NATURAL RESOURCES

# Geologic Map of the Carlsborg 7.5-minute Quadrangle, Clallam County, Washington

by Henry W. Schasse
and Karl W. Wegmann

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Open File Report 2000-7
December 2000

Location of quadrangle

WASHINGTON STATE DEPARTMENT OF
**Natural Resources**
**Jennifer M. Belcher** - Commissioner of Public Lands

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*Produced in cooperation with the U.S. Geological Survey*
*National Cooperative Geologic Mapping Program*
*Agreement Number 99HQAG0136*

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# Geologic Map of the Carlsborg 7.5-minute Quadrangle, Clallam County, Washington

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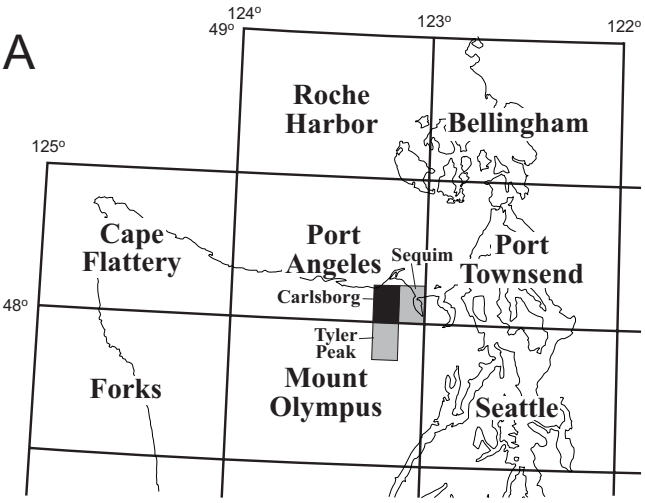
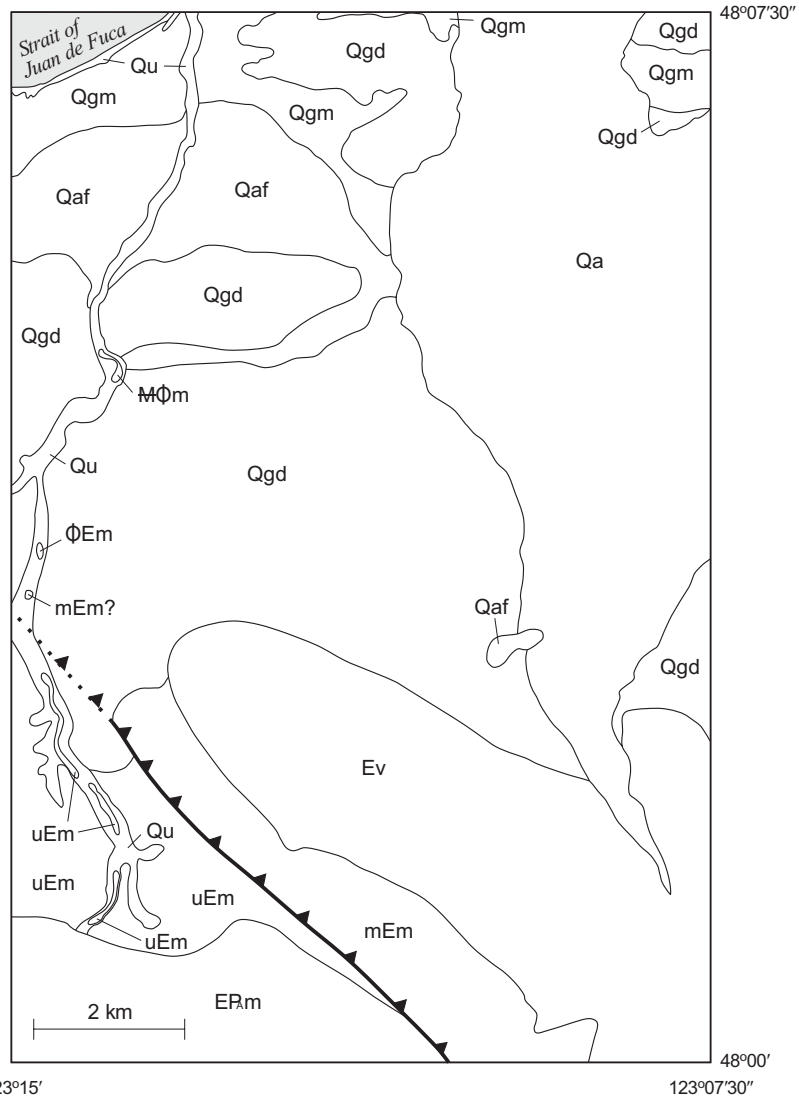
## INTRODUCTION

This report consists of a geologic map and cross sections (Plates 1 and 2) accompanied by descriptions and a correlation diagram of the geologic units. The report also discusses late Quaternary glacial and nonglacial deposition as well as our interpretation of the bedrock structure, based in part on data from water-well records from the Carlsborg quadrangle, geologic structure in the adjoining Sequim quadrangle to the east, and geologic structure mapped by others in the adjoining areas to the west and south. Tertiary sedimentary units, previously mapped as undivided rocks of the Twin River Group, are herein assigned to the Pysht, Makah, and Hoko River Formations (Snavely and others, 1978, 1980).

The Carlsborg 7.5-minute quadrangle is located in the southeast quarter of the Port Angeles 30- by 60-minute quadrangle (Fig. 1A). It 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. The Olympic Mountains are an accreted subduction complex composed of two geologic terranes. A peripheral belt of Lower and Middle Eocene oceanic basaltic rocks, partly intertongued with Paleocene(?) to Eocene continental sediments of the Blue Mountain unit, are collectively included with the Crescent Formation and, together with




B

**EXPLANATION**

**Quaternary Surficial Deposits**

| | |
|---|---|
| Qa | Alluvium, undivided (Holocene to Pleistocene?) |
| Qaf | Alluvial fan deposits (Holocene to Pleistocene?) |
| Qgm | Glaciomarine drift (Pleistocene) |
| Qu | Undifferentiated sediments—Includes landslide deposits, alluvium, and undivided glacial and nonglacial deposits (Holocene to Pleistocene) |
| Qgd | Glacial drift, undivided—Includes till, recessional outwash, and ice-contact stratified recessional outwash (Pleistocene) |

**Tertiary Sedimentary and Volcanic Rocks**

| | |
|---|---|
| MΦm | Marine sedimentary rocks (Miocene to Oligocene) |
| ΦEm | Marine sedimentary rocks (Oligocene to Eocene) |
| uEm | Marine sedimentary rocks (upper Eocene) |
| mEm | Marine sedimentary rocks (middle Eocene) |
| Ev | Volcanic rocks of the Crescent Formation (Eocene) |
| ERm | Marine sedimentary rocks of the Blue Mountain unit of the Crescent Formation (Eocene to Paleocene?) |

Thrust fault—Dotted where concealed

**Figure 1. A.** 1:100,000-scale quadrangles in the northwestern part of Washington State and location of the Carlsborg 7.5-minute quadrangle. **B.** Simplified geologic map of the Carlsborg 7.5-minute quadrangle. Areas of glacial cover over bedrock (units Ev, ERm, uEm, and mEm) in the southern third of the quadrangle not shown.

an overlying sequence of Middle Eocene to Upper Miocene marine sedimentary rocks, form what has been called the Crescent terrane by Babcock and others (1994). These rocks wrap around 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 the Juan de Fuca plate and later accreted to the Olympic Peninsula by thrust faulting (Brandon

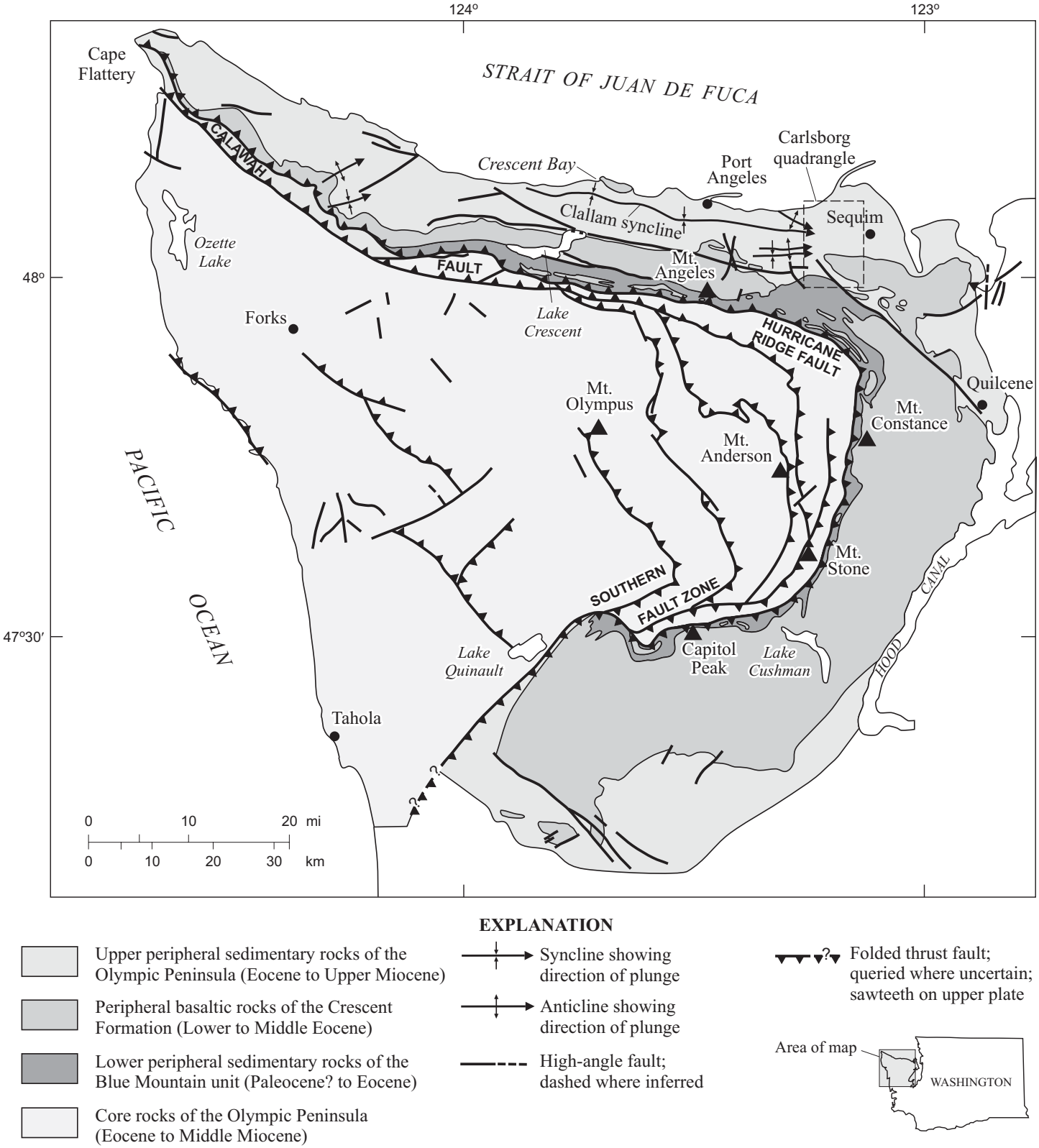



**Figure 2.** Geologic terranes and major folds and faults of the Olympic Peninsula. Peripheral rocks include the basalt (mostly oceanic) of the Crescent Formation, marine sedimentary rocks of the Blue Mountain unit of the Crescent Formation that underlie and intertongue with the basalts, and overlying 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).

and Calderwood, 1990). The Crescent Formation, the basal unit of the peripheral rocks, is a thick sequence of oceanic pillow basalt, breccia, and interbedded volcaniclastic rocks with minor pelagic sedimentary rocks and rare columnar basalt near the top of the section (Tabor and Cady, 1978b). These volcanogenic rocks were erupted in a marginal marine basin in which sediments of the Blue Mountain unit were also deposited (Babcock and others, 1994). Deposition of the Blue Mountain sediments apparently continued throughout much of the eruptive history of the Crescent volcanic rocks.

Geologic units in the Carlsborg quadrangle can be broadly grouped into Quaternary surficial deposits, Miocene to Paleocene sedimentary rocks, and Eocene volcanic rocks (Fig. 1B). Along the north flank of the Olympic Mountains, more than 19,000 ft of marine sedimentary rocks stratigraphically overlie the Crescent Formation (Snavely, 1983). Snavely and others (1980) suggest that these strata were deposited in a deep marginal basin whose axis generally paralleled the Clallam syncline. They call this the Tofino–Juan de Fuca basin. These fossiliferous rocks are moderately faulted and folded but, in general, are stratigraphically continuous. Fold axes trend eastward, subparallel to many of the faults, and plunge gently east (Fig. 2).

In the Carlsborg quadrangle, sedimentary rocks of the Aldwell Formation and Twin River Group overlie the volcanic rocks of the Crescent Formation. All of these units are folded together, apparently by a post–Early Oligocene tectonic event of unknown duration. Local cross-faulting appears to modify these folds.

More than 2,000 ft of unconsolidated Pleistocene sediments were deposited on the Tertiary sedimentary rocks, as identified in logs of the Dungeness Unit No. 1-54 gas exploratory well drilled northeast of Sequim in the mid-1950s for the Standard Oil Co. (McFarland, 1983). The most recent of these deposits were laid down during the Fraser Glaciation (20–10 ka) of the Cordilleran ice sheet, which advanced southward out of Canada and split in the area of the Sequim quadrangle just to the east of the study area. The Puget lobe flowed south, covering the present-day Puget Lowland, while the Juan de Fuca lobe flowed west through the Strait of Juan de Fuca to a terminal position on the continental shelf. Younger glacial deposits are thickest in the north half of the Carlsborg quadrangle, where they consist of glaciomarine drift, ice-contact deposits, recessional outwash, till, and advance outwash, all exposed at the surface. In the south half of the quadrangle, the glacial sediments consist of advance outwash covered by till that thins rapidly southward to the foothills where it forms 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 are glacial and nonglacial deposits that represent several pre-Fraser glacial and interglacial periods. The nonglacial deposits are mapped on coastal bluffs and are evident in water-well logs together with older glacial deposits. Bedrock and glacial deposits have been locally modified by Holocene fluvial and mass-wasting processes.

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

- Detailed mapping has delineated bedrock exposures previously mapped as ‘till over bedrock’ (Othberg and Palmer, 1979a).
- Bedrock geology and structure have been reinterpreted from field observations and water well log data, together with data collected in adjoining quadrangles.
- New foraminiferal data have been provided for the previously undivided Tertiary rocks, which aided us in our assignment of these rocks to the Miocene to Oligocene Pysht, Oligocene to Eocene Makah, and Upper Eocene Hoko River Formations.
- Two mappable marine sedimentary units within the Crescent Formation have been distinguished on Lost Mountain.
- Geochemical and petrographic analyses were conducted for basalt samples collected from the Eocene Crescent Formation within the Carlsborg quadrangle. These new analyses enhance the geochemical database of the upper (subaerial) basaltic rocks of the Crescent Formation on the northern Olympic Peninsula (also see Schasse and Logan, 1998).
- Three new radiometric $^{14}C$ ages have established an Olympia interglacial age for peat-bearing clays and silts cropping out near the base of the sea cliffs in the northwest corner of the quadrangle and imply an Olympia interglacial age for similar sediments that crop out in the stream bed of McDonald Creek.
- A tephra interbedded with sediments exposed in the upper canyon walls of McDonald Creek has been correlated with ash from Mount Mazama (Crater Lake, Ore.), establishing an age of 6,730 ±40 $^{14}C$ yr B.P. (Hallet and others, 1997) for unit Qaf in the northwestern part of the study area.

## METHODS, PREVIOUS WORK, AND RELATED STUDIES

Our mapping and interpretations are based on field work performed in 1999, as well as previous studies in the area. Areas included on previous geologic maps and pertinent topical studies are shown on Figure 3. Othberg and Palmer (1979a) produced a preliminary map of the surficial geology of the Carlsborg 7.5-minute quadrangle; our geologic map (Plate 1) incorporates significant amounts of their work. 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 to Lower Miocene marine sedimentary rocks as Tertiary undivided Twin River Formation [Group]. Brown and others (1960) mapped the area adjoining the west boundary of the Carlsborg quadrangle. We projected geology from Tabor and Cady (1978a) and Brown and others (1960) into the Carlsborg quadrangle to enable structural interpretation in areas with limited subsurface information. Cady and others (1972b) mapped the geology of the Tyler Peak 15-minute quadrangle, which adjoins the southern border of the Carlsborg quadrangle. We combined structural information from Cady and others (1972b) and Tabor and Cady (1978a) with our own observations to interpret the structure of the Crescent Formation underlying the foothills in the study area. Schasse and Logan (1998) provided water-well data, subsurface geology, and structural interpretations in the Sequim 7.5-minute quadrangle to the east that we carried over into the Carlsborg quadrangle. A study by Drost (1986) included a well location map and a well data catalog that we used in constructing our geologic cross sections. The Washington Department of Ecology (1978) mapped the coastal geology inland for 2,000 ft. The information contained therein was largely reflected in the study performed by Othberg and Palmer (1979a).

We supplemented our field mapping with Washington Department of Natural Resources (DNR) color 1:24,000-scale (1976) and black and white 1:12,000-scale (1997) aerial photo-

graphs to map surficial deposits and their contacts with bedrock in inaccessible areas. We also used DNR 1997 1:12,000 orthophotos to map in the field, because they provided the most current information on roads and trails.

Exposed bedrock in the Carlsborg quadrangle is mostly restricted to roadcuts, ditches, residential home foundation cuts, and stream bottoms. The best exposures of Tertiary sedimentary rocks are along the stream bottom and lower canyon walls of McDonald Creek and in the area where Pats and Rock Creeks join Canyon Creek. Limited exposures of Eocene sediments were seen along Caraco Creek. Good exposures of the basaltic rocks of the Crescent Formation were observed along Canyon Creek and along the Dungeness River where it cuts through the foothills in the southern part of the quadrangle. Four rock quarries also provided good exposures of the basalts. A quarry on the lower north slope of Lost Mountain provided excellent exposures of pelagic sediments invaded by basalt flows. Sea cliffs along the Strait of Juan de Fuca provided excellent exposures of Fraser glacial deposits and pre-Fraser interglacial sediments. Excellent exposures of Quaternary deposits were observed along McDonald Creek, particularly in the stretch between U.S. Highway 101 and the Strait of Juan de Fuca.

Due to the paucity of bedrock exposures, we found it necessary to rely on subsurface information contained in water-well logs for help in interpreting structure. All of the wells used in this study are shown on Plate 1. A listing of accurately located wells was provided by the U.S. Geological Survey (USGS) Water Resources Division, Tacoma office. This list was augmented by a few wells located in the field during this study. In addition, we purchased over 2,400 water-well records with well logs from the Washington Department of Ecology, Southwest Regional Office. These well records were cross-referenced with the list of wells that had been accurately located to identify a set of possible candidates for use in producing cross sections. We selected a second set of wells from those that could be reasonably located using a current Clallam County address location system augmented with information from a previously used address system. Wells from this category and those selected from the USGS list of located wells are illustrated with the same symbol on Plate 1. In order to have a uniform distribution of wells that penetrated deeper Quaternary sediments and bedrock units, we selected additional wells that we could locate to within the nearest quarter-quarter section based on the surface elevation of the wells. These wells are distinguished from the more accurately located wells with a different symbol on Plate 1.

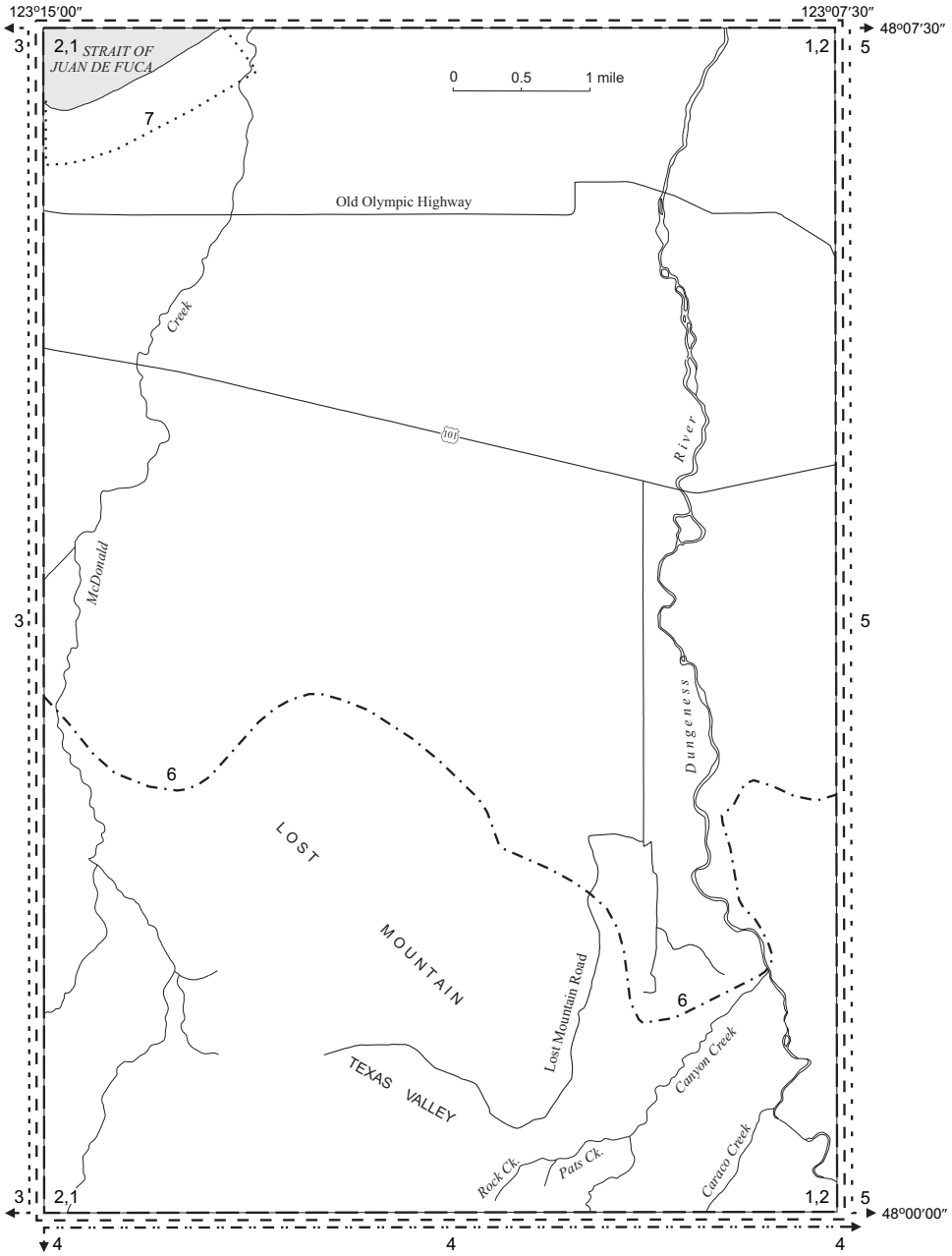



**Figure 3.** Previous geologic mapping and topical studies within and adjacent to the Carlsborg 7.5-minute quadrangle. **1.** Othberg and Palmer (1979a), 1:24,000; **2.** Tabor and Cady (1978a), 1:125,000; **3.** Brown and others (1960), 1:62,500; **4.** Cady and others (1972b), 1:62,500; **5.** Schasse and Logan (1998), 1:24,000; **6.** Drost (1986), 1:24,000; **7.** Washington Department of Ecology (1978), 1;24,000.

Our priority was to illustrate the geology of unconsolidated units and bedrock structure (cross section A–A′) without significant vertical exaggeration. We made our interpretations of the Pleistocene geology using the data in the driller's logs together with outcrop data (particularly from the exposures in the sea cliffs and within the deeply cut valley of McDonald Creek) and stratigraphic relationships of the glacial and postglacial units. Because of our scale selection, it was not possible to show the complex stratigraphy of the subsurface Pleistocene deposits as reflected in the well logs. Also, choosing a straight line of section, instead of a section line made up of line segments connecting individual wells, made it necessary to project wells into the line of the section, adding uncertainty to the interpretation.

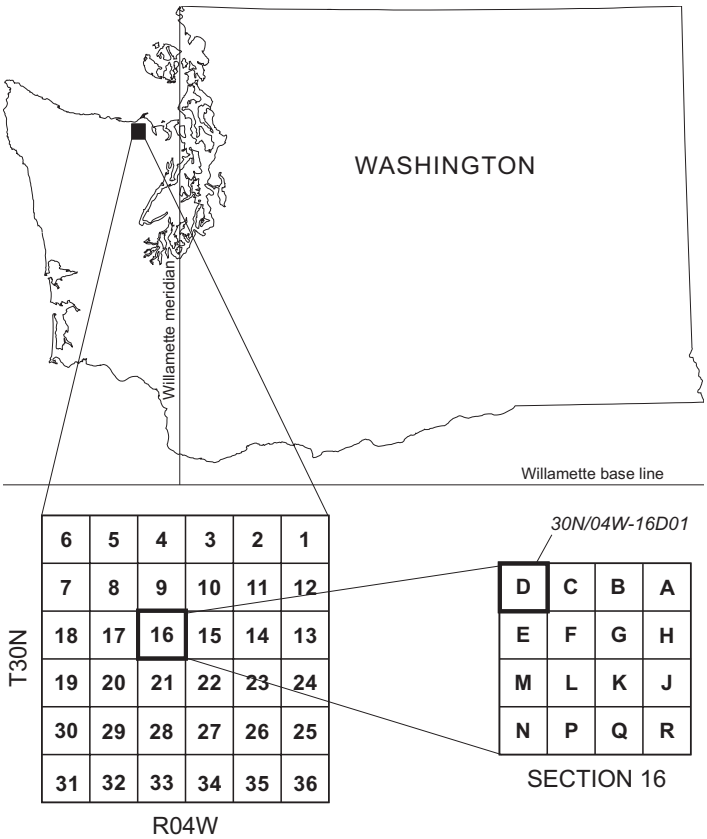



**Figure 4.** Well numbering system used by the U.S. Geological Survey. The two-digit number (01) following the letter D is the first in a sequence of wells recorded within the quarter-quarter section subdivision.

The USGS assigns water wells in Washington numbers that identify their location in a township, range, and section (Fig. 4). For example, well number 30N/04W-16D01 indicates, successively, the township (30N) and range (04W) north and west, respectively, of 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 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 (1) in the cross sections because of space limitations.

Ninety-eight wells, listed in Appendix 1, were selected to construct the cross sections (Plate 2). The wells are identified in the cross sections by an abbreviated identifying number, giving the section and alphanumeric well location number within that section. The township and range for that well can be identified by referring to the corresponding well location on the geologic map near the cross section line (Plate 1). These wells can be identified on the geologic map by the drilled depth associated with the well number. Wells that were not used to construct the cross sections do not have depth-drilled values.

Analytical results and geochemical correlation of a tephra are presented in Appendix 2. Radiocarbon ages are given in Appendix 3. Paleontological and geochemical analyses for this study are given in Appendices 4 and 5, respectively. Results of our petrographic study are incorporated in the unit descriptions in the text, and sample locations are shown on Figure 5.

## DESCRIPTIONS OF MAP UNITS

Geologic units are shown on Plates 1 and 2. Unit symbols provide information about the age, lithology, and name (if any) of the units: uppercase letters indicate age, lowercase letters indicate lithology, and subscripts identify named units. For example, Oligocene to Eocene marine rocks of the Makah Formation are shown with the symbol $\Phi Em_m$. 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 Folk (1980). Landslides are classified using Varnes (1978).

### Quaternary Sediments

#### NONGLACIAL DEPOSITS

Qf **Artificial fill and modified land (Holocene)**—Riprap, soil, sediment, rock, and solid waste material that has been added and reworked to modify topography. Artificial fill is used for bridge abutment support where U.S. Highway 101 and the Old Olympic Highway cross McDonald Creek and as a retention channel for diverting surface runoff from a large parking lot into a nearby irrigation ditch in the vicinity of Hooker Road and U.S. Highway 101.

Qa **Alluvium (Holocene)**—Generally well-stratified and well-sorted deposits of rounded cobble and pebble gravel, sandy gravel, gravelly sand, silt, clay, and peat; brown to gray, depending on composition and weathering; deposited in and along present streams. Cobbly stream gravels are laid down in channels, while finer sands, silts, and clays are deposited in a flood plain environment. Grain size varies both laterally and vertically due to stream migration. Thickness of alluvium varies; a maximum thickness of 40 ft was estimated from water-well data collected from the Dungeness River flood plain. Unit Qa overlies older alluvium (unit Qoa), Vashon glaciomarine drift (unit Qgdm), recessional outwash (unit Qgo), and ice-contact deposits (unit $Qgo_i$) in the lower alluvial valley of the Dungeness River. It overlies bedrock (units $Ev_c$ and $Em_{1c}$) and glacial till (unit Qgt) where the Dungeness has cut through the foothills in the southeast quarter of the quadrangle. Streams in the study area are reworking younger alluvial deposits (unit Qa), older alluvium (unit Qoa), and Fraser glacial deposits.

Unit Qa is mapped where McDonald Creek empties into the Strait of Juan de Fuca in the northwest corner of the quadrangle, along the banks of the Dungeness River in the southwest corner of the quadrangle, and within the flood plain of the Dungeness (eastern part of the quadrangle). The Dungeness has migrated over time, leaving behind alluvial terraces that mark previous higher flood plains; these terraces within unit Qa are illustrated on the geologic map (Plate 1). Minor amounts of unit Qa exist in and along the channels of McDonald Creek and many of the smaller streams within the quadrangle, especially north of the foothills. However, due to the map scale, we did not show these small deposits. Unit Qa is postglacial and thus Holocene in age.

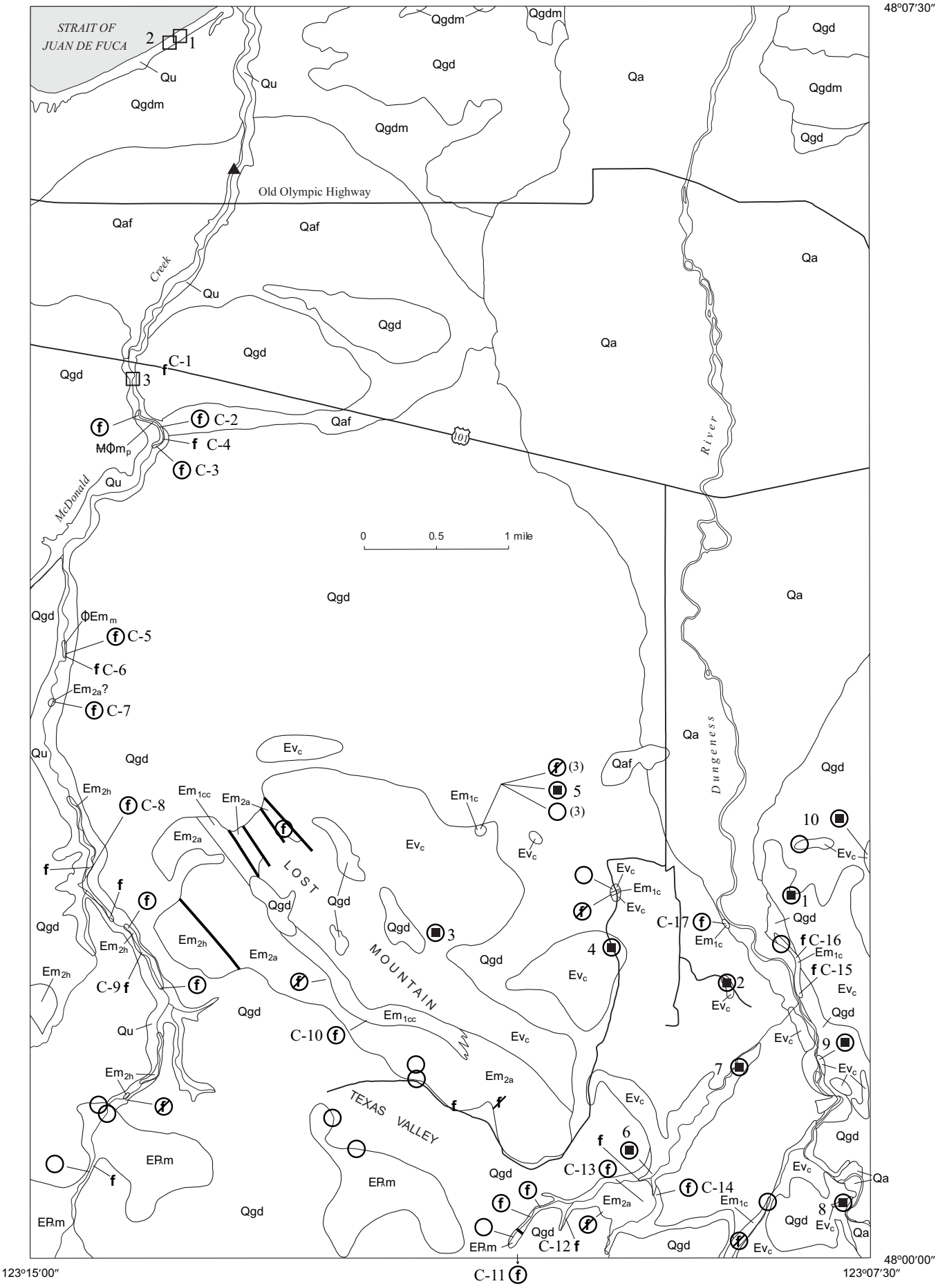



**Figure 5.** *See caption and explanation, facing page*

Qp **Peat and marsh deposits (Holocene)**—Fine, saturated 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. Two small areas of peat and marsh deposits were mapped in the northern third of the quadrangle. These deposits are Holocene in age.

## EXPLANATION

### QUATERNARY SEDIMENTARY DEPOSITS

Qa Alluvium, undivided (Holocene and Pleistocene)

Qu Undifferentiated sediments; includes landslide deposits, younger and older alluvium, alluvial fan deposits, glaciomarine drift, Fraser glacial drift, and pre-Fraser continental (nonglacial) deposits (Holocene and Pleistocene)

Qaf Alluvial fan deposits (Holocene and Pleistocene?)

Qgdm Glaciomarine drift (Pleistocene)

Qgd Glacial drift, undivided (Pleistocene)

### TERTIARY SEDIMENTARY AND VOLCANIC ROCKS

Twin River Group

$\cancel{M}\Phi m_p$ Pysht Formation (Miocene to Oligocene)

$\Phi Em_m$ Makah Formation (Oligocene to Eocene)

$Em_{2h}$ Hoko River Formation (Upper Eocene)

$Em_{2a}$ Aldwell Formation (Middle Eocene)

Crescent Formation (Eocene to Paleocene?)

$Ev_c$ Basalt, basalt breccia, and diabase (Lower to Middle Eocene)

$Em_{1cc}$ Granular sandstone and conglomerate (Lower to Middle Eocene)

$Em_{1c}$ Marine sedimentary rocks (Lower to Middle Eocene)

$\cancel{E}Rm$ Blue Mountain unit; sandstone and pebbly sandstone and conglomerate (Eocene to Paleocene?)

### SAMPLE LOCATION SYMBOLS

○ Sample site—petrography (thin section)*

f C-5 Sample site—foraminiferal assemblages (Appendix 4)

f Sample site—foraminiferal assemblages (insufficient for identification)

~~f~~ Sample site—foraminiferal assemblages (barren sample)

■ Sample site—geochemistry (Appendix 5)

▲ Sample site—tephra analysis (Appendix 2)

□ Sample site—radiocarbon ages (Appendix 3)

* may be combined with other symbols; where more than one sample was taken at a particular location, the number of samples is indicated in parentheses

**Figure 5.** *(facing page)* Sample site map for the Carlsborg 7.5-minute quadrangle. Analyses include petrography, foraminiferal assemblages, geochemistry, a tephra analysis, and radiocarbon ages.

Qls **Landslide deposits (Holocene)**—Poorly sorted, unstratified diamicton 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 ancient landslides. Landslides mapped in the quadrangle include the entire landform, from headwall to toe, and include both the landslide scarp and debris. Debris consists of a poorly sorted mixture of soil and rock fragments resulting from slumps and slides. Landslides were mapped along the steep-walled canyons of McDonald Creek, Dungeness River, and Canyon Creek. Most of the landslides are earth-slump blocks resulting from streams undercutting the toes of these blocks. Their head scarps generally originate in Vashon recessional outwash (unit Qgo) that overlies Vashon till (unit Qgt) or in Vashon till that overlies steep slopes in Eocene Crescent Formation basalt (unit $Ev_c$). A small slide was mapped in the steep east canyon wall of McDonald Creek in Holocene and Pleistocene alluvial fan deposits (unit Qaf) and Vashon glaciomarine drift (unit Qgdm). A few of the mapped landslide deposits are shallow debris flows and tend to be smaller than those described above, with a narrow elongate shape.

Othberg and Palmer (1979a) also mapped landslides in the north-facing sea cliffs on the Strait of Juan de Fuca that appear to be a series of earth-slump blocks, probably initiated by wave action.

Qoa **Older alluvium (Holocene to late Pleistocene?)**—Crudely stratified cobbly, pebbly, and bouldery gravel in a matrix of sand, silt, and clay. Clasts are poorly sorted; subangular to rounded; flattened, ellipsoidal, spherical, or elongate in shape; are of both exotic and Olympic Mountains origin. Deposits are dark yellowish brown, moderate brown, pale yellowish brown, and grayish brown. This unit is the product of reworking of Fraser-age glacial deposits (units Qgt, Qgo, Qga, and $Qgo_i$). It forms terraces ranging from 10 to 30 ft above the elevation of the modern Dungeness River alluvial flood plain. These exposures are axial-channel and flood-plain terrace deposits of an ancestral Dungeness River that formerly flowed northeast toward Sequim (Othberg and Palmer, 1979a). Small unit Qoa terrace deposits are also mapped along McDonald Creek where allowed by map scale.

The unit is mapped largely on the basis of geomorphology. On aerial photographs, unit Qoa has an anastomosing appearance that strongly resembles a braided stream pattern along the east-central portion of the quadrangle. Thickness in water wells ranges from a few feet to a maximum of 60 ft near the centers of former channels now occupied by these deposits. Average thickness of the unit is approximately 25 ft.

Unit Qoa overlies till, recessional outwash, and ice-contact deposits of the Vashon glacial stade (units Qgt, Qgo, and $Qgo_i$, respectively). A tephra that appeared to be preserved in a depression within unit Qoa was collected by Irv Tailleur (USGS, retired) during excavation for construction of a small pond on his property in the SE¼NW¼ sec. 35, T30N R4W. The tephra is believed to have been deposited as air fall between proba-

ble overbank and older alluvial channel gravels. The tephra was identified by Pat Pringle (Washington Div. of Geology and Earth Resources, oral commun., 1999) as Mazama ash, which has been dated elsewhere at 6,730 ±40 $^{14}$C yr B.P. (Hallet and others, 1997). This would establish a minimum age for unit Qoa for this area. The lower part of this unit may be as old as late Pleistocene, as illustrated in the correlation diagram (Plate 2).

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, well sorted; light gray to pale yellowish brown and pale brown; deposited on an alluvial fan of McDonald Creek. The fan surface grades to the surface of Vashon glaciomarine drift (unit Qgdm). Othberg and Palmer (1979a) called the unit 'Everson sand' (unit Qes on their map) and suggested that the unit may interfinger with unit Qgdm. The unit is the product of reworking of Fraser-age glacial deposits (units Qgd, Qgo, Qgt, and Qga).

Water-well data suggest that the unit overlies Vashon glacial drift (unit Qgd), recessional outwash (unit Qgo), and till (unit Qgt) (Plate 2, cross sections B–B′ and C–C′). A small alluvial fan deposit, mapped in sec. 35, T30N R4W, was identified from aerial photographs. It may have developed during ice recession, when Bear Creek had a higher sediment yield than it does today. The larger alluvial fan deposit in the McDonald Creek area has variable thickness and grades from a maximum thickness of 80 ft to less than 10 ft where it merges with unit Qgdm to the north and east (Plate 2, cross sections B–B′ and C–C′).

Forty-five feet of thin-bedded sand with interbedded silt and silty clay and local lenses of gravelly sand are exposed in steep canyon walls of McDonald Creek near the center of sec. 8, T30N R4W where the creek transects unit Qaf. A 2 in. thick reworked(?) white tephra layer occurs within the sequence of bedded sand and silt approximately 15 ft below the top of the canyon. A sample of the tephra was analyzed at the Washington State University Geoanalytical Laboratory by Dr. Franklin F. Foit, Jr., who correlated it with the Mazama ash dated at 6,730 ±40 $^{14}$C yr B.P. (Appendix 2; also see Fig. 5 for location of tephra sample). The alluvial fan of McDonald Creek must have developed prior to 6,730 ±40 $^{14}$C yr B.P. and may have begun forming in the late Pleistocene (see Discussion).

$Qc_o$ **Sediments of Olympia interglacial age (Pleistocene)**—Poorly bedded to nonbedded, greenish gray to brown, peat-bearing silts and clays with lenses of stratified, gray, sandy to pebbly fluvial gravel; clasts are well rounded and moderately well sorted.

Unit $Qc_o$ is exposed in the lower 15 to 30 ft of sea cliffs along the Strait of Juan de Fuca (see Plate 1, detailed stratigraphic section of sea cliff exposures in northwest corner of quadrangle). Exposures of the unit extend westward into the adjoining Morse Creek 7.5-minute quadrangle and northeastward into the Dungeness 7.5-minute quadrangle. Exposures of deformed greenish gray to bluish gray silty clay crop out in a regular pattern along the stretch of McDonald Creek between the Strait of Juan de Fuca and the vicinity of U.S. Highway 101. Deformation patterns suggest that these clays have been overridden by glacial ice. They apparently represent sediments deposited in a low-energy fluvial system during pre-Fraser time.

Unit $Qc_o$, as interpreted from water-well logs, is assigned to a sequence of relatively thin alternating clays and sands with small amounts of gravel and peat beds underlying a thicker sequence of water-bearing sands and gravels. We interpret the base of the unit to occur at the first hard gravelly clay or 'till' noted in the drillers' logs. Only a limited number of wells penetrated this horizon; thus, the thickness of the unit is uncertain in most of the cross sections. In the north end of cross section B–B′ (Plate 2), where water wells have penetrated the base of the unit, the unit appears to reach a maximum thickness of 180 ft, with an average thickness of 100 ft or less.

The Olympia interglacial interval has been dated outside the Carlsborg 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). For our study, we collected wood from non-bedded bluish gray silty clay exposed along sea cliffs west of McDonald Creek. This sample produced a $^{14}$C age of 34,930 ±850 yr B.P. We collected a second sample of wood from a 1.5 ft thick peat bed exposed at beach level at low tide, approximately 600 ft to the southwest along the beach and approximately 10 ft stratigraphically beneath the exposure of the first sample. This second sample produced a $^{14}$C age of >45,360 yr B.P. (See Fig. 5, radiocarbon sample sites 1 and 2, respectively, and Appendix 3). A third sample, consisting of plant material (wood and needles) from a well-sorted sand unit in an alternating sand and clay sequence exposed along the west bank of McDonald Creek 600 to 700 ft upstream of the Highway 101 bridge (see Fig. 5, radiocarbon sample site 3, and Appendix 3, sample KW 8-19-99-2), produced a $^{14}$C age of >50,000 yr B.P. The finite age of radiocarbon sample 1 places it in the Olympia interglacial interval. Although the infinite $^{14}$C ages of radiocarbon samples 2 and 3 do not indicate a particular interval, we are inclined to include both in the Olympia interglacial interval. We base our conclusion on (1) the stratigraphic separation of only 10 ft between radiometric sample sites 1 and 2, and (2) the small lateral distance and stratigraphic separation between radiocarbon sample site 1 and the glacially deformed sediments at radiocarbon sample site 3.

## GLACIAL DEPOSITS

### Fraser Glaciation, Vashon Stade (Pleistocene)

Qgdm **Glaciomarine drift**—Poorly sorted, weakly stratified to nonstratified, poorly compacted deposits of pebbly silt and clay and lesser discontinuous layers of silty sand; weathers to a pseudo-columnar appearance on naturally exposed vertical faces; dark to pale yellowish brown weathering, tan to gray in unweathered exposures; rare marine fossils. The maximum thickness in

the study area, as interpreted from water-well data, is about 35 ft, but the unit is more typically 20 to 25 ft thick and thins to 5 to 10 ft where it is exposed at the top of the coastal bluffs in the northwest corner of the quadrangle.

In the Carlsborg quadrangle, the glaciomarine drift underlies a narrow crescent-shaped band of high flats north of the Old Olympic Highway, forming a subtle terrace near the highest local glaciomarine drift elevation of >38 m (125 ft) reported by Dethier and others (1995, fig. 3). In the area of The Potholes in the northeast corner of the quadrangle and in a similar landscape north of the McCleay–Cameron Road, the drift interfingers with and/or fills small depressions in ice-contact stratified gravels (unit $Qgo_i$) of a kettled landscape. Interpretation of water-well records suggests that the glaciomarine drift overlies Vashon ice-contact deposits (unit $Qgo_i$) in the area of The Potholes and Vashon recessional outwash (unit Qgo) in the area just south of the McCleay–Cameron Road (cross sections B–B′, C–C′, and D–D′).

The Everson Interstade of the Fraser Glaciation began with marine incursion into the northern Puget Lowland during retreat of the Puget and Juan de Fuca glacial lobes. Dethier and others (1995) report radiocarbon ages for Everson and Everson-equivalent deposits throughout the northern Puget Lowland that range from 13,650 to 11,330 yr B.P. One of those ages came from a locality just north of The Potholes (their locality 11, fig. 2) in the Dungeness 7.5-minute quadrangle. That $^{14}C$ age of 12,600 ±200 yr B.P., from a shell in glaciomarine drift, establishes that the glaciomarine drift in the Carlsborg area is coeval with the Everson.

Subsequent to publishing the geologic map of the adjacent Sequim 7.5-minute quadrangle (Schasse and Logan, 1998), we have chosen not to refer to the glaciomarine deposits along the northern Olympic Peninsula between the Port Angeles and Sequim areas as Everson Glaciomarine Drift. The Juan de Fuca glacial lobe retreated east of the Carlsborg–Sequim area prior to the marine incursion marking the beginning of Everson Glaciomarine Drift deposition in the northern Puget Lowland. In a strict sense, glaciomarine drift already being deposited on submerged land in the Carlsborg area should not be given the name Everson.

$Qgo_i$ **Ice-contact stratified recessional outwash**—Moderately well-sorted, crudely to well-stratified coarse gravel and sand and gravel, locally grading to sand; clasts rounded to subrounded, exotic and Olympic Mountains provenances; pale yellowish brown to gray. These sediments show deformation, slumping, and collapse features resulting from the melting of supporting ice. Cross-stratified gravels exposed in a gravel pit in the area of The Potholes, just northeast of the quadrangle boundary in the northwest quarter of sec. 6, T30N R3W, indicate south-directed sediment transport. Eastward sediment transport is indicated by shallow-dipping stratified gravels that are exposed in a gravel pit in a low ridge north of Grennan Hill in the Sequim quadrangle. At this locality, glaciomarine drift (unit Qgdm) interfingers with the stratified gravel and overlies deformed sand and gravel. Othberg and Palmer (1979b) described similar contact relations between ice-contact stratified gravels and fossiliferous Everson-equivalent glaciomarine drift at two localities in the north-adjoining Dungeness quadrangle. This suggests that the stratified gravels were deposited near the margin of the melting ice (probably grounded stagnant ice) in a coastal marine environment. Water-well data indicate that these ice-contact deposits may be as thick as 80 ft and average 50 to 60 ft thick within the Carlsborg quadrangle (Plate 2, cross sections B–B′ and D–D′). These deposits were reported to be 130 ft thick in the area of The Potholes in the adjoining Sequim quadrangle (plate 2, cross section A–A′, unit $Qgo_{vi}$ in Schasse and Logan, 1998). Unit $Qgo_i$ is underlain by Vashon till (unit Qgt), or Vashon advance outwash deposits (unit Qga) where the till is absent.

In the northern part of the quadrangle, the unit interfingers with and is overlain by glaciomarine drift dated at 12.6 ka (Dethier and others, 1995, fig. 4).

Qgo **Recessional outwash**—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 and varied sediments resulting from deposition from or near stagnant ice. It includes sand and gravel deposited by streams that flowed off the bedrock highs in the southern part of the quadrangle. Streams were active as the ice receded in this area (Othberg and Palmer, 1979c), reworking and depositing detritus left by the retreating ice sheet. Deposits of this unit are located along moderately to gently north-sloping surfaces above and adjacent to the stream-cut canyon of McDonald Creek. In the northwest corner of the quadrangle, north of U.S. Highway 101 adjacent to McDonald Creek, recessional outwash deposits appear to grade to alluvial fan deposits (unit Qaf). We mapped remnant stream-cut terraces in recessional outwash along the upper banks of McDonald Creek between U.S. Highway 101 and the Bonneville Power Administration power line. We infer that these fill-cut terraces were formed by McDonald Creek during the latest Pleistocene to early Holocene. We also mapped higher-elevation terrace remnants along the Dungeness River in the southeastern part of the quadrangle as recessional outwash. Two such deposits were mapped along the western edge of the Dungeness Valley, west of the Taylor Cutoff Road, where they are situated topographically above the Holocene terrace deposits (unit Qoa). Water-well data indicate that the thickness of the recessional outwash varies from 0 to 90 ft and averages approximately 50 ft. The recessional outwash rests on Vashon till (unit Qgt), or Vashon advance outwash (unit Qga) where till is absent.

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 the Manis Mastodon site in sec. 31, T30N R3W in the Sequim quadrangle (Petersen and others, 1983). High outwash terraces along McDonald Creek and the Dungeness River, which record reworking and deposition of gla-

cial and glaciofluvial sediments, may be as young as early Holocene.

Qgl **Glaciolacustrine deposits**—Stratified, well-sorted clay, silt, and sand; rhythmically laminated, displaying alternating horizontal bands of silt and clay interrupted by thin beds of sand; greenish gray to bluish gray. This unit is depicted only on the cross sections; it is present along the bottom and lower stream banks of McDonald Creek but cannot be shown at map scale.

One area of these deposits was identified in water wells that penetrated beneath the Dungeness River alluvium (Plate 2, cross section D–D′). Here, they underlie older flood plain deposits (unit Qoa). At this location, we interpret unit Qgl to include 0 to 100 ft (average 70 ft) of stratified clays, sandy clays, and sand overlying till (unit Qgt) or advance outwash (unit Qga). We interpret these deposits to be recessional glaciolacustrine deposits on the basis of their stratigraphic position. A second outcrop area occurs near McDonald Creek, particularly along the stretch that passes through secs. 18, 30, and 31, T30N R4W. In this area, we observed horizontal beds of thinly laminated greenish gray and bluish gray silts and clays (glaciolacustrine deposits) cropping out in the low banks of the creek. These deposits are also well exposed in the north roadcut for U.S. Highway 101 just west of the McDonald Creek bridge. These deposits have not been dated. We correlate them with the Vashon recessional outwash (unit Qgo). Undeformed horizontal laminations suggest that they were not loaded with glacial ice.

A third area of glaciolacustrine deposits was interpreted in the subsurface from logs of water wells drilled in secs. 19 and 30, T30N R4W (Plate 2, cross section B–B′). The logs describe zones of clay, silt, and sand lying stratigraphically beneath till (unit Qgt) and above bedrock (units $\Phi Em_m$ and $\text{ꝶ}\Phi m_p$) and zones of sand and gravel (unit Qga).

We were unable to find datable material in unit Qgl. We correlate this unit with Vashon advance and recessional outwash (units Qga and Qgo, respectively), based on its stratigraphic position relative to Vashon till (unit Qgt) as shown in cross sections B–B′ and D–D′ (Plate 2).

Qgt **Till**—Unstratified diamicton of poorly sorted, pebbly, clayey, sandy silt with scattered cobbles and sparse boulders; yellowish gray to light gray and tan. This unit may locally include ablation till (generally a loose, nonstratified, pebbly silty sand of varied thickness, creating an irregular hummocky topography). Lodgment till (unit Qgt) lies stratigraphically between overlying recessional outwash (unit Qgo) and underlying advance outwash (unit Qga) in much of the subsurface. Locally, it underlies Vashon recessional ice-contact deposits (unit $Qgo_i$), alluvial fan deposits (unit Qaf), and, under the Dungeness Valley, alluvium (unit Qoa).

Approximately one-third of the surface of the quadrangle is covered by lodgment till. It underlies all of the upland areas except where bedrock crops out. The unit is varied in thickness; water-well data indicate that it may locally be as thick as 150 ft, particularly on the north-facing lower slopes of Lost Mountain. It pinches out locally in other places, particularly in the subsurface underlying the lowlands in the northern quarter of the quadrangle, where it averages only 10 to 15 ft thick and occurs only intermittently (Plate 2, cross section C–C′). In sea cliff exposures in the northwest corner of the quadrangle, the till thickness varies from 0 ft to a maximum of 15 ft. We believe that much of the till in this area was removed by subsequent glaciofluvial erosion during recession of the Vashon ice sheet. Till was mapped where thicker than about 5 ft.

Radiocarbon ages from outside the study area and from Vashon advance outwash at Port Williams in the adjoining Sequim quadrangle (included in unit Qgd there) indicate an age between about 14.5 and 17.5 ka (Schasse and Logan, 1998).

Qga **Advance outwash**—Parallel-bedded and locally cross-bedded, well-sorted, dominantly sand and sandy pebble to cobble gravel; gravel clasts well rounded; lesser silts and clays; gray to grayish orange. This unit was laid down by meltwater directly in front of the advancing Vashon glacier and includes some lacustrine beds consisting of alternating, thinly bedded sands, silts, and clays that were deposited in lakes that resulted from damming by the advancing glacier. Advance outwash is generally denser than recessional deposits due to compaction by the overriding glacier. It tends to be more iron-oxide stained (and in some places is iron-oxide cemented) and generally contains a larger percentage of silt and clay relative to recessional outwash. Advance outwash lacustrine beds, exposed in cutbanks of McDonald Creek, are not horizontal, likely indicating deformation due to glacial loading.

The unit is mapped where its stratigraphic position beneath Vashon till (unit Qgt) can be established. It lies stratigraphically above older (pre-Vashon) Pleistocene sediments (unit $Qc_o$) and locally rests on bedrock. In the Carlsborg quadrangle, the unit is only exposed at the surface in sea cliffs (see Plate 1, detailed stratigraphic section in northwest corner). It appears as very well-sorted, parallel-bedded or laminated, locally cross-bedded sands that overlie unit $Qc_o$. At this locality, unit Qga is approximately 20 ft thick but appears to thin eastward, and it grades westward to sand and gravel. In the subsurface, we identified advance outwash as the first relatively thick deposits of sand and gravel (and locally, lacustrine silt and clay) beneath the till. Where till is absent, we assumed a contact between recessional outwash (unit Qgo) and the advance outwash by connecting adjacent till ‘lenses’. These contacts are shown as dashed lines in the cross sections on Plate 2.

The thickness of the advance outwash is quite varied in the subsurface. The apparent variability may result from our difficulty in locating the contact between unit Qgo and unit Qga when unit Qgt is missing. The advance outwash appears to be relatively thick in the vicinity of McDonald Creek (Plate 2, cross section C–C′), where it has a maximum thickness of 150 ft, but thins markedly away from McDonald Creek to as little as 30 ft thick. Elsewhere, its thickness generally ranges from 30 to 70 ft and locally reaches a maximum of 180 ft, as illustrated on the geologic cross sections (Plate 2). Advance outwash appears to pinch out against bedrock in the foothills to the south.

The age of unit Qga in the study area is estimated at 18,265 ±345 yr B.P. to 17,350 ±1,260 yr B.P. by Blunt and others (1987) from bluff exposures at Port Williams in the adjoining Sequim quadrangle.

Qgd **Drift, undivided**—Applied to glacial deposits of Vashon age consisting of random mixtures of sand and gravel, lodgment till, sandy ablation(?) till, and lacustrine(?) silts. Deposits of this unit that are located in the north-central area of the quadrangle were described by Othberg and Palmer (1979a) as reworked till. The largest of these deposits is located between U.S. Highway 101 and Vautier Road in portions of secs. 16, 17, 20, and 21, T30N R4W and are shown on our cross section B–B′ (Plate 2). We interpret this larger deposit to be composed of mixed recessional outwash, recessional lacustrine deposits, and ablation till. Water-well data indicate that unit Qgd is 50 to 150 ft thick in the area. The drift appears to grade to lodgement till (unit Qgt) that veneers underlying bedrock to the south and is overlapped by alluvial fan deposits (unit Qaf) to the north. Elsewhere in the quadrangle, unit Qgd consists of isolated concentrations of loose sand and gravel in areas surrounded by till (unit Qgt) and other small areas as interpreted from aerial photographs. In cross section A–A′ (Plate 2), we have lumped units Qgo, Qgt, Qgl, and Qga into the all-inclusive unit Qgd, because the scale would not allow them to be shown separately.

The age range of unit Qgd is that of the included units as shown in the correlation diagram (approximately 12 to 19 ka) (Plate 2).

## GLACIAL AND NONGLACIAL DEPOSITS

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

### Deposits of Fraser and pre-Fraser events (Pleistocene)

Qguc **Glacial and nonglacial deposits, undivided**—This unit is found along steep slopes of stream valleys (for example, McDonald Creek) and some sea cliffs where exposures are poor and/or map scale does not allow detailed delineation. This unit is also used in cross section A–A′ (Plate 2) to include surficial geologic units older than Fraser glacial events. Where there is no subsurface control in the cross section, it also includes surficial units older than Holocene or Pleistocene(?) alluvium (unit Qoa).

### Deposits of pre-Fraser events (Pleistocene)

Qgpc **Glacial and nonglacial deposits, undivided**—Includes all units identified in a limited number of deep water wells that are older than Olympia interglacial age (unit $Qc_o$). Unit Qgpc is shown only in the cross sections (Plate 2).

# Tertiary Sedimentary And Volcanic Rocks

## POST-CRESCENT MARINE SEDIMENTARY ROCKS

As the volcanism that produced the Crescent Formation (unit $Ev_c$) on the northern Olympic Peninsula waned in the Early to Middle Eocene, sediment on-lapped the basaltic rocks in the adjacent deep Tofino–Juan de Fuca basin (Snavely and others, 1980). More than 19,000 ft of marine sedimentary rocks, which make up the upper peripheral sedimentary rocks of the Olympic Peninsula (Fig. 2), overlie the Crescent Formation along the north flank of the Olympic Mountains (Snavely, 1983). Although these rocks are faulted and folded, they generally are stratigraphically continuous; fold axes trend eastward, subparallel to many of the faults, and generally plunge east (Fig. 2). These fossiliferous rocks consist predominantly of siltstone, sandstone, and conglomerate of Eocene, Oligocene, and Miocene age. They are, in ascending stratigraphic order: an unnamed siltstone unit of Middle Eocene age; the Aldwell Formation of Middle Eocene age; the Lyre Formation and its lateral equivalents of Late Eocene age; the rocks of the Twin River Group (Hoko River Formation of Late Eocene age, Makah Formation of Late Eocene to Oligocene age, and Pysht Formation of Late Oligocene to Early Miocene age); and the Clallam Formation of Early Miocene age. The unnamed siltstone unit and the Clallam Formation are not present in the Carlsborg quadrangle but are present in the Cape Flattery 1:100,000-scale quadrangle to the west (Fig. 1A). The Lyre Formation was mapped in the Tyler Peak 15-minute quadrangle (Cady and others, 1972b) to the southeast and in the vicinity of Lake Aldwell west of Port Angeles (Brown and others, 1960; Tabor and Cady, 1978a), but was not identified in the Carlsborg quadrangle. We describe the post-Crescent sedimentary rocks in the study area in descending order, from youngest to oldest.

### Twin River Group (Miocene to Eocene)

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 Carlsborg quadrangle. Prior to the raising to group status, Brown and others (1960), who mapped the geology in the area west of and adjacent to the Carlsborg quadrangle, referred to these rocks as the upper, middle, and lower members, respectively, of the Twin River Formation.

#### *Pysht Formation (Miocene to Oligocene)*

The uppermost member of the Twin River Group, the Pysht Formation, was defined by Snavely and others (1978). Gower (1960) mapped it in the Pysht 15-minute quadrangle (southeastern part of the Cape Flattery 1:100,000-scale quadrangle) as the upper member of the Twin River Formation. The Pysht Formation is Upper Oligocene to Lower Miocene (upper Zemorrian to lower Saucesian; see Plate 2) and gradational with the underlying Makah Formation. Channel deposits of pebble and boulder conglomerate with clasts of distinctive felsic tuff mark the base of the formation (Snavely and others, 1978). At the type area, the Pysht consists of about 1,400 m (4,600 ft) of poorly indurated mudstone, sandy siltstone with calcareous concretions, and conglomeratic channel deposits.

Closer to the study area, Brown and others (1960) described the upper member of the Twin River Formation as predominantly massive semi-indurated mudstone and sandy siltstone with local beds of fine-grained calcareous sandstone. They noted that the argillaceous rocks in the unit contain sporadic calcareous concretions and that organic material, consisting of megafossils, foraminifera, and carbonized plant material, is common. In the Morse Creek quadrangle west of the study area, they mapped the Pysht Formation in small structural depressions along the axis of the Clallam syncline.

ᴍΦm$_p$ **Sandy siltstone and mudstone**—Present in intermittent outcrops along a single stretch of McDonald Creek (mapped as a continuous exposure because of scale): thin-bedded, interbedded fine-grained sandstone and siltstone, laminated sandy siltstone and silty sandstone, and poorly bedded to nonbedded poorly indurated mudstone and siltstone; sandstone is moderately to poorly sorted, angular to subrounded, quartzo-feldspathic and lithic graywacke; interbedded sandstone and siltstone are gray to dark gray and greenish gray where unweathered and grayish tan to tannish brown where weathered; nonbedded mudstone is dark gray; laminated siltstone and sandstone are olive-gray to bluish olive-gray and weather to light tan and light rusty brown. Small elongate concretions with calcium carbonate cores occur in the interbedded sandstones and siltstones. Golf-ball-sized concretions occur in the thinly laminated sandstones and siltstones. Mollusk shell fragments are common in the nonbedded mudstone. The thickness of the unit cannot be determined in the study area because of the limited and intermittent nature of the exposures. By projecting structure inferred from exposures in McDonald Creek to bedrock penetrated by water wells east of the creek (Plate 2, cross section B–B′), we infer that the thickness is approximately 600 ft. We interpret the thickest part of the unit to be restricted to a structural depression along the axis of the Clallam syncline. Foraminifera in the siltstone and mudstone were used to assign an Upper Oligocene to Lower Miocene age. (See Discussion for details of our assessment of the age of this unit.)

### *Makah Formation (Oligocene to Eocene)*

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 (Snavely and others, 1978). At its composite type section in the Cape Flattery 1:100,000-scale quadrangle to the west (Fig. 1A), the Makah consists of more than 2,800 m (9,200 ft) of predominantly thin-bedded siltstone with sandstone interbeds that define six mappable members: four turbidite units, an olistostrome, and a water-laid tuff. The contact with the underlying Hoko River Formation is in most places gradational and conformable (Snavely and others, 1978).

Closer to the study area, Brown and others (1960) mapped the Makah Formation (which they referred to as the middle member of the Twin River Formation) in the western three-quarters of the Port Angeles 1:100,000-scale quadrangle (Fig. 1A). They reported that the middle member varies in thickness from 0 to 5,100 ft in their map area. They noted that the member is locally thin or absent, due to post–Middle Oligocene erosion or onlap against older rocks. They also report that siltstone and clayey mudstone are the dominant lithologies and that beds of fine- to medium-grained feldspathic silty sandstone occur locally, but are most common in the eastern part of the mapped area. This suggests gradual coarsening of the unit to the east. Brown and others (1960) described a lentil composed of pebble and cobble conglomerate and granule sandstone at the base of the middle member about 2 mi west of the Elwah River. There, breccia composed almost entirely of volcanic debris is sporadically exposed at the base of the conglomerate lentil. They suggest that it may represent eroded Crescent Formation detritus.

In the east-adjacent Sequim 7.5-minute quadrangle, Schasse and Logan (1998) mapped the Makah Formation where they estimate 450 ft of fine-grained concretionary sandstone and siltstone on the basis of limited outcrop and water-well data. They also described a discontinuous basal unit consisting of granular sandstone and small pebble conglomerate.

ΦEm$_m$ **Siltstone with minor sandy siltstone and clayey mudstone**—Present in two small exposures in the bottom of McDonald Creek (mapped as a single exposure because of scale): poorly bedded to nonbedded siltstone; minor sandy siltstone, calcareous siltstone, and clayey mudstone; contains calcareous concretions; medium to dark gray, and tannish brown to light olive-brown on weathered surfaces. Little could be determined from thin sections, but a few sand-sized grains of quartz and lithics were recognized along with limonite, chlorite, and some microfossil fragments. Thickness of the unit could not be determined due to limited exposure. Neither the contact with the overlying Pysht Formation nor that with the underlying Hoko River Formation are exposed in the study area. The unit apparently underlies the area covered by glacial drift north of a concealed normal fault on the north side of Lost Mountain. We base this interpretation on projections of the unit along strike from the exposures in McDonald Creek and extension of the unit into the study area from the adjacent Sequim quadrangle (Schasse and Logan, 1998). Foraminifera within the late Narizian(?) to late Zemorrian stages were used to assign an age. (See Discussion for details of our assessment of the age of this unit.)

### *Hoko River Formation (Late Eocene)*

The lowest formation of the Twin River Group, the Hoko River Formation, is Late Eocene (late Narizian) in age. This 1,600 to 2,300 m thick (5,200 to 7,500 ft thick) formation conformably overlies, and near Cape Flattery intertongues with, sandstone and conglomerate of the Lyre Formation (Snavely and others, 1978). The Hoko River Formation in its type locality is predominantly massive to thin-bedded siltstone, with lesser phyllite-rich and basalt-rich sandstone and conglomerate. The Hoko River Formation is distinguished from the overlying Makah Formation by hackly fracturing in the siltstone and sparse conglomerate interbeds. Sandstone interbeds have been classified as lithic arenite and lithic graywacke (De Chant, 1989). The Hoko River Formation was deposited in greater water depths than the Lyre Formation, but not as deep as most of the Aldwell Formation (Rau, 1964).

In the Morse Creek area, 5 mi west of the study 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 good bedding and by the presence of chloritized basaltic debris, which imparts a dark greenish gray color to the rock. The strata consist 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) further stated that beds of pebbly sandstone and conglomerate are at the base of the unit elsewhere, including Morse and Siebert Creeks, 5 and 2 mi west of the Carlsborg quadrangle, respectively. They describe the sandstones as dark greenish gray or olive-gray and mostly well bedded, thin bedded, platy, and fine to medium grained. These are as much as 500 ft thick.

Em$_{2h}$ **Sandstone with minor siltstone**—Crops out fairly continuously in the streambed of McDonald Creek

along a 2 mi stretch that cuts through secs. 6 and 7, T29N R4W: predominantly well-bedded, thin- to medium-bedded, fine- to medium-grained sandstone and minor siltstone; some beds calcareous; rare very coarse-grained to granular sandstone and conglomerate interbeds; thin-bedded units characterized by hackly fractures; medium gray to medium dark gray, olive to greenish gray, and light greenish gray. Calcareous concretions commonly occur throughout the exposed section and vary in size and shape. Most of the concretions are round to elliptical and 3 to 13 cm (1 to 5 in.) in diameter, but may be as large as 25 cm (10 in.) in diameter; some are elongate parallel to bedding. In thin section, sandstones consist of angular to subrounded grains of mono- and polycrystalline quartz, plagioclase, chert, lithics (including sandstone and schist), and potassium feldspar, with lesser chlorite and opaques. Sandstones are feldspathic litharenites. The base of the Hoko River Formation is not exposed, but apparently rests unconformably on older sandstones of the Blue Mountain unit of the Crescent Formation (unit ERm). Outcrops in McDonald Creek show opposing dips between the Hoko River and Blue Mountain rocks, where the contact between them is covered by surficial deposits. Faulting interrupts the section in several places and the upper part of the section is cut by the high-angle thrust fault that passes under Texas Valley.

Foraminifera identified from this unit all represent faunal assemblages from the Narizian stage (see Fig. 5 and Appendix 4, sample sites C-8 and C-9). Each sample contained species from the *Uvigerina yazooensis* zone, which is characteristic of the lower part of the Hoko River Formation.

### Aldwell Formation (Middle Eocene)

The Aldwell Formation (Brown and others, 1960) was named for a sequence of well-indurated marine siltstone that overlies and interfingers with the Crescent Formation. Its type area is located in the south limb of the Clallam syncline along Lake Aldwell on the Elwah River west of Port Angeles. Brown and others (1960) stated that the lower part of the Aldwell Formation in some places interfingers with volcanics of the Crescent Formation, and suggested that the two formations may be partly equivalent in age. In the type area, the Aldwell Formation is about 2,950 ft thick, but it thins to less than 100 ft in the western part of the area mapped by Brown and others (1960); it has an average thickness of 2,000 ft in the south limb of the Clallam syncline west of the Carlsborg quadrangle.

Brown and others (1960) report that greenish gray to medium olive-gray siltstone makes up most of the Aldwell Formation. The siltstone generally is faintly but regularly bedded and in places contains laminae and very thin beds of fine-grained sandstone. Beds of fine- to medium-grained calcareous sandstone occur sporadically. Massive lenses of unsorted pebbles, cobbles, and boulders of basalt occur locally throughout the siltstone in Brown and others' (1960) study area. They stated that the massive nature of these lenses and their limited extent suggest that they may have been formed by landslides or debris flows in a marine environment.

Marcott (1984) delineated two lithofacies in the Aldwell Formation along the northwestern Olympic coast, from areas that include the Sekiu River south of Clallam Bay and the western shore of Lake Crescent, 18 miles to the west of the Carlsborg quadrangle: an eastern facies consists of thin-bedded laminated siltstone and lithic graywacke, and a western facies consists of chert-rich lithic arenite.

Lower Narizian foraminifera indicate a Middle Eocene age for the Aldwell Formation (Armentrout and others, 1983). At Pulali Point on Hood Canal, rocks that are mapped as Aldwell(?) Formation are described by Babcock and others (1992) as being interbedded with Crescent Formation basaltic flows. This conclusion is disputed by Squires and others (1992), who place the Crescent–Aldwell contact at Pulali Point at an angular unconformity well above the uppermost Crescent flows and suggest that the sediments interbedded with the basalt flows belong to the Crescent Formation.

$Em_{2a}$ **Siltstone and sandstone facies**—In the study area, the Aldwell Formation consists predominantly of thin- to medium-bedded siltstone and sandy siltstone with thin- to medium-bedded, fine- to very fine-grained sandstone interbeds; siltstone commonly contains thin sandy laminations; thin to medium beds of fine-grained limestone or limey very fine-grained sandstone occur locally; coarse-grained poorly sorted conglomerate with basalt clasts occurs locally near the contact with the underlying Crescent basalt in lower Pats Creek near its confluence with Canyon Creek; siltstone and sandy siltstone are predominantly shades of olive-gray to gray; sandstone is greenish gray and weathers to dark yellowish brown and moderate yellowish brown; limey beds are light tan on weathered surfaces; conglomerate at base of unit resembles basalt at first glance and is dark brown to grayish black. In thin section, the rock predominantly consists of varying amounts of angular quartz, chert, plagioclase, lithic fragments that appear volcanic in origin, and alteration products consisting of chlorite, calcite, and limonite. A visual assessment of the sandstone samples indicates a range from lithic arkose to graywacke and feldspathic graywacke.

Exposures of the Aldwell Formation in the Carlsborg quadrangle are generally poor, occurring in roadcuts and along creek bottoms and in the steep canyon walls of Canyon Creek and Pats Creek at their confluence. The Aldwell Formation was also mapped along the crest and southwest slope of Lost Mountain, along the southeast end of Texas Valley where the area is incised by Pats and Rock Creeks and their tributaries and Canyon Creek, and in logging roadcuts in the foothills on the west side of Caraco Creek.

The thickness of the Aldwell Formation in the study area cannot be accurately estimated because it is poorly exposed and is faulted on both sides of Lost Mountain (Plate 2, cross section A–A′). We infer that the lower 600 ft is preserved in the trough of the faulted syncline under Texas Valley.

The Aldwell Formation in the study area contains foraminifera that were dated as lower Narizian, Ulatisian, and older (Fig. 5 and Appendix 4, foraminiferal sample sites C-12, C-13, and C-14). Sample C-12, which produced Ulatisian or older fauna, was collected from olive-gray siltstones in the bottom of Pats Creek and is typical of most of the Aldwell Formation siltstones in the study area. Sample C-13 (which produced a lower Narizian fauna) was collected from greenish gray fine-grained sandstones that occur at the trough of a syncline between Pats and Canyon Creeks and which represent a higher stratigraphic level in the Aldwell

Formation. Sample C-14 (which produced Ulatisian or older fauna) was collected from siltstone interbedded with very fine-grained sandstone just above the contact (appearing conformable) between the Aldwell Formation and underlying basalts of the Crescent Formation in Canyon Creek. (See Discussion for our assessment of the age of this unit.)

## CRESCENT FORMATION (EOCENE TO PALEOCENE?)

The Crescent Formation was originally named by Arnold (1906) for exposures of basalt at Crescent Bay (Fig. 2). The Crescent Formation was redefined by Brown and others (1960) 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. Subaerial flows and mudflow breccias with subordinate interbeds of sandstone, siltstone, mudstone, and gray foraminiferal limestone characterize their upper member. Flows of the upper member are characterized by closely spaced random joints, or less commonly by columnar joints, or more rarely by pillows. Cady and others (1972b) mapped their upper basalt member in the Tyler Peak 15-minute quadrangle that adjoins the southern border of the Carlsborg quadrangle. Tabor and Cady (1978a) extended the upper member of Cady and others (1972b) to include the basaltic rocks that form the southern foothills of Lost Mountain and Burnt Hill in the Carlsborg and east-adjacent Sequim quadrangles. Our mapping supports their interpretation.

Babcock and others (1992) described a measured composite section of 8.4 km (5.2 mi) of predominantly submarine flows and 7.8 km (4.8 mi) of predominantly subaerial flows in the Dosewallips River area approximately 18 mi south of the Sequim quadrangle. In the Sequim quadrangle, water-well logs indicate that Crescent Formation basalts underlie the lowlands, where they are covered by Makah Formation and/or Quaternary deposits (Schasse and Logan, 1998).

There were no previously published ages for the Crescent Formation in the study area. However, foraminifera obtained from four samples collected from interbeds within the Crescent Formation in this study are Ulatisian or older. Foraminifera from interbeds in the Crescent Formation elsewhere range in age from Penutian to Ulatisian (Upper–Lower and Lower–Middle Eocene; Rau, 1981). In the Dosewallips section, the subaerial basalts, which we correlate with the basalt section in the Carlsborg quadrangle, were dated with $^{40}Ar/^{39}Ar$ geochronometry (Babcock and others, 1992) and range from 50.5 ±1.6 Ma near the top to 51.0 ±4.6 Ma near the base. Ages equivalent to Penutian to Ulatisian foraminiferal stages (Squires and others, 1992) from fossils in sediments interbedded with the uppermost Crescent basalts at Pulali Point (near the site of the dated basalts) are consistent with the 50.5 Ma age.

The Blue Mountain unit of the Crescent Formation 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 regionally crops out in a basal stratigraphic position between the Hurricane Ridge fault and the overlying and locally interbedded volcanic rocks of the Crescent Formation (Fig. 2). However, the Blue Mountain unit appears to fill the gap between separate volcanic centers on the northeast side of the 'Crescent horseshoe'. In this area, the Blue Mountain unit is overlain by Eocene to Miocene upper peripheral sedimentary rocks of the Olympic Peninsula (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. Subordinate very thick siltstone units are finely laminated or massive. Pebbly conglomerate and sandstone provide evidence of major submarine channels in the middle of the unit (Einarsen, 1987).

In the Carlsborg quadrangle, we infer a fault contact between the older Blue Mountain unit (unit ERm) and the younger Aldwell Formation (unit $Em_{2a}$) in the Rock Creek area and an unconformable depositional contact between the Blue Mountain unit and overlying Hoko River Formation (unit $Em_{2h}$) (see description of unit ERm, discussion under Structural Geology, and Plate 2).

Prior to this study, the only reference to a direct age from the Blue Mountain unit was cited in Einarsen (1987), which stated that fossils (unspecified) from the Blue Mountain unit south of the Sequim quadrangle are Early to Middle Eocene age. We have fossil evidence from sandstone beds approximately 650 ft south of the Carlsborg quadrangle (see description of unit ERm) that is consistent with the age cited in Einarsen (1987). Babcock and others (1994) reported $^{40}Ar/^{39}Ar$ ages from their study area and from other workers in the Olympic Mountains for the Crescent Formation volcanic rocks, with maximum ages older than 57 Ma (Paleocene) (Plate 2). These data provided the basis for assigning an Eocene to Paleocene age for the Blue Mountain unit.

$Ev_c$ **Basalt, basalt breccia, and diabase (Early to Middle Eocene)**—Mostly porphyritic to aphyric, sparsely jointed, and pillowed basalt and lesser basaltic breccia; basalts are greenish gray, greenish black, grayish black, and black, weathering to brown and dark brown. Basalt typically has a rounded blocky appearance due to moderately well-developed subvertical joint sets and a less well-developed subhorizontal joint set; less commonly, basalt flows have randomly oriented joints (possible flow tubes?) and locally display columnar joints. Basaltic breccia is much less common than the jointed flows and consists of angular clasts of basalt, typically 2 to 4 in. in diameter. Diabase was noted locally in the area of Canyon and Caraco Creeks.

Basaltic rocks in the Carlsborg 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 (typically 45–50%) and occurs as euhedral to subhedral laths, frequently bladed and intergranular with clinopyroxene, in some places as glomerocrysts, and as microlites with a trachytic texture. Subhedral to anhedral clinopyroxene (probably augite) is abundant (30–45%) and typically interstitial to plagioclase or has an ophitic to subophitic texture in the diabase; clinopyroxene is locally replaced by chlorite. Basalt locally contains mineral-filled amygdules; some fillings were identified as calcite. Accessories in-

clude unidentifiable matrix minerals (possibly clays), limonite, calcite, and unidentified opaque minerals.

Flows and breccias typically have basalt geochemistry (Appendix 5). A pillowed flow at the south end of the canyon of the Dungeness River produced a basaltic andesite analysis (Fig. 5, geochemistry sample site 9). Jointed diabase exposed in a small quarry has picrobasalt chemistry (Fig. 5, geochemistry sample site 2). The thickness of the unit cannot be determined within the quadrangle. In one of their cross sections, Cady and others (1972b) indicate a maximum thickness of about 3,300 ft for their upper basalt member just south of the Sequim quadrangle.

$Em_{1cc}$ **Granular sandstone and conglomerate (Early to Middle Eocene)**—This facies was mapped only on the south-facing slopes of Lost Mountain. It is poorly exposed, occurring as float in roadcuts in the hillside or in weathered logging roadcuts and ditches near the crest of Lost Mountain. The contact of this unit with the underlying basalt of the Crescent Formation is not exposed.

In places, the unit appears to be medium- to thick-bedded, granule to pebble and cobble conglomeratic sandstone or breccia; contains rounded to subrounded pebbles and cobbles consisting of basalt, sandstone, quartz, and chert, and large angular rip-up clasts of olive-gray siltstone and laminated light olive-gray sandstone set in a matrix of gray, very coarse to granule-size sandstone that weathers to light brown. In thin section, rounded grains and clasts were predominantly basaltic, but some difficult-to-identify weathered clasts may have been sandstone. The basalt pebbles are both porphyritic and aphyric and have intergranular, trachytic, and subophitic textures that are commonly observed in the Crescent Formation in the study area. The thickness of the unit could not be determined in the field, but on the basis of outcrop pattern and local dip we estimate that its thickness is 100 ft or less.

One sample from unit $Em_{1cc}$ (Fig. 5 and Appendix 4, sample site C-10) produced rare occurrences of warm-shallow-water foraminifera that were assigned an age of Ulatisian or older (the age of the Crescent Formation). See Discussion for our assessment of age of this unit.

$Em_{1c}$ **Marine sedimentary rocks (Early to Middle Eocene)**—Thin- to medium-bedded, very fine-grained, generally fossiliferous, calcareous sandstone, siltstone, and mudstone; colors range from light and medium greenish gray, light and dark olive-gray to black, and medium light gray to pale pinkish gray. The rocks locally display spheroidal weathering and hackly fractures on weathered surfaces.

Thin tongues and isolated lenses of foraminiferal fine-grained sedimentary rocks, interbedded in the basalt and stratigraphically near the top of the section (Plate 2, cross section A–A′), crop out in a northwest-trending pattern on the north slope of Lost Mountain (see Plate 1, outcrops of unit $Em_{1c}$), starting from the banks of the Dungeness River. The bedding in these rocks is generally discordant with the local structure of the basalt. An excellent exposure of one of these lenses of sedimentary rock occurs in a quarry on the north slope of Lost Mountain. Outcrops in the quarry show basalt invading fine-grained sandstone and siltstone. Columnar flows, exposed in the quarry walls, suggest subaerial basalts at this locality (Fig. 5, geochemistry sample site 5). A thin section selected from the contact of sediments and basalt shows a narrow quench zone where plagioclase grains are markedly finer than plagioclase outside this zone. We interpret this to indicate possible invasion of soft sediments by the basalt. Thin sections of this unit show very fine-grained rock, with sparse anhedral grains of plagioclase and clinopyroxene, volcanic rock fragments, broken foraminifera, calcite cement, and unidentified black opaques.

Three samples provided foraminiferal assemblages that date these rocks as Ulatisian or older (Fig. 5 and Appendix 4, foraminiferal sample sites C-15, C-16, and C-17). These dates are consistent with dates provided elsewhere for similar sediments interbedded with the Crescent Formation (Rau, 1964).

ERm **Blue Mountain unit, sandstone facies (Eocene to Paleocene?)**—Thick- to thin-bedded, fine- to very coarse-grained, angular, moderately to poorly sorted sandstone and lesser amounts of thin-bedded, fine-grained silty sandstone; lenses of very coarse sandstone and pebble conglomerate with pebbles of volcanics and 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; beds of calcareous concretions and conglomeratic limestone (with granule to elongate cobble-size clasts) occur even more rarely. In thin section, these rocks consist of angular to subrounded quartz (some polycrystalline), broken plagioclase grains that have been partially altered, volcanic lithic fragments, and chert; calcite cement noted locally; accessory minerals include epidote and hypersthene(?). The rocks are lithic feldspathic arenites.

The unit crops out in the southwest corner of the quadrangle, south of the thrust fault mapped along Texas Valley, in sporadic exposures along the bottoms of stream valleys including McDonald and Rock Creeks, in hillsides where exposed by logging roads, and in small quarries or borrow pits used for road metal. Neither the base of the unit nor its top is exposed in the Carlsborg quadrangle. We believe that unit ERm is unconformably overlain by the Hoko River Formation (unit $Em_{2h}$) (Plate 1; Plate 2, cross section A–A′).

A sample of very fine-grained sandstone, collected from a small road-metal quarry off U.S. Forest Service road 2875, 650 ft south of the Carlsborg quadrangle in the Tyler Peak 7.5-minute quadrangle, produced a foraminiferal age for unit ERm in this study (Fig. 5 and Appendix 4, foraminiferal sample site C-11). The sample suggests that the assemblage belongs to the Ulatisian Stage or possibly older, which is consistent with the age cited in Einarsen (1987).

$ERm_c$ **Blue Mountain unit, conglomerate and pebbly sandstone facies (Eocene to Paleocene?)**—Medium- to very thick-bedded conglomerate and pebbly feldspatholithic sandstone; clasts are predominantly pebbles and cobbles of volcanic rocks and chert; greenish gray weathering to brown; angular siltstone rip-up clasts are common throughout. The unit is mapped in

the extreme southwest corner of the quadrangle, where it crops out on the northeast side of Round Top hill. We observed exposures of this unit along logging roadcuts in the west-adjacent Morse Creek quadrangle. The unit is believed to be a submarine channel facies to the submarine fan facies of unit ERm (Einarsen, 1987).

## DISCUSSION

### Late Quaternary Deposits

Late Quaternary surficial deposits found in the area along McDonald Creek, between sec. 7, T29N R4W in the south and sec. 8, T30N R4W in the north, reflect various ice-recessional, glaciofluvial, glaciolacustrine, and fluvial environments. With the retreat of the Juan de Fuca lobe of the Cordilleran ice sheet to a position north of the Olympic Mountains foothills, north-draining streams (such as McDonald Creek) began to transport and redeposit glacially derived sediments.

We interpret well-sorted and rhythmically laminated deposits of clay, silt, and minor amounts of sand as representing deposition in a glaciolacustrine environment (unit Qgl, Plate 2). Glaciolacustrine deposits (unit Qgl) crop out sporadically along the stream bed and in low-bank exposures of McDonald Creek, especially in secs. 18, 19, 30, and 31, T30N R4W. We were able to distinguish at least two generations of glaciolacustrine deposition based on deformation of rhythmically laminated deposits. Therefore, the deformed glaciolacustrine beds were deposited in ice-marginal lake(s) and deformed by the advancing Fraser-age Juan de Fuca lobe or earlier glacial advances, and the undeformed glaciolacustrine beds were deposited in ice-marginal lake(s) as the last ice sheet retreated. It is possible that some of the outcrops of deformed glaciolacustrine sediments are pre-Vashon Stade in age. We obtained an infinite radiocarbon age (Fig. 5, radiocarbon sample site 3) on plant detritus collected from fluvial sands stratigraphically above deformed glaciolacustrine clays in a cutbank exposure approximately 600 ft south of the U.S. Highway 101 bridge over McDonald Creek. The glaciolacustrine clays at this locality form diapirs that intrude into the radiocarbon-dated fluvial sands.

Stratigraphically above (and interfingering with?) glaciolacustrine deposits (unit Qgl) are recessional outwash deposits (unit Qgo) that record the transport and redeposition of glacial sediments by McDonald Creek and the Dungeness River. These deposits form outwash terraces, which may have been graded to the retreating ice front, decreasing in elevation both northward and eastward as the ice front retreated. Such deposits are exposed in borrow pits in secs. 6 and 7, T29N R4W, and in a roadcut just south of the junction of Hooker and Roupe Roads in secs. 22 and 27, T30N R4W. Subsequent to deposition of the outwash sands and gravels (unit Qgo), a second set of terraces were cut into these deposits. The formation of these outwash terraces may be the result of incision by 1) hydrologic (sediment yield and/or discharge) changes in the southern uplands or 2) base-level fall resulting from glacial isostatic rebound. The recessional outwash terrace deposits may not be synchronous between drainages, and the deposition of those terraces may have persisted into the early Holocene.

North of U.S. Highway 101, where the gradient of the McDonald Creek valley decreases significantly, fluvial deposits of thin- to medium-bedded sand, interbedded silt, and clayey silt with lenses of sand and pebbly gravel are present. We interpret these deposits as an alluvial fan complex (unit Qaf; previously mapped by Othberg and Palmer, 1979a, as Everson Sand [their unit Qes]) that was inset into the recessional outwash terraces of McDonald Creek (see Plate 2, cross sections B–B′ and C–C′). We assume that formation of the fan began shortly after ice recession from the area. The distal (northern) edge of the alluvial fan, mapped between 130 and 145 ft elevation, was initially deposited at the paleoshoreline, with lower alluvial fan deposits likely interfingering with glaciomarine sediments (unit Qgdm). For the northern portion of the Carlsborg 7.5-minute quadrangle, Dethier and others (1995) reported isostatic rebound of approximately 40 m (about 130 ft), which would place the distal edge of the mapped alluvial fan near the maximum elevation of the marine deposits in the area. In a cutbank of McDonald Creek in sec. 8, T30N R4W, approximately 40 ft of unit Qaf is exposed. Approximately 30 ft from the bottom of the section, a 2 in. thick interbedded layer of Mazama tephra is present (see Fig. 5, tephra sample site, and Appendix 2). The presence of Mazama tephra, dated at 6,730 ±40 $^{14}$C yr B.P., interbedded with fan sediments indicates that fan development continued well into the middle Holocene and that the canyon of McDonald Creek was incised to its present configuration after the 6,730 $^{14}$C yr B.P. tephra. Cessation of fan deposition most likely occurred as the result of a prominent change in sediment yield and/or discharge from the southern uplands. It may have been this same upbasin change that initiated incision along the lower portion of McDonald Creek.

### Post-Crescent and Crescent Sedimentary Rocks

In an attempt to subdivide the Twin River Group, which is primarily exposed in the bottom of McDonald Creek, we carefully analyzed its foraminiferal assemblages. We also collected and analyzed fossils from the Aldwell and Crescent Formations. (See Fig. 5 and Appendix 4.)

Foraminiferal assemblages identified in the Crescent Formation sediments (units $Em_{1cc}$, $Em_{1c}$ and ERm) are Ulatisian or older, consistent with fossil ages reported elsewhere on the Olympic Peninsula. However, there are conflicts between field observations and fossil ages in the post-Crescent rocks that require further discussion.

Rocks that we identify as Pysht Formation (unit $MOm_p$) in McDonald Creek are a series of small outcrops of fine-grained sediments dominated by mudstones containing mollusk fragments. Rocks similar to these have been described by Brown and others (1960) in quadrangles to the west as characteristic of rocks of the Pysht Formation. Rocks mapped by Brown and others (1960) in Siebert Creek, 2 mi to the west of McDonald Creek, are apparently restricted to small structural depressions along the hinge of the Clallam syncline, which trends directly toward the rocks that we map as Pysht Formation along McDonald Creek. Foraminiferal assemblages from three samples (Fig. 5, sample sites C-2, C-3, and C-4) collected from the rocks along McDonald Creek during this study were either too small to meaningfully identify or not diagnostic of any specific foraminiferal stage.

Rocks that we map as Makah Formation (unit $OEm_m$) are from two small exposures along McDonald Creek. They consist predominantly of siltstone, with minor sandy siltstone, calcareous siltstone, and clayey mudstone. These rocks are similar to the Makah Formation outcrop 2 mi to the west in Siebert Creek (Brown and others, 1960). Although the rocks we map as Makah are on strike with the rocks along Siebert Creek, they are separated by the thrust fault that passes under Texas Valley. This fault extends into the adjoining Morse Creek quadrangle at the point where it transects McDonald Creek at the west boundary of the Carlsborg quadrangle. However, rocks mapped as Makah in the Sequim quadrangle (Schasse and Logan, 1998) also strike

in the direction of the rocks we map as Makah in McDonald Creek.

Foraminiferal assemblages contained in two samples collected from the outcrops that we map as Makah Formation along McDonald Creek are representative of the Narizian stage (Fig. 5 and Appendix 4, sample sites C-5 and C-6). One of the samples contains the species *Plectofrondicularia packardi packardi*. This species is representative of the Refugian foraminiferal stage (Rau, 1964, p. G11, fig. 2), further suggesting that these outcrops are part of the Makah Formation.

Sixteen-hundred feet south along McDonald Creek at sample site C-7 (Fig. 5 and Appendix 4), rocks lithologically similar to the Makah Formation outcrops discussed above contain a large Narizian assemblage, which is representative of the Hoko River Formation (unit $Em_{2h}$) or Aldwell Formation (unit $Em_{2a}$). To the southeast, Aldwell Formation beds exposed on the southwest limb of the anticline forming Lost Mountain trend directly toward these rocks. We assign these rocks to the Aldwell Formation on the basis of this structural trend as well as the fossil ages. We query their identity as Aldwell Formation because these rocks are lithologically similar to the rocks of the Twin River Group, although their fossil age and their being on trend with Aldwell Formation rocks on Lost Mountain favor calling them Aldwell Formation.

Rocks that we map as Hoko River Formation (unit $Em_{2h}$) crop out in the bed and lower cut banks of McDonald Creek south of the fault that passes under Texas Valley. They crop out in relatively continuous fashion along a 2 mi stretch of McDonald Creek and consist of well-bedded, thin- to medium-bedded sandstones with hackly fracturing in the thin-bedded units. These rocks have the same characteristics as the Hoko River–equivalent rocks mapped by Brown and others (1960) to the west. The Hoko River rocks mapped in the Carlsborg quadrangle are on strike with rocks to the west that were mapped by Brown and others as equivalent to the lower member of the Twin River Group and as Twin River–Lyre Formation undivided. Tabor and Cady (1978a) later mapped these rocks as Twin River [Group] undivided. We found no evidence for mapping them as Lyre Formation.

Two polygons of unit $Em_{2h}$ are mapped on either side of McDonald Creek. The polygon to the west is mapped on the basis of float that looks like, and is directly on strike with, Hoko River Formation rocks exposed in McDonald Creek. The polygon of Hoko River Formation beds to the east of the creek was mapped as Hoko River Formation purely on the basis of topography.

The fault that passes under Texas Valley separates Hoko River Formation beds from the Aldwell Formation and the Crescent Formation basalts exposed on Lost Mountain and from the Makah Formation exposed in McDonald Creek. Therefore, we infer a fault contact between the Hoko River and Aldwell Formations at this location.

Two samples collected from Hoko River Formation rocks in McDonald Creek contain foraminiferal assemblages belonging to the *Uvigerina yazooensis* zone (Fig. 5 and Appendix 4, sample sites C-8 and C-9). Because these rocks have foraminiferal assemblages and lithologies characteristic of the Hoko River Formation, we feel reasonably confident in mapping them as Hoko River Formation.

Rocks that we map as Aldwell Formation (unit $Em_{2a}$) crop out on the south slopes and crest of Lost Mountain, in stream-cut drainages and canyons at the southwest end of Texas Valley, and in the foothills above the west bank of Caraco Creek. They consist predominantly of thin-bedded, greenish to olive-gray siltstones with minor thin interbeds of sandstone. As noted in the description of unit $Em_{2a}$, two of three samples produced foraminiferal assemblages that are found in rocks older than the Aldwell Formation (Ulatisian or older). The rocks with the older assemblages look much like Aldwell Formation rocks. The thin-bedded fine-grained sediments that make up unit $Em_{1c}$ (marine sedimentary interbeds of the Crescent Formation) and unit ERm (sandstone facies of the Blue Mountain unit) could be confused with the Aldwell Formation based on lithology, and both units contain Ulatisian or older foraminiferal assemblages. However, unit $Em_{1c}$ elsewhere in the quadrangle is more calcareous and fossiliferous than the Aldwell Formation beds that we observed. Also, the rocks mapped as Aldwell Formation containing older (Ulatisian or older) foraminiferal assemblages may be reworked Crescent Formation sediments. Because we do not have sufficient age control, we elect to map the entire package as Aldwell Formation with the assumption that the older fossil assemblage represents reworked sediments.

Rocks mapped as the conglomeratic facies of the Crescent Formation (unit $Em_{1cc}$) on the southwest slopes of Lost Mountain produced one sample with Ulatisian or older fauna (Fig. 5 and Appendix 4, sample site C-10). The unit was not observed on the north side of the anticlinal structure forming Lost Mountain. This unit is poorly exposed but was mapped between exposures of basalts of the Crescent Formation and sediments of the Aldwell Formation. Unit $Em_{1cc}$ contains numerous rounded clasts of basalt that are petrographically similar to rocks mapped as Crescent Formation basalt in the Carlsborg quadrangle. The unit also contains chert clasts and angular clasts of olive-gray siltstone that look like Aldwell Formation siltstone. Note that it is possible that the angular siltstone clasts are from the Aldwell Formation, and that the Ulatisian or older foraminifera identified in the single sample from this unit may be from reworked sedimentary interbeds in the Crescent Formation. However, Brown and others (1960) have mapped unsorted basaltic sediments (and basalt) of the Crescent Formation interfingering with Aldwell Formation siltstones. They also mapped lenses of unsorted clastic materials in the Aldwell Formation, which they suggested had been formed by landslides or mudflows in a marine environment. This interpretation could account for the mixed source of unit $Em_{1cc}$ clasts. We consider this unit as part of the Crescent Formation on the basis of the Ulatisian or older foraminiferal assemblage it contains.

## Structural Geology

The major structures in the Carlsborg quadrangle are a northwest-trending anticline in the southern part of the quadrangle, a high-angle thrust fault that underlies Texas Valley, and a concealed normal fault on the north flank of Lost Mountain (see Plates 1 and 2). The northwest-trending anticline exposes resistant Crescent Formation basalts to form Lost Mountain, the western part of Burnt Mountain (see Sequim quadrangle; Schasse and Logan, 1998), and other hills in the southern part of the quadrangle. The anticline, a continuation of the anticlinal structure mapped in the Sequim quadrangle, loses its definition where Crescent rocks pass beneath glacial drift at the northwest end of Lost Mountain. We infer four small faults at the northwest end of Lost Mountain (where the anticline may begin to plunge), which we interpret as normal faults that juxtapose Crescent Formation basaltic rocks with Aldwell Formation strata that are discordant with the regional strike of the Crescent rocks in the area of Lost Mountain (Plate 1).

The high-angle thrust fault that passes under Texas Valley was first mapped by Tabor and Cady (1978a), who mapped it as

a high-angle reverse fault that juxtaposes rocks of the Aldwell Formation with the Blue Mountain unit and undivided Twin River [Group], both of which have significantly different strikes from the Aldwell Formation rocks. We believe this fault may be a splay of a deeper thrust on which the Crescent Formation and younger sedimentary rocks ramp up to form the anticlinal fold and back-limb normal fault on the north flank of the anticline. The concealed normal fault that bisects the southern third of the quadrangle (first identified by Tabor and Cady, 1978a) preserves Twin River Group rocks on its downthrown (northern) block. Mapping in the Sequim quadrangle (Schasse and Logan, 1998) and our mapping in the Carlsborg quadrangle suggest the existence of this fault. Our interpretation of the structure in the area of Lost Mountain is shown in cross section A–A′ on Plate 2.

We assume the presence of the Aldwell Formation (unit $Em_{2a}$) in the subsurface on the north limb of the anticline that forms Lost Mountain (Plate 2, cross section A–A′). These beds also form the footwall of the concealed normal fault on the north limb of the anticline. Water-well logs indicate the presence of sandstone and siltstone on the south limb but do not describe conglomerate. Therefore, we assume that unit $Em_{1cc}$ is not present.

We interpret the concealed contact between the Hoko River Formation (unit $Em_{2h}$) and the Blue Mountain unit (unit ERm) as an angular unconformity. We base our interpretation on two closely juxtaposed outcrops of these units in McDonald Creek. We favor the unconformity interpretation over a fault interpretation because we did not observe evidence of faulting in these outcrops. Six hundred feet north of this contact, along McDonald Creek, we infer a concealed fault of unknown lateral extent within the rocks of the Hoko River Formation. We base our inference on the dramatically divergent strikes and opposed dips in adjacent outcrops of the unit (Plate 1).

Brown and others (1960) mapped several structures in the eastern part of their map area that appear to continue eastward into the Carlsborg quadrangle. They include, from north to south, the Swamp Creek anticline, the Clallam syncline, the Morse Creek syncline, and an eastern offset segment of their Lake Creek Fault. We have extended these structures into the quadrangle where appropriate. The evidence for the extension of the Clallam syncline includes the outcrops of the Pysht Formation in McDonald Creek in restricted structural depressions along the hinge of this fold. Water wells penetrating bedrock along strike to the east of the Pysht outcrops were used to extend the unit along the synclinal structure.

To the south, Hoko River Formation beds exposed in McDonald Creek provide good evidence for extending the Morse Creek syncline into the study area. We have chosen to terminate this syncline where it meets the thrust fault that passes under Texas Valley. We extended the Lake Creek fault into the study area where there is a marked change in the strike of the strata between outcropping segments of Hoko River Formation in McDonald Creek.

The age of faulting in the Carlsborg area has not been determined precisely. Evidence from this study indicates post–Late Eocene displacement for the fault under Texas Valley and post–Early Oligocene displacement for the fault on the north side of Lost Mountain, because the faults cut Late Eocene rocks and Oligocene–Eocene rocks, respectively. 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 Pysht and Clallam Formations reflect shallow marine and emergent conditions in the Tofino–Juan de Fuca basin. Lithologic evidence in other areas of the Olympic subduction complex indicates uplift continued at least through the Pliocene. (See Babcock and others, 1994, and references therein.)

## ACKNOWLEDGMENTS

This report was produced in cooperation with the U.S. Geological Survey National Cooperative Geologic Mapping Program, Agreement Number 99HQAG0136, which partially supported the field and office activities of Schasse and Wegmann. We are indebted to Weldon W. Rau, biostratigrapher (retired), for his identification and analysis of foraminiferal assemblages that provided the ages of the sedimentary rocks of Crescent Formation and post–Crescent Formation rocks mapped in the Carlsborg quadrangle.

We thank Irv Tailleur, geologist (USGS, retired), for providing us with a tephra sample that enabled us to correlate the older alluvial deposits with the Mazama tephra of Oregon.

We also thank Blakemore E. Thomas (USGS, Water Resources Division, Tacoma, Wash.) for providing accurate field locations for many of the water wells used to construct the geologic cross sections. We thank Tom Schendler (Clallam Co. Planning Dept.) for providing information on the county's addressing system and providing us with an atlas of Clallam County streets and roads. Thanks also to staff of the Division of Geology and Earth Resources: Eric Schuster and Bill Lingley for their technical reviews; Keith Ikerd and Chuck Caruthers for cartographic support on the map, cross sections, correlation diagram, figures, and explanations; Karen Meyers for computer drafting, text layout, and editing; Connie Manson and Lee Walkling for assistance with references; and Josh Brown and Jan Allen for clerical support.

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# Appendix 1. Records of selected water wells used in constructing cross sections for the Carlsborg 7.5-minute quadrangle

To construct the cross sections, 98 wells were used: 62 were field checked by the USGS, located during field work for this study, and/or accurately located using the current Clallam County rural addressing system; 36 were approximately located using location to the nearest quarter/quarter section, surface elevation, and address submitted to the Department of Ecology. **Completed**, date completed; **Elev.**, elevation of land surface (ft); **Depth**, drilled depth (ft); **Quality**: C, location field checked; A, location determined from county address system; U, not field checked and/or located with current county address system.

| Location | Owner | Completed | Elev. | Depth | Quality |
|---|---|---|---|---|---|
| 29N/04W-04J01 | David L. Luebbert | 07/14/1997 | 1,540 | 284 | U |
| 29N/04W-04K01 | Saabiac | 09/26/1998 | 1,785 | 347 | U |
| 29N/04W-09A01 | Newton, Marvin | 11/19/1992 | 1,690 | 169 | U |
| 29N/04W-09A02 | Patten Pacific | 09/26/1989 | 1,830 | 144 | U |
| 29N/04W-09E01 | Crops, Loyd & Sandra | 08/24/1984 | 1,360 | 139 | U |
| 29N/04W-09L01 | King, John | 10/30/1997 | 1,445 | 206 | A |
| 29N/04W-09N01 | Axford, Dave | 06/14/1993 | 1,420 | 369 | A |
| 30N/04W-01L01 | McKillip, Richard | 01/04/1990 | 120 | 145 | A |
| 30N/04W-01P01 | Griffing, Milton | 06/10/1993 | 120 | 115 | A |
| 30N/04W-01R01 | Watters, Wayne | 04/20/1988 | 120 | 118 | U |
| 30N/04W-02E01 | Millet, Boyd | 07/07/1992 | 68 | 228 | C |
| 30N/04W-02M01 | Mahan, Raymond | 09/17/1975 | 70 | 239 | C |
| 30N/04W-02P01 | McCulloch, Tom & Brenda | 01/19/1991 | 80 | 170 | U |
| 30N/04W-03P01 | Sharp, Weldon | 04/16/1991 | 120 | 250 | C |
| 30N/04W-04N01 | Taylor, Gordon | 05/23/1995 | 120 | 162 | U |
| 30N/04W-04P01 | Taylor, Scott | 11/03/1997 | 125 | 302 | U |
| 30N/04W-04R02 | Dungeness Estates | 11/24/1982 | 125 | 607 | C |
| 30N/04W-05R01 | Willies, Robert | 04/25/1988 | 130 | 289 | C |
| 30N/04W-06R01 | Poley, Steve | 08/07/1985 | 128 | 290 | A |
| 30N/04W-07G01 | Monterra Development Corp. | 09/01/1976 | 150 | 221 | C |
| 30N/04W-07J01 | Sauer, Ken | 07/02/1974 | 162 | 164 | U |
| 30N/04W-07N01 | Mullins, Merylin | 10/27/1975 | 167 | 284 | C |
| 30N/04W-07Q01 | Norris, W. Hugh & Grace | 03/07/1978 | 180 | 111 | C |
| 30N/04W-08F01 | Lora-Lee Estate | 04/10/1986 | 140 | 526 | C |
| 30N/04W-08L01 | Mustitch, Wayne | 01/07/1999 | 165 | 80 | U |
| 30N/04W-08N01 | Gates, Charles | 03/23/1990 | 180 | 107 | C |
| 30N/04W-08Q01 | Halstead, Ray | 04/06/1993 | 165 | 130 | U |
| 30N/04W-10B01 | Tomajko, Frank & Kim | 10/30/1989 | 120 | 200 | C |
| 30N/04W-10L01 | Hope, Jim | 06/08/1995 | 125 | 104 | A |
| 30N/04W-10M01 | Schneider, Robert | 05/08/1978 | 125 | 52 | U |
| 30N/04W-11G01 | Gilbertson, Grover | 06/26/1986 | 110 | 75 | U |
| 30N/04W-11J01 | Gilbertson, Gil | 04/01/1977 | 122 | 76 | C |
| 30N/04W-11M01 | Egan, Harry | 06/16/1992 | 116 | 184 | C |
| 30N/04W-12E01 | Simmons, Arthur | 08/02/1996 | 90 | 102 | C |
| 30N/04W-12F01 | Talley, Glen | 04/15/1980 | 130 | 87 | C |
| 30N/04W-12L02 | Peele, Ray | 04/11/1994 | 115 | 57 | U |
| 30N/04W-12N01 | Van Laningham, Nathan | 05/07/1996 | 125 | 98 | U |
| 30N/04W-12Q01 | Lopez, Arturo | 11/10/1998 | 120 | 81 | A |
| 30N/04W-12R01 | Landess, Leila | 09/26/1986 | 120 | 138 | U |
| 30N/04W-13C01 | Myers, Gail | 01/23/1995 | 145 | 75 | A |
| 30N/04W-13K01 | Kraft, Tony | 10/03/1994 | 165 | 94 | A |
| 30N/04W-14F01 | Adams, Elmer E. | 05/08/1994 | 162 | 294 | C |
| 30N/04W-14P01 | Thompson, Ray | 06/16/1976 | 185 | 98 | C |
| 30N/04W-15J01 | Schmuck, E. | 10/08/1985 | 160 | 144 | C |
| 30N/04W-15M01 | Finley, Jerry | 08/25/1993 | 155 | 81 | U |
| 30N/04W-15R01 | Clallam County PUD #1 | 06/12/1990 | 190 | 177 | C |
| 30N/04W-16C01 | Rutledge, Dick | 03/07/1979 | 145 | 47 | C |
| 30N/04W-16D01 | Cramer, Bruce | 07/08/1992 | 150 | 230 | C |
| 30N/04W-16H01 | Espeseth, Johs | 05/23/1994 | 135 | 78 | A |
| 30N/04W-16K01 | Olson, Carl | 08/08/1977 | 165 | 50 | U |
| 30N/04W-16L01 | Jackson, L. A. | 11/17/1980 | 175 | 70 | U |
| 30N/04W-16P02 | Bull, Gerald | 07/04/1977 | 285 | 144 | C |
| 30N/04W-17A02 | Oaks, Charles | 09/04/1990 | 180 | 149 | U |
| 30N/04W-17D01 | Wiley, Steve | 10/10/1991 | 200 | 121 | C |
| 30N/04W-17F01 | East, Gary (Solmar Land) | 08/11/1974 | 220 | 137 | U |
| 30N/04W-17N01 | Schefcik, Don & Sue | 04/12/1988 | 350 | 220 | U |
| 30N/04W-17R01 | Tozier, Larry | 07/25/1978 | 320 | 211 | C |
| 30N/04W-18H01 | Uhlie, Vance | 02/21/1976 | 235 | 140 | C |
| 30N/04W-19J01 | Zabel, Oscar A. | 09/18/1991 | 400 | 100 | A |
| 30N/04W-19R01 | Sullivan, Bill | 09/14/1994 | 420 | 134 | A |
| 30N/04W-20B02 | Baker, Odie | 02/14/1979 | 375 | 345 | C |
| 30N/04W-20H02 | Warren, Marilyn | 01/12/1985 | 315 | 289 | U |
| 30N/04W-20J01 | Barker, Harry | 10/20/1979 | 360 | 220 | C |
| 30N/04W-20M02 | Sallee, Bill & Judith | 12/31/1998 | 410 | 180 | A |
| 30N/04W-22J01 | Brown, Lyle | 07/16/1994 | 258 | 262 | A |
| 30N/04W-22J02 | Stoican, Valier | 1959 | 238 | 150 | C |
| 30N/04W-22N02 | Lohr, Bill M. | 11/11/1976 | 355 | 417 | C |
| 30N/04W-22Q01 | Terry, Bill | 09/08/1995 | 360 | 260 | A |
| 30N/04W-23E03 | Bacon, Bill | 11/21/1977 | 240 | 201 | C |
| 30N/04W-23F01 | Richmond, Leo L. | 08/19/1977 | 215 | 141 | C |
| 30N/04W-23F03 | Dailey, James | 09/21/1997 | 230 | 165 | A |
| 30N/04W-23N01 | Mills Mobile Home Park | 12/28/1979 | 255 | 210 | C |
| 30N/04W-23Q01 | Johnson, Kent | 08/15/1997 | 260 | 122 | A |
| 30N/04W-25P01 | Reinke, Daryl H. | 01/20/1998 | 370 | 140 | A |
| 30N/04W-26D01 | Wayne, Gordon | 05/30/1979 | 300 | 85 | U |
| 30N/04W-27A02 | Jones, Elmetta | 11/04/1988 | 365 | 170 | U |
| 30N/04W-27A04 | Bayless, Howard | 03/27/1978 | 320 | 201 | C |
| 30N/04W-27E01 | Martin, Wayne | 01/31/1980 | 480 | 160 | C |
| 30N/04W-27H01 | Powell, Archie O., Jr. | 03/04/1972 | 380 | 144 | U |
| 30N/04W-29B02 | Hammond, Randy | 05/06/1991 | 520 | 158 | C |
| 30N/04W-29P01 | Cole, Oliver | 09/07/1983 | 600 | 75 | U |
| 30N/04W-30A01 | Nolan, Pat | 10/24/1988 | 470 | 380 | U |
| 30N/04W-30B01 | Dailey, Arline | 01/18/1990 | 450 | 70 | C |
| 30N/04W-30G01 | Brady, Tom | 08/02/1978 | 530 | 166 | C |
| 30N/04W-30H01 | Fox, Bill | 09/29/1977 | 510 | 190 | C |
| 30N/04W-30J01 | Hickox, Tim | 12/30/1997 | 560 | 110 | U |
| 30N/04W-30K01 | Cole, Dyane B. | 03/04/1975 | 600 | 108 | U |
| 30N/04W-30R01 | Bamsey, Bob | 03/31/1974 | 620 | 107 | U |
| 30N/04W-33K01 | Ridgway, Dean | 10/15/1994 | 770 | 360 | C |
| 30N/04W-34C01 | Skolar, Joe | 07/14/1995 | 620 | 126 | A |
| 30N/04W-34E01 | Hansen, Ted | 12/01/1989 | 645 | 321 | C |
| 30N/04W-34E02 | Crandall, Lynn | 10/24/1997 | 640 | 58 | U |
| 30N/04W-34G01 | Stetson, Donald L. | 11/23/1976 | 580 | 200 | C |
| 30N/04W-34L02 | White, Herb | 10/18/1986 | 660 | 289 | C |
| 30N/04W-34N02 | Esteb, Nancy | 07/26/1996 | 970 | 365 | U |
| 30N/04W-34R01 | Wall, Lorraine | 04/27/1993 | 620 | 530 | A |
| 30N/04W-35D02 | Scott, Gary | 10/28/1987 | 515 | 145 | U |
| 30N/04W-36L01 | Wanner, Matt | 01/30/1988 | 430 | 240 | U |

# Appendix 2. Glass chemistry of McDonald Creek tephra

Tephra analysis performed at the Washington State University Geoanalytical Laboratory and correlated with the Mazama ash by Dr. Franklin F. Foit, Jr.

Sample: McDonald Creek #11B.

| Oxide | Weight percent, normalized* | |
|---|---|---|
| $SiO_2$ | 73.29 | (0.17) |
| $Al_2O_3$ | 14.46 | (0.13) |
| $Fe_2O_3$ | 2.12 | (0.04) |
| $TiO_2$ | 0.43 | (0.02) |
| $Na_2O$ | 4.71 | (0.11) |
| $K_2O$ | 2.70 | (0.07) |
| MgO | 0.48 | (0.02) |
| CaO | 1.58 | (0.06) |
| Cl | 0.20 | (0.01) |
| Total | 100.00 | |

* Analyses normalized to 100 weight percent
Standard deviations of the analyses given in parentheses

Number of shards analyzed: 15
Probable source/age: Mazama O, 6,850 $^{14}$C yr B.P.** (Bacon, 1983)
Similarity coefficient: 0.99

** Radiocarbon age reported by Bacon (1983) has been revised by new accelerator mass spectrometry analyses to 6,730 ±40 $^{14}$C yr B.P. (Hallet and others, 1997). This refined age is used in the text.

# Appendix 3. $^{14}C$ ages collected for mapping of the Carlsborg 7.5-minute quadrangle

$^{14}C$ analyses performed by Beta Analytic, Inc. (Miami, Fla.). Dates are reported as radiocarbon years before present (RCYBP); present = A.D. 1950. By international convention, the modern reference standard was 95% of the $^{14}C$ content of the National Bureau of Standards' Oxalic Acid & 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 PDB-1 international standard and the RCYBP ages were normalized to -25 per mil. If the ratio and age are accompanied by an asterisk (*), then the $^{13}C/^{12}C$ value was estimated, based on values typical of the material type. The quoted results are not calibrated to calendar years.

### Sample KW 8-19-99-1: Unit Qguc ($Qc_o$)

Small wood fragments collected from a nonbedded blue-gray silty clay layer exposed along coastal bluff section west of McDonald Creek along the Strait of Juan de Fuca. Silt layer sampled is stratigraphically below till (Vashon till, unit Qgt) (~25 ft) and above the first peat bed (Olympia nonglacial beds[?], unit $Qc_o$) (~10 ft).

| Measured $^{14}C$ age (yr B.P.) | $^{13}C/^{12}C$ ratio | Conventional $^{14}C$ age (yr B.P.) |
|---|---|---|
| 34,930 ±850 | -25.0*‰ | 34,930 ±850* |

Beta-137208
Sample no.: KW 8-31-99-1
Analysis: radiometric-standard
Material (pretreatment): wood (acid/alkali/acid)
Location: Fig. 5, radiocarbon sample site 1

### Sample KW 8-31-99-2: Unit Qguc ($Qc_o$?)

Single piece of wood from 0.5 m thick peat bed collected at beach level west of McDonald Creek along the Strait of Juan de Fuca. This peat bed is about 10 ft stratigraphically beneath silty clay interval dated by sample KW 8-19-99-1.

| Measured $^{14}C$ age (yr B.P.) | $^{13}C/^{12}C$ ratio | Conventional $^{14}C$ age (yr B.P.) |
|---|---|---|
| >45,360 | -25.0*‰ | >45,360 |

Beta-139271
Sample no.: KW 8-31-99-2
Analysis: radiometric-standard
Material (pretreatment): wood (acid/alkali/acid)
Location: Fig. 5, radiocarbon sample site 2

### Sample KW 8-19-99-2: Unit Qguc ($Qc_o$?)

Small pieces of plant material (wood, needles) collected from a well-sorted sand unit in an alternating sand and clay sequence exposed along west bank of McDonald Creek about 600 to 700 ft upstream of U.S. Highway 101 bridge.

| Measured $^{14}C$ age (yr B.P.) | $^{13}C/^{12}C$ ratio | Conventional $^{14}C$ age (yr B.P.) |
|---|---|---|
| >50,030 | -26.9‰ | >50,000 |

Beta-137207
Sample no.: KW 8-19-99-2
Analysis: Standard-AMS
Material (pretreatment): plant material (acid/alkali/acid)
Location: Fig. 5, radiocarbon sample site 3

# Appendix 4. Foraminifera from the Carlsborg 7.5-minute quadrangle, Washington

by W. W. Rau

Sample **C-1** (H 8-98-37.5-38) contained an excellent Refugian assemblage. Particularly significant are *Ceratobulimina washburnei*, *Melonis halkyardi*, and *Valvulineria willapaensis*. The assemblage is typical of parts of the Lincoln Creek Formation of southwest Washington (Rau, 1948) and to a lesser extent to assemblages of the Twin River Group (Makah Formation) of the Port Angeles area (Rau, 1964). The above species together particularly with *Quinqueloculina imperialis* suggest an upper bathyal depth of deposition.

Numerous samples contain assemblages that can be assigned to the Narizian Stage with various degrees of precision. They are the following:

**C-9** (KW 8-13-99-3) is certainly Narizian and represents the *Uvigerina yazooensis* zone (Rau, 1981). It indicates bathyal depths of deposition, probably upper bathyal (Engle, 1980).

**C-8** (HS 8-17-99-1) is a fairly good representation of the *Uvigerina yazooensis* zone, containing this species together with *Bifarina nuttalli*. It is a bathyal assemblage and may best be considered upper bathyal.

**C-6** (HS 9-30-99-3) is similar to the above assemblage but not as complete. Thus its specific age in less certain.

**C-5** (HS 9-30-99-5)—Although this is a fairly large Narizian assemblage, it does not contain any key taxa for a particular zone. With *Plectofrondicularia packardi* present, it suggests a middle part of the Stage. This is distinctly a bathyal assemblage and may well represent a lower part of the middle bathyal zone.

**C-7** (HS 9-28-99-2)—This is a large Narizian assemblage and represents the *Uvigerina yazooensis* zone or possibly even older as indicated by the presence of especially *Lenticulina welchi*, *Uvigerina yazooensis*, *Spiroplectammina directa*, and *Bulimina lirata*. It is a bathyal assemblage possibly representing either middle to upper bathyal depths.

**C-3** (HS 10-1-99-2)—This meager assemblage contains nothing that can be used to even suggest its age. It apparently is from a weathered sample and contains only a few fragments (weathered) of unidentifiable foraminifera.

**C-4** (HS 10-1-99-3)—This is a small assemblage and, although not diagnostic, is probably Narizian, but could be as young as Refugian. It probably represents bathyal depths of deposition.

**C-2** (HS 10-1-99-4)—This assemblage is not particularly diagnostic of age. It has some aspect of the Refugian Stage but also some of the Narizian Stage; it could even be as high as Zemorrian. With *Gyroidina orbicularis planata* common and several species of *Quinqueloculina*, water depths were probably not greater than upper bathyal.

**C-13** (HS 10-15-99-6)—This assemblage distinctly represents a lower part of the Narizian Stage, the *Bulimina jacksonensis* zone, as indicated by this species as well as *Amphimorphina californica*. It may well be an Aldwell Formation fauna. These species and others indicate bathyal depths, most likely upper bathyal.

The following assemblages all indicate, in varying degrees, the Ulatisian Stage or older and are usually found in sedimentary interbeds associated with the Crescent Formation.

**C-11** (KW 8-10-99-4)—If I have correctly identified *Discocyclina* then this assemblage represents the Ulatisian Stage or possibly older, representing the *Vaginulinopsis vacavillensis* zone (Rau, 1981). This taxa represents shallow, warm water conditions.

**C-10** (HS 7-29-99-2a)—The presence of *Amphistegina* indicates that it is Ulatisian or older. *Amphistegina* is a warm, shallow water taxa.

**C-12** (HS 8-25-99-1)—*Amphistegina* is also present in this small assemblage and can be compared with the above assemblage.

**C-16** (HS 8-26-99-5)—This fairly large assemblage also contains *Amphistegina* together with *Nodosaria latejugata* and *Discorbis baintoni*, all taxa typically occurring no higher than the Ulatisian Stage. Warm, shallow water is indicated by the presence of *Amphistegina* and other taxa.

**C-15** (HS 8-26-99-6)—This assemblage contains nothing diagnostic. I suspect it is Ulatisian or older but there is nothing in it to confirm that age. It probably represents bathyal depths of deposition.

**C-17** (KW 8-27-99-1)—The presence of particularly both *Lenticulina* cf. *L. pseudovortex* and *Cibicidoides* cf. *C. venezuelanus* indicate a Ulatisian or older age. Other taxa not clearly identifiable tend to support this age. The overall assemblage indicates a bathyal depth of deposition, most likely an upper part of the bathyal zone.

**C-14** (KW 8-20-99-2)—This is an extremely meager assemblage. It appears to contain *Amphistegina* which, if properly identified, indicates a Ulatisian or older age. It would also indicate shallow, warm water.

## References Cited


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

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.

Localities in this table are identified by a combination of sample number, a DNR/DGER state slide file number (S-#), and a locality suffix (C-#). The locations from which the samples were collected in the Carlsborg 7.5-minute quadrangle are shown on Figure 5 with the parenthetical portion of the sample number only (for example, C-4). Sample KW 8-10-99-4 (locality C-11) is from a small quarry 650 ft south of the northern boundary of the Tyler Peak 7.5-minute quadrangle. Locality C-1 is a geotechnical borehole sampled at depth (interval 37.5–38.0 ft below the surface). C, common; F, few; R, rare; ?, identification uncertain.

| | Locality | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxa** | WADOT-H-8-98-37.5-38 (S-1180) (C-1) | HS 10-1-99-4 (S-1207) (C-2) | HS 10-1-99-2 (S-1205) (C-3) | HS 10-1-99-3 (S-1206) (C-4) | HS 9-30-99-5 (S-1203) (C-5) | HS 9-30-99-3 (S-1202) (C-6) | HS 9-28-99-2 (S-1204) (C-7) | HS 8-17-99-1 (S-1200) (C-8) | KW 8-13-99-3 (S-1198) (C-9) | HS 7-29-99-2A (S-1185) (C-10) | KW 8-10-99-4 (S-1181) (C-11) | HS 8-25-99-1 (S-1191) (C-12) | HS 10-15-99-6 (S-1183) (C-13) | KW 8-20-99-2 (S-1189) (C-14) | HS 8-26-99-6 (S-1194) (C-15) | HS 8-26-99-5 (S-1193) (C-16) | KW 8-27-99-1 (S-1195) (C-17) |
| *Cyclammina* spp. | | R | F | C | C | F | F | C | C | | | F | | | | | C |
| *Lenticulina* cf. *L. inornatus* (d'Orbigny) | F | | R | R | C | R | C | R | C | | F | | R | | F | F | |
| *Uvigerina* cf. *U. yazooensis* Cushman | | | | | | | C | R | R | | | | | | | | |
| *Bulimina* sp. (costate basal) | | | | | | | | | R | | | | | | | | |
| *Globobulimina* spp. | | | | C | | C | | C | ? | | ? | | | | | | |
| *Dentalina* spp. | | | | | R | R | R | F | R | | | | | | | R | R |
| *Allomorphina* sp. | | | | | | | | R | | | | R | | | | | |
| *Bifarina nuttalli* Cushman and Siegfus | | | | | | ? | | C | | | | | | | | | |
| *Virgulina* sp. | | | | | | | | ? | | | | | | | | ? | |
| *Globigerina* spp. | | R | | | C | C | | R | | | | | ? | R | | | |
| *Eponides* cf. *E. umbonatus* (Reuss) | | | | ? | R | | R | R | | | | | | | | | |
| *Quinqueloculina* sp. | | R | R | | | | | R | | | R | | | | | | |
| *Gyroidina orbicularis planata* Cushman | C | F | | C | | | C | F | | | | | | | R | ? | R |
| *Bathysiphon* sp. | | | F | | F | C | F | | | | | F | | R | R | | |
| *Karreriella* cf. *K. media-aguaensis* Mallory | | | | | | F | R | | | | | | | | | | |
| *Haplophragmoides* sp. | | | | | F | C | R | | | | | | | | | | |
| *Pseudoglandulina* sp. | | R | | | F | R | | | | | | | | | | | |
| *Globobulimina pacifica* Cushman | | ? | ? | R | R | C | R | | | | ? | | | | F | | ? |
| *Allomorphina* cf. *A. macrostomata* Karrer | | | | | C | F | ? | | | | | | | | | | C |
| *Saracenaria schencki* Cushman and Hobson | | | | | | R | | | | | | | | | | | |
| *Nodosaria longistagata* d'Orbigny | | ? | | | F | | R | | | | | | | | | | |
| *Plectofrondicularia vaughani* Cushman | | | | | F | | | | | | | | | | | | |
| *Plectofrondicularia packardi packardi* Cushman and Schenck | | | | | F | | R | | | | | | | | | | |
| *Eponides* cf. *E. minima* Cushman | | | | | R | | | | | | | | | | | | |
| *Marginulina* sp. | | | | | R | | | | | | | | | | | | |
| *Dentalina* sp. *b* (of Rau, costate) | | | | | R | | | | | | | | | | | | |
| *Globocassidulina globosa* (Hantken) | | | | | R | | R | | | | | | | | | | |
| *Eponides* cf. *E. mexicana* Cushman | | | ? | ? | R | | | | | | | | | | | | |
| *Uvigerina* cf. *U. garzaensis* Cushman and Siegfus | | | | | R | | F | | | | | | | | | | |
| *Ammodiscus* cf. *A. incertus* d'Orbigny | | | | | | | F | | | | | R | | | | | |
| *Spiroplectammina directa* (Cushman and Siegfus) | | | | | | | R | | | | | | | | | | |
| *Chilostomella* cf. *C. oolina* Schwager | | | | | | | R | | | | | | | | F | ? | F |
| *Bulimina* cf. *B. lirata* Cushman and Parker | | | | | | | R | | | | | ? | | | | | |
| *Lenticulina welchi* (Church) | | | | | | | R | | | | | | | | | | |
| *Cibicides* sp. | | R | | | | | R | | | | | R | F | | | C | |
| *Melonis pompilioides* (Fichtel and Moll) | R | ? | | | | | R | | | | | | | | | | |
| *Pseudoglandulina inflata* (Bornemann) | | | | | | | R | | | | | | | | | | |
| *Glandulina* sp. | | | | | | | C | | | | | | | | | | |
| *Quinqueloculina weaveri* Rau | | R | | | | | | | | | | | | | | | |
| *Pyrgo* cf. *P. lupheri* Rau | | R | | | | | | | | | | | | | | | |
| *Quinqueloculina minuta* Beck | | R | | | | | | | | | | | | | | | |
| *Discocyclina* sp. | | | | | | | | | | | ? | | | | | | |
| *Bulimina* cf. *B. jacksonensis* Cushman | | | | | | | | | | | | | F | | | | F |
| *Bolivina* sp. (small) | | | | | | | | | | | | | R | | | | |
| *Amphimorphina californica* Cushman and McMasters | | | | | | | | | | | | | R | | | | |

| | Locality | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxa** | WADOT-H-8-98-37.5-38 (S-1180) (C-1) | HS 10-1-99-4 (S-1207) (C-2) | HS 10-1-99-2 (S-1205) (C-3) | HS 10-1-99-3 (S-1206) (C-4) | HS 9-30-99-5 (S-1203) (C-5) | HS 9-30-99-3 (S-1202) (C-6) | HS 9-28-99-2 (S-1204) (C-7) | HS 8-17-99-1 (S-1200) (C-8) | KW 8-13-99-3 (S-1198) (C-9) | HS 7-29-99-2A (S-1185) (C-10) | KW 8-10-99-4 (S-1181) (C-11) | HS 8-25-99-1 (S-1191) (C-12) | HS 10-15-99-6 (S-1183) (C-13) | KW 8-20-99-2 (S-1189) (C-14) | HS 8-26-99-6 (S-1194) (C-15) | HS 8-26-99-5 (S-1193) (C-16) | KW 8-27-99-1 (S-1195) (C-17) |
| *Amphistegina* sp. | | | | | | | | | | R | | F | | ? | | F | |
| *Nodosaria* cf. *N. latejugata* Gumbel | | | | | | | | | | R | | | | | | R | |
| *Bulimina corrugata* Cushman and Siegfus | | | | | | | | | | | | ? | | | | | |
| *Lenticulina* cf. *limbosus hockleyensis* (Cushman and Applin) | | | | | | | | | | | | | | | | R | |
| *Discorbis baintoni* Mallory | | | | | | | | | | | | | | | | F | |
| *Guttulina* cf. *G. irregularis* d'Orbigny | | | | | | | | | | | | | | | | R | R |
| *Anomalina* cf. *A. garzaensis* Cushman and Siegfus | | | | | | | | | | | | | | | | R | |
| *Epistomina* sp. (large) | | | | | | | | | | | | | | | R | | |
| *Lenticulina* cf. *L. pseudovortex* (Cole) | | | | | | | | | | | | | | ? | | | R |
| *Pleurostomella* sp. | | | | | | | | | | | | | | | | | ? |
| *Valvulineria* sp. | | | | | | | | | | | | | | R | | | R |
| *Cibicidoides* cf. *C. venezuelanus* (Nuttall) | | | | | | | | | | | | | | | | | R |
| *Valvulineria* cf. *V. jacksonensis* Cushman | | | | | | | | | | | | | | | | | R |
| *Ceratobulimina washburnei* Cushman and Schenck | F | | | | | | | | | | | | | | | | |
| *Quinqueloculina imperialis* Hanna and Hanna | C | | | | | | | | | | | | | | | | |
| *Melonis halkyardi* (Cushman) | F | | | | | | | | | | | | | | | | |
| *Valvulineria willapaensis* Rau | F | | | | | | | | | | | | | | | | |
| *Guttulina frankei* Cushman and Ozawa | R | | | | | | | | | | | | | | | | |
| *Cibicides elmaensis* Rau | R | | | | | | | | | | | | | | | | |
| *Pseudoglandulina inflata* (Bornemann) | R | | | | | | | | | | | | | | | | |
| *Eponides Kleinpelli* Cushman and Fizzell | ? | | | | | | | | | | | | | | | | |
| *Lenticulina* cf. *L. weaveri* (Beck) | R | | | | | | | | | | | | | | | | |

# Appendix 5. Major, minor, and trace element geochemical analyses, this study

Rigaku automated X-ray fluorescence spectrometer (XRF) analyses of rocks in the Carlsborg 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 Figure 5. R, duplicate bead made from same rock powder; Loc., locality number; $basalt_f$, subaerial flow; $basalt_p$, pillowed flow.

**Unnormalized results (weight %):**

| Loc. | Sample | Rock Unit | $SiO_2$ | $Al_2O_3$ | $TiO_2$ | FeO | MnO | CaO | MgO | $K_2O$ | $Na_2O$ | $P_2O_5$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | HS 7-13-99-1A | $Ev_c$, $basalt_f$ | 47.88 | 16.21 | 2.154 | 13.11 | 0.173 | 9.69 | 4.39 | 0.27 | 3.52 | 0.242 | 97.64 |
| 2 | HS 7-27-99-3 | $Ev_c$, $picrobasalt_f$ | 40.93 | 7.26 | 0.489 | 12.44 | 0.193 | 6.94 | 27.37 | 0.02 | 0.08 | 0.035 | 95.76 |
| 3 | HS 7-28-99-3 | $Ev_c$, $basalt_p$ | 45.43 | 16.19 | 1.599 | 12.19 | 0.239 | 10.49 | 8.79 | 0.04 | 2.02 | 0.115 | 97.10 |
| 4 | HS 8-9-99-3 | $Ev_c$, $basalt_f$ | 46.92 | 15.83 | 1.395 | 11.30 | 0.201 | 10.49 | 7.98 | 0.21 | 2.92 | 0.108 | 97.35 |
| 4 | HS 8-9-99-3R | $Ev_c$, $basalt_f$ | 47.19 | 15.89 | 1.411 | 10.97 | 0.201 | 10.52 | 8.00 | 0.21 | 2.93 | 0.106 | 97.43 |
| 5 | HS 8-11-99-1B | $Ev_c$, $basalt_f$ | 47.47 | 14.13 | 1.173 | 10.45 | 0.169 | 9.48 | 10.04 | 0.07 | 3.52 | 0.078 | 96.58 |
| 6 | KW 8-20-99-1 | $Ev_c$, $basalt_p$ | 47.19 | 16.69 | 1.620 | 10.76 | 0.334 | 11.41 | 6.83 | 0.37 | 2.25 | 0.121 | 97.57 |
| 7 | HS 8-26-99-3 | $Ev_c$, $basalt_f$ | 46.57 | 16.10 | 1.164 | 10.20 | 0.182 | 11.77 | 9.54 | 0.07 | 1.84 | 0.077 | 97.51 |
| 8 | HS 9-29-99-1 | $Ev_c$, $basalt_f$ | 45.27 | 18.03 | 0.851 | 9.81 | 0.142 | 10.48 | 11.33 | 0.06 | 1.52 | 0.062 | 97.55 |
| 9 | HS 9-29-99-3 | $Ev_c$, basaltic $andesite_p$ | 54.20 | 14.90 | 1.407 | 9.76 | 0.178 | 8.56 | 5.55 | 0.67 | 3.63 | 0.161 | 99.01 |
| 10 | HS 10-14-99-2 | $Ev_c$, $basalt_f$ | 49.13 | 12.98 | 2.329 | 12.36 | 0.270 | 10.30 | 7.10 | 0.10 | 3.52 | 0.227 | 98.31 |

**Normalized results (weight %):**

| Loc. | Sample | Rock Unit | $SiO_2$ | $Al_2O_3$ | $TiO_2$ | FeO | MnO | CaO | MgO | $K_2O$ | $Na_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | HS 7-13-99-1A | $Ev_c$, $basalt_f$ | 49.04 | 16.60 | 2.206 | 13.43 | 0.177 | 9.92 | 4.50 | 0.28 | 3.61 | 0.248 |
| 2 | HS 7-27-99-3 | $Ev_c$, $picrobasalt_f$ | 42.74 | 7.58 | 0.511 | 12.99 | 0.202 | 7.25 | 28.58 | 0.02 | 0.08 | 0.037 |
| 3 | HS 7-28-99-3 | $Ev_c$, $basalt_p$ | 46.79 | 16.67 | 1.647 | 12.55 | 0.246 | 10.80 | 9.05 | 0.04 | 2.08 | 0.118 |
| 4 | HS 8-9-99-3 | $Ev_c$, $basalt_f$ | 48.20 | 16.26 | 1.433 | 11.60 | 0.206 | 10.78 | 8.20 | 0.22 | 3.00 | 0.111 |
| 4 | HS 8-9-99-3R | $Ev_c$, $basalt_f$ | 48.43 | 16.31 | 1.448 | 11.26 | 0.206 | 10.80 | 8.21 | 0.22 | 3.01 | 0.109 |
| 5 | HS 8-11-99-1B | $Ev_c$, $basalt_f$ | 49.15 | 14.63 | 1.215 | 10.82 | 0.175 | 9.82 | 10.40 | 0.07 | 3.64 | 0.081 |
| 6 | KW 8-20-99-1 | $Ev_c$, $basalt_p$ | 48.36 | 17.11 | 1.660 | 11.03 | 0.34 | 11.69 | 7.00 | 0.38 | 2.31 | 0.124 |
| 7 | HS 8-26-99-3 | $Ev_c$, $basalt_f$ | 47.76 | 16.51 | 1.194 | 10.46 | 0.187 | 12.07 | 9.78 | 0.07 | 1.89 | 0.079 |
| 8 | HS 9-29-99-1 | $Ev_c$, $basalt_f$ | 46.41 | 18.48 | 0.872 | 10.05 | 0.146 | 10.74 | 11.61 | 0.06 | 1.56 | 0.064 |
| 9 | HS 9-29-99-3 | $Ev_c$, basaltic $andesite_p$ | 54.74 | 15.05 | 1.421 | 9.85 | 0.180 | 8.65 | 5.61 | 0.68 | 3.67 | 0.163 |
| 10 | HS 10-14-99-2 | $Ev_c$, $basalt_f$ | 49.97 | 13.20 | 2.369 | 12.57 | 0.27 | 10.48 | 7.22 | 0.10 | 3.58 | 0.231 |

**Trace Elements (ppm):**

| Loc. | Sample | Rock Unit | Ni | Cr | Sc | V | Ba | Rb | Sr | Zr | Y | Nb | Ga | Cu | Zn | Pb | La | Ce | Th |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | HS 7-13-99-1A | $Ev_c$, $basalt_f$ | 32 | 67 | 35 | 347 | 50 | 1 | 186 | 159 | 42 | 11.0 | 19 | 113 | 96 | 2 | 17 | 33 | 0 |
| 2 | HS 7-27-99-3 | $Ev_c$, $picrobasalt_f$ | 1157 | 1575 | 24 | 135 | 0 | 1 | 65 | 28 | 9 | 2.5 | 10 | 62 | 71 | 1 | 0 | 7 | 0 |
| 3 | HS 7-28-99-3 | $Ev_c$, $basalt_p$ | 192 | 258 | 36 | 289 | 9 | 0 | 169 | 88 | 31 | 3.1 | 18 | 124 | 84 | 0 | 10 | 12 | 2 |
| 4 | HS 8-9-99-3 | $Ev_c$, $basalt_f$ | 111 | 163 | 46 | 284 | 48 | 2 | 350 | 84 | 26 | 5.4 | 18 | 148 | 78 | 1 | 5 | 0 | 1 |
| 4 | HS 8-9-99-3R | $Ev_c$, $basalt_f$ | 109 | 165 | 41 | 281 | 48 | 1 | 350 | 82 | 28 | 3.8 | 17 | 143 | 81 | 0 | 11 | 28 | 1 |
| 5 | HS 8-11-99-1B | $Ev_c$, $basalt_f$ | 160 | 388 | 47 | 314 | 42 | 1 | 197 | 63 | 26 | 3.9 | 14 | 165 | 49 | 0 | 0 | 11 | 1 |
| 6 | KW 8-20-99-1 | $Ev_c$, $basalt_p$ | 129 | 208 | 42 | 315 | 26 | 1 | 207 | 94 | 32 | 4.4 | 20 | 142 | 85 | 1 | 18 | 38 | 1 |
| 7 | HS 8-26-99-3 | $Ev_c$, $basalt_f$ | 144 | 288 | 40 | 256 | 25 | 1 | 149 | 63 | 21 | 3.8 | 18 | 129 | 63 | 1 | 6 | 8 | 2 |
| 8 | HS 9-29-99-1 | $Ev_c$, $basalt_f$ | 331 | 137 | 29 | 166 | 5 | 0 | 154 | 49 | 17 | 2.8 | 16 | 87 | 63 | 0 | 2 | 7 | 1 |
| 9 | HS 9-29-99-3 | $Ev_c$, basaltic $andesite_p$ | 80 | 143 | 32 | 239 | 117 | 9 | 160 | 236 | 52 | 15.0 | 21 | 110 | 87 | 1 | 19 | 39 | 3 |
| 10 | HS 10-14-99-2 | $Ev_c$, $basalt_f$ | 69 | 156 | 39 | 343 | 51 | 0 | 297 | 147 | 30 | 15.9 | 19 | 168 | 99 | 0 | 12 | 34 | 2 |