Geologic Map of the Washougal Quadrangle, Clark County, Washington, and Multnomah County, Oregon

By Russell C. Evarts, Jim E. O'Connor, and Terry L. Tolan

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Introduction

Geographic and Geologic Setting

The Washougal 7.5' quadrangle spans the boundary between the Portland Basin and the Columbia River Gorge, approximately 30 km east of Portland, Oregon (fig. 1). The map area contains the westernmost portion of the Columbia River Gorge National Scenic area as well as the rapidly growing areas surrounding the Clark County, Washington, cities of Camas and Washougal. The Columbia River transects the map area, and two major tributaries, the Washougal River in Washington and the Sandy River in Oregon, also flow through the quadrangle. The Columbia, Washougal, and Sandy Rivers have all cut deep valleys through hilly uplands, exposing Oligocene volcanic bedrock in the north part of the map area and lava flows of the Miocene Columbia River Basalt Group in the western Columbia River Gorge. Elsewhere in the map area, these older rocks are buried beneath weakly consolidated to well-consolidated Neogene and younger basin-fill sedimentary rocks and Quaternary volcanic and sedimentary deposits.

The Portland Basin (Evarts and others, 2009a) is part of the Coastal Lowland (Haugerud, 2004) that separates the Cascade Range from the Oregon Coast Range (fig. 1). The basin has been interpreted as a pull-apart basin located in the releasing stepover between two en echelon, northwest-striking, right-lateral fault zones (Beeson and others, 1985, 1989; Yelin and Patton, 1991; Blakely and others, 1995). These fault zones are thought to reflect regional transpression, transtension, and dextral shear within the forearc in response to oblique subduction of the Pacific plate along the Cascadia Subduction Zone (Pezzopane and Weldon, 1993; Wells and others, 1998). The southwestern margin of the Portland Basin is a well-defined topographic break along the base of the Tualatin Mountains, an asymmetric anticlinal ridge that is bounded on its northeast flank by the Portland Hills Fault Zone (Balsillie and Benson, 1971; Beeson and others, 1989; Blakely and others, 1995), which is probably an active structure (Wong and others, 2001). The nature of the corresponding northeastern margin of the basin is less clear, but a series of poorly defined and partially buried dextral extensional structures has been hypothesized from topography, microseismicity, potential-field anomalies, and reconnaissance geologic mapping (Yelin and Patton, 1991; Davis, 1987; Beeson and others, 1989; Blakely and others, 1995).

This map is a contribution to a program designed to improve the geologic database for the Portland Basin region of the Pacific Northwest urban corridor, the densely populated Cascadia forearc region of western Washington and Oregon. Updated, more detailed information on the bedrock and surficial geology of the basin and its surrounding area will facilitate improved assessments of seismic risk (Yelin and Patton, 1991; Bott and Wong, 1993; Palmer and others, 2004), ground-failure hazards (Wegmann and Walsh, 2001), and resource availability (Johnson and others, 2005) in this rapidly growing region.

Previous Geologic Investigations

The lower Columbia River region has attracted the attention of geologists for over a century. Among early descriptions of geologic relations in the Columbia River Gorge-Portland Basin region are those of Williams (1916), Hodge (1938), Lowry and Baldwin (1952), and Treasher (1942). Trimble (1963) mapped and described the geology of the Portland metropolitan area at a scale of 1:62,500 and established the basic stratigraphic framework and distribution of geologic units throughout the Portland Basin. Working simultaneously but independently, Mundorff (1964) mapped the northern part of the Washougal quadrangle at a scale of 1:48,000 as part of a groundwater-resources evaluation of Clark County, Washington. The maps of Trimble and Mundorff are very similar, and both reports provide detailed descriptions of the basin-fill deposits.

Tolan (1982) mapped the westernmost Columbia Gorge in detail, emphasizing stratigraphic relations in the Columbia River Basalt Group; his map area lies mostly east of the Washougal quadrangle but extends westward to Corbett Station. Phillips (1987a) compiled a geologic map of the Vancouver 30' x 60' quadrangle, which includes the Washougal 7.5' quadrangle at 1:100,000 scale as part of the state geologic mapping program of the Washington Division of Geology and Earth Resources (Walsh and others, 1987). Although relying heavily on previous work, he undertook some original reconnaissance mapping, and his was the first map to show major lithostratigraphic units within the Paleogene bedrock sequence. He acquired chemical analyses for some of the volcanic rocks of the region, as well as a few whole-rock K-Ar ages—including one that was obtained from a locality just north of the Washougal quadrangle.

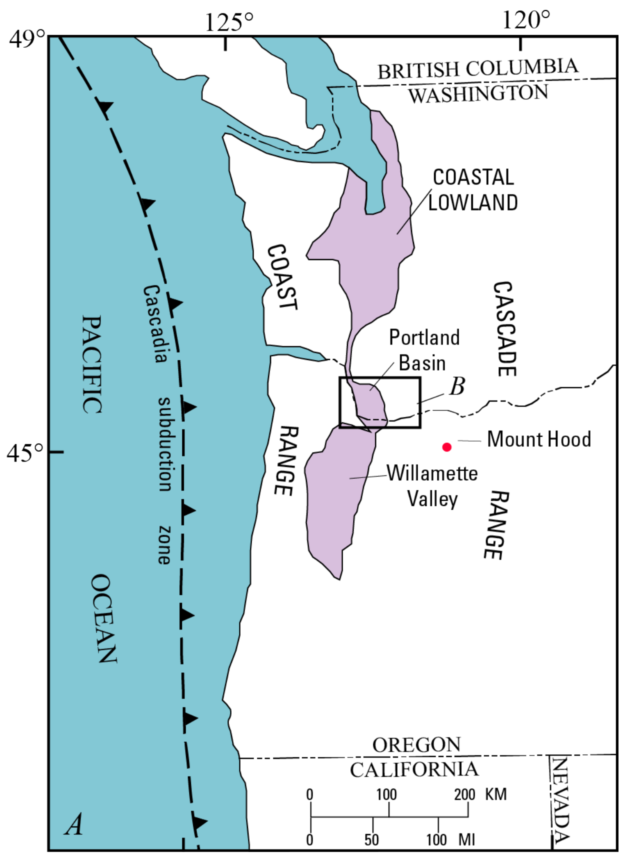

Figure 1. Regional setting of the Washougal 7.5' quadrangle. *A*, Major tectonic and physiographic features of the Pacific Northwest; *B*, Simplified geologic map of the Vancouver 30' x 60' quadrangle, modified from Phillips (1987a).

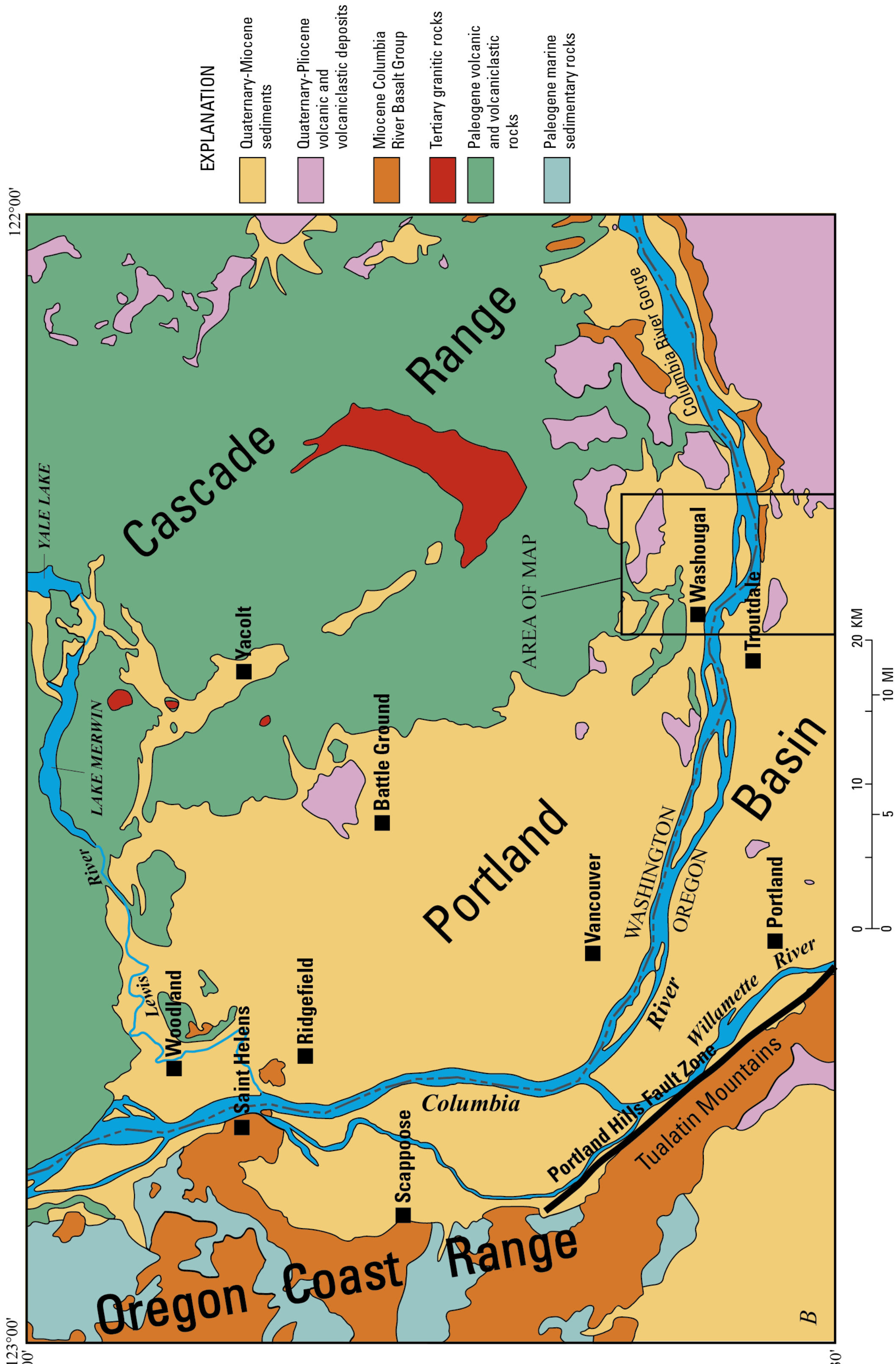

Figure 1. —Continued

More recently, detailed mapping has been conducted in the adjacent Sandy (Lite, 1992), Damascus (Madin, 1994), and Camas (Evarts and O'Connor, 2008) quadrangles. These maps provide considerable new information regarding stratigraphic relations and geologic structures associated with the development and sedimentation of the Portland Basin (Evarts and others, 2009a). Madin (1994) was the first to divide the young volcanic rocks of the Portland area (Boring Lava) based on geochemistry and K-Ar dates.

Other relevant studies conducted in and near the map area include several Portland State University Masters theses that examined the stratigraphy and composition of the sediments that fill the Portland Basin (Cole, 1983; Swanson, 1986, 1988; Gates, 1994; Rapp, 2005). Allen (1975) discussed the Quaternary volcanic rocks, some of which were analyzed and dated by Conrey and others (1996a). Bretz (1925), Allison (1978), and Waitt (1996) described features in the map area created by the Late Pleistocene cataclysmic Missoula Floods. Fiksdal (1975) published a map of landslides and landslide-prone areas for Clark County, Washington. Swanson and others (1993) compiled a hydrogeologic map of the Portland Basin. Geophysical investigations that bear on geologic relations in the map area include those of Ryan and Stephenson (1995), Blakely and others (1995), and Pratt and others (2001).

Acknowledgments

Many landowners granted access essential for detailed mapping in the Washougal quadrangle. Diane M. Johnson-Cornelius and Richard M. Conrey of Washington State University performed chemical analyses. Robert J. Fleck, Shannon A. Mahan, and Jonathan T. Hagstrum of the U.S. Geological Survey (USGS) provided $^{40}Ar/^{39}Ar$ ages, luminescence ages, and paleomagnetic data, respectively. Andrei Sarna-Wojcicki, Kenneth Bishop, and Judith Fierstein of the USGS made available essential laboratory facilities. We obtained water-well drillers' logs from the Washington Department of Ecology website (http://apps.ecy.wa.gov/welllog/) and the Oregon Water Resources Department website (http://apps.wrd.state.or.us/apps/gw/well_log/). Connie Manson and Lee Walkling aided in extracting information from the Washington Division of Geology and Earth Resources Library in Olympia, Washington, and Carol Edwards helped us acquire the unpublished field notes and map sheets of Donald E. Trimble from the USGS Field Records Library in Denver, Colorado. We have benefited immensely from discussions on various aspects of the regional stratigraphy, structure, and geologic history with Roger Ashley, Marvin Beeson, Paul Hammond, Lee Liberty, Ian Madin, Alan Niem, William Phillips, Thomas Pierson, Patrick Pringle, Elizabeth Rapp, Stephen Reidel, David Sherrod, James Smith, Rodney Swanson, James Vallance, Richard Waitt, Linton Wildrick, and Ray Wells. We thank Thomas Pierson and Daniel Malmon for technical reviews of the manuscript.

Synopsis of Geology

For the past 40 m.y., the Cascade Range has been the locus of an episodically active volcanic arc associated with underthrusting of oceanic lithosphere beneath the North American continent along the Cascadia Subduction Zone. In the Washougal quadrangle, Oligocene volcanic rocks of the ancestral Cascade arc are exposed along the Washougal River and underlie the ridge west from Woodburn Hill. These consist predominantly of basaltic andesite flows but locally include interbedded andesite flows and volcaniclastic beds. In middle Miocene time, huge volumes of basaltic lava erupted from fissure vents in Idaho and eastern Washington and Oregon. Between about 16 Ma and 12 Ma, several of these flood-basalt flows crossed the Cascade Range through a broad lowland and entered western Oregon and

Washington. These flows constitute the Columbia River Basalt Group. They form impressive cliffs throughout the Columbia River Gorge, which is located near the northern margin of the Miocene trans-arc lowland. The basalt flows exposed along the river shore between Corbett Station and Chanticleer Point are the westernmost outcrops of the Columbia River Basalt Group in the gorge.

In most of the map area, Oligocene and Miocene bedrock is buried beneath middle Miocene and younger sediments that consist largely of detritus carried into the Portland Basin by the ancestral Columbia River. Most of these sediments exposed in the map area are assigned to the Troutdale Formation, which consists of two distinct lithofacies: thick deposits of late Miocene cobble conglomerate that underlie the upland terrain east of Washougal, and Pliocene deposits containing abundant basaltic hyaloclastic debris that underlie most of the map area in Oregon. In both areas, the Troutdale Formation is locally overlain by Quaternary volcanic rocks of the Boring Volcanic Field (Treasher, 1942; Trimble, 1963; Allen, 1975; Evarts and others, 2009b). Mount Norway and Chamberlain Hill are eroded cinder cones surrounding vents of small Pleistocene volcanoes. Post-Troutdale lava flows in the northern and southeastern parts of the map area issued from vents located outside of the quadrangle. Gravel composed largely of andesitic clasts eroded from the Cascade Range unconformably overlies the Troutdale Formation in the southwestern part of the map area. This gravel records aggradation of the ancestral Sandy River during Middle to Late Pleistocene time, possibly in response to glaciation and volcanism. In latest Pleistocene time, the glacial-outburst Missoula floods poured through the Columbia River Gorge, building coarse-grained bars along the Columbia River and depositing sand and silt on upland surfaces and in the lower reaches of tributary streams. During the Holocene, the Columbia River has aggraded nearly 100 m in conjunction with sea level rise, forming a wide floodplain. In addition, abundant volcaniclastic debris generated by eruptions of Mount Hood moved down the Sandy River, building a prominent delta along the south shore of the Columbia River in the western part of the map area. Quaternary winds have entrained Columbia River sediment, building young dunes on the floodplain and mantling uplands with loess.

Several faults with predominantly northwest trends cross the map area. South of the Columbia River, these structures vertically offset the bedrock basement with west-side-down displacement and were evidently active during late Miocene and Pliocene subsidence and filling of the Portland Basin. A graben north of Washougal also developed during this time and partly controlled the route of the ancestral Columbia River. All of these structures may have experienced strike-slip motion. Compressional to transpressional faults projected eastward from the adjacent Camas quadrangle were apparently active in early to middle Pleistocene time, but no faults are known to exhibit late Quaternary or Holocene offsets.

Geologic exposures are sparse in much of the map area owing to intense weathering, obscuring vegetation, and urban development, and loess mantles much of the terrain south of the Columbia River. Therefore, many contacts are extrapolated on the basis of topography from limited surface observations. Surface observations were supplemented with lithologic data obtained from several hundred water-well reports in the files of the Washington Department of Ecology and Oregon Water Resources Department. Well locations were taken as described in logs or in published reports and were not field checked by us; only wells considered reliably located were used to infer the distribution and thicknesses of units in the subsurface.

Paleogene Volcanic and Sedimentary Rocks

Trimble (1963) mapped all Paleogene rocks in eastern Clark County, Washington, as the Skamania volcanic series (renamed Skamania Volcanics by Howard, 2002). We have not adopted this name because regional mapping has shown the term to have limited utility. Neither the top nor the base of the unit were adequately defined, and, as used by Trimble, the term is essentially a synonym for Tertiary volcanic rocks of the southern Washington Cascade Range. Furthermore, equivalent strata elsewhere in the region have been given other names (Wilkinson and others, 1946; Roberts, 1958; Wise, 1970; Hammond, 1980; Phillips, 1987a,b) and no reliable criteria have been found for mapping contacts between these various units. Therefore, we employ strictly lithologic units or, where appropriate, informal lithostratigraphic units.

Paleogene volcanic rocks presumably underlie the entire map but are well exposed only along the Washougal River where they consistently strike north-northeast and dip southeast at 20-40°. The section north of Washougal is dominated by basaltic andesite flows and flow breccia that constitute the upper part of the informal basaltic andesite of Elkhorn Mountain of Evarts (2005, 2006a,b). Andesite flows are locally intercalated with the uppermost part of this unit, and similar andesite flows, basalt, and volcaniclastic rocks overlie it.

Basaltic Andesite of Elkhorn Mountain

The basaltic andesite of Elkhorn Mountain (Tbem) consists almost entirely of subaerially erupted tholeiitic basaltic andesite and basalt flows; interbedded volcaniclastic sedimentary rocks are sparse. This package of flows extends about 35 km northward nearly to Amboy, Washington (Evarts, 2005, 2006a,b; Evarts and O'Connor, 2008). It has a maximum thickness of about 1.3 km in the map area. Individual flows are typically 4 to 10 m thick but locally are as thick as 70 m. They are characterized by blocky, platy, or columnar-jointed interiors that typically grade into upper and lower flow-breccia zones. The upper zones commonly contain abundant zeolite-, quartz- and clay-filled vesicles and have been oxidized to reddish-orange colors during cooling. All flows were apparently emplaced subaerially; many rest on red paleosols developed on previously emplaced flows or on thin sedimentary intervals, with no pillow lavas or other indications of subaqueous environments. No dikes were found in the map area, and few dikes have been mapped to the north (Evarts, 2005, 2006 a,b). The basaltic andesite of Elkhorn Mountain in the map area probably represents the upper flank of a large mafic shield volcano centered north of the Washougal quadrangle.

Flows in the basaltic andesite of Elkhorn Mountain range from aphyric to highly porphyritic. Aphyric and sparsely phyric flows commonly exhibit a closely spaced platy parting that is parallel to the alignment of feldspar microlites observed in thin section. Seriate to porphyritic flows contain phenocrysts of plagioclase and olivine, with or without augite, in an intergranular to trachytic groundmass. Highly porphyritic to glomeroporphyritic basalts are common in the unit to the north but are sparse in the map area.

The lava flows of the Elkhorn Mountain unit vary from basalt to mafic andesite, but most are basaltic andesite; they are uniformly tholeiitic and have low to medium potassium contents (table 1, fig. 2). Compared to mafic flows elsewhere in the southern Washington Cascade Range (du Bray and others, 2006; R.C. Evarts, unpub. data), the Elkhorn Mountain flows are relatively rich in Fe and poor in Sr (Evarts, 2005, 2006a,b).

Incremental-heating $^{40}Ar/^{39}Ar$ plateau ages ranging from 27.1±0.1 Ma to 25.5±0.2 Ma have been obtained for the basaltic andesite of Elkhorn Mountain from localities to the west and northwest of the Washougal quadrangle (Evarts, 2006a,b; Evarts and O'Connor, 2008). Phillips and others (1986) reported a similar K-Ar age of 27.9±1.9 Ma for a basaltic andesite exposed on State Route 140 directly north of the map area (table 2).

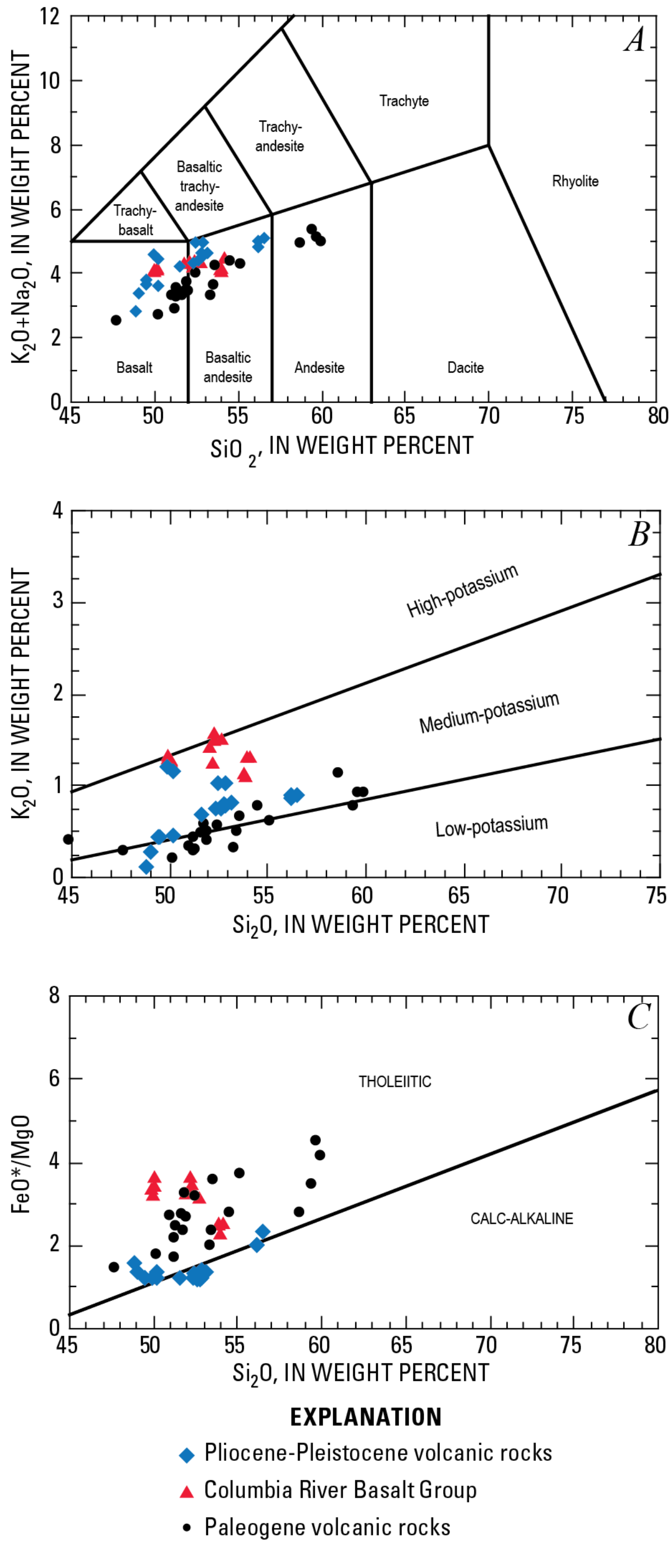

Figure 2. Chemical characteristics of volcanic rocks from the Washougal 7.5' quadrangle (analyses recalculated volatile-free). A, K_2O+ Na_2O versus SiO_2, showing IUGS classification (Le Maitre, 2002); B, K_2O versus SiO_2, showing low-, medium-, and high-potassium fields extrapolated from Gill (1981, p. 6); C, FeO*/MgO versus SiO_2, showing classification into tholeiitic and calc-alkaline rocks according to Miyashiro (1974). FeO*, total Fe as FeO.

Other Volcanic and Volcaniclastic Rocks

Sparsely to moderately porphyritic andesite flows (Ta) are interbedded with the upper part of the basaltic andesite of Elkhorn Mountain west of Woodburn Hill and near the mouth of the Little Washougal River. A highly porphyritic two-pyroxene andesite flow directly overlies the Elkhorn Mountain unit north of Washougal Memorial Cemetery and in the Washougal River 1 km northwest of Mount Norway. This flow is overlain by a bed of green, moderately welded lapilli tuff (Tt) that contains abundant euhedral to broken plagioclase crystals and sparse small pyroxene phenocrysts. Porphyritic two-pyroxene andesite crops out along the south shore of the Columbia River at Onion Rock. This is the only Paleogene rock exposed south of the river in the map area.

A single flow of olivine- and plagioclase-rich basalt (Tob) overlies the basaltic andesite of Elkhorn Mountain on the slope above the Washougal River about 2 km northwest of Mount Norway. Chemically it is a low-potassium tholeiite, a composition that is common among Pliocene–Quaternary volcanic rocks of the Oregon and southern Washington Cascade Range but generally rare in the Paleogene arc sequence of southern Washington (du Bray and others, 2006; R.C. Evarts, unpub. data). The age of the basalt is uncertain; the extent of alteration indicates it is probably Paleogene but a Pliocene age is possible. It is overlain by the Quaternary basalt of Bear Prairie.

Metamorphism and Hydrothermal Alteration

Paleogene rocks in the Washougal quadrangle have been subjected to zeolite-facies regional metamorphism, the general character of which is similar to that described from other areas in the southern Washington Cascade Range (Fiske and others, 1963; Wise, 1970; Evarts and others, 1987; Evarts and Swanson, 1994). This region-wide metamorphism reflects burial of the early Oligocene rocks by younger volcanic rocks within the relatively high-heat-flow environment of an active volcanic arc.

Zeolite-facies mineral assemblages are best developed in permeable volcaniclastic rocks; massive lava flows are commonly much less affected. In the mafic lava flows, the primary effect of very-low-grade metamorphism is the nearly universal development of clay minerals and zeolites replacing labile interstitial glass, filling vesicles, and deposited on joint surfaces. Feldspar commonly displays partial alteration along fractures and cleavage planes to clay minerals and (or) zeolites. Olivine phenocrysts in the basalts and basaltic andesites are replaced by smectite with or without hematite and calcite. Primary pyroxenes and Fe-Ti oxides are largely unaffected by the zeolite-facies metamorphism.

Columbia River Basalt Group

In Miocene time, between 16.5 and 6 Ma, more than 174,000 km^3 of basalt erupted from fissures in southeastern Washington and adjacent regions of Oregon and Idaho to form the Columbia River Basalt Group (Tolan and others, 1989, 2009). Some of the largest flows crossed the Cascade Range through a broad lowland and ultimately reached the Pacific Ocean (Snavely and others, 1973; Tolan and others, 1989, 2009; Beeson and others, 1989; Beeson and Tolan, 1990; Wells and others, 1989, 2009); the Columbia River is located near the northern margin of this Miocene valley. The majority of the flood-basalt flows erupted during a brief period between 16.5 and 14.5 Ma and constitute the voluminous Grande Ronde Basalt and Wanapum Basalt (Tolan and others, 1989, 2009; Reidel and others, 1989; Tolan and others, 2009; Barry and others, 2010; Reidel and Tolan, in press). Grande Ronde Basalt flows are aphyric to sparsely plagioclase-phyric, medium-potassium, tholeiitic basaltic andesites (fig. 2) that can be distinguished from other Columbia River Basalt Group units by their relatively low TiO_2 contents (Swanson and others, 1979; Mangan and others, 1986; Beeson and others, 1989; Reidel and others, 1989; Hooper, 2000; Reidel, 2005). The younger Wanapum Basalt flows are generally more mafic, have significantly higher TiO_2 contents, and typically contain scattered large plagioclase phenocrysts. Eruptions became progressively less frequent during Wanapum time, and the ancestral Columbia River was able to incise a deep canyon within which the last Wanapum flow to enter western Oregon, the Rosalia flow, was largely confined (Tolan and Beeson, 1984). The Grande Ronde Basalt and Wanapum Basalt flows near Corbett Station are the westernmost outcrops of the Columbia River Basalt Group in the Columbia River Gorge. Figure 3 shows the nomenclature of the Columbia River Basalt Group as adopted in this report and the stratigraphic position of flows found in the map area.

Grande Ronde Basalt

Using lithologic, chemical, and paleomagnetic criteria, Reidel and Tolan (in press) divided the Grande Ronde Basalt in the Columbia Basin into 25 members. The youngest and most widespread Grande Ronde member, the Sentinel Bluffs Member, was divided into informal compositional and stratigraphic units by Reidel (2005). The Columbia River Basalt Group flows near Corbett Station belong to the Sentinel Bluffs Member.

Sentinel Bluffs Member

Sentinel Bluffs Member flows are characterized by relatively high MgO contents (4.5 to 5.0 wt percent; table 1), normal magnetic polarity, and widely scattered plagioclase phenocrysts. West of the Cascade Range they typically exhibit a blocky to columnar style of jointing (Reidel, 2005). Three flows (Tgsb) are present near Corbett (Tolan, 1982). The uppermost flow, about 20 m thick and pillowed at its base, crops out on Corbett Hill Road. It has higher MgO and Cr and lower TiO_2 contents than the lower flows, which total at least 30 m thick and are well exposed in roadcuts along Interstate 84 and the Union Pacific Railroad line near Tunnel Point. All flows are chemically similar to Reidel's (2005) McCoy Canyon compositional type, which forms the oldest Sentinel Bluffs flows in the Columbia Basin.

Wanapum Basalt

The Wanapum Basalt has been divided into formal members (Swanson and others, 1979; Tolan and others, 1989), one of which, the Frenchman Springs Member, was subdivided into informal units by Beeson and others (1985). Four Wanapum Basalt flows crop out on the steep slope above Interstate Highway 84 east of Corbett Station (Tolan, 1982). Three of the flows belong to the Frenchman Springs Member and one flow belongs to the Priest Rapid Member of the Wanapum Basalt.

Frenchman Springs Member

Three flows that are assigned to the Frenchman Springs Member (Tolan, 1982) overlie the Sentinel Bluffs Member on Corbett Road along a contact marked by a distinct bench at 200 ft (65 m) elevation. The contact with the underlying Sentinel Bluffs Member of the Grande Ronde Basalt is not exposed here, but in the Columbia Basin and elsewhere it corresponds to a thin sedimentary interval, the Vantage Member of Ellensburg Formation (Swanson and others, 1979). The lower two flows ($Twfs_h$) contain sparse plagioclase phenocrysts as long as 3.5 cm and are assigned to the basalt of Sand Hollow of Beeson and others (1985) based on their relatively high Cr contents (~45 ppm) and normal magnetic polarity (J.T. Hagstrum, written commun., 2006). These are overlain by a thin, hackly jointed, microphyric flow ($Twfs_s$) chemically equivalent to the basalt of Sentinel Gap of Beeson and others

GROUP	SUBGROUP	FORMATION	MEMBER	AGE (Ma)	MAGNETIC POLARITY
COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP	SADDLE MOUNTAINS BASALT	**Lower Monumental Member**	6	N
			erosional unconformity		
			Ice Harbor Member	8.5	
			basalt of Goose Island		N
			basalt of Martindale		R
			basalt of Basin City		N
			erosional unconformity		
			Buford Member		R
			Elephant Mountain Member	10.5	R,T
			erosional unconformity		
			Pomona Member	12	R
			erosional unconformity		
			Esquatzel Member		N
			erosional unconformity		
			Weissenfels Ridge Member		
			basalt of Slippery Creek		N
			basalt of Tenmile Creek		N
			basalt of Lewiston Orchards		N
			basalt of Cloverland		N
			Asotin Member	13	
			basalt of Huntzinger		N
			Wilbur Creek Member		
			basalt of Lapwai		N
			basalt of Wahluke		N
			local erosional unconformity		
			Umatilla Member	13.5	
			basalt of Sillusi		N
			basalt of Umatilla		N
			local erosional unconformity		
		WANAPUM BASALT	***Priest Rapids Member***	14.5	
			basalt of Lolo		R
			basalt of Rosalia		R
			local erosional unconformity		
			Roza Member		T,R
			Shumaker Creek member		N
			Frenchman Springs Member		
			basalt of Lyons Ferry		N
			basalt of Sentinel Gap		N
			basalt of Sand Hollow	15.0	N
			basalt of Silver Falls		N,E
			basalt of Ginkgo		E
			basalt of Palouse Falls		E
			Eckler Mountain Member		
			basalt of Dodge		N
			basalt of Robinette Mountain		N
			local erosional unconformity		
		GRANDE RONDE BASALT	***Sentinel Bluffs Member***	15.5	
			basalt of Museum		
			basalt of Spokane Falls		
			basalt of Stember Creek		
			basalt of Airway Heights		
			basalt of California Creek		
			basalt of McCoy Canyon		
			Winter Water Member		N_2
			Fields Spring Member		
			Indian Ridge Member		
			Buttermilk Canyon member		
			Armstrong Canyon member		
			Ortley member		
			Slack Canyon Member		
			Meyer Ridge Member		
			Grouse Creek member		R_2
			Wapshilla Ridge Member		
			Mount Horrible member		
			Cold Springs Ridge Member		
			Hoskins Gulch Member		
			China Creek Member		N_1
			Frye Point member		
			Downey Gulch member		
			Brady Gulch member		?
			Kendrick Grade member		
			Center Creek member		
			Skeleton Creek member		R_1
			Rogersburg member		
			Teepee Butte Member	16.0	
			basalt of Pruitt Draw		
			basalt of Joseph Creek		
			basalt of Limekiln Rapids		
			Birch Creek member		
			Buckhorn Springs Member		T,R
		IMNAHA BASALT		16.0	N_0

Figure 3. Stratigraphic nomenclature of the Columbia River Basalt Group, after Tolan and others (2009), Reidel (2005), and Reidel and Tolan (in press). Magnetic polarity designations are N, normal; R, reversed; T, transitional; E, excursional. Subscripts refer to magnetostratigraphic units of Swanson and others (1979). Units present in the Washougal 7.5' quadrangle are shown in blue bold italics.

(1985). The top of the Sentinel Gap flow is a loess-mantled strath, cut into the overlying Troutdale Formation (Ttfh), that forms a prominent bench at approximately 400 ft (120 m) elevation. In the quarry at Corbett Station, one of the Sand Hollow flows, offset from the Corbett Road section along a northwest-striking normal fault, consists of large pillowed lobes interspersed with palagonitic hyaloclastic breccia, indicating interaction of basalt lobes with water in the channel during emplacement (Tolan, 1982).

Priest Rapids Member

At Chanticleer Point, a thick flow (>200 m) of the Priest Rapids Member abuts the southern wall of a paleocanyon incised into the older Wanapum Basalt and Grande Ronde Basalt. The main channel of this paleocanyon is located at Crown Point, about 1.5 km east of Chanticleer Point (Waters, 1973; Tolan, 1982; Tolan and Beeson, 1984). The Priest Rapids flow unit consists of a hackly jointed entablature and basal colonnade that overlies and invades crudely bedded hyaloclastite of the same chemical composition (Tolan, 1982). As interpreted by Tolan and Beeson (1984), the hyaloclastite was generated by interaction of the basalt with a shallow lake in the eastern Columbia Basin and flushed downstream in front of the advancing lava flow. Its chemistry (table 1) indicates the flow is of the Rosalia chemical type, typical of the first Priest Rapids Member flows.

Basin-Fill Deposits

As the Portland Basin gradually subsided during late Miocene and Pliocene time, it filled with continental fluvial and lacustrine sediments transported through the Cascade Range by the ancestral Columbia River and with locally derived detritus carried in by tributaries draining the surrounding highlands (Evarts and others, 2009a).

Most previous workers (Wilkinson and others, 1946; Lowry and Baldwin, 1952; Trimble, 1957; Mundorff, 1964; Tolan and Beeson, 1984; Madin, 1994; Howard, 2002) have mapped the bulk of this fill as the Troutdale Formation, which was named by Hodge (1938) for exposures near Troutdale, Oregon (fig. 1*B*). Throughout most of the Portland Basin, the older part of this nonmarine section, resting unconformably on Paleogene bedrock or Miocene Columbia River Basalt Group, consists predominantly of fine-grained beds that are quite different in lithology than the coarse-grained sandstone and conglomerate that typifies the Troutdale Formation in the type area (Swanson and others, 1993). This observation prompted Trimble (1957), Mundorff (1964), and Howard (2002) to divide the Troutdale Formation of Hodge (1938) into informal upper and lower members based on the pronounced lithologic difference. Trimble (1963) formally named the lower, fine-grained member the Sandy River Mudstone. He also noted that the youngest conglomeratic beds south of the Columbia River included volcanic mudflow deposits and consisted largely of clasts derived from the nearby Cascade Range rather than deposited by the Columbia River. He mapped these beds as the Springwater Formation of probable Pleistocene age (Trimble, 1963). Similarly, Howard (2002) and Evarts (2004a,b,c, 2006b) concluded on lithologic and geomorphologic grounds that some conglomerates in Washington previously included in the Troutdale Formation were probably late Pliocene or Pleistocene deposits that unconformably overlie the Troutdale Formation, and he mapped them separately. These post-Troutdale deposits are locally overlain or intercalated with mafic volcanic rocks, the Boring Lava of Treasher (1942), which erupted from scattered local centers in Quaternary time (Evarts and others, 2009b).

Recent studies (Evarts and others, 2009a) have shown that stratigraphic relations within the basin fill of the eastern Portland Basin are considerably more complex than relations portrayed by Trimble (1963) and Mundorff (1964). These complications are well illustrated in the adjacent Camas quadrangle, where subsurface information and surface exposures show that the stratigraphic intervals previously mapped as Troutdale Formation and Sandy River Mudstone from surface outcrops are interbedded. In the Washougal quadrangle and elsewhere, contact relations between fine-grained beds of the Sandy River Mudstone and coarse-grained beds of the Troutdale Formation vary from gradational to unconformable, reflecting both lateral variations in depositional setting within the ancestral Columbia River valley and alternating episodes of deposition and incision driven by changes in sediment supply (Hogenson and Foxworthy, 1965; Hoffstetter, 1984; Swanson, 1986; Hartford and McFarland, 1989; Swanson and others, 1993; Bet and Rosner, 1993; Koreny and Fisk, 2000; Evarts and O'Connor, 2008; Evarts and others, 2009a). Figure 4 shows a comparison of our nomenclature with the schemes employed by previous workers; these relations are discussed in more detail below.

Sandy River Mudstone

The Sandy River Mudstone (Tsr) as defined by Trimble (1963) consists largely of thin-bedded claystone, siltstone, and sandstone with minor interbeds of pebbly conglomerate, fine-grained tuff, and lignite. Most of the sandy beds are micaceous lithic and arkosic sandstones, indicative of an eastern Washington and Idaho provenance and deposition in an ancestral Columbia River. Claystone beds are commonly carbonaceous and locally contain well-preserved leaf impressions; early Pliocene fossil floras have been collected from the upper part of the Sandy River Mudstone at several localities (Chaney, 1944; Treasher, 1942; Trimble, 1963; Tolan and Beeson, 1984). Trimble interpreted the Sandy River Mudstone as a lacustrine deposit but current structures indicate deposition in low-energy fluvial or overbank settings, presumably along the ancestral Columbia River.

Strata lithologically similar to the Sandy River Mudstone crop out at several localities in the map area, but most are too small and discontinuous to map except along the north bank of the Sandy River at the south edge of the quadrangle, where they intertongue with coarse-grain sediments assigned to the hyaloclastic sandstone member of the Troutdale Formation (Ttfh). Water-well logs indicate that as much as 150 m of fine-grained beds, which we assign to the Sandy River Mudstone, underlie the basaltic andesite of Mount Norway and landslide deposits of the Washougal River valley. The well logs indicate that the Sandy River Mudstone in the Mount Norway area underlies the conglomerate member of the Troutdale Formation (Ttfc) along a sharp, south-dipping, apparently unconformable contact, hence these beds are considerably older than the beds exposed along the Sandy River.

Fine-grained beds assigned to the Sandy River Mudstone were deposited in the Portland Basin throughout late Miocene and Pliocene time (Evarts and others, 2009a). They largely postdate the middle Miocene Wanapum Basalt (Trimble, 1963; Tolan and Beeson, 1984; Madin, 1994, 2004; Mabey and Madin, 1995; but see Evarts, 2004a) and intertongue with the late Pliocene hyaloclastic sandstone member of the Troutdale Formation. The only direct age information for the unit comes from late Pliocene paleofloras obtained from the upper part of the formation at localities just west and south of the Washougal quadrangle (Chaney, 1944; Treasher, 1942; Trimble, 1963; Tolan and Beeson, 1984).

Troutdale Formation

The Troutdale Formation is mapped as two lithologically distinct informal members. The older member (Ttfc) consists of quartzite-bearing conglomerate and arkosic sandstone. The younger member (Ttfh) is composed largely of hyaloclastic basaltic debris. These two members correspond closely to the informal upper and lower members of the Troutdale Formation as mapped by Tolan and Beeson (1984) in the western Columbia River Gorge.

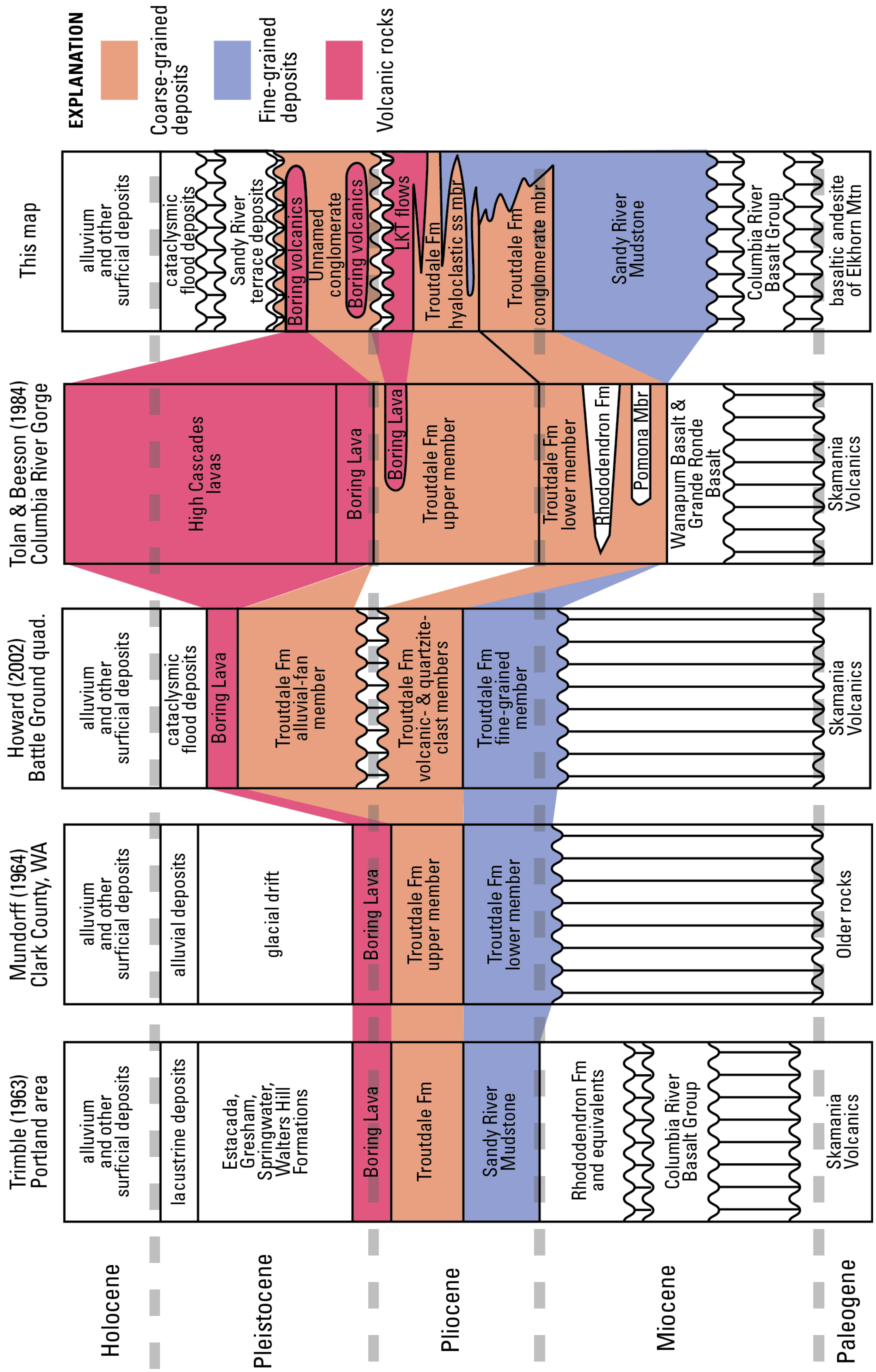

Figure 4. Comparison of stratigraphic nomenclature and age assignments for Neogene and younger basin-fill units of the Portland Basin and vicinity. LKT, low-potassium tholeiite.

Conglomerate Member

The conglomerate member (Ttfc) underlies the upland terrain east and south of the Washougal River, where it is at least 200 m thick. West of the Washougal River it is unconformably overlain by a younger but lithologically similar conglomerate (QTc).

The Troutdale Formation conglomerate member consists of weakly to moderately cemented pebble and cobble conglomerate and scattered thin lenses of medium to coarse sandstone. Well-rounded pebbles and cobbles eroded from the Columbia River Basalt Group are the most abundant constituent of the conglomerate; the remainder includes light-colored granitic and quartzofeldspathic metamorphic rocks, Fe-oxide-stained quartzite, and minor amounts of volcanic rocks eroded from the Cascade Range. The interbedded sandstone ranges in composition from basaltic to muscovite-bearing arkosic and quartzose and is lithologically similar to the sandy matrix of the conglomerate. Significantly, the conglomerate member of the Troutdale Formation (Ttfc) lacks clasts of Pliocene and younger basalts like those that are abundant in the basaltic hyaloclastic sandstone member (Ttfh). Sedimentological characteristics of the conglomerate, such as massive to crudely stratified beds, clast support, moderate to good sorting, and clast imbrication, are consistent with deposition within a large, braided, gravel-bed river (Miall, 1977, 1996; Rust, 1978). Clast imbrication is common and consistently indicates a westward transport direction, parallel to the flow direction of the Columbia River through the map area.

Hyaloclastic Sandstone Member

In its type area along the lower Sandy River, the Troutdale Formation consists of complexly interbedded sandstone and conglomerate and includes a distinctive lithofacies, composed largely of basaltic hyaloclastic debris, that earlier workers called yellow grit, tuffaceous sandstone, or vitric sandstone (Williams, 1916; Hodge, 1938; Lowry and Baldwin, 1952; Trimble, 1963; Tolan and Beeson, 1984). The hyaloclastic sediment is generally coarse-grained to very coarse-grained sandstone that is moderately well sorted to poorly sorted and composed chiefly of angular fragments of vesicular to nonvesicular, vitric to lithic basalt that contains olivine and plagioclase microlites. The black basaltic glass is partly to completely altered to palagonite, which imparts a distinctive yellow-brown color to the sandstone in outcrop and serves as a cementing agent.

Beds and lenses of conglomerate are intercalated with and locally dominate the hyaloclastic sandstone member. Conglomerate beds range from well sorted to poorly sorted. The former consist largely of well-rounded cobbles and pebbles of dark aphyric basalts eroded from the Columbia River Basalt Group; clasts of light-colored granitic and quartzofeldspathic metamorphic rocks and Fe-oxide-stained quartzite that were derived from Precambrian source areas east of the Cascade Range are minor but persistent components. Poorly sorted conglomerate contains abundant rounded to subangular cobbles and boulders of variably vesicular olivine- and plagioclase-phyric basalt in a matrix of basaltic sand compositionally similar to the associated sandstone beds. They resemble deposits of hyperconcentrated flood-flows (Smith, 1986).

The angular vitric clasts were generated by rapid chilling and quench fragmentation during interaction of basaltic lava with water. Crude to distinct stratification, foreset bedding, cut-and-fill structures, intergradational contacts with conglomerate, and the presence of minor but nearly ubiquitous nonvolcanic debris all signify fluvial reworking of the hyaloclasts. However, the textural immaturity, poor sorting, and nearly monolithologic character of many beds suggest relatively short transport distances and rapid deposition. Following Trimble (1963), Tolan and Beeson (1984), and Swanson (1986, 1988), we interpret these sediments as hyaloclastic debris that was generated when basalt lava entered the ancestral Columbia River upstream from the map area. This voluminous debris was almost immediately swept downstream and deposited in the eastern Portland Basin. The distribution of hyaloclastic strata (Swanson and others, 1993) indicates that the ancestral western Columbia River valley at the time of deposition was considerably wider than the present gorge. A patch of weathered hyaloclastic sandstone inset against the Troutdale Formation conglomerate member north of Washougal approximates the location of the north wall of the paleovalley. Paleocurrent directions inferred from foreset bedding and clast imbrication measured in the Sandy River valley (Cole, 1983) indicates transport to the north-northwest in this area.

Tolan (1982) and Tolan and Beeson (1984) mapped an apparently unbroken section of Troutdale Formation conglomerate and sandstone more than 335 m thick in the adjacent Bridal Veil quadrangle and observed that the distinctive hyaloclastic sandstone beds were restricted to the upper part (about 75 m) of the section. They divided the Troutdale in that area into informal upper and lower members on this basis (fig. 4). Their upper member is correlative with our hyaloclastic sandstone member. Tolan and Beeson (1984) also suggested that the contact between their members was correlative with the Troutdale Formation-Sandy River Mudstone contact mapped by Trimble (1963, p. 34) along the Sandy River near the south boundary of the Washougal quadrangle. However, the fine-grained beds along the Sandy River that were mapped as Sandy River Mudstone by Trimble can be traced in the subsurface to the Portland Well Field, where they are underlain by hyaloclastic sandstone and conglomerate (fig. 4) (Swanson, 1986; Hartford and McFarland, 1989; Swanson and others, 1993). Hence, as described above, the Sandy River Mudstone exposed on the banks of the Sandy River is actually a tongue of fine-grained beds within the hyaloclastic sandstone-bearing sequence. This tongue separates two intervals dominated by hyaloclastic debris that may represent hyaloclastites generated by two large eruptive events to the east. The base of the informal upper member of Tolan and Beeson (1984) likely corresponds approximately to the base of the lower hyaloclastite-rich interval.

In the Washougal quadrangle, the hyaloclastite-bearing section is largely restricted to south of the Columbia River, where it overlies the Frenchman Springs Member of the Wanapum Basalt and underlies late Pliocene low-potassium tholeiite. Its thickness, as inferred from water-well logs, increases irregularly westward from less than 30 m at Chanticleer Point to as much as 150 m at the west edge of the quadrangle. In Washington, a thin patch of weathered hyaloclastic sandstone is inset against the conglomerate member of the Troutdale Formation west of Campen Creek.

Chemical analyses (Swanson, 1986; Andrei Sarna-Wojcicki, written commun., 2005) show that vitric clasts in the hyaloclastic sandstone and olivine+plagioclase-phyric basalt cobbles in the associated conglomerate (Evarts and O'Connor, 2008) both possess a distinctive low-potassium tholeiite composition. This composition matches that of basalt flows (Tlkt) that are interbedded with and overlie the hyaloclastic sandstones in the eastern part of the map area and in the Cascade Range to the east but is dissimilar to that of lavas in the Boring Volcanic Field (Swanson, 1986; Lite, 1992; R.C. Evarts and R.M. Conrey, unpub. data). This indicates that the hyaloclastic sediments are genetically related only to the low-potassium tholeiites (Swanson, 1986; Lite, 1992; R.C. Evarts and R.M. Conrey, unpub. data).

Unnamed Conglomerate

Evarts (2004a,b,c, 2006b) mapped an unnamed conglomerate unit (QTc) northwest of the Washougal quadrangle that is lithologically similar to but considerably younger than nearby Troutdale Formation conglomerate. Although included with the Troutdale Formation by most previous workers, the younger conglomerate differs from the older unit in that it contains sparse clasts of olivine basalt and interbeds of reworked hyaloclastic sands, has a higher proportion of volcanic clasts derived from the Cascade Range, and commonly is more poorly sorted. Beds of weathered conglomerate that underlie the highland surface south of the Little Washougal River are assigned to this unit. To the west, this conglomerate unconformably overlies the Sandy River Mudstone and the Troutdale Formation (Hartford and McFarland, 1989; Swanson and others, 1993; Bet and Rosner, 1993; Evarts and O'Connor, 2008). The unnamed conglomerate is probably of latest Pliocene or early Pleistocene age; in the Camas quadrangle, it overlies the hyaloclastic sandstone member of the Troutdale Formation and is overlain by the circa 590-ka basaltic andesite of Prune Hill (Evarts and O'Connor, 2008). This gravel records regional aggradation of the Columbia River, owing either to increased upstream sediment loads or downstream impoundment.

Unnamed Fan Gravel of the Ancestral Sandy River

The distal edge of a broad, west-northwest-sloping, moderately dissected piedmont extends into the southwesternmost part of the map area. Where exposed west of the map area (Evarts and O'Connor, 2008), the deposits (QTfg) beneath this surface consist of weathered fluvial gravel of Cascade Range provenance interbedded with lithic-rich sand and matrix-supported diamicts containing angular hornblende-andesite clasts to 1 m in diameter. Trimble (1963, p. 48) provided a similar description for a locality about 8 km southeast of the lone occurrence in the map area. Surface exposures and drillers' logs in the map area show that these deposits are locally overlain by about 25 m of strongly oxidized micaceous silt and clay interpreted as loess (Qlo).

This piedmont is apparently the remnant of a broad alluvial fan formed by an aggrading ancient Sandy River. Geomorphic relations southeast of the map area show that this fan emanated from a confined valley located near Sandy, about 10 km south of the quadrangle boundary. Fan aggradation probably occurred in conjunction with alpine glaciation and associated outwash-gravel production in the Cascade Range punctuated by lahars. The volcaniclastic deposits may have been derived from the early Pleistocene Sandy Glacier volcano (Wise, 1969; Sherrod and Scott, 1995) located in the Mount Hood area.

The fan deposits were mapped by Trimble (1963) and Madin (1994) as Springwater Formation, but their slightly lower elevation and less dissected surface indicate that they are probably younger than the Springwater Formation in the type area, about 30 km south of Gresham. There are no direct age determinations on these deposits, but the profile of this piedmont grades to an elevation 50 to 70 m higher than the base of the basaltic andesite exposed at Broughton Bluff (which is uneroded and not covered by these piedmont gravels). The unnamed fan gravels, therefore, probably predate the basaltic andesite, which has an $^{40}Ar/^{39}Ar$ age of 1,292±19 ka (table 2).

Volcanic Rocks

Pliocene to Pleistocene basalt and basaltic andesite flows in the Washougal quadrangle represent eruptions from two distinct sources. The oldest flows are low-potassium tholeiites (Tlkt) that probably issued from shield volcanoes and fissure vents in the distant Oregon Cascade Range and moved down a broad paleoslope into the eastern Portland Basin. Later, compositionally diverse lavas erupted from several vents in and near the map area. These local centers belong to the Boring Volcanic Field (Evarts and others, 2009b), a collection of several dozen monogenetic vents scattered throughout the greater Portland area (Treasher, 1942; Trimble, 1963; Allen, 1975).

Low-potassium tholeiites are readily distinguished from the other volcanic rocks by their coarse-grained, aphyric, diktytaxitic texture and their distinctive chemistry (table 1), which resembles that of some mid-ocean-ridge basalt. Remnants of these flows rest on hyaloclastic sandstone (Ttfh) in the headwall of the landslide at Rooster Rock and to the south. East of the map area, low-potassium tholeiite flows are interbedded with hyaloclastic sandstone (Williams, 1916; Lowry and Baldwin, 1952; Tolan and Beeson, 1984; R.C. Evarts and R.M. Conrey, unpub. mapping). As noted above, vitroclasts in the sandstone are compositionally equivalent to the intercalated flows, indicating that interaction of the low-potassium tholeiite flows with water of the ancestral Columbia River generated the hyaloclastite

(Trimble, 1963; Tolan and Beeson, 1984). Several low-potassium tholeiite flows from areas to the east and south of the Washougal quadrangle have yielded late Pliocene radiometric ages of 3.0 to 3.6 Ma (Conrey and others, 1996a,b; R.J. Fleck, written commun., 2012).

In upper Bridal Veil Creek, 7–10 km east of Washougal quadrangle, low-potassium tholeiites are overlain by the basalt of Bridal Veil Creek (Qbbv), composed of coarsely olivine-phyric basalt flows (R.C. Evarts, unpub. mapping). These flows are tholeiitic but have much higher K_2O contents (>1.9 wt percent) than the low-potassium tholeiites (table 1). One Bridal Veil Creek flow moved westward down a paleocanyon into the map area and now caps the ridge north of Howard Canyon, an excellent example of inverted topography. This flow exhibits a well-developed colonnade-entablature jointing pattern, unusual for a Boring flow. Flaring of columns indicates that the paleochannel occupied by the flow was not much wider than the present ridge. An $^{40}Ar/^{39}Ar$ age of 2,284±16 ka was obtained for a sample from the columnar zone (table 2).

The oldest eruptive center in the map area is Chamberlain Hill, an eroded cinder cone that apparently erupted lavas of two different compositions. The basalt of Chamberlain Hill (Qbch) crops out close to the cone, whereas the older basaltic andesite of Broughton Bluff (Qmbb) is found farther to the west. The Chamberlain Hill basalt is diktytaxitic, contains olivine and plagioclase phenocrysts, and is tholeiitic (table 1). An $^{40}Ar/^{39}Ar$ experiment on a sample collected in an abandoned rockpit on Mershon Road yielded an age of 1,159±14 ka (table 2). The basaltic andesite of Broughton Bluff forms prominent cliffs that extend east and south from Broughton Bluff at the west edge of the map area. It consists of two flows, distinguished by slight differences in MgO, TiO_2, Ba, and Sr (table 1), that overlie the hyaloclastic sandstone member of the Troutdale Formation (Ttfh). Compared to the basalt of Chamberlain Hill, these flows have fewer plagioclase phenocrysts and are calc-alkaline, with significantly higher concentrations of K_2O (0.8 wt percent), P_2O_5 (0.28 wt percent), and incompatible trace elements (Ba, Sr, Zr, Nb), although TiO_2 contents are similar. Chamberlain Hill is the presumed source for the Broughton Bluff flows; alternatively, they may have issued from a vent to the north or west that was subsequently eroded away by the Columbia River. A sample collected at Broughton Bluff yielded an $^{40}Ar/^{39}Ar$ age of 1,292±19 ka, consistent with a low-precision K-Ar age of 1.53±0.39 Ma reported by Conrey and others (1996a) for a nearby locality (table 2).

Near the southeast corner of the map area, a ridge underlain by low-potassium tholeiite flows is capped by the distal end of a basalt flow that issued from a cinder cone at Pepper Mountain, about 6 km to the east (R.C. Evarts and R.M. Conrey, unpub. mapping). Where exposed in the adjacent Bridal Veil quadrangle, the basalt is very platy and olivine-microphyric. It is calc-alkaline, with K_2O content of 1.0–1.2 wt. percent. A sample collected northwest of Pepper Mountain yielded an $^{40}Ar/^{39}Ar$ age of 846±6 ka (R.J. Fleck, written commun., 2012).

The oldest Boring volcanic unit in the Washougal quadrangle north of the Columbia River is the basaltic andesite of Bear Prairie (Qmbp), which erupted from vents located in the adjacent Larch Mountain quadrangle to the north at 1,220±8 ka ($^{40}Ar/^{39}Ar$ plateau age, R.J. Fleck, written commun., 2012). The Bear Prairie flow, having been erosionally isolated from its source area by the Washougal River, underlies the area west of Mount Norway. The base of the flow is approximately 75 m above river level, implying an incision rate of 0.06 mm/yr during the past 1.2 million years. Flows of this unit are olivine-phyric and calc-alkaline, containing about 1.5 wt percent TiO_2 and 1.0 wt percent K_2O (table 1). Their low Ba/Nb (about 15), however, are more like those of oceanic than volcanic-arc magmas (Leeman and others, 2005).

Mount Norway is a degraded cinder cone that issued a thick flow of platy, aphyric, basaltic andesite (Qmmn) that is well exposed in the headwall of the landslide north of Mount Norway. Nichols Hill is a subsidiary cone of similar composition. The basaltic andesite of Mount Norway is more silicic than most Boring volcanic rocks and is chemically transitional between calc-alkaline and tholeiitic (fig. 2) with a moderate K_2O content (0.9 wt percent, table 2). West of Mount Norway, it overlies the basaltic andesite of Bear Prairie. A sample collected from a roadcut directly northwest of Mount Norway yielded an $^{40}Ar/^{39}Ar$ age of 693±9 ka (table 2).

Quaternary Alluvial, Eolian, and Mass-Wastage Deposits

Deposits related to the present arrangement of rivers and topography in the Washougal quadrangle include terrace-forming gravels, sediment deposited by the cataclysmic Missoula floods, deposits along the Sandy River related to eruptions of Mount Hood, and various alluvial, eolian, and landslide deposits.

Terrace Deposits

Sand and gravel deposits border the Sandy, Washougal, and Little Washougal Rivers, recording channel positions older and higher than modern levels.

Sandy River Terraces

Three sequences of gravel deposits underlie benches in the Sandy River valley in the southwestern part of the map area. The highest gravel deposit ($Qtds_3$) underlies undulating and dissected surfaces with elevations between 300 and 540 ft (90 and 165 m); its basal contact with the Troutdale Formation lies consistently between 300 and 350 ft (90 and 105 m) elevation. A lower, inset gravel deposit ($Qtds_2$) underlies less-dissected benches ranging between 230 and 300 ft (70 and 90 m) elevation and typically lies atop Troutdale Formation at elevations between 140 and 205 ft (40 and 60 m). Both of these units are overlain by Missoula flood deposits (Qfs). A younger, post-Missoula flood, Sandy River terrace ($Qtds_1$) underlies a prominent bench on the west edge of the map area between the Sandy River and Beaver Creek in the Camas quadrangle (Evarts and O'Connor, 2008).

Where exposed along Gordon Creek Road at the south edge of the map area, the higher, older deposits ($Qtds_3$) consist of 35 m of sand and gravel of Cascade Range provenance with a basal lithic-rich diamict containing abundant light-gray hornblende-andesite clasts, overlain by a better-sorted, round-cobble, sandy gravel. The upper 20 m is not well exposed here, but along Woodward Road, 5 km to the east-northeast, the gravel is also composed of Cascade Range rock types and is extensively weathered with about 50 percent of the cobbles readily sliced by shovel. Here the gravel is overlain by 5 to 8 m of reddish, silty, very fine sand. A polymineral thermoluminescence-age experiment on the lithic-rich sand near the base of this unit where exposed along Gordon Creek Road gave an age of >220 ka (table 3).

The older alluvium ($Qtds_3$) closely corresponds to the Gresham Formation as mapped by Trimble (1963), although we do not follow his nomenclature because of uncertain relations between $Qtds_3$ and the gravel mapped as Gresham Formation near the town of Gresham. As noted by Trimble (1963, pg. 52–56), this gravel deposit reflects aggradation of the Sandy River within a valley entrenched into older fan deposits (QTfg), largely following the present Sandy River course. Aggradation may have owed to upstream glaciation and enhanced sediment production or, perhaps, to aggradation of the Columbia River downstream during deposition of the unnamed conglomerate unit (Qtc). Alluviation was punctuated by lahars, probably from ancestral Mount Hood, resulting in the lithic-rich sand lenses and bouldery diamicts. The fluvial gravel and lahar deposits are capped by as much as 8 m of clay, silt, and fine sand, which likely represents loess locally supplemented by thin accumulations of Late Pleistocene Missoula flood slackwater deposits at elevations below 400 ft (120 m).

Inset into the higher gravel deposits are younger sand and gravel ($Qtds_2$), underlying prominent benches flanking both sides of the Sandy River east of Dabney Park, and a bench north of the river near the south map boundary. Everywhere capped by Missoula flood slackwater deposits and sitting atop Troutdale Formation, this unit is only poorly exposed in steep faces along the Sandy River valley walls and in cuts for roads and tracks descending to the river. The thickness of this unit varies from a few centimeters, where a one-clast-thick layer separates Troutdale Formation and Missoula flood slackwater deposits on the Stark Street Grade, to 20 m thick at the southern extension of Hinkle Road at the southern map boundary. At most exposures, the unit consists of subhorizontal sheets, 0.5–5 m thick, of poorly sorted sandy gravel, locally separated by thin sand lenses, that varies from compact with sand matrix to loose open-work texture. The clasts are subangular to well rounded, locally imbricated, and minimally weathered. Locally, large (to 1 m diameter) boulders of hornblende andesite are found near the base of the unit. At the south edge of the map area, the unit is capped by >3 m of horizontally bedded feldspar- and lithic-rich sand and a diamict composed of angular andesite-clast gravel with a silt and sand matrix. These deposits are inferred to be lahar and lahar-runout deposits, probably from Mount Hood eruptions, and are probably correlative to similar but thicker sequences that cap Sandy River terrace deposits south of the map area (J.W. Vallance and J.E. O'Connor, unpub. mapping).

The younger alluvium ($Qtds_2$) is typically deposited on a strath cut into the hyaloclastite member of the Troutdale Formation (Ttfh) at elevations between 165 and 245 ft (50 and 75 m) and is everywhere capped by the sand and silt facies of the Missoula flood deposits (Qfs). The age of this deposit is uncertain, but the lack of weathering at its contact with overlying fine-grained Missoula-flood silt (Qfs) indicates that, in part, the unit closely pre-dates the 20–15 ka Missoula floods; infrared-stimulated luminescence ages from correlative deposits south of the map area range from >155 ka to 22.4±2.5 ka (table 3). The distribution and composition of the unit indicate deposition during a period of Sandy River aggradation that likely coincides in part with late Wisconsin (30–20 ka) glaciation of Mount Hood region and late last-glacial eruptive events at Mount Hood (Crandell, 1980). This unit corresponds in part to the Estacada Formation as defined and mapped by Trimble (1963) but is probably older than the 14–12 ka (Wampler, 2004) gravel composing the type section of the Estacada Formation along the Clackamas River.

A small but prominent bench flanking the Sandy River on the western edge of the quadrangle has a surface about 160 to 190 ft (50 to 60 m) above sea level and is underlain by as much as 20 m of sand and gravel of Sandy River provenance ($Qtds_1$). Like the other Sandy River terrace deposits, this unit consists of subhorizontal gravel sheets, 0.5–5 m thick, locally separated by thin sand lenses. The deposits are poorly sorted, locally imbricated, and vary from compact with sand matrix to loose open-work texture. Clasts are subangular to well rounded and are dominated by volcanic rocks derived from the Cascade Range. Within this unit, a 1-m-thick bed of silty lithic-rich sand inferred to be the distal facies of a Mount Hood lahar is exposed just west of the map area along Beaver Creek in the adjacent Camas quadrangle (Evarts and O'Connor, 2008).

The weakly developed soil profile, <1 mm weathering rinds on fine-grain volcanic clasts, and absence of overlying Missoula flood deposits indicate a post-15-ka, late Pleistocene or Holocene age. Consistent with this, thermoluminescence analysis on the lithic-rich sand 0.5 km west of the map area gave an age of 14.3±1.2 ka (table 3). These deposits may reflect aggradation behind the immense Missoula-flood bar that extends southwestward from Broughton Bluff, which temporarily blocked the

Sandy River at its confluence with the Columbia River (Evarts and O'Connor, 2008). The distal lahar deposits within this unit indicate Mt. Hood eruptive activity during the time sediment was accumulating behind the blockage. These deposits were mapped as Estacada Formation by Trimble (1963), although they are distinctly younger than unit $Qtds_2$, which was also included within the Estacada Formation by Trimble (1963).

Washougal and Little Washougal River Terraces

Three groups of terrace deposits are distinguishable in the Washougal River drainage within the map area. The Little Washougal River (Qtdl) and upper Washougal River ($Qtdl_u$) terrace deposits are composed of poorly to moderately well sorted sand and gravel of volcanic and granitic rocks eroded from the Cascade Range. They underlie surfaces at multiple levels ranging to 20 m above the present channel. They are associated with valley walls that show extensive landsliding, leading us to infer that these deposits formed during short-lived periods of aggradation following valley blockage by landslides. The lack of weathering indicates that these deposits are Holocene or late Pleistocene.

A sequence of at least three terrace treads flanks the lower Washougal River as the river bends west to its confluence with the Columbia River. These terraces ($Qtdw_l$) have elevations ranging between 50 and 130 ft (15 and 40 m) and are formed of sand and gravel derived from Tertiary volcanic and granitic rocks of the Cascade Range, the Columbia River Basalt Group, and the Troutdale Formation. The deposits are minimally weathered, have rinds less than 1 mm thick on fine-grained volcanic rocks, and are not overlain by Missoula flood deposits, indicating a Late Pleistocene or Holocene age. The age and position of these deposits indicates aggradation and subsequent incision behind the coarse-grained Missoula flood bar (Qfg) that diverts and constricts the lower Washougal River.

Cataclysmic Flood Deposits

During the last glacial maximum in Late Pleistocene time, an ice dam at Pleistocene Lake Missoula in western Montana failed repeatedly, and each breach generated enormous floods or jökulhlaups, commonly referred to as the Missoula floods, that coursed down the Columbia River and into the Portland Basin (Bretz, 1925, 1959, 1969; Trimble, 1963; Allison, 1978; Baker and Bunker, 1985; Waitt, 1985, 1994, 1996; O'Connor and Baker, 1992; Benito and O'Connor, 2003). The sediment-laden floodwaters were hydraulically dammed by the relatively narrow constriction of the Columbia River valley at the north end of the Portland Basin, causing temporary ponding in the Portland Basin and tributary valleys to elevations as high as 400 ft (120 m). Radiocarbon ages, paleomagnetic measurements, and tephrochronologic data indicate that these floods occurred chiefly between about 20 and 15 ka (Waitt, 1994; Clague and others, 2003; O'Connor and Benito, 2009).

The Washougal quadrangle is located at the west end of the Columbia Gorge, which formed one of the most significant constrictions along the flood route. Because of this constriction, the largest floods achieved flow velocities as great as 35 m/s between Chanticleer Point and Mount Pleasant (Benito and O'Connor, 2003). Velocities rapidly diminished as flood waters emerged from the gorge into the broad Portland Basin, resulting in deposition of debris carried as bedload by the deep and fast flows. Where flow first expanded, large, broadly convex bars of coarse, foreset-bedded gravel were deposited, including the prominent bar underlying the cities of Camas and Washougal (Qfg). Subsurface data west of the map area, in eastern Portland, show correlative bouldery gravel as much as 68 m thick that extends 230 ft (70 m) below sea level (Hoffstetter, 1984; Hartford and McFarland, 1989), which is consistent with the low sea level elevation at the time of the Missoula floods (Gates, 1994).

Within the map area, floodwaters scoured the landscape near Washougal, completely denuding Paleogene bedrock and the Troutdale Formation of soil and other surficial material to elevations as high as 400 ft (120 m). Later Missoula floods were smaller than earlier ones (Benito and O'Connor, 2003) and were probably confined to the immediate Columbia River valley (floor about 90 m below modern sea level (Gates, 1994; Pratt and others, 2001)) but left thin onlapping sequences of sand and gravel on the margins of the older flood deposits.

The suspended load of the floods, composed of micaceous quartzofeldspathic silt, clay, and sand entrained from the loess-covered plains of eastern Washington, was deposited in slack-water areas along the flood route; in the map area, such deposits (Qfs) are found mainly at elevations less than 400 ft (120 m) on top of Pleistocene terrace deposits along the Sandy River and on benches carved into older deposits north of the Columbia River. Rare exposures reveal massive silt that resembles and may include compositionally similar loess. Where better exposed in eastern Washington and the Willamette Valley, multiple graded slack-water beds separated by tephra layers and bioturbated zones are the primary evidence that several dozen Missoula floods affected the lower Columbia River (Glenn, 1965; Waitt, 1980, 1985; Atwater, 1986; Smith, 1993; O'Connor and others, 2001; Benito and O'Connor, 2003).

Alluvial and Lahar Deposits Derived from Mount Hood Volcano

The lower Sandy River has been episodically inundated by volcaniclastic debris generated at Mount Hood. As described above, Pleistocene terrace-gravel deposits along the Sandy River within and upstream from the map area locally contain lahar deposits and several-meter-thick sections of stratified gray sand that record lahar-runout deposition and post-eruption channel aggradation (J.W. Vallance and J.E. O'Connor, unpub. mapping). In addition to these Pleistocene deposits of Mount Hood eruptive materials, two late Holocene episodes of eruptive activity are recorded by stratified sand and gravel and diamictons that locally filled the bottom of the Sandy River valley (Qh). These deposits range from 130 ft (40 m) above sea level (and 20 m above the modern Sandy River) at the southern boundary of the map area to near the present Columbia River level (3 ft (1 m) above sea level at low flow) in the area at the confluence of the Sandy River with the Columbia River known informally as the Sandy River delta.

The Timberline eruptive period (Crandell, 1980) began at or slightly after A.D. 400 and may have persisted episodically for several decades or perhaps centuries. Eruptive activity included numerous pyroclastic flows and ash clouds affecting the edifice area and extensive lahars that moved down several drainages (Cameron and Pringle, 1986; Scott and others, 1997; Pierson and others, 2009). At least three Timberline-age lahars flowed down the Sandy River into the map area and presumably all the way to the Columbia River (Rapp, 2005). These lahars, and subsequent eruption-induced sedimentation, constructed the extensive lowland of the Sandy River delta at the mouth of the Sandy River. Charcoal in Columbia River sediment beneath the oldest lahar indicates that all three lahars postdate A.D. 433 (Rapp, 2005; calibration reported in Evarts and O'Connor, 2008). River-bank exposures, excavations, auguring, and drill logs show that locally more than 8 m of lahar deposits and stratified sand associated with the Timberline Eruptive Period underlie much of the delta. In places, these deposits buried standing forests of large conifers. Little or no pedogenic alteration within this sequence suggests that aggradation was rapid and essentially continuous. Radiocarbon dating of Columbia River sediment inset into Timberline-age deposits in the Camas quadrangle to the east indicates that incision to near present levels, at least near the Columbia River confluence, was accomplished by A.D. 890 (Rapp, 2005; calibration reported in Evarts and O'Connor, 2008). Upstream, the lower Sandy River valley within the map area was filled by more than 25 m of diamict and stratified sand during and shortly after the Timberline eruptive episode, forming broad benches with remnants now locally more than 20 m above the present channel elevation (Pierson and others, 2009).

Following a several-century-long hiatus when the Sandy River incised to at least a few meters below its present level in parts of the map area (Pierson and others, 2009), renewed volcanic activity at Mount Hood triggered another period of Sandy River aggradation. The Old Maid eruptive period (Crandell, 1980), as dated by dendrochronology, began in A.D. 1780 and may have ended about AD

1801 (Pierson and others, 2009). This was a smaller eruptive episode, producing only about one fifth as much clastic debris as generated during the Timberline period. Several lahars flowed into and down the Sandy River (Cameron and Pringle, 1986), including one that probably reached the map area (Pierson and others, 2010). Although lahar deposits of this age are not evident, downstream fluvial transport and reworking of Old Maid-age volcaniclastic debris caused more than 20 m of local aggradation along the lower Sandy River in the southern part of the map area (Pierson and others, 2009), overtopping all but the highest of the Timberline-age deposits, and as much as 5 m of aggradation and the occupation and abandonment of several channels on the Sandy River delta (Rapp, 2005). These channel fills are composed of very loose stratified sand and gravel, locally enclosing standing conifer snags, and are subject to rapid bank erosion at high flows where they form banks of the present Sandy River. Aggradation ceased by 1806 in the Camp Collins area and by 1806 or shortly thereafter on the Sandy River delta (Pierson and others, 2010).

The similar maximum elevations of the Timberline and Old Maid aggradation sequences along the Sandy River resulted in the valley bottom mostly, but not everywhere, being coated by the younger Old Maid-age deposits. Consequently, the Timberline and Old Maid deposits are not distinguished on this map.

Other Alluvial, Eolian, and Mass Wastage Deposits

Holocene Columbia River Alluvium

Since the end of the last glacial epoch, sea level has been rising and the Columbia River has aggraded its channel and floodplain. Borehole data from Warrenton, Oregon, at the modern mouth of the Columbia River, shows that river level was about 365 ft (112 m) below present sea level at approximately 15 ka (Baker, 2002). Consistent with this, well records and seismic-reflection profiles indicate that nearly 100 m of predominantly sand and silt fill a buried Late Pleistocene paleochannel in the Portland-Vancouver area (Gates, 1994; Pratt and others, 2001; Rapp, 2005). In the map area, the paleochannel thalweg is located near the south shore of the modern river (Pratt and others, 2001).

Sea level rise slowed in the late Holocene, and most deposits above present low-water elevation of the Columbia River (about 3 ft (1 m) above sea level) are less than 2,000 years old (table 4). These deposits (Qac) have accumulated by overbank deposition and bar accretion, primarily during snowmelt floods that inundated the historic floodplain each summer before 20th-century construction of dams and floodplain dikes. The largest floods, such as those in 1894 and 1948, achieved stages of nearly 40 ft (12 m) above sea level in the map area, but their deposits are too thin to map above 30 ft (10 m) elevation. Local diatomaceous beds and layers of organic-rich sediment probably formed in floodplain marshes, ponds, and lakes.

Several islands in the Columbia River are formed mostly of Holocene alluvium, including Reed Island and Flag Island. Reed Island, like most of the upper several meters of the Columbia River floodplain, is underlain by couplets of fine sand and silt as much as 30 cm thick, probably representing vertical accretion of overbank deposits during large spring freshets prior to mid-20th-century flow regulation. Very slight westward dips for traceable beds and westward onlap of younger beds on Reed Island indicate that the island grew by downstream progradation in conjunction with vertical accretion. Radiocarbon dates from beds near river level indicate that most deposits forming the island accumulated after A.D. 1500 (table 4).

Holocene Alluvium of Tributary Streams

Thin, areally restricted alluvium and lacustrine deposits (Qa) flank the Sandy, Washougal, and Little Washougal Rivers and smaller tributary streams in the map area. Although not directly dated, they almost certainly postdate the 20–15 ka Missoula floods. The deposits mapped along the Sandy River postdate the early 1800s culmination of the Old Maid eruptive period on Mount Hood. Some of these areas have been modified by diking and draining.

Landslide and Talus Deposits

Much of the Washougal quadrangle is underlain by weakly consolidated or deeply weathered sedimentary deposits, and landslides (Qls) are therefore common, especially where lava flows overlie the sediments. The 5-km-long Mount Norway landslide on the south side of the Washougal River valley, part of the Washougal River landslide complex (Palmer, 1977) is a composite feature. The eastern part of the slide formed when clayey fine-grained sediments of the Troutdale Formation (Ttfc) and (or) Sandy River Mudstone (Tsr) failed beneath the >100-m-thick basaltic andesite of Mount Norway (Qmmn), whereas the western part was caused by failure of weathered Oligocene tuffaceous rocks beneath the basaltic andesite of Bear Prairie (Qmbp). A continuous apron of post-landslide talus (Qt) has accumulated at the base of the headwall scarp of the Mount Norway landslide. Collapse of Troutdale and (or) Sandy River sediments, overlain by the basaltic andesite of Bear Prairie, was responsible for the Bear Prairie landslide north of the river. Small landslides are widespread in areas underlain by the Troutdale Formation, but larger ones typically occur where the Troutdale overlies Sandy River Mudstone, most notably in the Little Washougal River valley.

The Rooster Rock landslide east of Chanticleer Point appears to be a composite feature with two discrete failure planes. In the uppermost headwall, a columnar-jointed Pliocene lava flow (Tlkt) overlies the weathered hyaloclastic sandstone member of the Troutdale Formation (Ttfh). Failure of the hyaloclastic sandstone member has produced landslides elsewhere, such as northwest of Chamberlain Hill, and is clearly responsible for active slumping of the Historic Columbia River Highway directly east of the map boundary. At lower elevations, however, slide debris includes abundant large blocks (including Rooster Rock itself[1]) of the basalt of Rosalia flow that forms Chanticleer Point, indicating that another failure plane lies within or below the Columbia River Basalt Group. Exposures at the base of the upper headwall show that the Troutdale Formation rests on a yellow-orange to brick-red earthy paleosol at least 3 m thick. Lowry and Baldwin (1952) and Trimble (1963) also recognized this paleosol ("laterite"), which they interpreted as weathered Columbia River Basalt. Below the paleosol is a bench above a steep lower headwall. Outcrops on the lower headwall consist of one or two flows of the Frenchman Springs Member of the Wanapum Basalt ($Twfs_h$). Therefore two failure planes are involved in the Rooster Rock landslide, an upper one within the Troutdale Formation and a lower one within a paleosol that developed on the Frenchman Springs Member before emplacement of the Rosalia flow less than 1 m.y. later. Mechanically weak pillow breccia zones at the base of the basalt of Rosalia likely also contributed to landsliding. A discontinuous mantle of micaceous silts, probably related to the cataclysmic Missoula floods, covers the slide, and undercutting by the floods may have triggered the slope failure. Such landslides may have also been promoted by significant incision (as much as 100 m) of the Columbia River during glacial episodes, resulting in debuttressing of valley sides.

[1] Rooster Rock is misidentified on the topographic base map; its actual location, as shown on the topographic map of the adjacent Bridal Veil quadrangle, is north of Interstate highway 84.

Loess

Massive, micaceous, quartzofeldspathic silt (Qlo) blankets most upland surfaces in the map area above the 400-ft (120-m) maximum stage of the largest Missoula floods, although these high deposits are mapped only on uplands south of the Columbia River, where they are exceptionally thick and obscure the underlying geology. The loess deposits are pedogenically reddened and probably accumulated over several episodes during the Quaternary, probably most significantly during glacial ages. They are equivalent to the Portland Hills Silt, a regionally extensive loess deposit found on uplands west of the Portland Basin (Lentz, 1981). In the type area, the Portland Hills Silt contains paleosols, which indicate episodic accumulation separated by periods of relative surface stability enabling soil development (Lentz, 1981). The general westward thinning of the loess in the Portland area indicates deposition by easterly winds. Such winds are not the prevailing condition but are common in winter when atmospheric high pressure in the interior drives easterly airflow in the Columbia Gorge. Easterly winds may have been more common during Quaternary glacial ages. Such winds could readily entrain particles from Columbia River beach and floodplain deposits and redeposit them on surrounding uplands (Lentz, 1981).

Lower and younger loess deposits cover benches etched into Tertiary rocks between Chamberlain Hill and Chanticleer Point. These accumulations are composed of massive micaceous fine sand and silt, to 5 m thick, and locally contain multiple weakly developed soil horizons. Their position in areas that would presumably be stripped by Missoula flooding and a circa 1 ka radiocarbon age (table 4) signify Holocene deposition.

Eolian Deposits

Small dunes of medium to coarse sand (Qe) have locally accumulated on the Holocene floodplain and islands of the Columbia River. Most of these dunes probably formed near the shoreline from strong easterly winds entraining exposed Columbia River beach sand during winter low flow periods prior to significant flow regulation commencing in the 1930s. These dunes, formed on top of the Holocene floodplain, are all late Holocene in age, as corroborated by a post-A.D. 780 age (table 4) for the small dune on the northern edge of the Sandy River delta. Most of these dunes, except where actively eroding, are vegetated, and original dune morphology is obscure. Dune formation has probably diminished historically as a consequence of flow regulation reducing winter-time exposure of Columbia River shoals and beaches.

Structural Features

The Washougal quadrangle lies near the east margin of the Portland Basin, a structural and topographic depression that began to form in middle Miocene time (Beeson and others, 1989; Beeson and Tolan, 1990). In contrast to the sharply well defined southwest side of the basin (fig.1*B*), the east and north margins are topographically and structurally complex, reflecting a complex interplay between local tectonics and Columbia River fluvial processes (Evarts and others, 2009a).

Oligocene strata in the northwestern part of the map area dip about 20–25° southeast, whereas correlative strata in areas to the northwest and west (Evarts, 2006b; Evarts and O’Connor, 2008) exhibit lower dips (<10°), suggesting that bedrock exposed along the lower Washougal River constitutes a fault-bounded block that has been tilted relative to adjacent areas. This deformation largely predates deposition of the conglomerate member of the Troutdale Formation (Ttfc), the surface of which dips gently southwestward from the Mount Norway area. Comparable surfaces to the northwest also dip basinward (Mundorff, 1964; Howard, 2002; Evarts, 2004a, 2006a,b). We interpret these surfaces to be primarily depositional and suggest that the dip reflects postdepositional tilting and uplift of the east margin of the Portland Basin, perhaps related to late Pliocene regional uplift of the Cascade Range (Tolan and Beeson, 1984). Regional tilting probably also accounts for the gentle (<2°) southwestward dips of Grande Ronde Basalt and Wanapum Basalt flows and overlying strata of the younger part of the Troutdale Formation (Ttfh) south of the Columbia River, although dips of the hyaloclastic beds may in part be primary and reflect deposition on an aggrading west-sloping alluvial surface.

Faults

Several predominantly northwest-striking faults cross the map area. Most are inferred from vertical offsets of Oligocene bedrock or Miocene Columbia River Basalt Group flows, and the regional tectonic setting suggests they may have experienced strike-slip motion as well (Beeson and Tolan, 1990; Blakely and others, 2000). These structures played an important role in the development of the Portland Basin during late Miocene and Pliocene time but none are known to have been active in the Holocene.

Sandy River Fault

Beeson and others (1989), Beeson and Tolan (1990), and Blakely and others (1995) inferred the presence of one or more northwest-trending faults along the lower Sandy River. Working in the Sandy quadrangle south of the map area, Lite (1992) suggested that the top of the Grande Ronde Basalt was displaced approximately 245 m down to the west on the Sandy River Fault, but he found no evidence for comparable deformation in the overlying sedimentary units. The Sandy River Fault apparently originated in Miocene time as one of a set of basin-bounding normal faults, but significant vertical motion ceased before deposition of Troutdale Formation hyaloclastic sandstone and conglomerate in late Pliocene time. Subsequent displacement, if any, has been predominantly lateral.

Faults near Corbett

Two faults with orientations and displacements similar to that of the Sandy River Fault offset the Grande Ronde Basalt and Wanapum Basalt near Corbett. Collectively, these faults and a nearby northeast-trending fault drop the Columbia River Basalt Group at least 200 m between Chanticleer Point and Corbett Station. They are projected toward the southeast corner of the map area based on well logs that indicate that the top of the basalt bedrock is more than 100 m lower near the Sandy River than it is in eastern Howard Canyon. Along with the Sandy River Fault, these structures define the complex eastern margin of the Portland Basin. The westernmost fault juxtaposes the Troutdale Formation against the basalt of Sand Hollow, so it must be late Pliocene or younger; whether movement on the other faults in the Corbett zone is similarly young is unknown.

Graben along Little Washougal River

Two northwest-striking faults define a graben that is roughly coincident with the valley of the lower Little Washougal River and continues to the northwest of the map area (Evarts, 2006a; Evarts and O’Connor, 2008). The river flows on a bedrock surface that is about 150 m lower than bedrock on the flanks of the valley. Water-well logs indicate that these structures displace the Sandy River Mudstone and the conglomerate member of the Troutdale Formation but not, apparently, the younger unnamed conglomerate. The axis of the graben projects eastward toward the thickest section of the conglomerate member of the Troutdale Formation, south of Mount Norway, and toward the deep, conglomerate-filled, post-Priest Rapids paleocanyon in the adjacent Bridal Veil quadrangle described by Tolan (1982) and Tolan and Beeson (1984). During late Miocene and Pliocene time, the Columbia River may have been confined within this developing graben, until eventually its valley filled with Troutdale Formation sediments and the river’s location shifted to its present course.

Other Faults

The Blue Lake Fault and the Lacamas Lake Fault are projected eastward from the Camas quadrangle, where they bound an uplifted block at Prune Hill (Evarts and O'Connor, 2008). The Blue Lake Fault is interpreted as a north-side-up reverse fault and may explain why Paleogene rocks crop out only north of the Columbia River. We speculate that it is truncated by the northwest-striking faults near Corbett, although subsurface information to verify this is lacking. The Lacamas Lake Fault is thought to be a dextral oblique-slip structure and may extend as far as Corbett, where similar faults are mapped. Unlike the graben-bounding faults to the north, both of these faults appear to have moved during the Pleistocene (Evarts and O'Connor, 2008).

The northeast-striking fault inferred near Campen Creek is based on water-well logs that show that the top of Oligocene bedrock drops from near the surface to the west to more than 170 m deep to the east. Because of rapid facies changes in the Troutdale Formation, it is unclear whether they, too, are offset, although the pronounced northeast grain to the drainage pattern east of Campen Creek Fault is suggestive of structural control.

Age of Deformation

Subsidence of the Portland Basin and accumulation of its fluvial sedimentary fill occurred throughout late Neogene time. Some of this subsidence clearly took place on northwest-striking structures in the map area, but the movement history of these faults is complex, diverse, and poorly understood. The Sandy River Fault, for example, vertically displaces the Wanapum Basalt but not the overlying sediments, whereas similarly oriented faults near Corbett offset hyaloclastic sandstone beds showing they must be as young as late Pliocene. The graben north of Washougal grew during deposition of the conglomerate member but became inactive by the late Pliocene or early Pleistocene time when the unnamed conglomerate was deposited across it. The graben appears to be truncated by more northerly faults. Evidence in the Camas quadrangle indicates that the Blue Lake Fault and segments of the Lacamas Lake Fault are compressional structures that were active in the early Pleistocene, although the latter may have originated earlier as a normal fault (Evarts and O'Connor, 2008). All of these faults may have experienced strike-slip motion, which is difficult to detect from well logs.

Late Quaternary deformation in the map area is possible but difficult to detect, owing in large part to the effects of cataclysmic floods in latest Pleistocene time. Evidence for Late Pleistocene or younger faulting in the map area from seismic reflection surveys along the Columbia River is equivocal (Ryan and Stephenson, 1995; Pratt and others, 2001).

Geologic Resources

Known geologic resources available in the Washougal quadrangle are limited to nonmetallic industrial materials, chiefly aggregate for road construction and similar purposes (Johnson and others, 2005). Quarries for crushed rock (all now inactive) have been developed in Oligocene basaltic andesite (Tbem) near Woodburn Hill, in Wanapum Basalt ($Twfs_h$) at Corbett Station, in Quaternary volcanic rocks (Qbch) near Chamberlain Hill, and in Holocene alluvium and volcaniclastic sediment near the Sandy River confluence with the Columbia River. The columnar-jointed basalt of Bridal Veil Creek (Qbbv) on the ridge north of Howard Canyon is currently mined for landscape rock.

Sand and gravel have been obtained from the conglomerate member of the Troutdale Formation near the mouth of Gibbons Creek and from young alluvial deposits directly west of the map area in the city of Camas.

Geologic Evolution

Paleogene volcanic bedrock exposed in the western Washougal quadrangle comprises tholeiitic lava flows of the basaltic andesite of Elkhorn Mountain. These flows form a chemically related suite and were probably emplaced on the middle and lower flanks of a large shield volcano. Neither dikes nor hydrothermal alteration are present in the map area, indicating that the vent for this volcano is located outside the quadrangle, most likely to the north. Age determinations in adjacent quadrangles (table 2; Phillips and others, 1986; Evarts, 2006a,b; Evarts and O'Connor, 2008) show that this volcano was active in Oligocene time, about 27–25.5 Ma. Andesite flows that interfinger with the upper part of the Elkhorn Mountain unit may be late differentiates of the same magmatic system. The Oligocene rocks exhibit minor but widespread zeolite-facies metamorphism owing to shallow burial. Deformation reflected in the southeastward dips of these strata may be related to middle Miocene regional folding in the southern Washington Cascade Range described by Evarts and Swanson (1994).

Between 16 to 12 m.y. ago, massive flood-basalt flows entered western Oregon and Washington from the east though a 60-km-wide ancestral Columbia River valley, the Cascade trans-arc lowland of Beeson and others (1989) and Beeson and Tolan (1990). The route of the modern Columbia River in the map area coincides with the north margin of the trans-arc lowland, because the Columbia River Basalt Group is not present north of the river. Grande Ronde Basalt and early Wanapum Basalt flows issued so rapidly that the ancestral river was rarely able to re-establish integrated drainage between eruptions, and the flows spread out into vast horizontal sheets that constitute useful datums for recording regional post-basalt deformation (Beeson and Tolan, 1990). Roughly 1 m.y. separated emplacement of the Frenchman Springs Member and the basalt of Rosalia (Tolan and others, 1989). During this interval, the ancestral Columbia River incised a deep canyon in the northern part of the trans-arc lowland, and a deep weathering profile developed on basalt underlying adjacent highlands. At 14.5 Ma, the Rosalia flow filled this canyon to overflowing, generating substantial hyaloclastite (Tolan, 1982; Tolan and Beeson, 1984).

During and after emplacement of the Columbia River Basalt Group, the Portland Basin gradually subsided, in part along northwest-striking normal faults such as the Sandy River Fault, and accumulated predominantly fine-grained sediments of the ancestral Columbia River. These sediments, the Sandy River Mudstone, were deposited in low-energy fluvial environments, probably near sea level. In latest Miocene time, the sedimentary regime of the lower Columbia River changed dramatically as cobbly gravel of the older Troutdale Formation (Ttfc) accumulated within a relatively narrow, possibly fault-controlled, channel in the map area and prograded northwestward across the wider Portland Basin. As much as 200 m of gravel, now preserved beneath uplands east of Washougal, were deposited in the channel during this time. The pronounced change in Columbia River sedimentation may record regional uplift east of the Cascade Range, integration of upstream basin areas, or climate changes resulting in a higher-energy gravel-rich river system. As the supply of coarse sediment diminished, the river incised the gravelly deposits, which were subsequently uplifted and are preserved only north of the modern river.

During an episode of intra-arc rifting in Pliocene time, about 4–3 Ma, voluminous basaltic lava flows (Tlkt) erupted in the Cascade Range east of the map area (Tolan and Beeson, 1984; Conrey and others, 1996b, 2004). Some of these lavas entered the Columbia River and interacted explosively with river water to produce huge quantities of hyaloclastite. This debris was rapidly flushed downriver and deposited where the Columbia River valley opened into the broad eastern Portland Basin (Tolan and Beeson, 1984). The distal parts of some of these flows overlie the hyaloclastite member of the Troutdale Formation south of Chanticleer Point. To the west, hyaloclastic sandstone beds of the Troutdale

Formation are now located at depths as great as 150 m below sea level (Hartford and McFarland, 1989; Swanson and others, 1993; Evarts and O'Connor, 2008), indicating that subsidence of the basin depocenter continued into at least the late Pliocene.

During Pliocene and early Pleistocene time, dominantly andesitic volcanism at a long-lived center at the site of Mount Hood (Conrey and others, 2004) generated voluminous debris that was transported as lahars and flood-flows down the ancestral Sandy River drainage. These volcaniclastic flows and associated fluvial deposits built multiple west-sloping surfaces along the west flank of the northern Oregon Cascade Range; the erosional remains constitute the Springwater Formation of Trimble (1963). Simultaneous aggradation of the Columbia River is recorded by the unnamed conglomerate unit (QTc). Compared to the older Troutdale Formation conglomerate (Ttfc), the unnamed conglomerate contains a higher proportion of volcanic clasts derived from the adjacent Cascade Range, reflecting both enhanced volcanism and uplift-driven erosion in the volcanic arc in post-Miocene time.

Beginning about 2.6 Ma, mafic volcanic activity spread westward from the Cascade Range into the Portland Basin to form the Boring Volcanic Field (Treasher, 1942; Trimble, 1963; Allen, 1975; Conrey and others, 1996a; Evarts and others, 2009b). Volcanic rocks of this age in the Washougal quadrangle include the products of several eruptive centers, two of which, Mount Norway and Chamberlain Hill, are within the map area. The oldest Boring flow in the Washougal quadrangle is the basalt of Bridal Veil Creek (Qbbv), which erupted from a vent east of the map area at about 2.25 Ma. Between 1.3 and 1.1 Ma, basalt and basaltic andesite issued from the vent at Chamberlain Hill (Qmbb and Qbch) and from a vent at Bear Prairie (Qmbp) north of the map area. A lava flow from Pepper Mountain (Qmpm) entered the map area from the east at about 850 ka. The youngest volcanic activity in the quadrangle, at 693±9 ka, produced two small cinder cones and the thick basaltic andesite flow of Mount Norway (Qmmn), which partially buried the basalt of Bear Prairie.

The Washougal quadrangle lies beyond the limits of Pleistocene glaciers emanating from the Cascade Range (Crandell, 1980; Mundorff, 1964; Evarts, 2006a), although glacial outwash gravel may be present in the Quaternary terraces flanking the Sandy River ($Qtds_2$ and $Qtds_2$) and loess episodically blanketed uplands, probably chiefly during glacial periods. The map area was, however, profoundly affected by the latest Pleistocene glacier-outburst floods from Glacial Lake Missoula (Bretz, 1925; Trimble, 1963; Allison, 1978; Waitt, 1994, 1996; Benito and O'Connor, 2003; Minervini and others, 2003). Scores of these floods jetted through the western Columbia River Gorge between 20 and 15 ka, probably attaining flow velocities of 35 m/s in the map area (Benito and O'Connor, 2003) and stripping the valley flanks. As the flows decelerated upon entering the Portland Basin, they deposited immense, coarse-grained bars (Qfg) that apparently blocked both the Sandy and Washougal rivers, leading to aggradation of the lower portions of each of these rivers. In backflooded areas, the Missoula floods also mantled much land surface below 120 m elevation with locally bedded micaceous sand and silt (Qfs).

Since the last glacial sea-level low stand of about 112 m below present sea level at 15 ka (Baker, 2002), the Columbia River has aggraded more than 60 m in the map area to its present low-water elevation of about 1 m above sea level and formed the historic floodplain, beach deposits, and mid-channel islands (Qac), locally covered with small eolian dunes (Qe). Coarse-grained volcaniclastic deposits (Qh) generated by two late Holocene eruptive periods of Mount Hood covered the Sandy River valley bottom. These volcaniclastic deposits constitute much of the Holocene sediment entering the Columbia River within the map area and substantially built out the Sandy River delta (Rapp, 2005). Since the early 1900s, much of the historic Columbia River floodplain has been diked and drained, and in-channel patterns and processes of deposition have been modified by dike and jetty construction, dredging, and upriver impoundments that now strongly control the flow regime.

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Table 1. Chemical and modal analyses of volcanic rocks, Washougal 7.5' quadrangle, Clark County, Washington, and Multnomah County, Oregon.

[X-ray fluorescence analyses. Rock-type names assigned in accordance with IUGS system (Le Maitre, 2002) applied to recalculated analyses. FeO*, total Fe calculated as FeO; Mg#, atomic ratio 100 Mg/(Mg+Fe^{2+}) with Fe^{2+} set to 0.85 x Fe^{total}. Modal analyses, secondary minerals counted as primary mineral replaced. -, not present; tr, trace. X-ray fluorescence analyses by D.M. Johnson Cornelius at GeoAnalytical Laboratory of Washington State University using methods described in Johnson and others (1999)]

Map No.	1	2	3	4	5	6	7	8	9
Field sample No.	**02CM-T27**	**03CM-T189B**	**03CM-T166**	**03CM-T234B**	**03CM-T200A**	**03CM-T189A**	**03CM-T194**	**03CM-T195**	**03CM-T192**
Latitude (N)	45°37.375'	45°36.031'	45°37.442'	45°36.100'	45°35.571'	45°36.074'	45°35.516'	45°35.573'	45°35.703'
Longitude (W)	122°19.230'	122°20.443'	122°19.859'	122°20.232'	122°21.544'	122°20.474'	122°22.283'	122°19.642'	122°22.019'
Map unit	Tob	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem
Rock type	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basaltic andesite	Basaltic andesite
Analyses as reported (wt percent)									
SiO_2	47.45	50.55	51.26	51.63	51.69	51.62	51.73	51.31	52.14
TiO_2	1.46	1.15	1.59	1.21	1.24	1.89	1.82	1.63	1.90
Al_2O_3	17.44	18.41	16.84	18.51	18.06	16.42	16.26	17.48	15.82
FeO*	11.59	10.19	12.50	9.45	10.50	11.94	12.35	10.24	13.02
MnO	0.20	0.21	0.23	0.19	0.19	0.29	0.23	0.21	0.26
MgO	7.87	5.64	4.57	5.45	4.76	4.80	4.44	4.32	3.97
CaO	10.38	11.32	9.70	10.87	10.56	9.47	9.44	9.93	9.00
Na_2O	2.26	2.55	3.00	2.67	2.90	3.28	2.87	2.86	3.25
K_2O	0.29	0.21	0.35	0.29	0.44	0.32	0.49	0.58	0.50
P_2O_5	0.16	0.13	0.17	0.16	0.13	0.21	0.20	0.19	0.22
Total	99.09	100.35	100.20	100.44	100.44	100.24	99.81	98.74	100.10
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)									
SiO_2	47.88	50.37	51.16	51.41	51.46	51.49	51.83	51.97	52.09
TiO_2	1.47	1.14	1.58	1.21	1.23	1.88	1.82	1.65	1.90
Al_2O_3	17.60	18.34	16.80	18.43	17.98	16.38	16.29	17.70	15.81
FeO*	11.70	10.15	12.47	9.41	10.45	11.92	12.37	10.37	13.01
MnO	0.20	0.21	0.23	0.19	0.19	0.29	0.23	0.21	0.26
MgO	7.94	5.62	4.56	5.43	4.74	4.79	4.45	4.38	3.97
CaO	10.47	11.28	9.68	10.82	10.51	9.45	9.45	10.06	8.99
Na_2O	2.28	2.54	3.00	2.66	2.88	3.27	2.88	2.89	3.25
K_2O	0.29	0.21	0.35	0.29	0.44	0.32	0.49	0.59	0.50
P_2O_5	0.16	0.12	0.17	0.16	0.12	0.21	0.20	0.20	0.22
Mg#	58.8	53.8	43.4	54.7	48.8	45.8	43.0	47.0	39.0
Modes (volume percent)									
Plagioclase	24.0	15.9	11.1	20.5	12.4	4.3	28.8	18.6	5.1
Clinopyroxene	1.6	0.9	0.8	-	0.3		1.0	0.1	0.4
Orthopyroxene	-	-	-	-	-	-		-	-
Olivine	8.8	3.3	1.3	2.4	0.9	0.9	0.5	0.5	1.2
Fe-Ti Oxide	0.1	-	-	trace	-	-	-	-	0.1
Hornblende	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	xenoliths - tr	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Groundmass	65.5	79.9	86.8	77.1	86.4	94.8	69.7	80.8	93.2
No. points counted	800	800	800	800	790	800	840	800	800
Texture (rock/ groundmass)	seriate/ intergranular	porphyritic/ intergranular	seriate/ intergranular	porphyritic/ trachytic	porphyritic/ trachytic	seriate/ trachytic	seriate/ intergranular	porphyritic/ intergranular	seriate/ intergranular
Trace element analyses (ppm)									
Ba	85	104	130	125	118	125	163	153	148
Rb	5	3	5	4	11	5	10	16	10
Sr	256	259	263	268	285	263	269	293	258
Y	26	21	28	23	21	32	32	27	34
Zr	91	71	101	93	76	117	116	111	121
Nb	7.2	4.2	6.4	5.6	4.1	8.5	8.4	7.6	8.6
Ni	74	24	8	24	10	11	9	23	3
Cu	182	141	237	187	198	311	221	181	232
Zn	85	90	107	88	87	111	116	98	115
Cr	120	66	21	93	29	39	15	58	0
Sc	38	38	42	34	39	42	41	38	45
V	278	284	337	233	304	352	341	294	351

Table 1. Chemical and modal analyses of volcanic rocks, Washougal 7.5' quadrangle, Clark County, Washington, and Multnomah County, Oregon—Continued

Map No.	10	11	12	13	14	15	16	17	18
Field sample No.	**02CM-T33**	**03CM-T153A**	**03CM-T213C**	**03CM-T235**	**03CM-T213B**	**02CM-T32**	**07CM-T332**	**03CM-T212**	**03CM-T193**
Latitude (N)	45°36.866'	45°37.248'	45°36.315'	45°35.291'	45°36.372'	45°36.599'	45°32.531'	45°36.666'	45°35.689'
Longitude (W)	122°20.584'	122°20.261'	122°20.319'	122°22.237'	122°20.347'	122°21.082'	122°16.012'	122°20.437'	122°21.892'
Map unit	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem	Ta	Ta	Ta
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Andesite	Andesite	Andesite
Analyses as reported (wt percent)									
SiO_2	51.84	52.67	53.93	53.94	54.79	54.67	57.28	59.86	60.12
TiO_2	1.17	1.75	1.17	1.95	1.59	1.71	1.26	1.38	1.42
Al_2O_3	20.34	16.25	18.07	15.31	16.22	15.22	16.21	16.30	15.47
FeO*	8.71	12.71	9.67	12.74	10.88	11.61	8.13	8.67	9.91
MnO	0.17	0.23	0.22	0.26	0.22	0.26	0.18	0.19	0.20
MgO	3.21	3.96	4.05	3.55	3.87	3.10	2.91	2.48	2.19
CaO	10.37	8.24	9.52	8.05	7.94	7.73	6.30	5.91	5.72
Na_2O	3.06	3.49	3.21	3.62	3.64	3.66	3.74	4.62	4.27
K_2O	0.40	0.58	0.51	0.67	0.79	0.62	1.12	0.78	0.93
P_2O_5	0.15	0.20	0.16	0.27	0.25	0.21	0.21	0.27	0.27
Total	99.42	100.08	100.51	100.35	100.18	98.79	97.34	100.47	100.49
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)									
SiO_2	52.15	52.63	53.66	53.75	54.69	55.34	58.84	59.59	59.83
TiO_2	1.17	1.75	1.17	1.95	1.59	1.73	1.30	1.37	1.41
Al_2O_3	20.46	16.24	17.98	15.25	16.19	15.41	16.66	16.23	15.39
FeO*	8.76	12.70	9.62	12.69	10.86	11.76	8.36	8.63	9.86
MnO	0.17	0.22	0.22	0.26	0.22	0.26	0.19	0.19	0.20
MgO	3.23	3.96	4.03	3.54	3.86	3.14	2.99	2.47	2.18
CaO	10.43	8.23	9.47	8.02	7.92	7.82	6.47	5.88	5.69
Na_2O	3.08	3.48	3.19	3.60	3.64	3.70	3.84	4.60	4.25
K_2O	0.40	0.58	0.51	0.67	0.78	0.63	1.15	0.78	0.92
P_2O_5	0.15	0.20	0.16	0.27	0.25	0.21	0.21	0.27	0.27
Mg#	43.6	39.5	46.8	36.9	42.7	35.9	42.8	37.5	31.7
Modes (volume percent)									
Plagioclase	25.5	2.0	19.1	0.3	2.8	6.4	7.8	2.8	5.9
Clinopyroxene	trace	trace	0.9	trace	0.6	0.3	0.7	0.5	0.5
Orthopyroxene	-	-	-	-	-	-	0.5	0.3	0.4
Olivine	0.8	0.2	2.0	-	1.3	0.5	-	trace	-
Fe-Ti Oxide		trace	-	-	-		-	0.1	0.2
Hornblende	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Groundmass	73.7	97.8	78.0	99.7	95.3	92.8	91.0	96.3	93.0
No. points counted	800	800	800	800	800	800	850	792	784
Texture (rock/ groundmass)	seriate/ intergranular	sparsely intergranular	seriate/ intergranular	sparsely microphyric	porphyritic/ trachytic	seriate/ pilotaxitic	seriate/ pilotaxitic	seriate/ pilotaxitic	seriate/ pilotaxitic
Trace element analyses (ppm)									
Ba	108	157	143	171	188	166	258	209	234
Rb	7	13	12	18	19	11	32	18	23
Sr	298	279	265	252	249	245	306	279	240
Y	24	30	26	39	35	36	27	38	38
Zr	86	115	102	142	155	129	151	155	170
Nb	6.2	7.6	6.2	9.6	10.7	10.6	8.7	10.8	11.2
Ni	5	6	9	0	8	5	0	2	0
Cu	108	219	208	161	95	245	146	60	60
Zn	84	108	97	122	105	115	94	108	119
Cr	28	0	29	1	13	13	0	4	7
Sc	33	36	37	44	35	48	26	28	28
V	186	284	228	257	242	249	171	80	75

Table 1. Chemical and modal analyses of volcanic rocks, Washougal 7.5' quadrangle, Clark County, Washington, and Multnomah County, Oregon—Continued

Map No.	19	20	21	22	23	24	25	26	27
Field sample No.	**05CM-T303A**	**03CM-T204B**	**04CM-T262**	**07CM-T327**	**05CM-T312**	**MBCG-17***	**04CM-T261**	**04CM-T263**	**11CM-T341A**
Latitude (N)	45°37.487'	45°37.492'	45°32.471'	45°32.580'	45°32.486'	45°32.471'	45°32.388'	45°32.474'	45°32.125'
Longitude (W)	122°17.553'	122°19.457'	122°17.138'	122°16.440'	122°16.277'	122°16.864'	122°17.143'	122°17.635'	122°15.150'
Map unit	Ta	Tiba	Tgsb	Tgsb	Tgsb	Tgsb	Twfs$_h$	Twfs$_h$	Twfs$_h$
Rock type	Andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite
Analyses as reported (wt percent)									
SiO_2	58.73	53.66	53.54	52.74	53.34	54.35	50.63	51.09	51.88
TiO_2	1.02	1.08	1.88	1.91	1.92	1.99	2.83	2.89	2.87
Al_2O_3	16.99	18.05	13.94	13.60	13.83	14.23	12.96	13.30	13.31
FeO*	7.98	9.11	11.38	11.82	11.96	11.40	14.27	12.91	13.91
MnO	0.13	0.17	0.21	0.21	0.21	0.22	0.24	0.21	0.22
MgO	1.92	4.50	5.00	4.66	4.75	4.60	3.83	4.02	4.29
CaO	5.78	10.19	8.75	8.49	8.55	8.70	8.04	8.28	8.25
Na_2O	4.01	3.03	2.83	2.88	2.93	2.97	2.86	2.75	2.90
K_2O	0.91	0.34	1.29	1.08	1.13	1.31	1.22	1.47	1.44
P_2O_5	0.24	0.15	0.29	0.28	0.28	0.31	0.56	0.58	0.57
Total	97.71	100.27	99.11	97.68	98.90	100.08	97.45	97.50	99.64
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)									
SiO_2	60.11	53.51	54.01	53.99	53.94	54.30	51.96	52.40	52.07
TiO_2	1.04	1.07	1.90	1.95	1.95	1.99	2.91	2.96	2.88
Al_2O_3	17.39	18.00	14.07	13.93	13.98	14.22	13.30	13.64	13.35
FeO*	8.16	9.08	11.48	12.10	12.09	11.39	14.64	13.24	13.96
MnO	0.14	0.16	0.21	0.21	0.21	0.22	0.25	0.22	0.23
MgO	1.96	4.49	5.04	4.77	4.80	4.60	3.93	4.12	4.31
CaO	5.91	10.17	8.83	8.69	8.6	8.7	8.2	8.5	8.3
Na_2O	4.11	3.03	2.86	2.95	2.96	2.96	2.94	2.82	2.91
K_2O	0.93	0.34	1.31	1.11	1.14	1.31	1.25	1.51	1.45
P_2O_5	0.25	0.15	0.30	0.29	0.29	0.31	0.57	0.59	0.58
Mg#	33.5	50.9	47.9	45.3	45.4	45.9	36.0	39.5	39.3
Modes (volume percent)									
Plagioclase	trace	17.3	trace	trace	-	-	0.2	trace	trace
Clinopyroxene	-	0.1	-	-	-	-	-	-	-
Orthopyroxene	-	-	-	-	-	-	-	-	-
Olivine	-	0.8	-	-	-	-	-	-	-
Fe-Ti Oxide	-	-	-	-	-	-	-	-	-
Hornblende	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Groundmass	100.0	81.8	100.0	100.0	100.0	100.0	99.8	100.0	100.0
No. points counted	800	800	800	800	-	-	800	-	-
Texture (rock/ groundmass)	~aphyric/ intergranular	porphyritic/ trachytic	~aphyric/ intergranular	~aphyric/ intergranular	aphyric/ intergranular	aphyric/ intergranular	~aphyric/ intergranular	aphyric/ intergranular	aphyric/ intersertal
Trace element analyses (ppm)									
Ba	236	142	481	464	453	488	563	571	590
Rb	21	17	26	27	28	30	35	36	37
Sr	289	245	307	312	320	328	316	327	322.1
Y	25	25	33	32	33	34	42	45	42
Zr	165	108	157	156	156	163	186	199	198
Nb	9.0	6.2	9.6	9.8	10.7	11.0	15.6	16.6	14
Ni	8	15	7	4	15	16	22	20	21
Cu	30	139	34	28	27	29	30	28	31
Zn	87	84	117	115	117	129	143	148	142
Cr	5	66	37	22	22	27	40	38	39
Sc	19	34	39	37	37	38	37	36	37
V	113	223	323	330	337	348	409	404	398

*Analysis provided by S.P. Reidel, written commun., 2004

Table 1. Chemical and modal analyses of volcanic rocks, Washougal 7.5' quadrangle, Clark County, Washington, and Multnomah County, Oregon—Continued

Map No.	28	29	30	31	32	33	34	35	36
Field sample No.	**11CM-T341B**	**05CM-T307**	**05CM-T297**	**05CM-T294A**	**05CM-T295**	**05CM-T296†**	**03CM-T252**	**05CM-T292B**	**03CM-T253A**
Latitude (N)	45°32.106	45°32.251'	45°32.455'	45°32.415'	45°32.373'	45°32.280'	45°30.611'	45°31.940'	45°31.060'
Longitude (W)	122°15.208'	122°15.664'	122°15.814'	122°15.961'	122°15.925'	122°16.140'	122°17.817'	122°15.400'	122°15.483'
Map unit	Twfs$_h$	Twpr$_r$	Twpr$_r$	Twpr$_r$	Twpr$_r$	Twpr$_r$	Tlkt	Tlkt	Qbbv
Rock type	Basaltic	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
Analyses as reported (wt percent)									
SiO_2	51.65	48.82	48.21	49.02	48.91	49.36	46.73	48.95	49.87
TiO_2	2.81	3.53	3.58	3.61	3.57	3.63	1.23	1.25	1.50
Al_2O_3	13.29	12.52	12.45	12.79	12.54	12.87	16.64	16.98	16.48
FeO*	14.02	15.27	15.03	14.54	15.10	13.77	11.49	11.20	9.17
MnO	0.23	0.26	0.25	0.26	0.22	0.33	0.13	0.18	0.16
MgO	4.47	4.18	4.39	4.51	4.38	3.66	7.36	8.17	7.57
CaO	8.31	7.92	8.36	8.52	8.01	8.62	9.03	9.29	9.68
Na_2O	2.83	2.81	2.61	2.66	2.78	2.57	2.57	3.09	3.41
K_2O	1.39	1.25	1.27	1.31	1.23	1.17	0.11	0.27	1.17
P_2O_5	0.57	0.77	0.78	0.81	0.76	0.81	0.11	0.12	0.40
Total	99.55	97.33	96.92	98.02	97.51	96.79	95.39	99.48	99.42
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)									
SiO_2	51.88	50.16	49.74	50.01	50.16	50.99	48.99	49.20	50.16
TiO_2	2.82	3.62	3.69	3.68	3.66	3.75	1.29	1.25	1.51
Al_2O_3	13.35	12.86	12.84	13.05	12.86	13.30	17.44	17.07	16.58
FeO*	14.09	15.69	15.50	14.83	15.48	14.22	12.04	11.26	9.23
MnO	0.23	0.27	0.26	0.26	0.23	0.34	0.14	0.18	0.16
MgO	4.49	4.30	4.53	4.60	4.50	3.78	7.71	8.21	7.62
CaO	8.3	8.1	8.63	8.69	8.21	8.91	9.47	9.3	9.74
Na_2O	2.84	2.88	2.69	2.72	2.85	2.66	2.69	3.10	3.43
K_2O	1.40	1.29	1.31	1.33	1.27	1.21	0.11	0.27	1.18
P_2O_5	0.57	0.80	0.81	0.82	0.78	0.84	0.12	0.1	0.40
Mg#	40.1	36.5	38.0	39.4	37.8	35.8	58.5	60.6	63.5
Modes (volume percent)									
Plagioclase	trace	-	-	-	trace	-	-	-	-
Clinopyroxene	-	-	-	-	-	-	-	-	-
Orthopyroxene	-	-	-	-	-	-	-	-	-
Olivine	-	-	-	-	-	-	-	-	8.6
Fe-Ti Oxide	-	-	-	-	-	-	-	-	-
Hornblende	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Groundmass	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	91.4
No. points counted	-	-	-	-	-	-	-	800	790
Texture (rock/ groundmass)	aphyric/ intergranular	~aphyric/ intergranular	microphyric/ intersertal	microphyric/ intersertal	~aphyric/ intergranular	microphyric/ intersertal	aphyric/ intergranular	aphyric/ subophitic	porphyritic/ trachytic
Trace element analyses (ppm)									
Ba		582	561	547	576	1116	43	100	360
Rb	573	33	30	30	31	36	0	2	10
Sr	34	266	288	285	266	298	239	315	869
Y	322	52	50	51	51	51	23	20	24
Zr	42	221	227	221	218	222	81	74	152
Nb	194	18.3	15.9	17.8	18.0	17.7	5.1	3.3	14.5
Ni	15	19	21	20	19	16	125	149	149
Cu	22	23	27	22	20	23	68	55	69
Zn	30	158	162	160	151	166	85	94	87
Cr	147	13	15	15	14	14	251	199	328
Sc	42	38	38	39	39	41	30	29	28
V	38	409	413	423	417	428	182	192	208

† clast in hyaloclastite

Table 1. Chemical and modal analyses of volcanic rocks, Washougal 7.5' quadrangle, Clark County, Washington, and Multnomah County, Oregon—Continued

Map No.	37	38	39	40	41	42	43	44	45
Field sample No.	**03CM-T253A**	**03CM-T253B**	**QV00-23**	**02CM-T26**	**02CM-T25**	**03CM-T210**	**05CM-T311**	**07CM-T328B**	**QV01-47**
Latitude (N)	45°31.060'	45°31.131'	45°36.998'	45°37.343'	45°36.715'	45°36.435'	45°36.374'	45°31.758'	45°32.400'
Longitude (W)	122°15.483'	122°15.384'	122°18.002'	122°19.377'	122°15.798'	122°17.264'	122°15.060'	122°21.947'	122°22.470'
Map unit	Qbbv	Qbbv	Qmbp	Qmbp	Qmmn	Qmmn	Qmmn	Qmbb	Qmbb
Rock type	Basalt	Basalt	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite
Analyses as reported (wt percent)									
SiO_2	49.87	49.69	52.43	52.54	56.04	56.36	56.38	52.43	51.78
TiO_2	1.50	1.52	1.52	1.49	1.17	1.27	1.19	1.35	1.35
Al_2O_3	16.48	16.58	17.70	17.70	18.53	18.38	18.61	17.19	17.21
FeO*	9.17	9.56	8.55	8.48	7.84	7.69	7.47	8.09	8.35
MnO	0.16	0.15	0.14	0.14	0.13	0.12	0.13	0.14	0.13
MgO	7.57	7.11	6.28	6.02	3.61	3.19	3.71	6.67	6.54
CaO	9.68	9.32	8.10	7.96	7.18	6.96	7.37	8.36	8.24
Na_2O	3.41	3.23	3.94	3.94	4.03	4.13	4.10	3.69	3.76
K_2O	1.17	1.14	1.02	1.02	0.85	0.87	0.89	0.76	0.77
P_2O_5	0.40	0.40	0.35	0.35	0.29	0.31	0.30	0.28	0.29
Total	99.42	98.69	100.04	99.64	99.67	99.28	100.14	98.96	98.42
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)									
SiO_2	50.16	50.35	52.41	52.73	56.22	56.77	56.30	52.98	52.61
TiO_2	1.51	1.54	1.52	1.49	1.17	1.28	1.19	1.37	1.37
Al_2O_3	16.58	16.80	17.69	17.77	18.59	18.52	18.58	17.37	17.49
FeO*	9.23	9.69	8.55	8.51	7.87	7.74	7.46	8.17	8.48
MnO	0.16	0.15	0.14	0.14	0.13	0.12	0.13	0.14	0.14
MgO	7.62	7.20	6.28	6.04	3.62	3.21	3.70	6.74	6.64
CaO	9.74	9.44	8.10	7.99	7.21	7.01	7.36	8.44	8.37
Na_2O	3.43	3.27	3.93	3.95	4.04	4.16	4.09	3.73	3.82
K_2O	1.18	1.15	1.02	1.03	0.86	0.87	0.89	0.77	0.78
P_2O_5	0.40	0.41	0.35	0.35	0.29	0.31	0.30	0.28	0.29
Mg#	63.5	61.2	60.6	59.8	49.1	46.5	51.0	63.6	62.5
Modes (volume percent)									
Plagioclase	-	-	-	-	-	-	-	0.1	-
Clinopyroxene	-	-	-	-	-	-	-	-	-
Orthopyroxene	-	-	-	-	-	-	-	-	-
Olivine	8.6	8.3	5.9	6.5	-	-	-	6.2	8.7
Fe-Ti Oxide	-	-	-	-	-	-	-	-	-
Hornblende	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-		-
Other	-	-	-	-	-	-	-	-	
Groundmass	91.4	91.7	94.1	93.5	100.0	100.0	100.0	93.8	91.3
No. points counted	790	800	800	800	--	--	--	850	812
Texture (rock/ groundmass)	porphyritic/ trachytic	porphyritic/ trachytic	porphyritic/ intergranular	porphyritic/ trachytic	aphyric/ pilotaxitic	aphyric/ trachytic	aphyric/ trachytic	microphyric/ trachytic	porphyritic/ trachytic
Trace element analyses (ppm)									
Ba	360	359	271	270	231	244	230	254	247
Rb	10	8	10	10	6	7	6	6	6
Sr	869	803	660	646	710	729	711	635	687
Y	24	23	28	56	22	22	19	20	21
Zr	152	145	169	166	139	136	136	136	132
Nb	14.5	13.9	17.9	17.1	8.8	9.2	8.0	10.1	12.8
Ni	149	140	110	110	38	29	39	116	121
Cu	69	64	50	46	56	42	58	48	42
Zn	87	84	87	85	93	96	93	82	85
Cr	328	329	163	163	39	32	43	235	220
Sc	28	28	24	23	17	14	18	25	23
V	208	207	189	186	138	132	135	170	169

Table 1. Chemical and modal analyses of volcanic rocks, Washougal 7.5' quadrangle, Clark County, Washington, and Multnomah County, Oregon—Continued

Map No.	46	47	48	49	50	51	52	53	54
Field sample No.	**05CM-T300A**	**05CM-T300B**	**08CM-T334B**	**08CM-T334C**	**03CM-T249**	**03CM-T250**	**07CM-T331**	**05CM-T299**	**03CM-T217C**
Latitude (N)	45°32.393'	45°32.381'	45°32.350'	45°32.337'	45°31.699'	45°31.630'	45°32.324'	45°32.279'	45°34.718'
Longitude (W)	122°21.245'	122°21.249'	122°20.930'	122°20.942'	122°21.018'	122°20.252'	122°20.617'	122°20.052'	122°17.877'
Map unit	Qmbb	Qmbb	Qmbb	Qmbb	Qbch	Qbch	Qbch	Qbch	Ttfc
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basalt	Basalt	Basalt	Basalt	Basalt
Analyses as reported (wt percent)									
SiO_2	51.74	51.73	52.56	51.91	49.87	50.12	51.42	49.00	49.32
TiO_2	1.34	1.28	1.35	1.28	1.28	1.27	1.29	1.30	2.26
Al_2O_3	17.29	17.21	17.52	17.33	17.67	17.69	17.34	17.37	16.37
FeO*	7.81	7.92	8.33	8.22	9.37	8.91	8.65	9.03	10.15
MnO	0.14	0.14	0.13	0.15	0.18	0.17	0.16	0.17	0.15
MgO	5.78	6.77	6.30	6.78	7.71	7.27	7.02	7.37	6.92
CaO	8.25	8.46	8.33	8.73	10.46	10.07	9.26	10.55	10.07
Na_2O	3.70	3.58	3.74	3.53	3.30	3.18	3.53	3.34	3.06
K_2O	0.78	0.73	0.77	0.74	0.43	0.45	0.61	0.42	0.66
P_2O_5	0.26	0.27	0.28	0.26	0.19	0.22	0.24	0.19	0.38
Total	97.09	98.09	99.31	98.93	100.46	99.34	99.51	98.72	99.33
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)									
SiO_2	53.29	52.73	52.93	52.47	49.64	50.45	51.67	49.64	49.65
TiO_2	1.38	1.31	1.36	1.30	1.28	1.28	1.29	1.31	2.28
Al_2O_3	17.81	17.55	17.64	17.52	17.59	17.81	17.43	17.59	16.48
FeO*	8.05	8.08	8.39	8.31	9.32	8.97	8.69	9.14	10.22
MnO	0.14	0.15	0.13	0.15	0.18	0.17	0.16	0.17	0.15
MgO	5.96	6.90	6.35	6.85	7.68	7.32	7.05	7.46	6.97
CaO	8.50	8.62	8.38	8.82	10.42	10.13	9.30	10.69	10.14
Na_2O	3.81	3.65	3.77	3.57	3.29	3.20	3.54	3.38	3.08
K_2O	0.80	0.74	0.77	0.75	0.43	0.45	0.62	0.43	0.67
P_2O_5	0.27	0.27	0.28	0.26	0.19	0.22	0.24	0.19	0.38
Mg#	61.5	64.6	61.5	63.6	63.2	63.3	63.1	63.4	59.0
Modes (volume percent)									
Plagioclase	0.3	0.1	0.4	-	3.0	3.5	1.4	1.9	
Clinopyroxene	-	-	-	-	-	-	-	-	
Orthopyroxene	-	-	-	-	-	-	-	-	
Olivine	4.9	6.0	2.3	4.1	4.5	4.9	5.5	4.3	
Fe-Ti Oxide	-	-	-	-	-	-	-	-	
Hornblende	-	-	-	-	-	-	-	-	
Biotite	-	-	-	-	-	-	-	-	
Quartz	-	-	-	-	-	-	-	-	
K-feldspar	-	-	-	-	-	-	-	-	
Other									
Groundmass	100.0	100.0	100.0	100.0	95.5	95.1	94.5	100.0	
No. points counted	800	800	800	800	812	740	840	800	
Texture (rock/ groundmass)	microphyric/ trachytic	microphyric/ intergranular	seriate/ subophitic	porphyritic/ intergranular	seriate/ intergranular	seriate/ intergranular	seriate/ trachytic	seriate/ trachytic	
Trace element analyses (ppm)									
Ba	253	226	247	228	172	220	225	150	195
Rb	6	5	6	5	3	3	5	3	7
Sr	673	595	660	588	454	572	569	455	563
Y	19	21	20	22	27	25	23	24	22
Zr	130	129	134	131	106	113	124	104	154
Nb	10.1	9.4	10.0	10.1	5.4	6.6	7.5	5.2	18.8
Ni	115	140	114	125	118	107	102	95	100
Cu	67	43	60	65	68	69	67	45	30
Zn	84	80	84	83	77	75	76	75	98
Cr	225	240	228	245	259	239	237	222	169
Sc	24	27	24	28	37	35	31	36	24
V	170	176	163	175	234	214	194	235	221

† clast in conglomerate

Table 2. Summary of K-Ar and 40Ar/39Ar incremental-heating age determinations, Washougal 7.5' quadrangle, Clark County, Washington, and Multnomah County, Oregon.

Field sample no.	Location Latitude (N)	Longitude (W)	Map unit	Rock type	Material dated	Method	Age (±1σ error)	Source
MM0903851*	45°37.52'	122°19.58'	Tbem	Basaltic andesite	Whole rock	K-Ar	27.9±1.9 Ma	Phillips and others, 1986
02CM-T25	45°36.715'	122°15.798'	Qmmn	Basaltic andesite	Whole rock	$^{40}Ar/^{39}Ar$	693±9 ka	R.J. Fleck, written commun., 2012
03CM-T250	45°31.630'	122°20.252'	Qbch	Basalt	Groundmass separate	$^{40}Ar/^{39}Ar$	1,159±14 ka	R.J. Fleck, written commun., 2012
QV01-47	45°32.400'	122°22.470'	Qmbb	Basaltic andesite	Groundmass separate	$^{40}Ar/^{39}Ar$	1,292±19 ka	R.J. Fleck, written commun., 2012
92TB-8	45°32.49'	122°22.37'	Qmbb	Basaltic andesite	Whole rock	K-Ar	1.53±0.39 Ma	Conrey and others, 1996a
03CM-T253A	45°31.060'	122°15.483'	Qbbv	Basalt	Groundmass separate	$^{40}Ar/^{39}Ar$	2,284±16 ka	R.J. Fleck, written commun., 2012

*Locality is directly north of map area in Larch Mountain quadrangle.

Table 3. Summary of feldspar infrared stimulated luminescence and thermoluminescence age determinations, Washougal 7.5' quadrangle, Clark County, Washington, and Multnomah County, Oregon.

[Sample location on quadrangle indexed by map letter, leaders (--) indicate sample from adjacent quadrangle but within units correlative to those in Washougal quadrangle; age from silt sized potassium feldspar using multiple aliquot additive dose, fit by linear plus exponential regression, errors are one sigma; potassium, thorium, and uranium contents by gamma spectrometry; cosmic doses and attenuation with depth were calculated using methods of Prescott and Hutton (1994); ages calculated assuming water content of 50–55 percent saturation; all analyses and calculations conducted by S.A. Mahan, U.S. Geological Survey Luminescence Dating Laboratory, Denver, Colorado]

Map Letter	Field sample No.	Location Latitude (N)	Longitude (W)	Stratigraphic context	Sample water content in wt percent (value at saturation)
A	**RW05-916-12:45**	45°30.005'	122°17.140'	Within $Qtds_3$, in hornblende-feldspar lithic sand (Mount Hood lahar runout?), less than 1 m above basal contact with hyaloclastic sandstone member of Troutdale Formation (Ttfh)	18 (22)
--	**RW05-916-10:40**	45°28.721'	122°17.932'	Within $Qtds_2$, in hornblende-feldspar fine sand, fluvial, 10.2 m below top of deposit; 9 m above basal contact with hyaloclastic sandstone member of Troutdale Formation (Ttfh)	14 (27)
--	**RW05-916-10:20**	45°28.721'	122°17.932'	Within $Qtds_2$, in hornblende-feldspar lithic medium sand, fluvial, 3.5 m below top of deposit; 15.7 m above basal contact with hyaloclastic sandstone member of Troutdale Formation (Ttfh)	19 (25)
--	**RW05-916-15:45**	45°31.883'	122°22.700'	Within $Qtds_1$, in poorly sorted hornblende-feldspar lithic medium-coarse sand (inferred to be Mount Hood lahar runout), 15 m below surface; at basal contact with hyaloclastic sandstone member of Troutdale Formation (Ttfh)	29 (41)

Map Letter	Field sample No.	Thorium in parts per million	Uranium in parts per million	Cosmic dose additions in Grays per thousand years	Total dose rate in Grays per thousand years	Equivalent dose in Grays	Age in thousands of years
A	**RW05-916-12:45**	2.93±0.13	0.88±0.06	0.11±0.01	1.26±0.05	>270[1]	>220
--	**RW05-916-10:40**	3.15±0.12	1.00±0.05	0.07±0.01	1.75±0.06	>155[1]	>220
--	**RW05-916-10:20**	3.20±0.13	0.93±0.06	0.14±0.01	1.65±0.07	37.1±2.77[1]	22.4±2.46
--	**RW05-916-15:45**	3.13±0.11	0.93±0.04	0.26±0.01	1.65±0.05[3]	23.6±1.54[2]	14.3±1.22[3]

[1]Anomalous fading experiments indicate a fade of 0 to 2 percent, and this has been applied to the calculated equivalent doses.

[2]Anomalous fading experiments indicate a fade of 10 to 15 percent, and this has been applied to the calculated equivalent doses.

[3]Dose rate and age by thermoluminescence rather than infrared stimulated luminescence due to high glass content of sample.

Table 4. Summary of radiocarbon age determinations, Washougal 7.5' quadrangle, Clark County, Washington, and Multnomah County, Oregon.

[Conventional corrected radiocarbon ages, referenced to A.D. 1950, calculated on basis of Libby half-life of 5,568 years; 1-σ error based on combined measurements of sample, background, and modern reference standards. "Modern" results indicate a post-A.D. 1950 age and are not calibrated; calibrated ages, referenced to A.D. 1950, calculated on basis of CALIB REV4.4.2 using intcal98 calibration data set (Stuiver and others, 1998) and a laboratory error multiplier of 1; where multiple intercepts calculated, we list solutions in order of greatest likelihood summing to >90 percent of the probability density function]

Map No.	Field sample No.	Lab sample No. †	Location Latitude N	Location Longitude W	Stratigraphic context	Material dated
1	**TCP 000816-2Z**	Beta 146978	45°30.029'	122°19.843'	Within Qh, near base of Old Maid age fluvial deposits, ~18 m below surface	Douglas-fir cone
2	**TCP 930714-2**	Beta 66189	45°31.076'	122°21.102'	Within Qh, detrital charcoal in Timberline-age fluvial deposits 0.5 m below surface	charcoal
3	**TCP 991020-1**	Beta 146979	45°31.040'	122°21.087'	Within Qh, in Timberline-age fluvial deposits, 4.8 m below surface	charcoal
3	**4/11/97-1(1)**	Beta 118283	45°31.040'	122°21.087'	Within Qh, in Timberline-age fluvial deposits, 4.8 m below surface	wood
3	**8/7/02-1(1)**	Beta 170599	45°31.040'	122°21.087'	Within Qh, in Old Maid-age fluvial deposits, 3.1 m below surface	charcoal
4	**7/20/93-2**	Beta 66181	45°31.003'	122°21.176'	Within Qh, charred soil overlain by Old Maid age fluvial deposits	charcoal
4	**7/20/93-5**	Beta 66182	45°31.003'	122°21.176'	Within Qh, outer wood of growth-position tree buried by Old Maid age fluvial deposits	wood
5	**10/4/01-1(9)**	WW 3985	45°33.051'	122°18.593'	Within Qac, 3.6 m below surface of Reed Island	plant fragments
5	**10/4/01-1(14)**	WW 3981	45°33.051'	122°18.593'	Within Qac, 4.0 m below surface of Reed Island	Douglas-fir needles
6	**9/24/02-1(8)**	WW 4356	45°32.834'	122°22.200'	Within Qh in Timberline-age fluvial deposits, 2.1 m below surface (probably re-transported charcoal)	charcoal
6	**9/24/02-1(12)**	WW 4681	45°32.834'	122°22.200'	Within Qh in Timberline-age lahar, 3.0 m below surface	wood
6	**9/24/02-1(23)**	WW 4658	45°32.834'	122°22.200'	Within Qac, below Qh, 8.0 m below surface	charcoal
7	**9/26/02-1(7)**	WW 4359	45°32.913'	122°22.504'	Within Qh in Old Maid-age fluvial deposits, 2.5 m below surface	wood
7	**9/26/02-1(27)**	WW 4360	45°32.913'	122°22.504'	Within Qac, below Qh, 5.7 m below surface (bad result)	wood
7	**9/26/02-1(31)**	WW 4834	45°32.913'	122°22.504'	Within Qac, below Qh, 6.2 m below surface	charcoal
7	**9/26/02-1(35)**	WW 4361	45°32.913'	122°22.504'	Within Qac, below Qh, 6.2 m below surface	wood
8	**9/27/02-1(1)**	WW 4362	45°32.727'	122°22.332'	Within thin, unmapped Columbia River alluvium above Timberline-age Qh, 0.27 m below surface	charcoal
8	**9/27/02-1(10)**	WW 4363	45°32.727'	122°22.332'	Within Qh in Timberline-age lahar, 3.7 m below surface	wood
8	**9/27/02-1(19)**	WW 4364	45°32.727'	122°22.332'	Within Qac, below Qh, 8.1 m below surface	alder cone
9	**3/12/04-2(1)**	WW 4837	45°33.103'	122°20.960'	Within Qac, below Qe, 6.2 m below surface	charcoal
10	**3/12/04-4(2)**	WW 4939	45°32.959'	122°20.998'	Within Qac, 2.5 m below surface	wood
11	**3/16/04-3(1)**	WW 4840	45°32.914'	122°21.923'	Within Qh in Timberline-age fluvial deposits, 1.8 m below surface	charcoal
12	**3/16/04-4(2)**	WW 4841	45°32.941'	122°21.907'	Within Qh in Old Maid-age fluvial deposits, 1.8 m below surface	organic fragments
13	**2/21/03-1(1)**	Beta 176999	45°33.501'	122°15.466'	Buried log within Qac	wood
14	**9/30/03-1(4)**	WW 4835	45°32.405'	122°16.602'	Within Qe, 5.0 m below surface	charcoal
15	**9/30/03-2(8)**	WW 4836	45°32.219'	122°18.126'	Within Qlo, 2.5 m below surface (bad result)	plant fragments

*$^{13}C/^{12}C$ not measured; value of -25‰ assumed for determining conventional corrected age.

† WW samples analyzed in U.S. Geological Survey radiocarbon laboratory, Reston, Virginia, by J. McGeehin; Beta samples analyzed by Beta Analytic, Inc., Miami, Florida.

Table 4. Summary of radiocarbon age determinations, Washougal 7.5' quadrangle, Clark County, Washington, and Multnomah County, Oregon.—Continued

[Conventional corrected radiocarbon ages, referenced to A.D. 1950, calculated on basis of Libby half-life of 5,568 years; 1-σ error based on combined measurements of sample, background, and modern reference standards. “Modern” results indicate a post-A.D. 1950 age and are not calibrated; calibrated ages, referenced to A.D. 1950, calculated on basis of CALIB REV4.4.2 using intcal98 calibration data set (Stuiver and others, 1998) and a laboratory error multiplier of 1; where multiple intercepts calculated, we list solutions in order of greatest likelihood summing to >90 percent of the probability density function]

Map No.	Field sample No.	Conventional age in ^{14}C yr B.P. ±1- σ error	$^{13}C/^{12}C$*	Calibrated 2- σ age ranges in calendar yr B.P. (fraction of 46robability density function)	Source
1	**TCP 000816-2Z**	240±30	-23.2	272-318 (0.60); 146-191 (0.31)	T.C. Pierson, written commun., 2000
2	**TCP 930714-2**	1330±60	-26.0	1167-1347 (0.93)	T.C. Pierson, written commun., 1993
3	**TCP 991020-1**	2000±70	-26.5	1816-2131 (0.99)	T.C. Pierson, written commun., 2000
3	**4/11/97-1(1)**	1650±50	-26.3	1414-1630 (0.90)	
3	**8/7/02-1(1)**	300±40	-24.8	291-466 (1.0)	this report
4	**7/20/93-2**	520±110	-26.4	501-563 (0.81); 596-636 (0.09)	this report
4	**7/20/93-5**	170±80	-24.9	0-319 (0.98)	this report
5	**10/4/01-1(9)**	242±49	*	259-341 (0.38); 138-223 (0.31); 347-461(0.24)	this report
5	**10/4/01-1(14)**	224±44	*	137-225(0.47); 255-324 (0.36); 1-33(0.07); 369-429(0.07)	this report
6	**9/24/02-1(8)**	6125±45	*	6863-7098 (0.80); 7109-7160 (0.16)	Rapp (2005; delta hole #2)
6	**9/24/02-1(12)**	1650±40	*	1477-1627 (0.82); 1418-1473 (0.12)	Rapp (2005; delta hole #2)
6	**9/24/02-1(23)**	2970±50	*	2970-3267 (0.96)	Rapp (2005; delta hole #2)
7	**9/26/02-1(7)**	165±40	*	64-232 (0.64); 240-291 (0.19); 0-38 (0.17)	Rapp (2005; delta hole #4)
7	**9/26/02-1(27)**	modern	*		Rapp (2005; delta hole #4)
7	**9/26/02-1(31)**	520±60	*	473-571 (0.67); 578-649 (0.33)	Rapp (2005; delta hole #4)
7	**9/26/02-1(35)**	415±45	*	425-530 (0.76); 320-392 (0.24)	Rapp (2005; delta hole #4)
8	**9/27/02-1(1)**	450±40	*	439-545 (0.97)	Rapp (2005; delta hole #5)
8	**9/27/02-1(10)**	1985±40	*	1861-2004 (0.95)	Rapp (2005; delta hole #5)
8	**9/27/02-1(19)**	1575±40	*	1385-1541 (0.96)	Rapp (2005; delta hole #5)
9	**3/12/04-2(1)**	1165±35	*	1046-1172 (0.72); 974-1036 (0.28)	this report
10	**3/12/04-4(2)**	190±35	*	137-225 (0.57); 255-303 (0.23); 1-33 (0.16)	this report
11	**3/16/04-3(1)**	1820±60	*	1605-1882 (0.99)	this report
12	**3/16/04-4(2)**	185±35	*	136-226 (0.56); 253-301 (0.21); 1-34 (0.17)	this report
13	**2/21/03-1(1)**	64±40	-23.2	22-143 (0.70); 217-267 (0.25); 0-3 (0.05)	A. Bourdeau, written commun., 2003
14	**9/30/03-1(4)**	1290±35	*	1169-1291 (0.98)	this report
15	**9/30/03-2(8)**	modern	*		this report