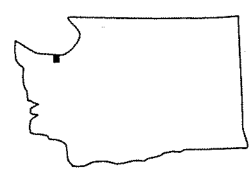
NATURAL RESOURCES

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

by Henry W. Schasse
and Robert L. Logan

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Open File Report 98-7
June 1998



Location of quadrangle

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

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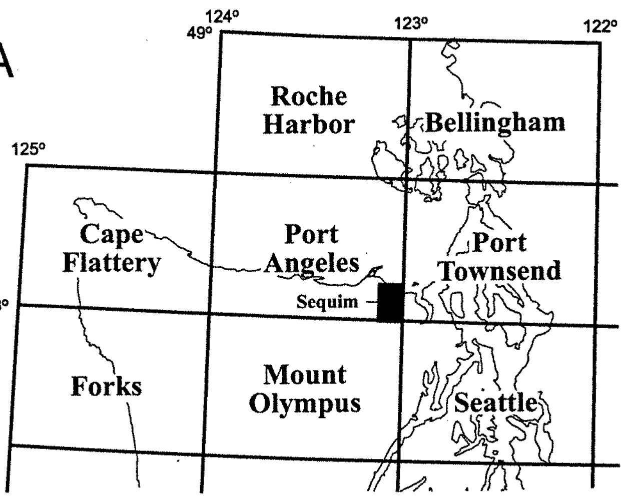
INTRODUCTION

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 shown on the map and cross sections. The report also discusses our interpretation of the bedrock structure, based largely on data from water-well records and logs of an oil and gas test well. Tertiary sedimentary units, previously mapped as undivided rocks of the Twin River Group, are herein assigned to the Makah Formation (Snavely and others, 1978, 1980).

The Sequim 7.5-minute quadrangle is located in the southeast corner of the Port Angeles 30- x 60-minute quadrangle (Fig. 1A). The Sequim quadrangle is situated on the northeast part of the Olympic Peninsula (Fig. 2) 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: (1) A peripheral belt of lower and middle Eocene oceanic basaltic rocks of the Crescent Formation and an overlying sequence of middle Eocene to upper Miocene marine sedimentary rocks wrap around (2) a core of marine sedimentary rocks and minor volcanogenic rocks that are approximately coeval with the peripheral rocks but everywhere in fault contact with them. The Crescent Formation, the basal unit of the peripheral rocks, is a thick sequence of oceanic pillow basalt, breccia, and interbedded volcaniclastic rocks with

A



B

EXPLANATION

Quaternary Sedimentary Deposits

Qa Alluvium, undivided (Holocene and Pleistocene?)

Qu Undifferentiated sediments—Includes glacial and nonglacial deposits, undivided, beach deposits, artificial fill, and modified land (Holocene and Pleistocene)

Qgm Everson Glaciomarine Drift (Pleistocene)

Qgm_u Everson Glaciomarine Drift and Vashon ice-contact deposits, undivided (Pleistocene)

Qgo Vashon recessional and advance outwash, undivided (Pleistocene)

Qgt Vashon till (Pleistocene)

Tertiary Sedimentary and Volcanic Rocks

ΦEm Marine sedimentary rocks (Oligocene and Eocene)

Ev Volcanic rocks of the Crescent Formation (Eocene)

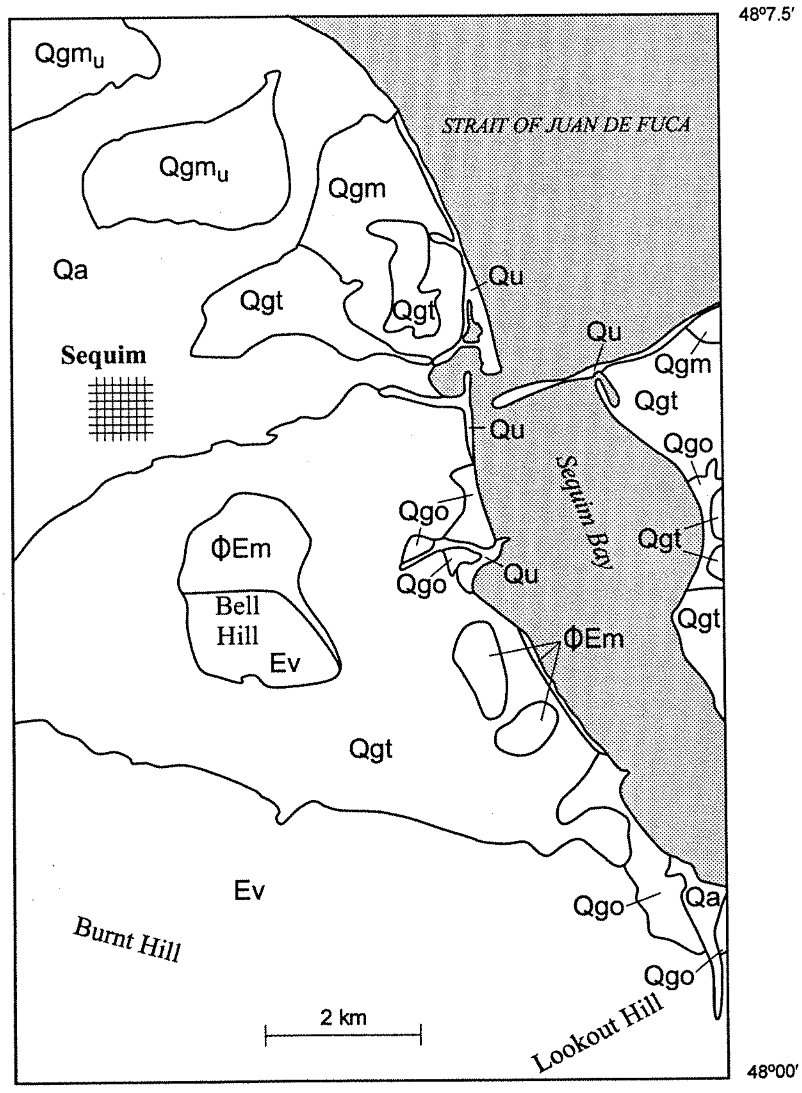


Figure 1. **A.** 1:100,000-scale quadrangles in the northwestern part of Washington State and location of the Sequim 7.5-minute quadrangle. **B.** Simplified geologic map of the Sequim 7.5-minute quadrangle. Areas of glacial cover over bedrock (units ΦEm and Ev) not shown.

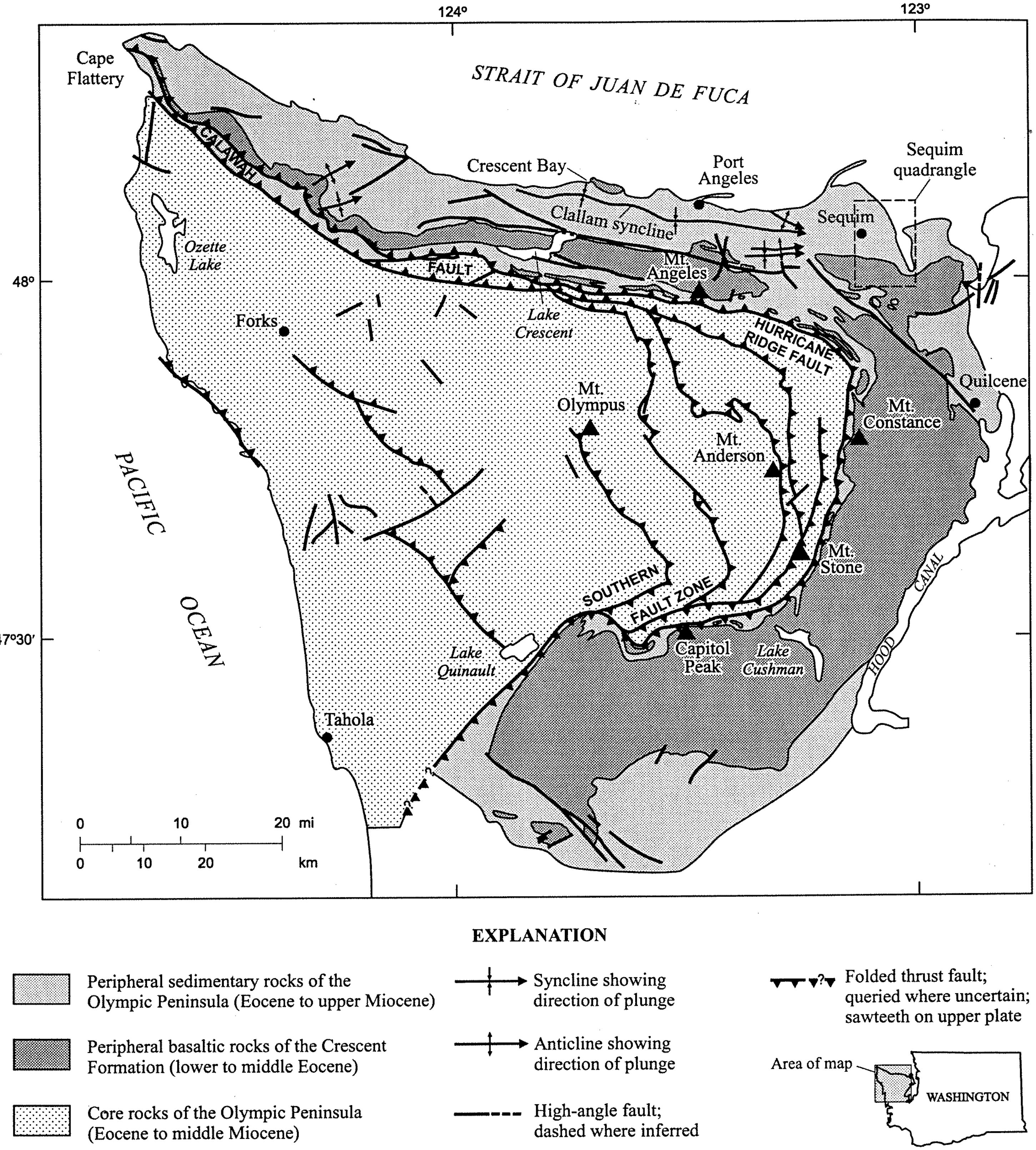


Figure 2. Major folds and faults and geologic terranes of the Olympic Peninsula. Peripheral rocks include the basalt (mostly oceanic) of the Crescent Formation and overlying marine sedimentary rocks. They form a horseshoe-shaped belt around the mountainous core. Folds in core rocks, the Crescent Formation,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

minor pelagic sedimentary rocks, and rare columnar basalt near the top of the section (Tabor and Cady, 1978b). Geologic units in the Sequim quadrangle can be broadly grouped into surficial deposits, Oligocene–Eocene 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 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, and they refer to it as the Tofino–Juan de Fuca basin. These fossiliferous rocks are faulted and folded but, in general, are stratigraphically continuous. Fold axes are subparallel to many of the faults, trend eastward, and plunge gently east (Fig. 2).

In the Sequim quadrangle, sedimentary rocks of the Makah Formation unconformably overlie the volcanic rocks of the Crescent Formation. All of these units appear to be folded together, apparently by a post-early Oligocene tectonic event of unknown duration. Local cross faulting appears to overprint these folds.

More than 2,000 ft of unconsolidated Pleistocene sediments, identified from logs of an oil and gas test well drilled northeast of Sequim in the mid-1950s, were deposited on the Tertiary sedimentary rocks. The most recent of these deposits were left during the Fraser Glaciation (20–10 ka) from lobes of the Cordilleran ice sheet that advanced southward out of Canada and split in the area of the Sequim quadrangle. The Puget lobe flowed south, covering the area now known as the Puget Lowland, and the Juan de Fuca lobe flowed west through the Strait of Juan de Fuca to a terminal position on the continental shelf. The younger glacial deposits are thickest in the north half of the 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 sediment cover consists of advance outwash covered by till that thins rapidly southward to veneer the foothills and their outlier, Bell Hill, forming a patchwork pattern of till (where it fills depressions) and bedrock (where the till was eroded away). Pleistocene strata underlying the Fraser glacial deposits are glacial and nonglacial deposits that represent one and possibly two pre-Fraser glaciations and possibly two pre-Fraser nonglacial periods. These deposits are mapped on coastal bluffs and are evident in water-well logs. Bedrock and glacial deposits have been locally modified by Holocene alluvial and mass-wasting processes.

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

- Detailed mapping has delineated bedrock exposures that were formerly mapped as "till over bedrock" in an earlier map of the quadrangle (Othberg and Palmer, 1979).
- We have made an interpretation of the bedrock geology and structure from field observations augmented by subsurface data from logs of water-wells and an oil and gas test well. This includes a high-angle fault on the southeast side of Bell Hill, which we infer from the subsurface from water-well drilling records
- We provide new foraminiferal data for the previously undivided Tertiary Twin River Group rocks. The data allow us to assign these rocks to the Oligocene–Eocene Makah Formation. Two mappable facies within the Makah are recognized on Bell Hill. (See Discussion.)
- Geochemistry and petrography for samples collected from the Eocene Crescent Formation to characterize these rocks in the Sequim quadrangle have resulted in the identification of rhyolite not previously reported in the Crescent Formation.
- We have reinterpreted sea-cliff exposures extending 6,500 ft north of Marlyn Nelson Park (Clallam County) at Port Williams in light of an age estimate by Blunt and others (1987) for a pre-Fraser glaciomarine drift mapped by Othberg and Palmer (1979). The identification of that drift as Possession age by Blunt and others led us to tentatively identify older nonglacial sediments near the base of the bluff section at both its north and south ends as Whidbey Formation(?).
- An Atterberg limits test (Appendix 4) performed on a representative sample of the Everson Glaciomarine Drift to determine if silty clays from this unit are expansive indicates that the inherent swelling capacity of these materials is low to medium. We conclude from this that the potential for the Everson Glaciomarine Drift to cause foundation problems in the study area through swelling is low to moderate.

METHODS, PREVIOUS WORK, AND RELATED STUDIES

Our mapping and interpretations are based on field work performed in 1997. Previous geologic mapping and pertinent topical studies are outlined in Figure 3. Othberg and Palmer (1979) produced a preliminary map of the surficial geology of the Sequim 7.5-minute quadrangle. Our geologic map (Plate 1) incorporates significant amounts of their work. Tabor and Cady's (1978a) map of the geology of the Olympic Peninsula included the study area; their map was published at a much smaller scale, and they mapped the sedimentary rocks as Tertiary undivided Twin River Formation [Group]. The Washington Department of Ecology (1978) mapped the coastal geology inland for 2,000 ft. Some of that mapping was incorporated in this study. Cady and others (1972b) mapped the geology of the Tyler Peak 15-minute quadrangle, which adjoins the Sequim quadrangle on its southern border. We incorporated structural information from their mapping with our observations to arrive at a structural interpretation of the Crescent Formation underlying the foothills in the study area. The study by Drost (1986) included a well location map and a well data catalog that we used to construct our geologic cross sections.

Bedrock exposures in the Sequim quadrangle are largely limited to roadcuts in the foothills area of the map, limited exposures in ditches and new residential home foundation cuts in the Bell Hill area, creek bottoms, and a few weathered exposures near/along U.S. Highway 101. The best exposures of the Tertiary sedimentary rocks are along the west shore of Sequim Bay near Sequim Bay State Park.

Due to the paucity of bedrock exposures, we found it necessary to rely heavily on subsurface information contained in water-well logs to interpret the structure illustrated in the geologic cross sections. Our primary goal was to use wells that had been located accurately in the field. We acquired a listing of such wells for the study area from 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 1,500-plus 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 possible candidates for use in producing cross sections. However, many of those wells did not intercept the Makah and (or) Crescent bedrock units. In order to have a uniform distribution of wells with data penetrating underlying bedrock units, we selected additional wells. We selected this second category of wells from those that could be reasonably located within a quarter-quarter section of land based on a combination of surface elevation and (or) address listed on the well record for the well location.

This process resulted in the selection of the approximately 220 wells plotted on the geologic map (Plate 1). Wells with both appropriate depth and adequate quality of information in the well log were highlighted in a working document. The highlighted wells were used in conjunction with geologic structural data collected in the field to determine the location of the cross sections (Plates 1 and 2).

Our priority was to illustrate bedrock structure at map scale, while showing as much of the surficial detail as possible within the map-scale constraint, and simultaneously not exaggerating the vertical scale to make the bedrock structure appear unreal. This led to our selection of a 2x vertical exaggeration for the bedrock cross sections. Two additional cross sections were constructed for areas where water wells did not penetrate bedrock. We selected a vertical exaggeration of 4x for those to illustrate the surficial geology in greater detail. 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 located off the section line to the section. Surface elevation differences between the well being projected and the elevation of the section at the point of projection adds to the difficulty of accurately portraying the complex surficial stratigraphy. We made our interpretations of the Pleistocene geology using the data in the drillers logs together with outcrop data and stratigraphic relations of the glacial and postglacial units.

A list of water wells selected in constructing the cross sections is given in Appendix 1. From the approximately 220 wells plotted on the geologic map, 114 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 a depth drilled value associated with the well number. Wells that were not used to construct the cross sections do not have a depth drilled value.

The USGS assigns water wells in Washington numbers that identify their location in a township, range, and section. Well number 30N/04W-16D01 indicates, successively, the township (T30N) and range (R04W) 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) of the section, as shown in Figure 4. The number (01) following the letter is the sequence number of the well recorded within the quarter-quarter section subdivision. We have rendered this number as a single digit (1) in the cross sections because of space limitations.

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–Eocene marine rocks of the Makah Formation are shown with the symbol ΦEm$_m$. We used the geologic time scale for the "Correlation of Stratigraphic Units of North Amer-

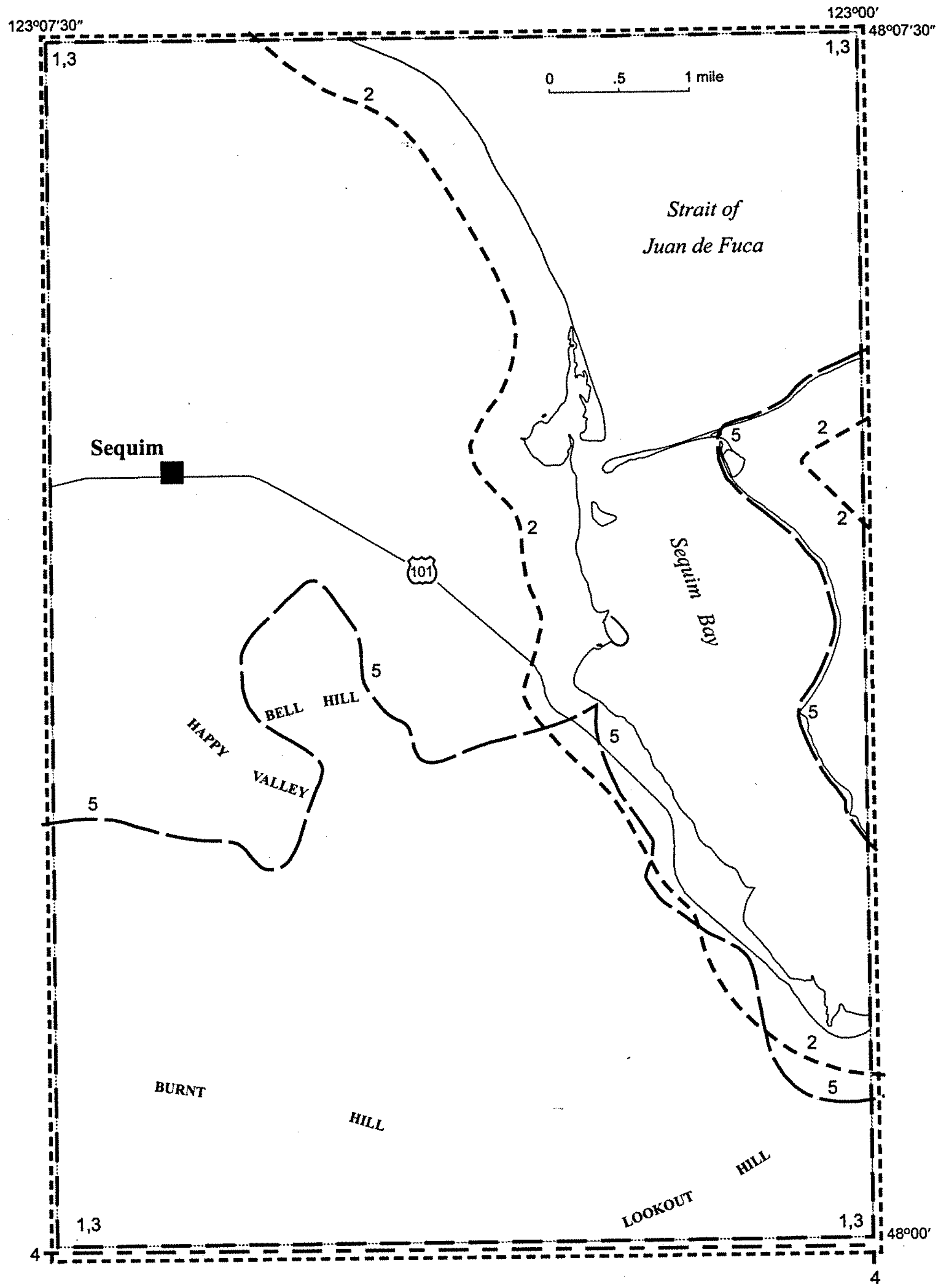


Figure 3. Previous geologic mapping and topical studies within and adjacent to the Sequim 7.5-minute quadrangle. **1**, Othberg and Palmer, 1979 (1:24,000); **2**, Washington Department of Ecology, 1978 (1:24,000); **3**, Tabor and Cady, 1978a (1:125,000), covers entire map area and adjacent areas in all directions; **4**, Cady and others, 1972b (1:62,500); **5**, Drost, 1986 (1:24,000).

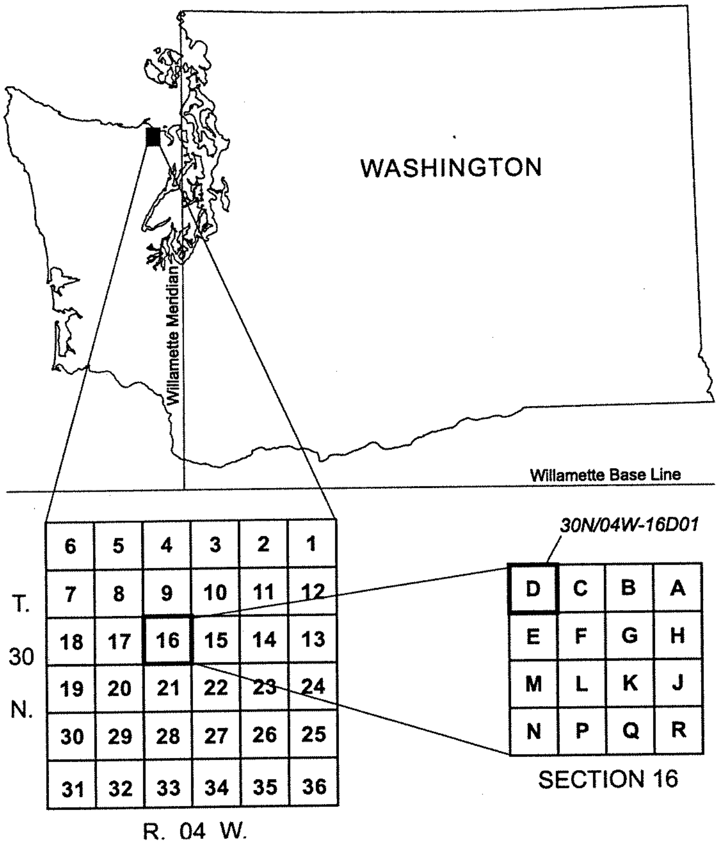


Figure 4. Well numbering system used by the U.S. Geological Survey; explained in text. The two-digit number (01) following the letter D is the first in a sequence of wells recorded within the quarter-quarter section subdivision.

ica (COSUNA)" project of the American Association of Petroleum Geologists (Salvador, 1985), with boundary-age modifications of Montanari and others (1985). Some of the volcanic rocks are identified using whole-rock geochemistry and total-alkali silica diagrams (Zanettin, 1984). Sandstones are named using the classification scheme of Dickinson (1970). Landslides are classified using Varnes (1978). Results of paleontological and geochemical analyses for this study are given in Appendices 2 and 3, respectively. Results of our petrographic study are incorporated in the unit descriptions in the text; sample locations are shown on Figure 5.

Field mapping was supplemented by using Washington Department of Natural Resources (DNR) color 1:24,000-scale (1976) and black and white 1:12,000-scale (1990) aerial photographs to map surficial deposits and bedrock contacts with surficial deposits in areas not accessible by roads or trails. We also used DNR 1994 1:12,000 orthophotographs to map in the field, because they provided the most current information on roads and trails.

DESCRIPTION OF MAP UNITS

Quaternary Sediments

NONGLACIAL DEPOSITS

Qf **Artificial fill and modified land (Holocene)**—Consists of rip rap and other material placed to make an area more suitable to a particular use and of topography modified by the addition of and reworking of soil, sediment, rock, and solid waste material. Artificial fill is located along the west shore of Sequim Bay, where shoreline stability and improvement in foundation support was desired; included in this category is a marina, parking lots, short access roads, and a landing of a logging operation. An area of mollusk shell waste that is reworked modified land is located southwest of the marina at Pitship Point.

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 nearshore and deltaic environments. Thickness of alluvium varies; a maximum thickness of 33 ft was estimated from water-well data in the Blyn area.

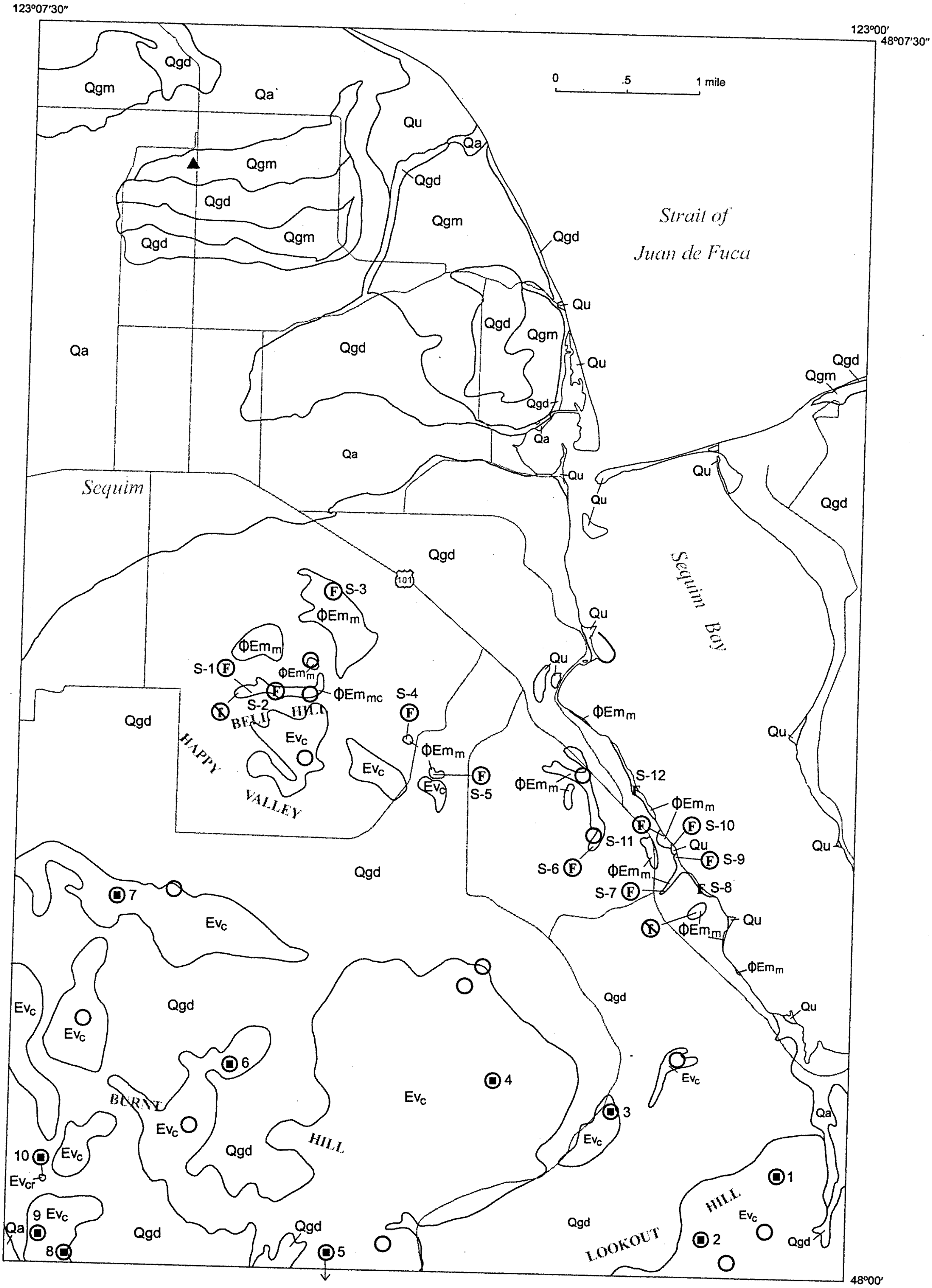
Streams in the study area are reworking older alluvium (unit Qoa) and Fraser glacial deposits.

Alluvium is mapped at the mouth of Bell Creek where it empties into the north end of Sequim Bay, along the banks of the Dungeness River in the southwest corner of the quadrangle, and at the mouth of Jimmycomelately Creek where it enters Sequim Bay. Alluvium is postglacial and thus Holocene in age.

Qb **Beach deposits (Holocene)**—Locally well-sorted deposits of silt, sand, pebbles, and cobbles; tan to gray; found within the influence of the surf zone throughout the study area. Most larger clasts in coarser deposits are well rounded and platy as a result of wave action. The unit includes spits and bars created by longshore drift.

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. The largest deposit in the study area is at Grays Marsh at Katakala Point, where Gierin Creek enters the Strait of Juan de Fuca. Rigg (1958, p. 44-45) reported on peat in the area; a hole bored near the west margin of the peat area penetrated 7 ft of dark-brown fibrous peat mixed with woody peat in the bottom 1 ft of the peat; the peat overlies 6 in. of dark-brown muck (distinguished from peat where decomposition of plant remains has gone so far as to render recognition of the material as a peat impossible), which overlies gray sand. The fibrous peat is raw at the top, disintegrated at the middle, and decomposed at the bottom.

Qls **Landslide deposits (Holocene and late Pleistocene?)**—Poorly sorted, unstratified diamicton consisting of angular to rounded boulders, cobbles, and gravel in a sand, silt, and (or) clay matrix at various locations; mapped where there is a geomorphic expression of active or ancient landslides. Most of the landslides mapped in the quadrangle include the entire landform, from headwall to toe, and may include both the landslide scarp and debris. Debris consists of a poorly sorted mixture of soil and rock fragments resulting from slumps and slides. Scarps are shown on two landslides that are mapped in the foothills in the south part of the quadrangle.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EXPLANATION

Quaternary Sedimentary Deposits

Qa Alluvium, undivided (Holocene and Pleistocene?)

Qu Undifferentiated sediments, includes beach deposits, peat and marsh deposits, artificial fill and modified land (Holocene)

Qgm Everson Glaciomarine Drift (Pleistocene)

Qgd Glacial drift, undivided; nonglacial deposits (Pleistocene)

Tertiary Sedimentary Rocks

Makah Formation, Twin River Group (Oligocene and Eocene)

ΦEm$_m$ Sandstone facies

ΦEm$_{mc}$ Granular sandstone and small-pebble conglomerate facies

Tertiary Volcanic Rocks

Crescent Formation (Eocene)

Ev$_c$ Basalt and basalt breccia; minor sedimentary interbeds and diabase

Ev$_{cr}$ Rhyolite

Sample Location Symbols

○ Sample site—petrography (thin-section)*
F Sample site—foraminiferal assemblages (Appendix 2)
F̸ Sample site—foraminiferal assemblages (barren)
■ Sample site—geochemistry (Appendix 3)
▲ Sample site—Atterberg limits test (Appendix 4)

* may be combined with other symbols

Figure 5. *(facing page)* Sample site map for the Sequim 7.5-minute quadrangle. Analyses include petrography, foraminiferal assemblages, geochemistry, and Atterberg limits test.

Two landslides were mapped on moderately steep east- and northeast-facing slopes in the headwaters basin of Johnson Creek. They appear to be large earth-slump blocks that originate in Vashon sandy lodgment till (unit Qgt$_v$) that veneers the bedrock of the Crescent Formation (unit Ev$_c$). The slide in secs. 8 and 17, T29N, R3W, appears to have reached and possibly blocked the creek sometime in the past. The two slides do not appear to be recent, on the basis of our observation of subdued hummocky topography and tree stumps remaining from logging operations that show no evidence of leaning. Small, relatively young scarps (not mapped), adjacent to the old scarp within the landslide in secs. 7 and 8, T29N, R3W, indicate reactivated sliding on the main scarp.

Small landslides were mapped by Othberg and Palmer (1979) south of Gaskell Slough in the northwest corner of the Sequim quadrangle. The slides here apparently originated in silts of the Everson Glaciomarine Drift (unit Qgdm$_e$) in a high bank adjacent to an older river channel that currently contains deposits of Holocene to Pleistocene(?) older alluvium (unit Qoa). Our interpretation of aerial photographs, at this locality, suggests that the slopes forming the high bank were undercut by streams that deposited the older alluvium. Othberg and Palmer also mapped a landslide in the north-facing sea cliffs on the Miller Peninsula that appears to be an earth-slump block, probably initiated by wave action undercutting its toe at beach level.

Qoa **Older alluvium (Holocene and late Pleistocene?)**—Stratified cobbly gravel, sand and gravel, sand, silt, and clay; brown to dark reddish brown; consists of cobble gravels near Sequim and upslope to the southwest to progressively finer grain sizes downslope to the northeast, following the underfit streams, Cassalery, Gierin, and Bell Creeks. These exposures are flood-plain terrace deposits of an ancestral Dungeness River whose current channel and flood plain have moved west; this alluvium probably represents older deposition by an early Dungeness River (Othberg and Palmer, 1979).

The unit is mapped on the basis of geomorphology and texture. Thickness is varied and ranges from a few feet to more than 70 ft near the centers of former flood-plain channels now occupied by these deposits. On aerial photographs, unit Qoa has an anastomosing appearance that strongly resembles a braided stream pattern.

Unit Qoa overlies till and ice-contact deposits of the Vashon glacial stade (units Qgt$_v$ and Qgo$_{vi}$); at shallow depth it may locally lie disconformably on glaciomarine drift of the Everson Interstade (unit Qgdm$_e$). Water-well logs indicate that the unit overlies older nonglacial fluvial channel sands and gravels, overbank silts, and estuarine silty clay deposits in the lower drainage of present-day Bell Creek. These deposits can be seen in the bluff exposures at nearby Washington Harbor.

Qc$_o$ **Sediments of Olympia interglacial age(?) (Pleistocene)**—Stratified fluvial, sandy pebble to cobble gravel, well-rounded and moderately well sorted; interbeds of sand and silt; sand and gravel commonly iron-oxide stained and partially cemented; brown to reddish brown. Deposits consist mostly of brown pebble to cobble sand and gravel, locally characterized by fluvial cut and fill structures, with lesser planar interbeds or lenses of varied lengths and thicknesses and rip-up fragments of tan sand and silt.

Unit Qc$_o$ is exposed in sea cliffs extending from Marlyn Nelson Park (Clallam County) at Port Williams north for approximately 3,800 ft; thickness is a few feet in the upper part of the cliffs at the county park and gradually increases to more than 50 ft as the unit arches downward (due to cut and fill) to beach level to the north. The unit overlies Possession glaciomarine drift (unit Qgpm$_p$) and Possession Drift (unit Qgp$_p$) at the county park and pinches out against Possession till (unit Qgpt$_p$) to the north, but it reappears farther north as a 2- to 3-ft-thick bed of yellowish brown silty (overbank(?) clay overlying Possession glaciomarine drift (unit Qgpm$_p$) and Possession till (unit Qgpt$_p$). The unit is overlain by Vashon Drift (unit Qgd$_v$) as illustrated in section H–H′, Plate 2. Large pebble clasts are basalt and sandstone probably derived from the Olympic Mountains; unit Qc$_o$, where it is mapped in the sea cliffs north of Port Williams, probably represents fluvial gravels and overbank deposits in a delta environment of an ancient Dungeness River. These deposits are tentatively identified as of Olympia interglacial age because they lie between Vashon Drift and Possession Drift.

The Olympia interglacial interval has been dated outside the Sequim quadrangle using the radiocarbon method. 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). Deposits associated with this period are as old as 40.5 ±1.7 ka and perhaps 58.8 +2.9/-2.1 ka (^{14}C sample numbers GSC-2167 and Ql-195; Clague, 1981, p. 5)

Qc **Undifferentiated sediments (Pleistocene)**—Moderately to well-sorted, subrounded to rounded, cobble to pebble gravel and sand and gravel layers exposed at Washington Harbor in a 2,000-ft stretch of sea cliff; interbedded with sand, silty laminated sand, silt, and laminated silt; gravel is locally cross-bedded and cuts across silty layers. Gravel is brown, orange, and grayish orange and resembles the gravel that largely makes up unit Qc_o exposed in the sea cliffs north of Port Williams, 1.2 mi to the north. The silty layers are planar but occur locally as lenses within the gravel layers; these layers are tan, grayish yellow, gray, bluish gray, greenish gray, and olive. A 10- to 15-ft-thick bed of greenish gray silt contains abundant, delicate (0.25 in.) gastropods and fine carbon (plant?) hash, suggesting an estuarine environment. Interbedded coarse gravelly beds and fine silty layers are approximately equal in thickness throughout most of the exposed section and range from 5 to 20 ft thick (see detailed section at Washington Harbor, Plate 1), except at the north end of the exposures, where the silty facies tends to predominate. Cliff exposures are generally 60 to 80 ft high. The gravelly beds appear to be fluvial channel deposits, the silts estuarine deposits. Resting on the nonglacial sediments exposed at Washington Harbor are 5 to 7 ft of Vashon till (unit Qgt_v), making that unit demonstrably older than Fraser glacial drift.

On the Miller Peninsula, the unit is exposed in a landslide slump block that is largely intact. (See western detailed bluff section on the Miller Peninsula, Plate 1.) It is a 40-ft-thick section of gray to light-gray moderately well sorted, stratified, laminated sand. It underlies an equally thick section of Vashon till (unit Qgt_v) and advance outwash (unit Qga_v). Unit Qc overlies a 35-ft section of gray gravelly outwash(?) (unit Qgp). Beneath unit Qgp is 5 ft of bedded gray silt exposed at beach level (also identified here as unit Qc), which appears to be nonglacial. Othberg and Palmer (1979) suggest that the 40-ft section of unit Qc may include the Esperance Sand Member, the oldest member of the Vashon Drift, and for that reason, we queried the unit. This uncertainty is also reflected in the correlation diagram (Plate 2). The 5-ft section of unit Qc is demonstrably older than the overlying units of Fraser Glaciation drift, because it is in normal stratigraphic succession.

Qc_w **Whidbey Formation(?) (Pleistocene)**—Horizontally stratified, compact, slightly sandy, olive-colored silt; locally distorted, with soft sediment deformation within layers 0.5 to 1 ft thick; contains calcareous concretions as much as 4 in. in diameter; exposed at beach level at both ends of sea cliff exposures north of Port Williams (cross section H–H′, Plate 2). At the county park at Port Williams, about 7 ft of the unit is exposed intermittently for approximately 300 ft along the bluff, where it conformably underlies an approximately 25-ft-thick section of Possession Drift (unit Qgp_p). At the north end of the sea cliff exposures, 6,500 ft north of the county park, about 4 ft of the unit is exposed for 150 to 175 ft, where it conformably underlies locally deformed sands that we have tentatively interpreted as Possession advance outwash deposits (unit $Qgpa_p$). We tentatively identified unit Qc_w as Whidbey Formation, because it underlies units tentatively dated as of Possession Glaciation age (Blunt and others, 1987).

Easterbrook (1994, and references therein) listed ages for the Whidbey Formation that include three amino-acid ages on Whidbey Island that ranged from 96 to 107 ka; three thermoluminescence (TL) ages measured on clay also on Whidbey Island, that ranged from 102 to 142 ka; and a TL age of 151 ka (with a large uncertainty) at Point Wilson at Port Townsend.

GLACIAL DEPOSITS

Fraser Glaciation (Pleistocene)
Everson Interstade

$Qgdm_e$ **Everson Glaciomarine Drift**—Poorly sorted, weakly stratified to nonstratified, poorly compacted (Easterbrook, 1962) deposits of pebbly silt and clay and lesser discontinuous layers of silty sand; weathers to a pseudo-columnar appearance; includes bedded silt and sand near Gierin Creek valley and northeast of the Sunland development (Othberg and Palmer, 1979); gray to tan; rare marine fossils. The maximum thickness in the study area, as interpreted from water-well data, is about 50 ft, but the unit is more typically 20 to 30 ft thick and thins to about 10 ft where it is exposed at the top of the coastal bluffs north of Port Williams (cross section H–H′, Plate 2).

In the Sequim quadrangle, the Everson Glaciomarine Drift underlies the high flats northeast of Gierin Hill, forming a subtle terrace near the maximum local glaciomarine drift elevation of 33+ m reported by Dethier and others (1995). The drift also occurs elsewhere in the quadrangle at similar elevations—the Miller Peninsula and the low hills of Grennan and The Potholes. In the latter two areas, the drift interfingers with and (or) fills small depressions in ice-contact stratified gravels (unit Qgo_{vi}) of a kettled landscape. Our interpretation of water-well records suggests that the glaciomarine drift overlies Vashon ice-contact deposits (unit Qgo_{vi}) in the area of Grennan Hill and The Potholes and overlies Vashon till elsewhere. In the high terrace area northeast of Gierin Hill, the glaciomarine drift also overlies Vashon till where the till is very thin and cannot be shown at the scale of the cross sections, but crops out in the upper parts of the sea cliffs north of Port Williams as lenses or remnants overlying a thick section of Vashon advance outwash (shown together as Vashon Drift (unit Qgd_v)).

The Everson Interstade of the Fraser Glaciation began with marine incursion during retreat of the Puget and Juan de Fuca glacial lobes. Dethier and others (1995) report radiocarbon ages for Everson 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 northwest of the Sequim quadrangle in The Potholes area (their locality 11) 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 Sequim area falls within the Everson Interstade age range.

Vashon Stade

Qgo_{vi} **Ice-contact stratified recessional outwash**—Moderately well sorted, crudely to well-stratified coarse gravel to sand; clasts rounded to subrounded; brown to gray. These sediments show deformation, slumping, and collapse features as a result of melting of supporting ice. Cross-stratified gravels exposed in a gravel pit just north of the quadrangle boundary in the northwest quarter of sec. 6, T30N, R3W, in The Potholes area, indicate south-directed sediment transport; shallow dipping stratified gravels exposed in a gravel pit at the west end of the ice-contact gravels forming the low ridge north of Grennan Hill indicate eastward sediment transport. At this locality, Everson Glaciomarine Drift ($Qgdm_e$) interfingers with the stratified gravel and also overlies deformed sand and gravel exposed in the pit walls. Othberg and Palmer (1979) described similar contact relations between ice-contact stratified gravels and the Everson Glaciomarine Drift in the Sunland development north of Grennan Hill. This suggests that the stratified gravels were deposited near the melting ice margin in association with a coastal marine environment. Water-well data indicate that these ice-contact deposits may be as thick as 130 ft in The Potholes area and 100 ft thick north of Grennan Hill (cross section A–A′, Plate 2). We mapped a small isolated deposit of cross-stratified sand and gravel at the base of the foothills in the northeast quarter of sec. 6, T29N, R3W, as an ice-contact deposit. Cross beds at this locality indicate northward sediment transport. Unit Qgo_{vi} is everywhere underlain by Vashon till.

The unit in the northern part of the quadrangle, where it interfingers with and is overlain by Everson Glaciomarine Drift, is therefore contemporaneous with to slightly older than 12.6 ka. The isolated deposit of unit Qgo_{vi} at the base of the foothills at an elevation of 800 ft would be somewhat older than the deposits at the lower elevations. We have chosen to call these recessional ice-contact deposits Vashon rather than Everson because of uncertainty as to their depositional age.

Qgo_{vr} **Recessional outwash**—Stratified, well-sorted sand and well-rounded pebble to cobble gravel; thin- to thick-bedded; gray, tan, and light-brown; primarily sand and gravel meltwater deposits and varied sediments resulting from deposition from or near stagnant ice; includes sand and gravel and alluvial fans deposited by streams that flowed off the bedrock highs in the southern part of the quadrangle. Streams may have been active as the ice receded in this area (Othberg and Palmer, 1979). Deposits of this unit are located near the shore of Sequim Bay. At the south end of Sequim Bay, in the Blyn area, deposits with distinctive foreset beds have north-directed paleocurrent indicators. One such deposit is currently being mined for sand and gravel and is probably a recessional delta that was formed as meltwater deposited sediments in Sequim Bay during a period of higher sea level. Water-well data indicate that the recessional outwash varies from 0 to more than 100 ft in thickness. The recessional outwash everywhere rests on Vashon till (unit Qgt_v).

The age of the unit is constrained within the age limits 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).

Qgl_v **Lacustrine deposits**—Stratified, well-sorted clay, silt, and sand; rhythmically laminated, displaying alternating bands of silt and clay interrupted by thin beds of very coarse sand; tan to gray; minimum thickness about 10 ft.

A single isolated outcrop in the southwest corner of the quadrangle (sec. 18, T29N, R3W) is an erosional remnant adjacent to a small creek at elevation 1,020 ft on the west slope of Burnt Hill, east of the Dungeness River. Contacts with other units are concealed by colluvium, but it appears the unit is resting on Vashon till (unit Qgt_v) that covers Crescent Formation basalt (unit Ev_c) in this area. Therefore, we interpret the deposit as an elevated, recessional, ice-marginal, lake deposit. The lake beds dip 20 degrees to the north, probably reflecting slump.

This deposit is not dated. Based on our interpretation that the deposit is recessional, we have correlated it with the Vashon recessional outwash (Unit Qgo_{vr}).

Qgt_v **Till**—Unstratified diamicton of poorly sorted pebbly, clayey, sandy silt with scattered cobbles and sparse boulders; yellowish gray to light-gray and tan; dense to very dense lodgment till. This unit supports near-vertical slopes in bluffs on the east shore of Sequim Bay. This unit may locally include ablation till (generally a loose, nonstratified, pebbly silty sand of varied thickness, creating an irregular hummocky topography); ablation till is not mapped separately, but we found most exposures on the Miller Peninsula where it seems to grade into recessional outwash. Lodgment till lies stratigraphically above advance outwash, bedrock, and older glacial and nonglacial deposits. It locally underlies recessional and ice-contact deposits and the Everson Glaciomarine Drift.

Approximately 70 percent of the surface of the quadrangle is covered by lodgment till. It underlies all the upland areas except where bedrock crops out. Thickness is varied; water-well data indicate it may locally be as thick as 150 ft and that it pinches out in other places; it typically averages 30 ft thick in the subsurface. Till was mapped where its thickness is greater than approximately 3 ft.

Radiocarbon dates from outside the area and from the underlying advance outwash (unit Qga_v) at Port

Williams (included in unit Qgd_v there) indicate an age between about 14.5 and 17.5 ka.

Qga_v **Advance outwash**—Stratified, well-sorted, dominantly sand and sandy pebble to cobble gravel; gravel clasts well rounded; lesser silts and clays; gray to grayish orange; laid down by meltwater just in front of the advancing Vashon glacier; includes some lacustrine beds formed in lakes dammed by the advancing glacier that consist of alternating, thinly bedded sands, silts, and clays. Advance outwash is denser than recessional deposits due to the weight of the overriding glacier; it tends to be more iron stained and, in some places, is iron cemented, and generally contains a large percentage of silt and clay relative to recessional outwash.

The unit is mapped where its stratigraphic position beneath Vashon till (unit Qgt_v) can be established. It lies stratigraphically above older (pre-Vashon) Pleistocene sediments and locally rests on bedrock. The advance outwash crops out dominantly on steeper slopes. The unit is best exposed in sea cliffs north of Port Williams and on the Miller Peninsula. (See western detailed stratigraphic section, Miller Peninsula, Plate 1.) It is less well exposed in the southeast quarter of the quadrangle where Dean Creek and another nearby creek have incised a fairly thick section of interbedded sand, gravel, and silty clay. These deposits crop out intermittently along a bulldozed roadcut above Dean Creek near the center of sec. 11, T29N, R3W. They are less well exposed in the next drainage to the north in the southwest quarter of sec. 2.

The thickness of the advance outwash is varied. In the 6,500-ft-long section of sea-cliff exposures north of Port Williams (cross section H–H′, Plate 2), it ranges from less than 5 ft thick at the county park grounds to approximately 70 ft thick 4,000 ft to the north, and it maintains a 40- to 50-ft thickness for some distance before it eventually pinches out at the north end of the section. The advance outwash exposed in the sea cliff consists of stratified sand and gravel that exhibit excellent cross bedding in its thickest section. At the Port Williams sea-cliff exposures, it is mapped as undivided Vashon drift (unit Qgd_v), but it makes up most of the drift, where minor lenses or remnants of till were not mapped separately. The thickness of the advance outwash is even more varied in the subsurface, as is illustrated on the geologic cross sections (Plate 2). In most places the thickness ranges from 20 ft to more than 100 ft. The advance outwash is 300 ft thick in one area (cross section G–G′). These deposits underlie a subtle topographic terrace at about elevation 580 ft, which extends southeast from Palo Alto Road through secs. 3, 2, and 11, T29N, R3W. Water wells in this area penetrated a thick section of silty clays that we interpreted to have been glacial lacustrine silts and clays deposited in a proglacial lake. These silts and clays, interbedded with sand and sandy gravel, are exposed in the bulldozed road above Dean Creek in sec. 11. These deposits may also underlie the steep, deeply incised slopes that extend southeast to abut against the bedrock exposed on the nose of Lookout Hill.

We have assumed the age of the unit in the study area from two (radiocarbon?) ages recorded by Blunt and others (1987) for the advance outwash deposits from the bluff exposures at Port Williams: 18,265 ±345 yr B.P. and 17,350 +1,260, -1,085 yr B.P. These ages agree with others referenced in Blunt and others (1987) that limit the time of the Vashon glacial advance.

Qgd_v **Drift, undivided**—At Port Williams (cross section H–H′, Plate 2), where it is best exposed, the unit consists primarily of stratified, gray, sandy pebble-gravel advance outwash (see description for unit Qga_v) that underlies intermittently exposed minor lenses or remnants of yellowish gray till located high in the unit. Drift (outwash deposits and till) underlies the steep slopes along the valley of Gierin Creek. This unit probably includes Vashon till (unit Qgt_v), Vashon advance outwash (unit Qga_v), and possibly Vashon recessional ice-contact deposits (unit Qgo_{vi}) poorly exposed in the Gierin Creek valley and that we interpreted to exist locally in the subsurface on the basis of water-well data. The unit is as much as 70 ft thick.

The age range of this unit is that of the included units as shown in the correlation diagram (Plate 2).

Pre-Fraser Glaciation(s) (Pleistocene)

Qgp? **Drift(?), undifferentiated**—Crudely stratified, moderately well sorted, sandy pebbly gravel; clasts well rounded to rounded; gray; described by Othberg and Palmer (1979) and earlier by Washington Department of Ecology (1978) as gravelly outwash; queried because of its questionable glacial origin. The unit is mapped only on the Miller Peninsula. (See western detailed section of bluff exposures, Miller Peninsula, Plate 1.) The unit consists of a 35-ft section underlying 40 ft of nonglacial(?) stratified and laminated sands (unit Qc, which Otherberg and Palmer [1979] suggest may locally include the Esperance Sand Member, the oldest member of the Vashon Drift). Beneath the unit is 5 ft of compact, bedded, sandy silt and clay that Othberg and Palmer (1979) and Washington Department of Ecology (1978) consider to be nonglacial (unit Qc).

This unit is demonstrably older than Fraser Glaciation drift, but data are insufficient to correlate it with either Possession Drift (exposed elsewhere in the quadrangle) or Double Bluff Drift (exposed outside the quadrangle).

Qgp_p **Possession Drift, undivided**—Unstratified, compact diamicton of gray to grayish tan, poorly sorted sandy silty gravel with scattered cobbles and boulders (as much as 2 ft in diameter); locally crudely stratified sandy, pebbly, clayey silt and (or) very gravelly, sandy till; pebbles and cobbles generally subrounded. The high proportion of granitic clasts indicates a northern provenance.

The unit is best exposed in the sea cliffs north of Port Williams, where sandy till is mixed with underlying sandy gravels at the south end of the exposure and grades to mostly a sandy till toward the north, where the unit disappears beneath beach level. The unit is characterized by clastic dikes and radiating fractures at beach level in the middle of the unit (see cross section H–H′); at the sea cliffs, the unit conformably underlies a 2- to 3-ft-thick bed of Possession glaciomarine drift (unit $Qgpm_p$) at its south end. Both units underlie nonglacial fluvial sediments of presumed Olympia interglacial age (unit Qc_o). Unit Qgp_p conformably overlies distorted, olive-colored silt beds that we have tentatively identified as Whidbey Formation (unit Qc_w).

On the Miller Peninsula, a 50-ft-thick section (20 ft of pebbly silt that overlie 30 ft of compact gravelly sandy till(?)) is tentatively assigned to this unit. The silt and till underlie Vashon till (unit Qgt_v) and are tentatively identified as products of Possession Glaciation. (See easternmost stratigraphic section, Miller Peninsula, Plate 1.)

Amino-acid analyses of marine shells in Possession glaciomarine drift at Port Williams (unit $Qgpm_p$) and two other localities in the northern Puget Lowland suggest a mean age of 80 ±22 ka (Blunt and others, 1987; Easterbrook and Rutter, 1981,1982).

$Qgpm_p$ **Possession glaciomarine drift**—Unstratified, moderately compact diamicton; silty clay with sparse pebbles; contains marine shells and shell fragments; weathers to an unstratified material with penetrative vertical fractures; less compact than till; yellowish gray. In sea cliffs at Port Williams and locally exposed there, near the county park and approximately 4,500 ft north (cross section H–H', Plate 2), the unit conformably overlies unfossiliferous diamictons (units Qgp_p and $Qgpt_p$) and underlies fluvial channel gravels and overbank silts and clays, which we have tentatively identified as deposits of Olympia interglacial age (unit Qc_o); the unit is approximately 2 to 3 ft thick at the two exposures and is not recognized elsewhere in the quadrangle. This unit was first mapped by Othberg and Palmer (1979).

We made the tentative assignment of this and other units to the Possession Glaciation (units Qgp_p, $Qgpm_p$, $Qgpt_p$, and $Qgpa_p$) on the basis of amino-acid analyses of marine shells from this unit at Port Williams and two other localities in the northern Puget Lowland (Blunt and others, 1987).

$Qgpt_p$ **Possession till**—Unstratified compact diamicton of poorly sorted, sandy, pebbly silt and clay; dense to very dense; gray to tan. This unit, which is approximately 15 ft thick, was mapped at the base of the sea cliffs north of Port Williams for a distance of about 1,500 ft. It is exposed beneath Olympia-age fluvial overbank sediments (unit Qc_o) and underlies Vashon Drift where the Olympia-age deposits pinch out. It also conformably underlies a 2- to 3-ft-thick deposit of Possession glaciomarine drift (unit $Qgpm_p$). The till pinches out against the highly deformed, nonbedded to bedded, sand and clay breccia (unit $Qgpa_p$). (See cross section H–H', Plate 2.) We consider this unit to be part of the Possession Drift exposed farther south along the beach on the basis of its similar color and that it directly underlies Possession glaciomarine drift, fluvial Olympia-age sediments, and Vashon advance outwash gravels.

$Qgpa_p$ **Possession advance outwash(?)**—Massive to stratified, brecciated, compact, coarse sand, silt, and clay; gray to light tan. The unit is characterized by angular blocks of sand and clay of various sizes and shapes caught up in zones of chaotically deformed sediments, clastic dikes, and vertical fractures with associated injection features. Also includes zones of essentially intact stratified sand and silt. The unit may have been deformed by an overriding glacier.

The unit is exposed for more than 1,000 ft along the beach bluff at the north end of the Port Williams section and is as much as 30 ft thick in places. It underlies Possession till (unit $Qgpt_p$) at its south end, and both units underlie Vashon Drift (unit Qgt_v). At its north end, it conformably overlies olive-colored, compact, distorted, bedded, silty sediments that contain calcareous concretions, a unit that we have tentatively correlated with the Whidbey Formation. The unit is unconformably overlain by Everson Glaciomarine Drift at its north end. (See cross section H–H'.) Because of its stratigraphic relation with the overlying Possession till, we interpreted this unit as a glacial advance outwash deposit, correlated with the Possession Drift.

GLACIAL AND NONGLACIAL DEPOSITS

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

Deposits of pre-Fraser Events (Pleistocene)

Qgpc **Glacial and nonglacial deposits, undivided**—Includes all units identified in limited, deep water-wells that are older than Vashon Drift. Unit Qgpc is shown only on the cross sections (Plate 2).

Deposits of Fraser and pre-Fraser Events (Pleistocene)

Qguc **Glacial and nonglacial deposits, undivided**—This unit is found along steep slopes of stream valleys and along sea cliffs where exposures are poor and (or) scale does not allow more detailed delineation. However, the stratigraphic sections (Plate 1) show more detailed subdivision, correlations, approximate thicknesses, and lithologies at sea-cliff exposures.

Sedimentary and Volcanic Rocks

TERTIARY SEDIMENTARY ROCKS

Makah Formation, Twin River Group (Oligocene–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 Hoko River, the Makah, and the Pysht Formations. The Hoko River Formation is not exposed in the Sequim quadrangle. The middle formation of the group, the Makah Formation, described in detail by Snavely and others (1980), is late Eocene to Oligocene (late Narizian(?) to late Zemorrian) in age (Snavely and others, 1978). In its composite type section in the vicinity of the Hoko River 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 (referred to as the middle member of the Twin River Formation at that time) in the western three-quarters of the Port Angeles 1:100,000-scale quadrangle (Fig. 1A). East of Port Angeles, exposures of this unit are restricted to canyons of north-trending creeks, where interfluves are covered by glacial drift. The most easterly exposures of the middle member (Makah) mapped by Brown and others (1960) are on Siebert Creek, 8 mi west of the Sequim quadrangle. 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 erosion in post-middle Oligocene time and, in places, due to onlap against highs of 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. We interpret this as indicating a gradual coarsening of the unit to the east. Brown and others (1960) further 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, sedimentary breccia composed almost entirely of angular volcanic debris is sporadically exposed at the base of the conglomerate lentil. They suggest that it may represent material eroded from the Crescent Formation.

ΦEm_m **Sandstone facies**—In outcrop, thick-bedded with exfoliation partings, well-sorted, angular, very fine to medium-grained, subquartzose, feldspatholithic sandstone; in thin section, sandstones consist dominantly of quartz, feldspar, and volcanic lithic fragments with lesser muscovite, augite, limonite, and sanidine (sanidine grains in a carbonaceous sandstone at Johnson Creek); accessories include opaque minerals and rare zircon; generally greenish gray and dark olive-brown (where unoxidized) to grayish orange and yellowish brown (where oxidized); locally dark-gray to black (where carbonaceous); marine pelecypod and gastropod macrofossils; foraminiferan and plant fossils; well-indurated. Calcareous concretions (many containing fossil shells and plants) are present throughout unit but are most common in thick-bedded intervals; concretions are cobble-size, commonly spheroidal to elliptical but also occur as irregular masses, in places the size of boulders, in the thick-bedded intervals. Compositional layering is not distinct, making it difficult to differentiate bedding from a parting that is common in weathered outcrops. The unit is poorly exposed in the study area but occurs throughout the area in the subsurface. The unit is best exposed in low sea cliffs on the west shore of Sequim Bay; the unit is also exposed locally in creek bottoms, in logging roadcuts and highway cuts near and along U.S. Highway 101, in drainage ditches, and in foundation excavations for residential homesites. Maximum thickness in the study area is estimated from water-well data to be approximately 450 ft. See Discussion for our assessment of the age of this unit.

ΦEm_{mc} **Granular sandstone and small-pebble conglomerate facies**—Medium- to thick-bedded (in limited exposures), poorly to moderately sorted, rounded to subrounded, medium to very coarse grained subquartzose, feldspatholithic sandstone and granular to pebbly sandstone and sandy conglomerate (pebbles ranging from 2 to 10 mm [0.08–0.39 in.] in diameter); marine pelecypod and brachiopod macrofossils and foraminifera; in thin section, sandstones and conglomerates consist dominantly of lithic fragments of volcanic rocks with lesser quartz, plagioclase, augite, limonite, and rare sanidine; accessories include opaques and rare zircon; reddish and grayish brown to dark yellowish brown. Medium to very coarse sandstone is moderately well indurated and grain supported; coarse grains are well-rounded volcaniclastic fragments. The matrix consists of green, brown, and red alteration products and locally of calcite cement and fossil fragments. Granular to pebbly sandstone and sandy conglomerate is poorly indurated and easily disaggregated; conglomerate and sandstone subfacies are crudely stratified and are in gradational contact with each other. Pebbles are of basaltic composition, are locally porphyritic and vesicular, and have trachytic, intersertal, and hyalophitic textures that are commonly observed in the Crescent Formation (unit Ev_c). The unit is exposed only near the top of Bell Hill in drainage ditches and in foundation excavations for residential homesites. Thickness is estimated to be 50 ft or less on the basis of its outcrop pattern and local dip, and we show this schematically in cross section D–D′ (Plate 2). See Discussion for our assessment of the age of this unit.

TERTIARY VOLCANIC ROCKS

Crescent Formation (Eocene)

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 a subaerial upper 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 columnar to massive flows and mudflow breccias with subordinate interbeds of sandstone, siltstone, mudstone, and gray marine limestone characterize their upper member. Cady and others (1972b) mapped their upper basalt member in the east half of the Tyler Peak 15-minute quadrangle that adjoins the Sequim quadrangle at its southern border. Tabor and Cady (1978a) extended the upper member of Cady and others (1972b) to include the basaltic rocks that form the southern foothills of the Olympic Mountains and parts of Bell Hill in the Sequim quadrangle. 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 and near the Dosewallips River valley 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, as illustrated on the accompanying cross sections.

During the course of mapping, we found a small isolated outcrop of rhyolite (Plate 1, and Fig. 5, loc. 10). The rhyolite was surrounded by colluvium and till that mantle the Crescent Formation in the area. The rhyolite contains 72 percent silica and 7 percent total alkalis (Appendix 3, loc. 10). Spherulites, which commonly occur in the glassy groundmass of silicic lava flows, were observed in thin section and led us to interpret the rhyolite as a lava flow rather than an intrusion. Silicic tuffs have been mapped elsewhere in Eocene mafic volcanic rocks in the Oregon Coast Range (Ray Wells, USGS, 1998, oral commun.). On the basis of our observations and silicic rocks occurring with Eocene mafic volcanics elsewhere, we tentatively include the rhyolite with the Crescent Formation.

There are no published ages for the Crescent Formation in the study area. 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 basalt sections, which we correlate with the basalt section in the Sequim 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.

Ev_c **Basalt and basalt breccia; minor sedimentary interbeds and diabase**—Mostly porphyritic to aphyric, sparsely jointed basalt and basaltic breccia; basalts are greenish gray, greenish black, grayish black, and black weathering to brown, dark brown, and reddish brown. Breccias generally weather reddish to yellowish 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?). Several dikes noted in the Burnt Hill area appear to intrude along joint sets. Basalt breccia is as common as the jointed flows and consists of angular clasts of brecciated basalt (typically 2–4 in. in diameter) in contact with the basalt. Small, local, poorly exposed diabase was noted in the Burnt Hill area. A bedded sandstone consisting of angular basaltic sand grains interlaminated with a calcareous fossil hash was observed in the low foothills due south of Palo Alto Road.

Flows, breccias, and dikes typically have basalt geochemistry (Appendix 3). One dike is geochemically a basaltic trachyandesite (Appendix 3, loc. 8). The thickness of the unit cannot be determined within the quadrangle. Cady and others (1972b) indicate a maximum thickness of about 3,300 ft for their upper basalt member, just south of the Sequim quadrangle, in one of their cross sections.

Basaltic rocks in the Sequim 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, in some places as glomerocrysts, and microlites. Subhedral to anhedral augite is commonly abundant (30–45%) and typically interstitial to plagioclase or has an ophitic to subophitic texture in the diabase; augite is typically less than 0.3 mm but is locally as coarse as 3 mm and is locally replaced by chlorite. Basalt and basaltic trachyandesite contain mineral-filled amygdules, some fillings identified as zeolites. Accessories include unidentifiable matrix minerals (possibly clays), limonite, calcite, unidentified opaque minerals, and sanidine (grains identified in the bedded, fossiliferous basaltic sandstone).

Ev_{cr} **Rhyolite**—Poorly exposed, isolated outcrop (Plate 1, sec. 18, T29N, R3W) of porphyritic rhyolite; phenocrysts of milky white plagioclase in a light-gray and pale-pink, aphanitic groundmass; in thin section, euhedral to subhedral Carlsbad-, albite-, and a few pericline-twinned albite grains (anorthite content 5– 10%) and quartz-grain aggregates arranged in a glassy groundmass of altered spherulites (with possible glass cores); single grain of green, twinned, subhedral, partially resorbed hornblende. Accessories include zircon (0.25 mm) associated with feldspar phenocrysts.

DISCUSSION

Makah Formation

Tabor and Cady (1978a) mapped the Tertiary sedimentary rocks exposed in the Sequim quadrangle as undivided Twin River Formation [Group]. Othberg and Palmer (1979) also referred to these rocks as undivided Twin River, but they assigned the rocks exposed along the west shore of Sequim Bay to the lower member. One of the primary objectives of our study was to refine the stratigraphy of the Twin River Group by identifying foraminiferal assemblages in these rocks. We identified two mapable facies: (1) a sandstone facies (unit ΦEm_m) in exposures along the west shore of Sequim Bay in and around Sequim Bay State Park, in creek bottoms near the park, in highway cuts and logging road cuts along and near U.S. Highway 101, in drainage and irrigation ditches on Bell Hill, and in a foundation excavation for a homesite and in Johnson Creek on the southeast side of Bell Hill, and (2) a small-pebble conglomerate and granular and very coarse to medium-grained sandstone facies (unit ΦEm_{mc}) along an east trend at the top of Bell Hill. Twelve samples provided identifiable foraminiferal assemblages. Two samples were from unit ΦEm_{mc}, and ten were from unit ΦEm_m. The identifications are presented in Appendix 2. Fossil localities are illustrated in Figure 5.

Foraminifera from all samples collected in the Sequim quadrangle (Appendix 2) are included in the Refugian Stage. The Refugian Stage straddles the Oligocene–Eocene boundary as applied in the Pacific Northwest (Rau, 1981). These data indicate units ΦEm_m and ΦEm_{mc} are part of the Makah Formation.

A sample from unit ΦEm_{mc} at site S-2 (Fig. 5) also contained macrofossils. The sample was examined by Elizabeth Nesbitt, curator, Burke Museum of Natural History and Culture, University of Washington, Seattle. She was able to identify one brachiopod as *Terebratalia transvers caurina* (Gould), previously recorded from the Quimper Sandstone (Oligocene–Eocene marine sandstones that crop out on the Quimper Peninsula and eastern Miller Peninsula east of the Sequim quadrangle); a scallop, most probably *Pecten (Chlamys) landesi* (Arnold), a rare species identified only from the Cowlitz Formation (middle to late Eocene nearshore marine to nonmarine sandstones that occur in southwest Washington); part of a *Lima* sp.; and abundant oyster shell fragments, insufficient to identify. Nesbitt places the age of the sediment in which these specimens occur at middle to late Eocene.

The Makah Formation apparently is in unconformable contact with the underlying basaltic rocks of the Crescent Formation (unit Ev_c). Although that contact is not exposed in the quadrangle, on Bell Hill (where the contact is covered by deposits of Vashon till (unit Qgt_v), the small-pebble conglomerate and granular sandstone facies (unit ΦEm_{mc}) is mapped close to exposures of Crescent basaltic flows and breccias (unit Ev_c). There is at least 10 m.y. between the deposition of these two units. (See correlation diagram, Plate 2.) The well-rounded basalt pebbles and abundant volcanic lithic and oyster shell fragments identified in unit ΦEm_{mc} suggest a shallow-water (possibly beach) origin; volcanic rocks of the Crescent Formation provided the material that makes up the local basal unit of the Makah Formation.

Most of the foraminifera identified in the two samples of unit ΦEm_{mc} are deep-water species (samples S-1 and S-2, Appendix 2). This would seem to contradict our interpretation that the unit is a shallow-water facies. Given that the Makah was deposited in a deep marginal basin and that it elsewhere consists of turbidites and an olistostrome (Snavely and others, 1980), we suggest that the basal unit may have been transported along a submarine channel to deeper waters. In the Sequim quadrangle, the basal unit was observed only on Bell Hill where its contact with the overlying sandstone facies (unit ΦEm_{m}) is covered by Vashon till. We assume that the contact between the two facies is conformable. Water-well logs do not allow differentiation of the two facies in the subsurface, so we do not know if the basal unit exists elsewhere in the quadrangle. Most of the water-well logs refer to these rocks as shale (a small percentage noting sandstone, siltstone, or clay), which we have interpreted as unit ΦEm_{m} in the geologic cross sections.

The upper facies of the Makah Formation was apparently rapidly deposited in still deeper water than the basal conglomeratic unit exposed on Bell Hill, on the basis of its sorting, angular grains, and fine grain size. It occurs throughout the quadrangle in the subsurface, as illustrated in the geologic cross sections (Plate 2). We surmise that at one time it covered the basalts of the Crescent Formation, now exposed in the foothills in the southern part of the quadrangle, but has since been removed by erosional processes. Water-well data indicate that the unit is present in the subsurface under Happy Valley, south of Bell Hill, and that it may pinch out against the Crescent basalt where that unit rises above the valley to form the foothills. Water-well data suggest the unit may have an approximate maximum thickness of 450 ft. However, data from the Standard Oil Dungeness Unit 1-54 well, drilled in the mid-1950s northeast of Sequim (sec. 17, T30N, R3W) (McFarland, 1983, p. 14-15) indicate that the unit thickens at depth to the north, where bedrock structure steepens dramatically. A log of this well indicates that 3,061 ft (corrected with dipmeter) of fossiliferous marine rocks, predominantly medium to dark greenish gray sandy siltstone with sporadic intervals of carbonaceous siltstone, were penetrated at the well site. This section was identified by the operator as equivalent to the Oligocene–Eocene Makah and Miocene–Oligocene Pysht Formations. The operator also identified a 1,180-ft section of conglomerate in a yellow-brown siltstone matrix as Miocene-age Clallam Formation. On the basis of this evidence, it appears that only the lowest 450 ft of a 4,200-ft section of Tertiary sedimentary rock now remains. The overlying parts of the Twin River Group have been eroded away where the bedrock structure flattens and is exposed at the surface on the south limb of a synclinal structure. (See Structural Geology.)

Tabor and Cady (1978a) mapped an exposure of undivided Twin River Group rocks along the east shore of the Miller Peninsula, less than 5 mi east of the Sequim quadrangle, in the Gardiner 7.5-minute quadrangle. These rocks were mapped by Thoms (1959) and Allison (1959) as Marrowstone Shale (Durham, 1944). We collected samples at this exposure for foraminifera identification. The rocks are similar in appearance to the sandstone facies (unit ΦEm_{m}) exposed along the west shore of Sequim Bay. We also collected another sample at an area identified on geologic mapping by Thoms (1959) and Allison (1959) as underlain by Quimper Sandstone (Durham, 1942) for identification of possible foraminiferal assemblages. The foraminiferal assemblages in the two sample sites and their locations are listed respectively as G-2 and G-1 in the checklist in Appendix 2. Sample G-2 contained a relatively complete foraminiferal assemblage diagnostic of the Refugian Stage. The assemblage in sample G-1 may be Refugian, but it is not sufficiently complete for age assignment.

Allison (1959) studied the macrofossils and Thoms (1959) studied the microfossils of the Quimper Sandstone and Marrowstone Shale and assigned them to the Refugian Stage. Armentrout and Berta (1977), after reviewing Thoms' samples, also assigned the Quimper Sandstone and Marrowstone Shale to the Refugian Stage. For these reasons, we believe these rocks correlate with the Quimper Sandstone and Marrowstone Shale or, less probably, with the Makah Formation. Rau (Appendix 2) suggests that the Refugian assemblages identified in the marine rocks from the Sequim and Gardiner quadrangles are more similar to the Lincoln Creek Formation of southwest Washington than they are to the Twin River Group to the west. Further study will be necessary to determine these correlations with more certainty.

Structural Geology

The major structures in the Sequim quadrangle are a west-trending anticline, which has elevated resistant rocks of the Crescent Formation to form the foothill highlands that make up the southern one-third of the quadrangle, and an adjacent east-trending syncline that lies to the north. A secondary anticlinal fold on the north-dipping limb of the major anticline forms a southern outlier (Bell Hill) (cross section D–D′). This secondary fold apparently plunges westward and is expressed in the subsurface (cross section C–C′). It is modified east of Bell Hill by a local, northwest-trending transverse fault that we have interpreted from water-well logs (cross section E–E′). This structure does not crop out. Subsurface control from water-well records coupled with limited structural data from surface outcrops allow us to infer tertiary folds in the north limb of the major anticline east of Bell Hill (cross sections E–E′ and F–F′).

Evidence of the major syncline comes from well logs of the Standard Oil Dungeness Unit No. 1-54 oil and gas test well. (See cross section D-D′ for its position relative to the structure.) This well penetrated dark-green, hard, slightly altered volcanic rock, which we interpret to be the Crescent Formation, at a depth of 6,363 ft and continued to penetrate these rocks for an additional 1,130 ft to total depth (7,493 ft). A dipmeter log indicates 5 to 7 degree dips in the interval of the Twin River Group. We interpret these low dips to indicate that the well penetrated the hinge of the synclinal structure. The distance from the projection (to cross section D–D′) of the Dungeness Unit test well to the nearest water well to the south (well 28 F1, cross section D–D′) that penetrates the contact between the Makah Formation and the Crescent Formation is approximately 7,800 ft. This translates into a northward dip of approximately 39 degrees for the south limb of the postulated syncline.

The synclinal structure is probably a continuation of the Clallam syncline mapped by Brown and others (1960). They show the axial trace of this structure trending eastward. On a regional map (Tabor and Cady, 1978a), the axial trace of the Clallam syncline trends toward Sequim; we show this at a smaller scale in Figure 2. Although we do not have the structural control to show the axial trace, we surmise that it would trend almost due east across the northern quarter of the quadrangle and would pass very near the location of the Dungeness Unit No. 1-54.

We infer the position of the hinge of the major anticlinal structure by projecting structure from the Tyler Peak 15-minute quadrangle northward into the Sequim quadrangle and combining it with structural data available from limited exposures of jointed Crescent Formation basalt in the Sequim quadrangle.

The axial trace of the westward-plunging secondary anticlinal fold that exposes the lowest parts of the Makah Formation and the upper parts of the Crescent Formation on Bell Hill is inferred from water-well data, as illustrated in cross section C–C′.

The northwest-trending transverse fault (concealed) was inferred from a combination of water well-data and structural data collected from the Makah sandstone facies (unit $\Phi\mathrm{Em}_\mathrm{m}$) where it is exposed in the streambed of Johnson Creek and is separated by 100 ft of cover (till) from exposures of Crescent Formation basalt (unit Ev_c). The displacement on this fault is roughly 500 ft, with down to the south normal(?) displacement. (See cross section E–E′.) We extended the fault to the northwest where relatively steep topography on the southeastern slopes of Bell Hill flattens abruptly. There is no evidence of the fault in either of the adjoining cross sections (D–D′ and F–F′).

The age of faulting in the Sequim area has not been determined precisely. Evidence from this study indicates post-early Oligocene displacement because the fault cuts Oligocene–Eocene sediments of the lower Makah Formation. In the northern Olympic Peninsula, thrusting and resultant uplift persisted from middle Eocene time (ca. 45 Ma) at least through deposition of the Makah Formation (ca. 25 Ma) (Babcock and others, 1994). Thereafter, the Pysht and Clallam Formations reflect the filling of the Tofino–Fuca basin to shallow marine and emergent conditions. 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.) Therefore, folding in the Sequim area may have occurred throughout the Tertiary from the middle Eocene and faulting after early Oligocene time.

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

To construct the cross sections, 114 wells were used: 61 were field checked by the USGS or located during field work for this study; 53 were approximately located using location to the nearest quarter/quarter section, surface elevation, and address submitted to the Department of Ecology. **Completed**, date completed; **Altitude**, altitude of land surface (feet); **Depth**, drilled depth (feet); **Quality**: C, location field checked; U, not field checked.

Location	Owner	Completed	Altitude	Depth	Quality
29N/03W-02C01	State Parks Committee	02/??/47	130.0	492.5	U
29N/03W-02G01	Tyler, H. H.	04/26/74	200.0	200.0	C
29N/03W-02L02	Sequim Bay Park Trust	09/02/97	300.0	159.0	C
29N/03W-02N01	Sequim Bay Park Trust	07/11/97	388.0	261.0	C
29N/03W-03A01	McCormick, T. L.	08/25/81	200.0	285.0	U
29N/03W-03C01	Pellegrino, Michel	11/04/80	530.0	58.0	U
29N/03W-03E01	Fernie, Bruce	07/06/78	575.0	120.0	C
29N/03W-03F01	Kipperhan, Charles	07/28/81	570.0	362.0	U
29N/03W-03J01	Johnson, Bob	09/30/97	520.0	236.0	C
29N/03W-03K02	Layman, Steve	06/17/97	560.0	160.0	U
29N/03W-03N01	Horton, Gerald	09/21/82	660.0	105.0	U
29N/03W-03Q02	Herman, Robert	03/10/76	620.0	116.0	C
29N/03W-03R01	Swinford, Dave	09/15/93	600.0	86.0	U
29N/03W-04D01	Buyers, Otto H.	08/09/60	675.0	121.0	C
29N/03W-04H01	Gummen, Jack	12/09/94	610.0	158.0	U
29N/03W-04L01	Flowers, Terry	08/26/87	860.0	106.0	C
29N/03W-04L02	Krenek, Stanley	09/01/79	840.0	180.0	U
29N/03W-05C02	Kelley, Le Roy	05/26/78	740.0	76.0	C
29N/03W-05C03	Kelly, John	07/25/69	710.0	183.0	U
29N/03W-05D01	Lane, Douglas	09/15/81	720.0	188.0	C
29N/03W-05E01	Miller, Bud	12/10/75	850.0	112.0	C
29N/03W-05F01	Shirley, A. D.	10/02/77	800.0	64.0	C
29N/03W-06A01	Alwine, Dennis	02/25/93	820.0	81.0	U
29N/03W-06H01	Sachs, Emberto	07/12/96	1,120.0	204.0	C
30N/03W-06G01	Townsend, George R.	05/22/67	80.0	122.0	U
30N/03W-06J01	Olympic Straits Development Corp.	09/23/74	80.0	329.0	U
30N/03W-06K01	Martin, Terry	07/28/93	90.0	105.0	C
30N/03W-06R01	Bratoria, Mark	05/27/81	60.0	58.0	U
30N/03W-07C01	Gaskel, Robert	11/16/88	100.0	210.0	C
30N/03W-07L01	Griffith, J. T.	08/15/60	100.0	46.0	C
30N/03W-07Q01	Blair, Ed and Jeanine	07/18/91	120.0	116.0	C
30N/03W-08J01	Stone, Stacy	02/23/76	121.0	342.0	C
30N/03W-08M01	Sunland Associates	04/15/63	120.0	250.0	C
30N/03W-08N01	Alexander, Jim	01/09/90	115.0	118.0	U
30N/03W-09R01	Gray's Marsh Farms	08/17/88	105.0	591.0	U
30N/03W-15G01	Coulter & Scott	04/13/51	20.0	574.0	C
30N/03W-16B01	Lancaster, Lester	05/05/76	105.0	113.0	C
30N/03W-16C01	Woodman, R. C.	06/01/74	111.0	184.0	C
30N/03W-16C03	Anderson, Kent & Barbara	07/06/91	115.0	240.0	C
30N/03W-16D01	Andrews, Chris	07/24/92	130.0	190.0	U
30N/03W-16N01	Bolster, Perry	11/17/80	158.0	102.0	U
30N/03W-17C01	Stone, Gregge	08/05/81	100.0	320.0	U
30N/03W-17E01	Fink, Margaret	07/10/90	120.0	133.0	C
30N/03W-17P01	Remak, John	09/21/92	140.0	55.0	C
30N/03W-18A01	Sequim Baptist Chapel	06/08/78	115.0	96.0	C
30N/03W-18G01	R & R Enterprises	07/08/87	135.0	355.0	C
30N/03W-18K01	Schade, Francis	08/28/96	150.0	85.0	U
30N/03W-18M01	Sturdevent, J. H.	10/23/75	165.0	50.0	C
30N/03W-18R01	Gollehon, Jesse	09/22/75	150.0	28.0	C
30N/03W-19D01	Cameron, Dave	10/11/72	208.0	49.0	C
30N/03W-19M01	Shaw, Glen	08/31/93	240.0	161.0	C
30N/03W-20C02	Pedlar, James	05/08/71	135.0	36.0	C
30N/03W-20C03	Foster, J. C.	08/14/78	145.0	75.0	U
30N/03W-20D01	King, James	07/27/93	140.0	151.0	C
30N/03W-20E01	Macedo, Stanley T.	10/11/77	172.0	76.0	C
30N/03W-20Q01	Belfield, W. J.	05/20/66	160.0	235.0	U
30N/03W-21A01	Smith, Gary	10/10/73	100.0	46.0	C
30N/03W-21D01	Halgerson, Hill	10/03/79	90.0	230.0	U
30N/03W-21H01	Baywood Village	02/10/70	130.0	298.0	C
30N/03W-21K01	Fishel	08/11/60	140.0	117.0	C
30N/03W-21K02	Kreml, Susan	07/01/95	160.0	290.0	C
30N/03W-22K01	Battelle Pac. NW Labs.	02/13/81	10.0	416.0	U
30N/03W-22K02	Kennedy, George	07/25/95	130.0	140.0	U
30N/03W-22M01	Williams, Charles	07/18/93	170.0	332.0	C
30N/03W-22M02	Diltz, Darlene & Les	02/23/79	170.0	235.0	U
30N/03W-25Q01	Linden, Steve	07/30/90	180.0	402.0	C
30N/03W-27C01	Parsons, Frank	08/01/88	160.0	194.5	C
30N/03W-27D01	Akers, Timothy W.	01/10/75	220.0	300.0	U
30N/03W-27F01	Carlson, Jerry	04/28/86	210.0	308.0	C
30N/03W-27L01	Wayne Enterprise	02/03/84	175.0	241.0	U
30N/03W-28B01	Boggs, William A.	05/25/89	180.0	122.0	C
30N/03W-28F01	Newton, Gordon	10/08/91	300.0	730.0	U
30N/03W-28F02	Fromhold, Linda	02/20/93	250.0	76.0	C
30N/03W-28J01	Turner, Howard	03/18/94	250.0	534.0	U
30N/03W-28K01	Martin, Ray	11/18/74	250.0	145.0	U
30N/03W-28M01	Walla, Donald	07/12/77	540.0	200.0	U
30N/03W-28P01	Beitzel, John	03/15/94	400.0	465.0	C
30N/03W-28P02	Costello, H. D.	01/29/94	420.0	746.0	U
30N/03W-28R02	Shephard, William	04/21/93	225.0	187.0	U
30N/03W-30C01	Peterson, Jon C.	04/13/79	280.0	185.0	C
30N/03W-30D01	Southerlund, Ed	05/30/74	300.0	172.0	C
30N/03W-30H02	Gerhardt, Anton	02/04/75	400.0	265.0	U
30N/03W-30J01	Minker, Fred L.	09/16/76	470.0	27.0	U
30N/03W-30K01	Belcher, Ruth	10/22/79	400.0	199.0	C
30N/03W-30L01	Armstrong, Dwight	11/25/74	390.0	64.0	C
30N/03W-30M01	Smith, Ron	04/17/81	410.0	79.0	U
30N/03W-30Q02	King, Roy	10/16/74	500.0	125.0	U
30N/03W-31B01	Johnston, Richard L.	03/08/78	515.0	185.0	U
30N/03W-31C01	Graham, Charles E.	10/27/89	540.0	56.0	U
30N/03W-31J01	Archambault, Darwin	12/19/79	560.0	48.0	U
30N/03W-31J02	Gray, Steve	02/28/94	580.0	91.0	U
30N/03W-31N01	Finnigan, Andrew	04/22/90	640.0	222.0	C
30N/03W-31P01	Emerson, Kenneth	05/02/79	680.0	109.0	U
30N/03W-31P02	Hall, William K., Jr.	04/14/94	700.0	124.0	U
30N/03W-32D01	Gagner, Ron	06/03/95	525.0	324.0	U
30N/03W-32E01	Haller, Albert	04/01/70	540.0	118.0	C
30N/03W-32M02	Laurenson, James W.	03/24/71	600.0	88.0	U
30N/03W-32Q01	Hughes, Robert R.	11/24/69	660.0	201.0	C
30N/03W-32R01	Bittman, Herbert	09/24/90	660.0	199.0	C
30N/03W-33A01	Mennell, June	12/19/96	400.0	351.0	U
30N/03W-33A02	Gaither, Steve & Debbie	09/05/90	340.0	136.0	C
30N/03W-33G01	Lowper, Inc.	03/16/91	440.0	670.0	U
30N/03W-33L01	Boyle, Joe	10/27/77	680.0	140.0	U
30N/03W-33P01	Blume, Art S.	04/05/77	640.0	150.0	C
30N/03W-34D01	O'Connor, Sara Lee	08/23/91	280	508	C
30N/03W-34H01	Bonar, Leonard J. O.	02/20/74	70	265	C
30N/03W-34K01	Dorrel, Fred J.	04/09/80	405	160	U
30N/03W-34L01	Pace, Frank	02/13/76	350	310	U
30N/03W-34N02	Ganje, Sharon	12/15/94	540	640	C
30N/03W-34N03	Nelson, Richard	01/27/95	540	212	U
30N/03W-34Q01	Pearson, Lloyd	04/20/78	335	340	U
30N/03W-35E01	Michlidge, H.	10/07/74	60	370	C
30N/03W-35M01	Bell, Jim	05/19/75	20	460	C
30N/03W-36C01	Mishko, Steve	08/03/94	140	283	C

Appendix 2. Foraminifera from the Sequim–Gardiner area, Washington

by W. W. Rau

Foraminiferal assemblages from all samples listed on the checklist except HS-10-15-97-2 are diagnostic of the Refugian Stage as applied in the Pacific Northwest (Rau, 1981). Assemblage HS-10-15-97-2 may also be Refugian, but it is not compete enough for specific identification.

Significant to a Refugian age in other samples are *Uvigerina cocoaensis*, *Ceratobulimina washburnei*, *Valvulinaria willapaensis*, *Melonis halkyardi*, and *Eponides kleinpelli*. All species are found in the Lincoln Creek Formation of southwest Washington. The assemblage of HS-10-15-97-4 is the same as that in the Lincoln Creek Formation exposed in the Porter bluffs between Centralia and Elma, Washington (Rau, 1948).

Refugian assemblages known to the west of these locations (Twin River Group, etc.) are also similar but not as much so as the Lincoln Creek Formation of southwestern Washington.

With respect to the environment of deposition of the sediments in which these assemblages occur, upper bathyal conditions (150-500 m) probably prevailed (Engle, 1980). Common and persistently occurring taxa particularly significant for such water depths are *Uvigerina cocoaensis*, *Ceratobulimina washburnei*, *Valvulineria willapaensis*, and *Pseudoglandulina inflata*. Shallower water forms do also make significant occurrences, such as *Eponides kleinpelli* and *Quinqueloculina imperialis*, but, in the same assemblages, deep water taxa, particularly *Melonis pompilioides*, also occur. Although elements show both deep and shallow water depths, the preponderance of the evidence suggests upper bathyal conditions.

References Cited

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

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

Rau, W. W., 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 and a locality suffix (S-#). The locations from which the samples were collected in the Sequim 7.5-minute quadrangle are shown on Figure 5 with the parenthetical portion of the sample number only (for example, S-4). Two samples were collected in the Gardiner quadrangle: HS-10-15-97-2 (G-1), 48°02′35″N, 122°54′23″W; HS-10-15-97-4(G-2), 48°03′11″N, 122°53′55″W. A, abundant; C, common; F, few; R, rare; ?, identification uncertain

Species	Locality													
	HS-8-7-97-3(S-1)	HS-8-7-97-4(S-2)	HS-8-8-97-3(S-3)	HS-9-25-97-5(S-4)	HS-9-25-97-3(S-5)	HS-10-15-97-9(S-6)	HS-8-15-97-3(S-7)	HS-9-19-97-4(S-8)	HS-8-15-97-1(S-9)	HS-9-9-97-1(S-10)	HS-9-18-97-1(S-11)	HS-8-21-97-5(S-12)	HS-10-15-97-2(G-1)	HS-10-15-97-4(G-2)
Quinqueloculina spp.	F	R			R								?	
Cassidulina cf. *C. galvinensis* Cushman & Frizzell	?	R						?	?			R		
Pseudoglandulina cf. *P. conica* (Neugeboren)	F												C	
Melonis halkyardi (Cushman)	R	R	?		A							R		
Eponides umbonatus (Reuss)	R													
Sigmomorphina sp.	?													
Valvulineria willapaensis Rau	R	F		R	A		C	R	R	R				
Cassidulina sp.	?													
Cibicides sp.		F	R		R									
Nodosaria latejugata Gumbel		?												
Quinqueloculina imperialis Hanna & Hanna			?		F	R	C	F	F	F	F	F		C
Lenticulina spp.			R											
Cassidulina globosa Hantken			F											
Pseudoglandulina inflata (Bornemann)				R	R			F	R	R	R		F	R
Uvigerina cocoaensis Cushman				A	F	C	C	C	C	A	C	A		
Eponides kleinpelli Cushman & Frizzell				C	F	F	C	C	F	C	F	C		
Melonis pompilioides (Fichtel & Moll)				C			F	C	F	F		R		R
Sigmomorphina cf. *S. undulata* Rau				R										
Ceratobulimina washburnei Cushman & Schenck				F	F		R			R		F		F
Polymorphina sp.					R									
Dentalina cf. *D. dusenburyi* Beck						F								R
Cornuspira byramensis Cushman							R	R						R
Guttulina irregularis d'Orbigny							R				R			R
Globigerina sp.							R					R	?	
Globobulimina spp.							R						C	
Cibicides elmaensis Rau							R	R	R			R		C
Lenticulina weaveri (Beck)								R		R				F
Sigmomorphina schencki Cushman & Ozawa										?				R
Guttulina frankei Cushman & Ozawa											?			
Cyclamina pacifica Beck														R
Spiroloculina texana Cushman and Ellison														R
Quinqueloculina weaveri Rau														?
Gaudryina alazanensis Cushman														R
Lenticulina cf. *L. texanus* (Cushman & Applin)														R
Planularia cf. *P. markleyana* Church														R
Gyroidina orbicularis planata Cushman														R
Hoeglundina eocenica (Cushman & M. A. Hanna)														F

Appendix 3. Major, minor, and trace element geochemical analyses, this study

Rigaku x-ray fluorescence analyses of rocks in the Sequim 7.5-minute and Tyler Peak 15-minute quadrangles, 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). Analyses are normalized on a volatile-free basis. Sample HS-7-18-97-1 (Loc. 5) is from a quarry 450 ft south of the northern boundary of the Tyler Peak quadrangle. *, total iron reported as FeO; R, duplicate bead made from same rock powder; +, values >120 percent of WSU's highest standard; Loc., locality number (see Fig. 5).

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-8-29-97-4	Ev$_c$, basalt	47.84	13.45	2.674	13.57	0.219	11.25	6.58	0.33	2.25	0.262	98.42
2	HS-7-3-97-5	Ev$_c$, basalt	49.43	14.31	2.329	11.02	0.213	11.93	6.99	0.23	2.37	0.229	99.05
2	HS-7-3-97-5R	Ev$_c$, basalt	48.83	14.18	2.313	11.68	0.212	11.87	6.91	0.23	2.37	0.233	98.83
3	HS-8-14-97-5	Ev$_c$, basalt	47.68	13.56	2.264	13.13	0.240	11.24	7.26	0.22	2.50	0.211	98.30
4	HS-7-8-97-4	Ev$_c$, basalt	48.10	14.73	2.095	12.39	0.212	11.83	5.78	0.11	2.49	0.215	97.95
5	HS-7-18-97-1	Ev$_c$, basalt	49.11	14.37	2.357	11.50	0.197	12.26	5.92	0.13	2.59	0.249	98.68
6	HS-7-10-97-1	Ev$_c$, basalt (dike)	48.25	14.59	2.068	11.57	0.193	12.59	6.86	0.10	2.16	0.192	98.57
7	HS-7-16-97-3	Ev$_c$, basalt (dike)	46.60	15.82	1.388	11.48	0.181	12.15	7.18	0.12	1.95	0.102	96.97
8	HS-11-13-97-1	Ev$_c$, basaltic trachyandesite (dike?)	49.43	14.59	1.294	10.06	0.162	5.64	8.72	6.02	0.66	0.124	96.70
8	HS-11-13-97-1R	Ev$_c$, basaltic trachyandesite (dike?)	49.46	14.61	1.295	9.99	0.162	5.64	8.64	6.00	0.66	0.125	96.58
9	HS-11-13-97-2	Ev$_c$, basalt (diabase)	45.66	19.56	0.914	8.88	0.128	10.99	9.79	0.06	1.90	0.080	97.96
9	HS-11-13-97-2R	Ev$_c$, basalt (diabase)	45.06	19.34	0.902	9.02	0.130	10.94	9.64	0.06	1.86	0.082	97.03
10	HS-11-13-97-8	Ev(cr), rhyolite	72.01	14.22	0.227	3.70	0.107	0.71	0.26	1.39	7.29	0.037	99.95

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-8-29-97-4	Ev$_c$, basalt	48.61	13.67	+2.717	13.79	0.223	11.43	6.69	0.34	2.29	0.266
2	HS-7-3-97-5	Ev$_c$, basalt	49.90	14.45	2.351	11.13	0.215	12.04	7.06	0.23	2.39	0.231
2	HS-7-3-97-5R	Ev$_c$, basalt	49.41	14.35	2.340	11.82	0.215	12.01	6.99	0.23	2.40	0.236
3	HS-8-14-97-5	Ev$_c$, basalt	48.50	13.79	2.303	13.36	0.244	11.43	7.39	0.22	2.54	0.215
4	HS-7-8-97-4	Ev$_c$, basalt	49.11	15.04	2.139	12.65	0.216	12.08	5.90	0.11	2.54	0.219
5	HS-7-18-97-1	Ev$_c$, basalt	49.77	14.56	2.388	11.65	0.200	12.42	6.00	0.13	2.62	0.252
6	HS-7-10-97-1	Ev$_c$, basalt (dike)	48.95	14.80	2.098	11.74	0.196	12.77	6.96	0.10	2.19	0.195
7	HS-7-16-97-3	Ev$_c$, basalt (dike)	48.06	16.31	1.431	11.84	0.187	12.53	7.40	0.12	2.01	0.105
8	HS-11-13-97-1	Ev$_c$, basaltic trachyandesite (dike?)	51.12	15.09	1.338	10.40	0.168	5.83	9.02	6.23	0.68	0.128
8	HS-11-13-97-1R	Ev$_c$, basaltic trachyandesite (dike?)	51.21	15.13	1.341	10.34	0.168	5.84	8.95	6.21	0.68	0.129
9	HS-11-13-97-2	Ev$_c$, basalt (diabase)	46.61	19.97	0.933	9.06	0.131	11.22	9.99	0.06	1.94	0.082
9	HS-11-13-97-2R	Ev$_c$, basalt (diabase)	46.44	19.93	0.930	9.30	0.134	11.27	9.93	0.06	1.92	0.085
10	HS-11-13-97-8	Ev$_{cr}$, rhyolite	72.05	14.23	0.227	3.70	0.107	0.71	0.26	1.39	7.29	0.037

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-8-29-97-4	Ev$_c$, basalt	61	224	36	378	42	2	224	164	34	19.0	21	+201	103	0	11	55	2
2	HS-7-3-97-5	Ev$_c$, basalt	75	236	41	339	46	2	238	140	27	16.4	21	48	94	0	15	39	3
2	HS-7-3-97-5R	Ev$_c$, basalt	75	235	35	336	32	0	243	142	29	15.9	19	51	96	0	3	40	2
3	HS-8-14-97-5	Ev$_c$, basalt	74	246	41	384	26	2	177	135	36	11.8	18	+190	103	0	7	29	1
4	HS-7-8-97-4	Ev$_c$, basalt	68	208	35	332	21	0	191	194	40	16.8	24	+946	106	3	4	36	2
5	HS-7-18-97-1	Ev$_c$, basalt	48	143	38	371	25	0	261	142	29	17.4	22	+165	102	0	10	42	4
6	HS-7-10-97-1	Ev$_c$, basalt (dike)	85	285	34	332	19	0	226	122	28	13.1	21	+170	91	2	11	26	2
7	HS-7-16-97-3	Ev$_c$, basalt (dike)	150	296	41	304	183	4	205	85	25	3.8	20	136	69	0	0	0	3
8	HS-11-13-97-1	Ev$_c$, basaltic trachyandesite (dike?)	144	183	25	240	1722	55	+1186	119	23	5.9	13	71	62	0	8	0	3
8	HS-11-13-97-1R	Ev$_c$, basaltic trachyandesite (dike?)	147	176	27	230	1729	55	+1179	119	24	5.5	11	77	65	1	0	9	0
9	HS-11-13-97-2	Ev$_c$, basalt (diabase)	225	116	32	169	12	2	181	60	18	4.1	15	78	50	2	0	14	1
9	HS-11-13-97-2R	Ev$_c$, basalt (diabase)	228	111	33	187	3	1	183	60	17	3.5	18	79	55	0	0	5	3
10	HS-11-13-97-8	Ev$_{cr}$, rhyolite	11	0	5	9	264	36	62	497	+95	35.6	30	11	108	1	29	76	5

Appendix 4. Atterberg limits test to characterize inherent swelling potential of the Everson Glaciomarine Drift

There was a question at the beginning of this project about the potential expansivity of the silts and clays that make up the Everson Glaciomarine Drift. In order to test the expansivity, we collected a sample believed to be typical of the Everson Glaciomarine Drift in the study area from a roadcut on Grennan Hill near the east boundary of sec. 7, T30N, R06E. (See Fig. 5.) The Washington Department of Transportation's Materials Testing Laboratory tested the sample for its Atterberg limits and made a gradation analysis.

The gradation analysis *(following page)* shows that the sample contained 98.8 percent fines passing through a #200-mesh US sieve; the remaining 1.2 percent consisted of fine sand.

The Atterberg limits test determined that the sample had a moisture content of 19 percent, a liquid limit of 37 percent, a plastic limit of 22 percent, and a plasticity index of 15. Seed and others (1962) characterize the inherent potential for a geologic material with a high clay content to swell using the plasticity index. Applying Seed and others' method, the inherent swelling capacity is low to medium. (Test results are shown graphically on the following page.)

The soil survey of Clallam County (Halloin, 1987) provides a listing of engineering properties for the Agnew soil, whose parent geologic material is the Everson Glaciomarine Drift. The plasticity indexes of three samples collected at three soil depths (ranging from 0 to 60 in.) ranged from 5 to 20, further substantiating a low to medium inherent swelling capacity. Therefore, we conclude that the potential for the Everson Glaciomarine Drift to cause foundation problems through swelling is low to moderate.

References Cited

Halloin, L. J., 1987, Soil survey of Clallam County area, Washington: U.S. Soil Conservation Service, 213 p., 67 pl.

Seed, H. B.; Woodward, R. J., Jr.; Lundgren, R., 1962, Prediction of swelling potential for compacted clays: American Society of Civil Engineers Journal of Soil Mechanics, v. 88, no. SM3, p. 53-87.

Job No.	NM0078	Date	November 4, 1997
Hole No.	DNR	Sheet	1 of 1
Project	Sequim Mapping Project		

Laboratory Summary

Washington State Department of Transportation

	Depth (ft)	Depth (m)	Sample No.	USCS	Color	Description	MC%	LL	PL	PI
●			*	CL	--------------------	LEAN CLAY (* Sample No. HS9-29-97-2)	19	37	22	15

GRADATION FRACTIONS

	%Gravel	%Sand	%Fines	Cc	Cu
●	0.0	1.2	98.8		

GRADATION VALUES

	D60	D50	D30	D20	D10
●