann (2000) describe the same contact relationship in the adjoining Carlsborg quadrangle, where these two units are exposed in close proximity to each other along McDonald Creek. Brown and others (1960) called rocks that we map as Blue Mountain unit (unit ERm) the Lyre and Twin River Formations undifferentiated and they show these rocks in apparent conformable contact with the overlying Aldwell Formation (unit Em_{2a}). Tabor and others (1972) mapped the continuation of those rocks in the Mount Angeles 15-minute quadrangle as sedimentary rocks associated with the Crescent Formation. Tabor and Cady (1978a) later informally named those rocks the Blue Mountain unit.

ERm **Blue Mountain unit, sandstone facies (Eocene to Paleocene?)**—Very thick- to thin-bedded, fine- to very coarse-grained, angular, moderately to poorly sorted, feldspatholithic to lithofeldspathic sandstone and lesser amounts of thin-bedded, fine-grained silty sandstone; lenses of very coarse sandstone and pebble conglomerate with pebbles of volcanic rocks, chert, and angular rip-up clasts of siltstone; sandstone is gray and weathers yellowish gray to brown; silty sandstone is medium dark gray to olive-black; coaly plant material, concentrated along fine-grained laminations, occurs locally. In thin section, these rocks consist of angular to subrounded quartz (some polycrystalline), broken plagioclase grains that have been partially altered, volcanic lithic fragments (with mafics altered to chlorite), and minor muscovite; calcite cement was also noted.

We were unable to date the Blue Mountain unit rocks in the Morse Creek study area. However, Weldon W. Rau (in Schasse and Wegmann, 2000) identified Ulatisian or older stage foraminiferal assemblages in the Blue Mountain unit just south of the Carlsborg quadrangle. Babcock and others (1994) reported ^{40}Ar/^{39}Ar ages from their study area on the north and northeast Olympic Peninsula and listed radiometric ages for the Crescent Formation reported by other workers in the Olympic Mountains. Some of those ages had maximums older than 57 Ma (Paleocene). These data provided the basis for our assigning an Eocene to Paleocene(?) age for the Blue Mountain unit (see correlation diagram, Plate 2).

ERm_{c} **Blue Mountain unit, conglomerate and pebbly sandstone facies (Eocene to Paleocene?)**—Medium- to very thick-bedded, gray conglomerate and pebbly feldspatholithic sandstone and minor interbedded siltstone; conglomerate clasts are predominantly angular to subrounded pebbles and cobbles of dark-gray chert, light-gray sandstone, felsic volcanic rocks, and very dark-gray to grayish black angular siltstone rip-up clasts; sandstone is very fine to medium grained, locally very coarse grained, angular, yellowish gray and grayish tan to olive, and poorly sorted; siltstone is very dark gray to black.

The unit is believed to be a submarine channel facies to the submarine fan facies of unit ERm (Einarsen, 1987).

STRUCTURAL GEOLOGY

Our interpretation of the bedrock structure is based in part on geologic structure mapped by Brown and others (1960) and Tabor and Cady (1978a), structural interpretations by MacLeod and others (1977) and Tabor (1983), data from water-well records from the Morse Creek quadrangle, and geologic structure in the adjoining Carlsborg quadrangle to the east (Schasse and Wegmann, 2000) and other quadrangles in the adjoining areas to the west and south.

The known major structures in the Morse Creek quadrangle are a series of folds trending northwest–southeast to nearly east–west, two high-angle thrust faults, and a north-northwest-trending high-angle fault (see Plates 1 and 2). Most of these structures were mapped by Brown and others (1960) and are shown on Plate 2 (cross section C with accompanying map; also see cross section A). The principal fold in the area is the doubly plunging Clallam syncline, which Brown and others (1960) mapped over a distance of 30 mi. In the Morse Creek quadrangle, the syncline contains rocks ranging from late Eocene to late Oligocene or early Miocene.

Several smaller eastward-plunging folds involve rocks that range in age from middle Eocene to early Oligocene. One of these folds, the Swamp Creek anticline, along with the Clallam syncline, extends eastward into the adjacent Carlsborg quadrangle (Schasse and Wegmann, 2000). We show two of the eastward-plunging folds, the Mount Pleasant anticline and the Morse Creek syncline, terminating against the concealed, unnamed, high-angle thrust fault that cuts diagonally across the northern part of the Morse Creek quadrangle (Plate 1). Because we see no evidence of the aforementioned folds in bedrock exposures in McDonald Creek, less that 1 mi to the east, we have inferred that the high-angle thrust fault mapped in the adjacent Carlsborg quadrangle (Schasse and Wegmann, 2000) extends into the Morse Creek quadrangle. Schasse and Wegmann (2000) mapped what they thought was the eastern extension of the Morse Creek syncline in the Carlsborg quadrangle, where rocks of the Hoko River Formation crop out along McDonald Creek in a syncline that is apparently of local extent. Detailed mapping in the Morse Creek quadrangle now indicates that the axial trace of the Morse Creek syncline trends farther north than reported earlier by Schasse and Wegmann.

Two high-angle thrust faults are mapped in the quadrangle. The fault with the greatest displacement, the Lake Creek fault, was first mapped by Brown and others (1960). They show a down-to-the-south stratigraphic displacement along the fault of about 5,000 ft (Plate 2, cross section C). The Lake Creek fault is offset by a younger, concealed, north-northwest-trending fault. Brown and others (1960) inferred the existence of this concealed fault to account for the juxtaposition along strike of rocks of the older Aldwell Formation (unit Em_{2a}) against rocks of the younger Hoko River Formation (unit Em_{2h}). The Lake Creek fault extends eastward, where Schasse and Wegmann (2000) map it in the adjoining Carlsborg quadrangle. There, they show the Lake Creek fault extension terminating against an unnamed high-angle thrust fault that extends into the Morse Creek quadrangle. We show the unnamed high-angle thrust fault cutting across the northern part of the Morse Creek quadrangle. MacLeod and others (1977), on the basis of geophysical data and then-current published geology, interpreted a thrust fault that they thought was the northwestward extension of a fault mapped by Cady and others (1972b) in the Tyler Peak 15-minute quadrangle to the southeast. MacLeod and others showed their fault extending to the northwest and terminating at Crescent Bay. Tabor (1983, p. 32) (citing MacLeod and others, 1977) also showed this fault on a simplified map of the Hurricane Ridge area, apparently agreeing with the interpretation of MacLeod and others. We concur with the interpretation of MacLeod and others (1977) and Tabor (1983) and have chosen to include their fault in our interpretation of the geology of the Morse Creek quadrangle. The rocks of the Pysht(?) and Makah Formations, where they are cut by this fault in the Morse Creek quadrangle, indicate minor stratigraphic offset in the subsurface (Plate 1 and Plate 2, cross section A). We believe this fault and the Lake Creek fault may be separate splays of a deeper thrust on which rocks of the Crescent Formation and younger sedimentary rocks ramp up and, along with the faults themselves, are rotated to near vertical and (or) overturned.

The age of faulting in the Morse Creek area has not been determined precisely. Evidence from this study indicates post–late Eocene displacement for the Lake Creek fault (Plate 1 and Plate 2, cross sections A and C) and post–late Oligocene to early Miocene displacement for the northern unnamed high-angle thrust fault (Plate 1). On the northern Olympic Peninsula, thrusting persisted from the middle Eocene (about 45 Ma) past the time of deposition of the Makah Formation (about 25 Ma) (Babcock and others, 1994). The Clallam Formation (mapped outside the study area) and the Pysht Formation reflect shallow marine and emergent conditions in the Tofino–Juan de Fuca basin. Lithologic evidence in other areas of the Olympic subduction complex indicates that uplift continued at least through the Pliocene. (See Babcock and others, 1994).

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REFERENCES CITED

Armentrout, J. M.; Hull, D. A.; Beaulieu, J. D.; Rau, W. W., coordinators, 1983, Correlation of Cenozoic stratigraphic units of western Oregon and Washington; Draft: Oregon Department of Geology and Mineral Industries Open-File Report O-83-5, 268 p., 1 pl.

Arnold, Ralph, 1906, Geological reconnaissance of the coast of the Olympic Peninsula, Washington: Geological Society of America Bulletin, v. 17, p. 451-468.

Arnold, Ralph; Hannibal, Harold, 1913, The marine Tertiary stratigraphy of the north Pacific coast of America: American Philosophical Society Proceedings, v. 52, no. 212, p. 559-605.

Babcock, R. S.; Burmester, R. F.; Engebretson, D. C.; Warnock, A. C.; Clark, K. P., 1992, A rifted margin origin for the Crescent basalts and related rocks in the northern Coast Range volcanic province, Washington and British Columbia: Journal of Geophysical Research, v. 97, no. B5, p. 6799-6821.

Babcock, R. S.; Suczek, C. A.; Engebretson, D. C., 1994, The Crescent "terrane", Olympic Peninsula and southern Vancouver Island. In Lasmanis, Raymond; Cheney, E. S., convenors, Regional geology of Washington State: Washington Division of Geology and Earth Resources Bulletin 80, p. 141-157.

Blunt, D. J.; Easterbrook, D. J.; Rutter, N. W., 1987, Chronology of Pleistocene sediments in the Puget Lowland, Washington. *In* Schuster, J. E., editor, Selected papers on the geology of Washington: Washington Division of Geology and Earth Resources Bulletin 77, p. 321-353.

Brandon, M. T.; Calderwood, A. R., 1990, High-pressure metamorphism and uplift of the Olympic subduction complex: Geology, v. 18, no. 12, p. 1252-1255.

Brown, R. D., Jr.; Gower, H. D., 1958, Twin River Formation (redefinition), northern Olympic Peninsula, Washington: American Association of Petroleum Geologists Bulletin, v. 42, no. 10, p. 2492-2512.

Brown, R. D., Jr.; Gower, H. D.; Snavely, P. D., Jr., 1960, Geology of the Port Angeles–Lake Crescent area, Clallam County, Washington: U.S. Geological Survey Oil and Gas Investigations Map OM-203, 1 sheet, scale 1:62,500.

Cady, W. M.; Sorensen, M. L.; MacLeod, N. S., 1972a, Geologic map of the Brothers quadrangle, Jefferson, Mason and Kitsap Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-969, 1 sheet, scale 1:62,500.

Cady, W. M.; Tabor, R. W.; MacLeod, N. S.; Sorensen, M. L., 1972b, Geologic map of the Tyler Peak quadrangle, Clallam and Jefferson Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-970, 1 sheet, scale 1:62,500.

Clague, J. J., 1981, Late Quaternary geology and geochronology of British Columbia; Part 2, Summary and discussion of radiocarbon-dated Quaternary history: Geological Survey of Canada Paper 80-35, 41 p.

Dethier, D. P.; Pessl, Fred, Jr.; Keuler, R. F.; Balzarini, M. A.; Pevear, D. R., 1995, Late Wisconsinan glaciomarine deposition and isostatic rebound, northern Puget Lowland, Washington: Geological Society of America Bulletin, v. 107, no. 11, p. 1288-1303.

Dickinson, W. R., 1970, Interpreting detrital modes of greywacke and arkose: Journal of Sedimentary Petrology, v. 40, no. 2, p. 695-707.

Drost, B. W., 1986, Water resources of Clallam County, Washington—Phase 1 report: U.S. Geological Survey Water-Resources Investigations Report 83-4227, 263 p., 5 pl.

Easterbrook, D. J., 1976, Quaternary geology of the Pacific Northwest. *In* Mahaney, W. C., editor, Quaternary stratigraphy of North America: Dowden, Hutchinson and Ross, p. 441-462.

Easterbrook, D. J.; Rutter, N. W., 1981, Amino acid ages of Pleistocene glacial and interglacial sediments in western Washington [abstract]: Geological Society of America Abstracts with Programs, v. 13, no. 7, p. 444.

Easterbrook, D. J.; Rutter, N. W., 1982, Amino acid analyses of wood and shells in development of chronology and correlation of Pleistocene sediments in the Puget Lowland, Washington [abstract]: Geological Society of America Abstracts with Programs, v. 14, no. 7, p. 480.

Einarsen, J. M., 1987, The petrography and tectonic significance of the Blue Mountain unit, Olympic Peninsula, Washington: Western Washington University Master of Science thesis, 175 p.

Engle, J. C., Jr., 1980, Cenozoic paleobathymetry and depositional history of selected sequences within the southern California continental borderland: Cushman Foundation Special Publication 19, p. 163-195.

Hansen, B. S.; Easterbrook, D. J., 1974, Stratigraphy and palynology of late Quaternary sediments in the Puget Lowland, Washington: Geological Society of America Bulletin, v. 85, no. 4, p. 587-602.

Heusser, C. J., 1973, Environmental sequence following the Fraser advance of the Juan de Fuca lobe, Washington: Quaternary Research, v. 3, no. 2, p. 284-306.

Hooper, P. R.; Johnson, D. M.; Conrey, R. M., 1993, Major and trace element analyses of rocks and minerals by automated X-ray spectrometry: Washington State University Geology Department Open File Report, 36 p.

Kleinpell, R. M., 1980, The Miocene stratigraphy of California revisited: American Association of Petroleum Geologists Studies in Geology 11, 349 p.

MacLeod, N. S.; Tiffin, D. L.; Snavely, P. D., Jr.; Currie, R. G., 1977, Geologic interpretation of magnetic and gravity anomalies in the Strait of Juan de Fuca, U.S.–Canada: Canadian Journal of Earth Sciences, v. 14, no. 2, p. 223-238.

Mallory, V. S., 1959, Lower Tertiary biostratigraphy of the California Coast Ranges: American Association of Petroleum Geologists, 416 p., 7 pl.

Montanari, Alessandro; Drake, Robert; Bice, D. M.; Alvarez, Walter; Curtis, G. H.; Turrin, B. D.; DePaolo, D. J., 1985, Radiometric time scale for the upper Eocene and Oligocene based on K/Ar and Rb/Sr dating of volcanic biotites from the pelagic sequence of Gubbio, Italy: Geology, v. 13, no. 9, p. 596-599.

Mullineaux, D. R.; Waldron, H. H.; Rubin, Meyer, 1965, Stratigraphy and chronology of late interglacial and early Vashon glacial time in the Seattle area, Washington: U.S. Geological Survey Bulletin 1194-O, 10 p.

Othberg, K. L.; Palmer, Pamela, 1979a, Preliminary surficial geologic map of the Carlsborg quadrangle, Clallam County, Washington: Washington Division of Geology and Earth Resources Open File Report, 79-20, 1 sheet, scale 1:24,000.

Othberg, K. L.; Palmer, Pamela, 1979b, Preliminary surficial geologic map of the Sequim quadrangle, Clallam County, Washington: Washington Division of Geology and Earth Resources Open File Report 79-18, 4 p., 1 pl., scale 1:24,000.

Petersen, K. L.; Mehringer, P. J., Jr.; Gustafson, C. E., 1983, Late-glacial vegetation and climate at the Manis Mastodon site, Olympic Peninsula, Washington: Quaternary Research, v. 20, no. 2, p. 215-231.

Rau, W. W., 1948, Foraminifera from the Porter shale (Lincoln Formation), Grays Harbor County, Washington: Journal of Paleontology, v. 22, no. 2, p. 152-174.

Rau, W. W., 1964, Foraminifera from the northern Olympic Peninsula, Washington: U.S. Geological Survey Professional Paper 374-G, 33 p., 7 pl.

Rau, W. W., 1981, Pacific Northwest Tertiary benthic foraminiferal biostratigraphic framework—An overview. *In* Armentrout, J. M., editor, Pacific Northwest Cenozoic biostratigraphy: Geological Society of America Special Paper 184, p. 67-84.

Salvador, Amos, 1985, Chronostratigraphic and geochronometric scales in COSUNA stratigraphic correlation charts of the United States: American Association of Petroleum Geologists Bulletin, v. 69, no. 2, p. 181-189.

Schasse, H. W.; Logan, R. L., 1998, Geologic map of the Sequim 7.5-minute quadrangle, Clallam County, Washington: Washington Division of Geology and Earth Resources Open File Report 98-7, 22 p., 2 plates.

Schasse, H. W., Wegmann, K. W., 2000, Geologic map of the Carlsborg 7.5-minute quadrangle, Clallam County, Washington: Washington Division of Geology and Earth Resources Open File Report 2000-7, 27 p, 2 plates.

Snavely, P. D., Jr., 1983, Day 1—Peripheral rocks—Tertiary geology of the northwestern part of the Olympic Peninsula, Washington. In Muller, J. E.; Snavely, P. D., Jr.; Tabor, R. W., The Tertiary Olympic terrane, southwest Vancouver Island and northwest Washington: Geological Association of Canada Victoria Section Field Trip 12, p. 6-31.

Snavely, P. D., Jr.; Niem, A. R.; MacLeod, N. S.; Pearl, J. E.; Rau, W. W., 1980, Makah Formation—A deep-marginal-basin sequence of late Eocene and Oligocene age in the northwestern Olympic Peninsula, Washington: U.S. Geological Survey Professional Paper 1162-B, 28 p.

Snavely, P. D., Jr.; Niem, A. R.; Pearl, J. E., 1978 [1979], Twin River Group (upper Eocene to lower Miocene)—Defined to include the Hoko River, Makah, and Pysht Formations, Clallam County, Washington. *In* Sohl, N. F.; Wright, W. B., Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1977: U.S. Geological Survey Bulletin 1457-A, p. 111-120.

Tabor, R. W., 1983, Day 2—Eastern core rocks of the Olympic Mountains, Washington. *In* Muller, J. E.; Snavely, P. D., Jr.; Tabor, R. W., The Tertiary Olympic terrane, southwest Vancouver Island and northwest Washington: Geological Association of Canada Victoria Section Field Trip 12, p. 31-45.

Tabor, R. W.; Cady, W. M., 1978a, Geologic map of the Olympic Peninsula, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-994, 2 sheets, scale 1:125,000.

Tabor, R. W.; Cady, W. M., 1978b, The structure of the Olympic Mountains, Washington—Analysis of a subduction zone: U.S. Geological Survey Professional Paper 1033, 38 p.

Tabor, R. W.; Yeats, R. S.; Sorensen, M. L., 1972, Geologic map of the Mount Angeles quadrangle, Clallam and Jefferson Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-958, 1 sheet, scale 1:62,500.

Varnes, D. J., 1978, Slope movement types and processes. *In* Schuster, R. J.; Krizek, R. J., editors, Landslides—Analysis and control: National Research Council Transportation Research Board Special Report 176, p. 11-33.

Washington Department of Ecology, 1978, Coastal zone atlas of Washington; Volume 12, Clallam County: Washington Department of Ecology, 1 v., maps, scale 1:24,000.

Zanettin, Bruno, 1984, Proposed new chemical classification of volcanic rocks: Episodes, v. 7, no. 4, p. 19-20. ■

Appendix 1. Water wells used in constructing cross sections

To construct the cross sections, 61 wells were used: 18 were field checked by the USGS, located during field work for this study, and (or) accurately located using the current Clallam County rural and urban addressing system; 43 were approximately located using location to the nearest quarter-quarter section, surface elevation, and address submitted to the Washington Department of Ecology. **Completed**, date completed; **Elev.**, elevation of land surface in feet; **Depth**, drilled depth in feet; **Qual.**, quality of location information: C, location field checked or determined from county address system; U, not field checked and (or) not located using county address system.

Location	Owner	Completed	Elev.	Depth	Qual.
29N/05W-01F01	Pamela Sanguinelli	06/05/1985	1,080	240	U
29N/05W-01G01	James Bower	08/04/1978	1,100	79.5	U
29N/05W-01L01	John Gawley	12/11/1997	1,145	200	U
29N/05W-01N01	John and Bev King	06/06/1996	1,275	170	U
29N/05W-01N02	Nick Larson	01/28/1977	1,225	210	U
29N/05W-12E01	Alain De Chantel	07/03/1992	1,550	264	U
29N/05W-12F01	Williard Henkes	07/25/1998	1,610	700	U
29N/05W-12F03	Ronald L. Kallock	10/20/1994	1,425	200	U
29N/05W-12M01	Bob Montgomery	05/17/1994	1,585	184	U
29N/05W-12M02	Greg Peterson	05/24/1994	1,480	286	U
29N/05W-12N01	Bob Montgomery	12/08/1999	1,425	62	U
29N/05W-13D01	Kathy White	04/11/1996	1,485	104	U
29N/05W-13L01	Dechantal Development	09/24/1996	1,600	254	U
29N/05W-13P01	Richard Sherman	09/05/1996	1,650	100	U
29N/05W-14A01	Willard Henkes	01/05/1996	1,450	42	U
30N/05W-10F01	PUD #1 of Clallam Co.	01/03/1966	190	214	C
30N/05W-11A01	Gail Seward	05/05/1989	150	313	U
30N/05W-11M01	Allen Paulson	04/12/1982	260	262	C
30N/05W-11Q01	Alfred V.D. Doering	06/18/1999	225	300	U
30N/05W-12E01	Tom Erickson	09/18/1996	170	102	U
30N/05W-12K01	Richard Bruckner	08/28/1975	172	130	C
30N/05W-12L01	Yvonne Luce	07/20/1994	170	121	U
30N/05W-12N01	Larry Sampson	06/24/1995	190	75	U
30N/05W-12R01	Jerry Schmidt	09/12/1985	170	169	U
30N/05W-14B01	Greg Houghton	11/13/1996	250	366	U
30N/05W-14C01	C.I.P. Inc.	06/09/1995	310	342	C
30N/05W-14H01	Ray H. Petersen	04/23/1966	255	235	U
30N/05W-15P01	D & V Bodhaine	12/12/1990	410	140	U
30N/05W-19A01	Jake Schenefeld	12/21/1994	460	110	U
30N/05W-19B01	Lars E. Sharpe	01/03/1978	470	127	U
30N/05W-19G01	Dean Roark	10/26/1998	590	170	U
30N/05W-19Q02	Vic Hulse	03/16/1977	640	152	C

Location	Owner	Completed	Elev.	Depth	Qual.
30N/05W-20A01	Byron Rogers	05/11/1979	440	95	U
30N/05W-20G01	Ed Petersen	02/11/1994	490	132	C
30N/05W-20G02	DeAnne Chapman	09/21/1994	515	167	U
30N/05W-21B01	John E. Schmocker	06/10/1963	450	90	C
30N/05W-22D01	Great Northern Savings and Loan	08/24/1982	465	125	U
30N/05W-22L01	Bill Morris	08/05/1986	580	143	U
30N/05W-22R01	Stephen Ramsey	04/14/1997	660	168	U
30N/05W-23B01	Bob Beaudette	05/28/1990	375	105	C
30N/05W-23C01	Dave Deaver	04/07/1983	450	162	C
30N/05W-23J01	Clallam Co. Dept. of Public Works	08/28/1974	510	104	U
30N/05W-23N01	Tom Schmid	06/13/1992	625	100	C
30N/05W-25A01	Kevin Size	10/25/1997	620	241	C
30N/05W-25B01	Gordon Barnett	01/23/1990	600	221	C
30N/05W-25C01	Charles Athay	08/27/1978	570	120	U
30N/05W-25D01	Robert Gratton	09/22/1978	610	154	C
30N/05W-26J01	Sal Neilsen	02/08/2000	700	104	U
30N/05W-26K01	Keith Peters	08/17/1978	690	261	C
30N/05W-26K02	Jace Schmitz	06/04/1997	720	149	U
30N/05W-26Q01	Hugh Hoffner	10/02/1990	825	122	C
30N/05W-26R01	Sharon Page	06/15/1999	770	198	U
30N/05W-27A01	Roland West	07/01/1992	670	155	C
30N/05W-28C01	James Loran	09/05/1995	640	260	U
30N/05W-29C01	Richard L. Ward	08/08/1998	550	200	U
30N/05W-30B01	Rod and Jana Daebelliehn	01/25/1999	650	209	U
30N/05W-30C01	Dick Shores	04/23/1977	670	240	C
30N/05W-35J01	David Jackson	06/24/1996	880	90.5	U
30N/05W-35Q01	Roger Wiswell	08/07/1996	950	228	U
30N/05W-36D01	Brad Varner	06/22/1988	860	213	C
30N/05W-36E01	Chris Griffith	03/14/1977	840	94	U

Appendix 2. Radiocarbon ages

Radiocarbon sample sites are shown on Plate 1. Analyses were performed by Beta Analytic, Inc. (Miami, Fla.). Dates are reported as radiocarbon years before 'present' (RCYBP; 'present' = 1950 AD). By international convention, the modern reference standard was 95% of the ^{14}C content of the National Bureau of Standards' Oxalic Acid and calculated using the Libby ^{14}C half life (5568 years). Quoted errors represent 1 standard deviation (68% probability) and are based on combined measurements of the sample, background, and modern reference standards. Measured $^{13}C/^{12}C$ ratios were calculated relative to the Pacific Deep Belemnite No. 1 (PDB-1) international standard and the RCYBP ages were normalized to -25 per mil. If the ratio is accompanied by an asterisk (*), then the $^{13}C/^{12}C$ value was estimated, based on values typical of the material type. Quoted results are not calibrated to calendar years.

Radiocarbon sample site 1: unit Qguc (Qc_o?)

Wood fragments collected from peat about 18 ft above beach level. Peat occurs 2.5 ft below the top of a 8 ft thick unit of dark gray, (late?) Pleistocene nonglacial silt and clay (unit Qc_o?) overlying 7 ft of sand and gravel. Sample is stratigraphically below glacial sediment (Vashon drift, ~80 ft, with ~5 ft of till mid-section).

Measured ^{14}C age (yr B.P.)	$^{13}C/^{12}C$ ratio	Conventional ^{14}C age (yr B.P.)
>44,850	-25.0*‰	>44,850

Sample no. MP-7-12-00-5 (analysis ID: Beta-154456)
Material (pretreatment): wood (acid/alkali/acid)
Analysis: radiometric-standard

Radiocarbon sample site 2: unit Qguc (Qc_o?)

Flattened wood fragments collected from a 5 to 8 ft thick zone containing significant amounts of peat with wood. This zone occurs within a 11 to 17 ft thick, (late?) Pleistocene nonglacial silt to silty clay unit (unit Qc_o?). The wood is exposed about 20 ft above beach level, along a coastal bluff section about 0.9 mi (shoreline distance) east of Siebert Creek (Green Point) along the Strait of Juan de Fuca. The sample lies stratigraphically below glacial sediment (Vashon drift, ~100 ft). Sample overlies compact, cross-bedded sand and gravel (15 ft) of indeterminate age and association.

Measured ^{14}C age (yr B.P.)	$^{13}C/^{12}C$ ratio	Conventional ^{14}C age (yr B.P.)
>45,900	-25.0*‰	>45,900

Sample no. MP-7-12-00-3 (analysis ID: Beta-152493)
Material (pretreatment): wood (acid/alkali/acid)
Analysis: radiometric-standard

Radiocarbon sample site 3: unit Qguc (Qc_o?)

Wood fragment from stream cutbank along Siebert Creek, about 1 mi south of the shoreline of the Strait of Juan de Fuca. Cut bank exposes greenish gray, (late?) Pleistocene nonglacial silty clay (5 ft) with contorted pockets of silty gravel (unit Qc_o?). Sample collected about 2 to 3 ft above water line from silty clay just beneath a gravel packet. Sample site is laterally continuous with clayey silt of sample site 4. Sampled unit is stratigraphically overlain by 10 ft of brown, loose, bouldery, Holocene terrace deposits.

Measured ^{14}C age (yr B.P.)	$^{13}C/^{12}C$ ratio	Conventional ^{14}C age (yr B.P.)
>41,400	-25*‰	>41,400

Sample no. HS-7-24-00-4 (analysis ID: Beta-152496)
Material (pretreatment): wood (acid/alkali/acid)
Analysis: radiometric-standard

Radiocarbon sample site 4: unit Qguc (Qc_o?)

Peaty wood fragments sampled about 4 to 5 ft above a (low discharge) water line in stream cutbank along Siebert Creek, about 0.5 mi south of the shoreline of Strait of Juan de Fuca. Cut bank exposes olive black to grayish brown, late Pleistocene nonglacial clayey silt with fragments and wavy layers of peaty wood (unit Qc_o?). Sample is of uppermost observed wood fragments. At stream level, the silt contains thin lenses of olive black, small pebble gravel. Sampled clayey silt is laterally continuous with silty clay of sample site 3. Clayey silt is stratigraphically overlain by 2 ft of oxidized, grayish orange sand and cobbly gravel.

Measured ^{14}C age (yr B.P.)	$^{13}C/^{12}C$ ratio	Conventional ^{14}C age (yr B.P.)
>45,040	-25*‰	>45,040

Sample no. HS-7-24-00-3 (analysis ID: Beta-152495)
Material (pretreatment): wood (acid/alkali/acid)
Analysis: radiometric-standard

Radiocarbon sample site 5: unit Qp

Chunks of peat (0.5 ft) sampled from road cut exposure of a sheet of homogeneous, hard and fine-grained peat within gray, sandy silt with few pebbles and cobbles. Silt also forms thin, weakly developed surface soil above peat.

Measured ^{14}C age (yr B.P.)	$^{13}C/^{12}C$ ratio	Conventional ^{14}C age (yr B.P.)
6,330 ±60	-25*‰	6,330 ±60
(Corresponds to calendar date of BC 5460 to 5220)		

Sample no. HS-7-19-00-8 (analysis ID: Beta-1152494)
Material (pretreatment): peat (acid/alkali/acid)
Analysis: radiometric-standard

Appendix 3. Foraminifera from the Morse Creek quadrangle

by Weldon W. Rau

Sample numbers below correspond to sample numbers in the table on page 17.

SITE 1—HS-9-29-00-1

This assemblage is diagnostic of the Refugian Stage. Particularly significant are the presence of *Sigmomorphina schencki*, *Plectofrondicularia* cf. *P. packardi,* and *Guttulina frankei*. Although not clearly indicated, it may best be referred to a lower part of the stage, largely because of the presence of *Sigmomorphina schencki* (Rau, 1948, 1981).

Water depths of deposition were likely upper bathyal to upper middle bathyal (400–1500 m), based largely on the common occurrence of *Anomalina* cf. *A. garzaensis*, *Gyroidina orbicularis planata*, and *Melonis pompilioides* (Engle, 1980).

SITE 2—HS-9-27-00-5

An Oligocene, Zemorrian Stage age is distinctly indicated by this assemblage. The common presence of *Anomalina californiensis* together with *Valvulineria* cf. *V. menloensis*, *Lenticulina* cf. *L. calcar*, and *Dentalina* cf. *D. quadrulara* are most significant stratigraphically (Rau, 1948, 1981).

Water depths of deposition, based on the common occurrence of *Anomalina californiensis* together with a few *Cassidulina* cf. *C. crassipunctata* and *Pseudoglandulina* sp. suggest upper to upper middle bathyal conditions (400–1000 m) (Engle, 1980).

SITE 3—HS-9-27-00-2

This assemblage distinctly represents the Narizian Stage and more specifically an upper part. *Gyroidina* cf. *G. condoni*, *Valvulineria tumeyensis*, and *Valvulineria jacksonensis* cf. *J. welcomensis* are particularly significant stratigraphically (Rau, 1964, 1981).

Water depths during deposition were probably upper bathyal to upper middle bathyal (400–2000 m), as suggested particularly by *Gyroidina orbicularis planata*, *Valvulineria tumeyensis*, and *Gyroidina* cf. *G. condoni* (Engle, 1980).

SITE 4—HS-9-22-00-1

There is not sufficient material in this assemblage to make a determination.

SITE 5—HS-10-11-00-3B

Not enough material to make any determination.

SITE 6—HS-7-21-98-3

The common occurence of *Uvigerina cocoaensis* together with the presence of *Ceratobulimina* sp. and *Alabamina* sp. indicate a Refugian Stage age (Rau, 1948, 1981).

Water depths during deposition were quite deep, that is, no less than upper middle bathyal and perhaps as deep as upper lower bathyal depths (1000–2000 m), based on the common occurrence of *Uvigerina cocoaensis* and *Melonis pompilioides* together with the presence of *Alabamina* sp. (Engle, 1980).

SITE 7—HS-9-13-00-1

This assemblage, although not completely diagnostic, is best referred to a lower Refugian or uppermost Narizian Stage. *Plectofrondicularia* cf. *P. packardi* and *Valvulineria* cf. *V. willapaensis* are particularly significant in placing this assemblage stratigraphically (Rau, 1964, 1981).

Gyroidina orbicularis planata and *Valvulineria* cf. *V. willapaensis* are particularly significant in indicating bathyal conditions, probably upper to middle bathyal (400–2000 m) (Engle, 1980).

SITE 8—HS-8-31-00-3

Not enough material to make any determination.

Samples in this table are identified by a sample number followed by a DNR/DGER state slide file number (S-#) and a site number. The sites from which the samples were collected are shown on Plate 1. C, common; F, few; R, rare; ?, identification uncertain.	**Sample no. and locality**							
Taxa	HS-9-29-00-1 (S-1211) (1)	HS-9-27-00-5 (S-1215) (2)	HS-9-27-00-2 (S-1214) (3)	HS-9-22-00-1 (S-1213) (4)	HS-10-11-00-3b (S-1210) (5)	HS-7-21-98-3 (S-1216) (6)	HS-9-13-00-1 (S-1212) (7)	HS-8-31-00-3 (S-1209) (8)
Cyclammina sp.			C		R		F	F
Gyroidina sp.								R
Involutina sp.					R			
Cyclammina pacifica Beck	F							
Plectofrondicularia cf. *P. packardi* Cushman and Schenck	F						R	
Cornuspira byramensis Cushman	R	R						
Sigmomorphina schencki Cushman and Ozawa	F							
Anomalina cf. *A. garzaensis* Cushman and Siegfus	C							
Gyroidina orbicularis planata Cushman	C	F	C				F	
Quinqueloculina imperialis Hanna and Hanna	C	F	F			F		
Pyrgo lupheri Rau	R							
Melonis pompilioides (Fichtel and Moll)	C					C		
Cibicides elmaensis Rau	C		F				F	
Lenticulina cf. *L. inornatus* (d'Orbigny)	C	C	F	R			F	
Guttulina frankei Cushman and Ozawa	C	F						
Quinqueloculina weaveri Rau	C	C						
Entosolenia sp.	R							
Lagena sp.	R	R						
Dentalina spp.	F	F	F					
?*Karreriella* sp.							C	
Haplophragmoides sp.							C	
Allomorphina cf. *A. macrostomata* Karrer			R	R			F	
Nodosaria cf. *N. longiscata* (d'Orbigny)				R			R	
Valvulineria cf. *V. willapaensis* Rau							R	
Eponides umbonata (Reuss)			F					
Gyroidina cf. *G. condoni* (Cushman and Schenck)			R					
Cibicides cf. *C. pseudoungerianus* (Cushman)			F					
Valvulineria jacksonensis cf. *J. welcomensis* Mallory			R					
Valvulineria tumeyensis Cushman and Simonson			C					
Uvigerina sp.			R					
Karreriella cf. *K. elongata* Mallory			C					
Karreriella cf. *K. washingtonensis* Rau		R	R					
Dorothia cf. *D. principiensis* Cushman and Burmudez			R					
Globulimina sp.			R					
Pseudoglandulina sp.		F	R			R		
Chilostomella cf. *C. oolina* Schwager			R					
Eponides sp.			R					
Cassidulina cf. *C. crassipunctata* Cushman and Hobson		F				R		
Anomalina californiensis Cushman and Hobson		C						
Valvulineria cf. *V. menloensis* Rau		R						
Planulina sp.		R						
Dentalina cf. *D. communis* d'Orbigny		F						
Dentalina cf. *D. quadrulata* Cushman and Laiming		R						
Plectofronduculina cf. *P. packardi multilineata* Cushman and Simonson		R						
Lenticulina cf. *L. calcar* (Linne)		R						
Uvigerina cocoaensis Cushman						C		
Nodosaria cf. *N. grandis* Reuss						R		
Ceratobulimina sp.						R		
Alabamina sp.						R		
Guttulina sp.						R		

Appendix 4. Geochemical data

Rigaku automated X-ray fluorescence spectrometer (XRF) analyses of rocks in the Morse Creek 7.5-minute quadrangle, performed at the Geoanalytical Laboratory, Department of Geology, Washington State University (WSU), Pullman, WA 99164-2812. Methods and estimates of the precision and accuracy are described in Hooper and others (1993). Major element analyses are normalized on a volatile-free basis, with total Fe expressed as FeO. Sample locations are shown on Plate 1. One sample was collected just outside the boundary of the Morse Creek 7.5-minute quadrangle; sample HS-10-12-00-5 (locality 3) was collected 1000 ft west of the quadrangle boundary along an old logging road cut in the Port Angeles 7.5-minute quadrangle (lat 48°02′11″N, long 123°22′17″W). Loc., locality number; †, value is greater than 120 percent of the lab's highest standard; ppm, parts per million.

MAJOR AND MINOR ELEMENTS, UNNORMALIZED RESULTS (WEIGHT %)

Loc.	Sample no.	Rock unit	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	Total
1	HS-10-6-00-5	Ev_c, rhyolite	74.98	12.18	0.169	2.55	0.019	0.35	0.33	1.58	5.67	0.020	97.85
2	HS-10-11-00-2	Ev_c, trachybasalt	49.34	13.54	1.462	10.86	0.128	6.11	9.37	1.99	3.76	0.121	96.68
3	HS-10-12-00-5	Ev_c, trachybasalt	47.43	12.80	2.546	14.49	0.236	8.57	5.57	0.27	5.20	0.223	97.34
4	HS-10-13-00-1A	Ev_c, basalt	47.99	14.96	1.263	11.12	0.174	11.81	7.13	0.49	3.04	0.113	98.09
5	HS-9-7-00-3	Ev_c, basalt	47.76	15.82	1.051	10.43	0.186	10.04	7.19	0.78	3.70	0.116	97.08

MAJOR AND MINOR ELEMENTS, NORMALIZED RESULTS (WEIGHT %)

Loc.	Sample no.	Rock unit	SiO_2	Al_2O_3	TiO_2	FeO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	Total
1	HS-10-6-00-5	Ev_c, rhyolite	76.63	12.45	0.173	2.60	0.019	0.36	0.34	1.61	5.79	0.020	100.0
2	HS-10-11-00-2	Ev_c, trachybasalt	51.04	14.01	1.512	11.23	0.132	6.32	9.69	2.06	3.89	0.125	100.0
3	HS-10-12-00-5	Ev_c, trachybasalt	48.73	13.15	2.616	14.89†	0.242	8.80	5.72	0.28	5.34	0.229	100.0
4	HS-10-13-00-1A	Ev_c, basalt	48.92	15.25	1.288	11.34	0.177	12.04	7.27	0.50	3.10	0.115	100.0
5	HS-9-7-00-3	Ev_c, basalt	49.20	16.30	1.083	10.75	0.192	10.34	7.41	0.80	3.81	0.119	100.0

TRACE ELEMENTS (PPM)

Loc.	Sample no.	Rock unit	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th
1	HS-10-6-00-5	Ev_c, rhyolite	8	0	5	10	316	21	69	364	82	31.9	19	4	136	1	22	57	4
2	HS-10-11-00-2	Ev_c, trachybasalt	119	318	49	326	161	9	217	82	25	6.8	19	120	48	1	13	33	2
3	HS-10-12-00-5	Ev_c, trachybasalt	27	137	66†	437	164	1	102	189	54	8.3	22	151	95	3	3	40	1
4	HS-10-13-00-1A	Ev_c, basalt	74	281	47	329	131	6	222	78	32	7.1	17	167	87	7	24	19	0
5	HS-9-7-00-3	Ev_c, basalt	68	212	44	268	142	9	465	77	30	7.8	18	129	79	3	9	17	0