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

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INTRODUCTION

GEOGRAPHIC AND GEOLOGIC SETTING

The Camas 7.5' quadrangle is located within the eastern Portland Basin near the mouth of the Columbia River Gorge, approximately 20 km east of downtown Portland, Oregon (fig. 1). The Columbia River transects the map area and separates hilly terrain in Washington State to the north from low-relief terrain to the south in Oregon. Almost all parts of the map area are rapidly urbanizing. In Oregon, the Sandy River at the east edge of the quadrangle forms the eastern limit of the Portland metropolitan area urban growth boundary, and what were formerly areas of truck farms, nursery stock and pasture land have mostly converted to housing and light industry. In Washington, substantial and continuing residential development has replaced small farms, quarries, and forestlands in this part of Clark County over the last 20 years.

The geology of the Camas quadrangle reflects its setting along the eastern margin of the Portland Basin. Paleogene bedrock that floors this part of the basin is exposed only on the south side of Prune Hill and east of Lacamas Creek and Lacamas Lake. Elsewhere, these older rocks are buried beneath weakly to well-consolidated Neogene and younger basin-fill sedimentary rocks and Quaternary volcanic rocks. The Portland Basin is part of the Puget-Willamette Lowland that separates the Cascade Range from the Oregon Coast Range (fig. 1). The Portland 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). Young geologic units in the Camas map area record a variety of processes and events, including cataclysmic Columbia River flooding from glacial Lake Missoula at the end of the last glaciation, landslides, volcanic debris flows (lahars) and river aggradation triggered by eruptions of Mount Hood, Columbia River floodplain aggradation in response to post-glacial sea level rise, and deposition of wind-blown sediment.

This map is a contribution to a program designed to improve geologic knowledge of the Portland Basin region of the Pacific Northwest urban corridor, the densely populated Cascadia forearc region of western Washington and Oregon. Better and more detailed information on the bedrock and surficial geology in this rapidly growing region of the basin and its surrounding area will allow for refined 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).

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 (1957, 1963) mapped the Portland metropolitan area at a scale of 1:62,500, described the geology, 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 Camas 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 provided detailed descriptions of the basin-fill deposits.

Phillips (1987) compiled a geologic map of the Vancouver 30'x60' quadrangle, which includes the Camas 7.5' quadrangle, at 1:100,000 scale as part of the state geologic map 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 Tertiary 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, but none of these data were obtained from within this quadrangle.

More recently, Madin (1994) mapped the adjacent Damascus 7.5-minute quadrangle to the south, providing considerable detail particularly regarding geologic structures. He was the first to divide the young volcanic rocks of the Portland area (Boring Lava) into separate units based on geochemistry and K-Ar dates.
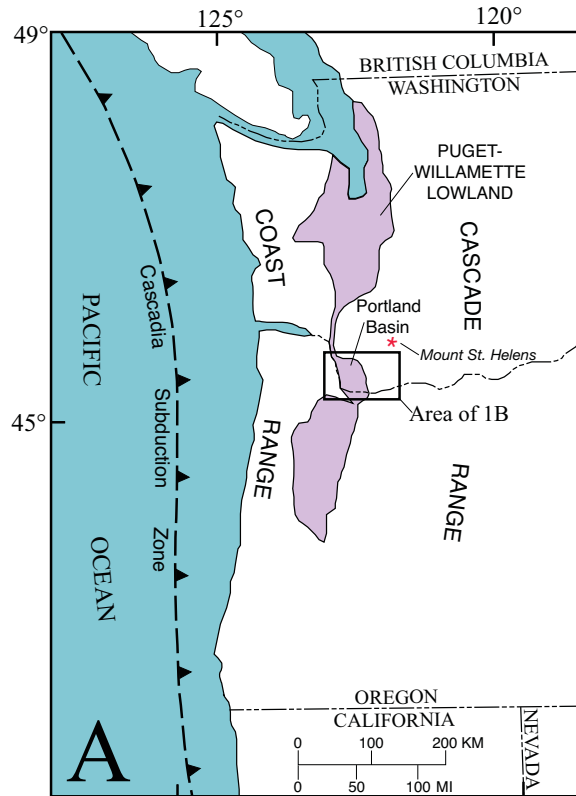
Figure 1A. Regional setting of the Camas quadrangle showing major tectonic and physiographic features of the Pacific Northwest.

Since 1975, considerable effort has been expended to understand the subsurface stratigraphy of the basin fill in the vicinity of the Portland Well Field, an area west of the Sandy River between Interstate Route 84 and the Columbia River that was developed as a ground-water source by the City of Portland Water Bureau (Hoffstetter, 1984; Hartford and McFarland, 1989, Bet and Rosner, 1993). Swanson and others (1993) used the detailed stratigraphic relations observed in the well field as the basis for an evaluation of ground-water resources throughout the Portland Basin. They analyzed lithologic logs of 1500 field-located water wells to produce a set of maps that show the elevations and thicknesses of hydrogeologic units throughout the basin, thus constructing a rough 3-dimensional view of the subsurface stratigraphy of the basin fill.

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, Lite, 1992; Gates, 1994). Allen (1975) discussed the Quaternary volcanic rocks, some of which were analyzed and dated by Conrey and others (1996a). Allison (1978), Waitt (1996), and Minervini and others (2003) 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. Rapp (2005) mapped and analyzed the Holocene stratigraphy in the area of the Sandy River confluence with the Columbia River. Geophysical investigations that bear on geologic relations in the map area include those of Davis (1987), Ryan and Stephenson (1995), Blakely and others (1995), Pratt and others (2001), and Liberty (2002; written commun., 2006).
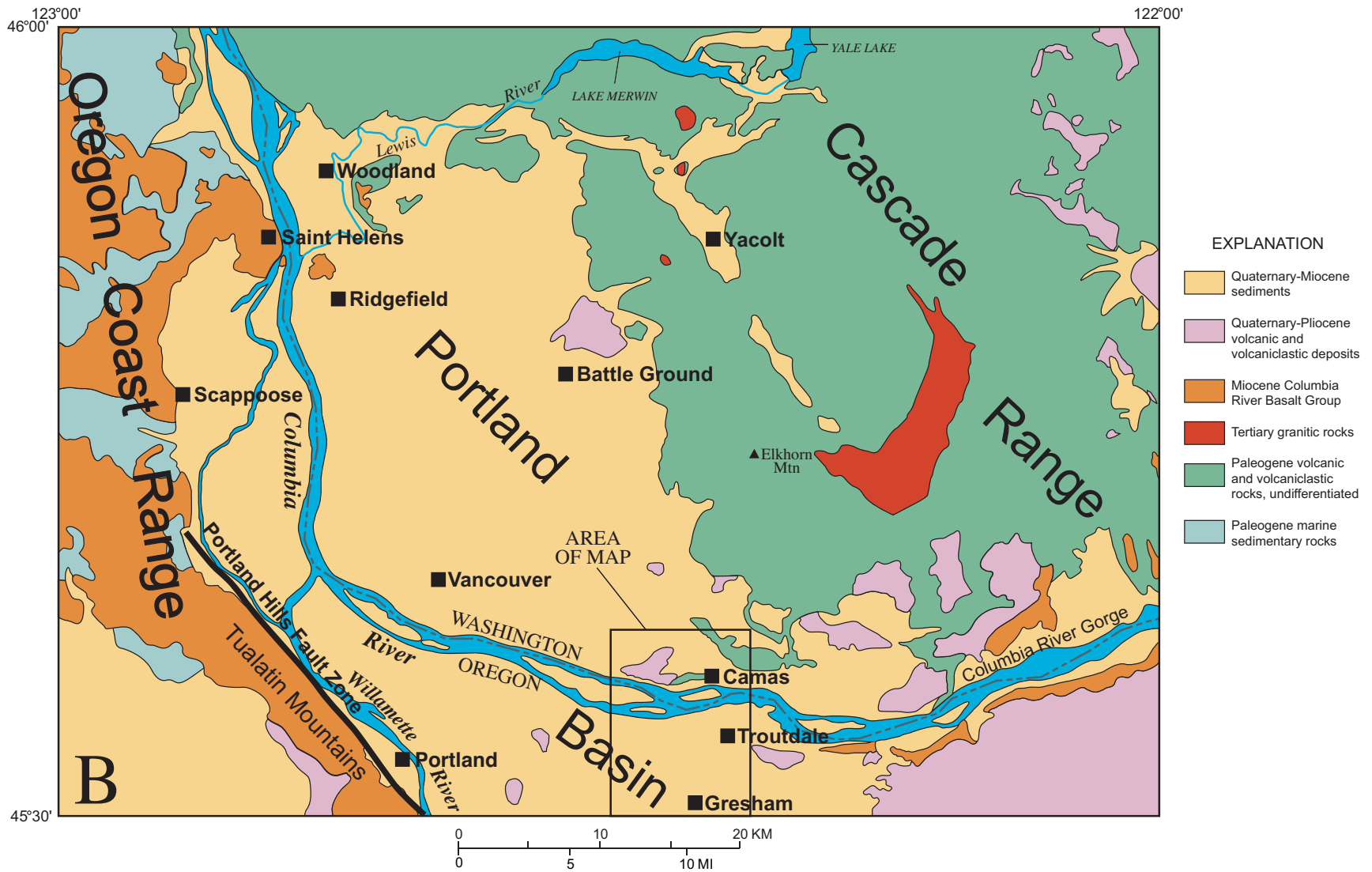
Figure 1B. Simplified geologic map of the Vancouver 30' x 60' quadrangle, modified from Phillips (1987).

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SYNOPSIS OF GEOLOGY

For the past 40 million years, 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. Bedrock exposed in the Camas quadrangle consists of volcanic rocks, predominantly basaltic andesite flows, erupted in the arc during Oligocene time. In most of the map area, this bedrock is buried beneath weakly lithified middle Miocene to Quaternary sediment, most of which was carried into the area by the ancestral Columbia River and accumulated in the slowly subsiding Portland Basin. Quaternary time has been marked by alternating episodes of incision and aggradation, leaving prominent gravel fills and terraces along the Columbia and Sandy Rivers. The depositional pulses, particularly along the Sandy River, were likely associated with alpine glaciations. In latest Pleistocene time, huge Columbia River floods from glacial Lake Missoula inundated the Portland Basin, eroding channels such as the Lacamas Lake trough but also leaving immense bars of sand and gravel and a blanket of sand, silt, and clay in slack water areas. During the late Pleistocene and Holocene sea-level rise associated with deglaciation, the Columbia River aggraded nearly 90

m, filling a deep paleovalley with sand and silt supplemented with volcaniclastic debris that moved down the Sandy River following eruptions of Mount Hood.

Several faults, some potentially active, offset the Paleogene floor of the basin as well as strata of the basin fill. Prune Hill is a block of basement rocks and overlying sediments that has been uplifted along some of these structures. West of Prune Hill, eroded scoria deposits mark the vent of a middle-Pleistocene volcano, one of several dozen late Neogene monogenetic volcanoes that constitute the Boring Volcanic Field of the greater Portland region (Treasher, 1942; Trimble, 1963; Allen, 1975: Fleck and others, 2002).

Geologic exposures are sparse in much of the map area owing to intense weathering, obscuring vegetation, and urban development. Scouring by the Missoula floods left Paleogene bedrock and basin-fill deposits below about 400 ft (120 m) elevation relatively well exposed, and quarries provide good local exposures of basin-fill and Missoula-flood deposits. At higher elevations, however, bedrock is buried beneath thick soils and loess accumulations, and most of the nearly flat-lying basin-fill strata in the map area are buried by flood gravel. Therefore, many contacts are extrapolated on the basis of topography from limited surface observations, and such information was 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. We have not adopted this name because regional mapping has shown it to have limited utility. Neither the top nor the base of the unit were adequately defined, and as used by Trimble the Skamania is simply 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, 1987) 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.

Structural attitudes in Paleogene rocks of the map area are difficult to determine because mappable

sedimentary interbeds are rare, and the commonly well-developed platy parting within flows tends to vary erratically over short distances. In places, however, individual flows can be traced laterally and indicate that these rocks generally dip 0 to 15° to the south or southeast.

BASALTIC ANDESITE OF ELKHORN MOUNTAIN

Most of the Paleogene rocks exposed in the Camas quadrangle are assigned to an informal unit, the basaltic andesite of Elkhorn Mountain (Tbem). This unit consists largely of tholeiitic basaltic andesite and basalt flows with sparse, thin, volcaniclastic interbeds. This package of flows extends from Lady Island northward nearly to Amboy, about 19 km north of the map area (Evarts, 2005, 2006a, b), and has a maximum thickness of at least 800 m. Individual flows are typically 4 to 10 m thick but locally reach 70 m thick. The flows 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 deposits, with no pillow lavas or other indications of subaqueous environments. Only one dike was found in the map area, and dikes are similarly rare to the north (Evarts, 2005, 2006 a, b). The basaltic andesite of Elkhorn Mountain probably formed the flank of a large mafic shield volcano that was centered northeast of the Camas 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. Extremely 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 low-silica andesite, but most are basaltic andesite (table 1); they are uniformly tholeiitic, with low to medium potassium contents (fig. 2). The densely plagioclase-phyric basalts exhibit exceptionally high Al_2O_3 contents (as high as 21 wt percent) that correlate with the abundance of plagioclase phenocrysts (fig. 3a). Rocks with more than about 18 percent Al_2O_3 almost certainly accumulated plagioclase crystals prior to eruption, and most basalts in the unit were actually basaltic andesite liquids that contained excess feldspar crystals (fig. 3b). Compared to mafic flows elsewhere in the southern Washington Cascade Range (duBray and others, 2006; R.C. Evarts, unpub. data), the Elkhorn Mountain flows are relatively rich in Fe (about 10.2 to 13.3 wt percent FeO* for sparsely phyric flows that approximate liquid compositions; fig. 3c) and poor in Sr (generally less than 310 ppm Sr; fig. 3d). Incompatible-element ratios such as Ba/Nb (about 10-20), Ba/Zr (about 1.5), and Zr/Nb (about 13.5) are constant throughout the suite, suggesting that the lavas are related primarily by fractional crystallization processes (Evarts, 2005, 2006a, b).

An incremental-heating $^{40}Ar/^{39}Ar$ plateau age of 25.5 ± 0.2 Ma was obtained for plagioclase in a lava flow north of Camas Slough, near the stratigraphic top of the basaltic andesite of Elkhorn Mountain (table 2). $^{40}Ar/^{39}Ar$ ages for this unit north of the Camas quadrangle range between 26.4 ± 0.1 and 27.1 ± 0.1 Ma (Evarts, 2006a, b). Collectively, these results indicate that most of the basaltic andesite of Elkhorn Mountain was emplaced between 27 and 25.5 Ma.

OTHER VOLCANIC AND VOLCANICLASTIC ROCKS

Andesite and dacite flows

The southernmost outcrop of Paleogene bedrock in the Camas quadrangle consists of porphyritic andesite (Ta, table 1, no. 24) that forms the islands of Ione Reef. A very platy, sparsely phyric dacite (Td, table 1, no. 25) crops out on Lady Island a short distance to the northeast. The stratigraphic relation of these isolated flows to the basaltic andesite of Elkhorn Mountain is uncertain, but the general southeasterly dips of structural attitudes in the map area indicates the more silicic flows most likely overlie the basaltic andesites. The chemistry of the andesite and dacite is consistent with an origin as silicic differentiates of the Elkhorn Mountain mafic magmas (fig. 2).

Tuff breccia and lapilli tuff

A section of stratified lithic tuff breccia, lapilli tuff, and minor tuff (Tmv) crops out on the bank of the Columbia River north of the west tip of Lady Island. This section, at least 50 m thick, is truncated on the east by a normal fault and is covered on the west by Quaternary deposits. The upper part of the unit, overlain by a basaltic andesite flow, is well exposed in roadcuts on State Route 14 west of the bridge over Camas Slough. Angular fragments of dense to scoriaceous basalt and basaltic andesite dominate the clast population, and broken crystals of plagioclase are abundant in the fine-grained fraction. The lithic clasts resemble associated Elkhorn Mountain flows. The beds are well indurated owing to cementation by calcite, clay, and zeolites; scoriaceous clasts are completely
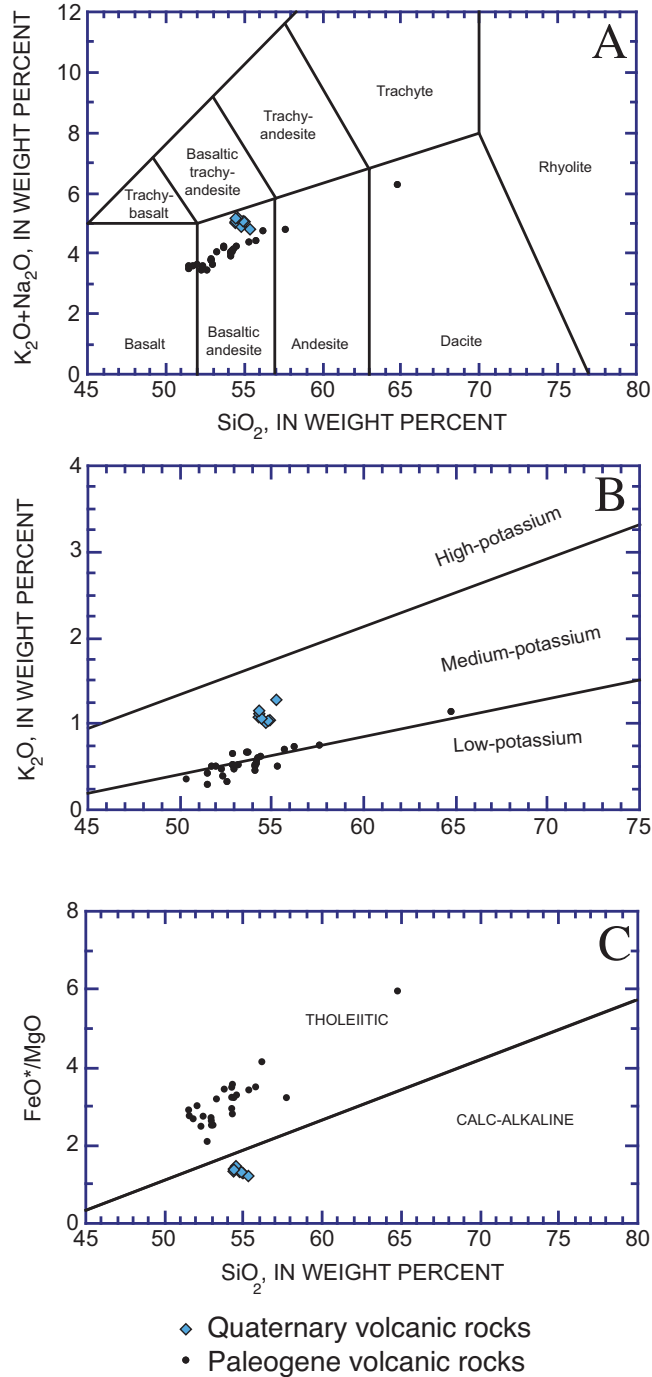
Figure 2. Chemical characteristics of volcanic rocks from the Camas 7.5' quadrangle (analyses recalculated volatile-free). A, K_2O+Na_2O versus SiO_2, showing IUGS classification (Le Maitre, 2002); B, K_2O versus SiO_2, showing low-, medium-, and high-potassium fields extrapolated from Gill (1981, p. 6); C, FeO*/MgO versus SiO_2, showing classification into tholeiitic and calc-alkaline rocks according to Miyashiro (1974). FeO*, total Fe as FeO.

replaced by palagonite. The unit is interpreted as mafic Elkhorn Mountain volcano. Local variations in bedding orientation probably reflect post-eruptive slumping or minor downslope transport.

A poorly exposed interval of volcaniclastic rocks (Tvs) is present within the basaltic andesite of Elkhorn Mountain east of Lacamas Creek. Roadcuts and excavations in that area reveal weathered, massive, poorly sorted tuff and lapilli tuff composed of angular to subrounded pumiceous and lithic volcanic clasts. Their textural and compositional characteristics indicate these are primarily debris-flow deposits.

METAMORPHISM AND HYDROTHERMAL ALTERATION

Paleogene rocks in the Camas 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

pyroclastic debris from an explosive eruption of the Swanson, 1994). This region-wide metamorphism reflects burial of the 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; associated 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 may display partial alteration to clay minerals and (or) zeolites along fractures and cleavage planes. Olivine phenocrysts in the basalts and basaltic andesites are totally replaced by smectite with or without hematite and calcite. Primary pyroxenes and Fe-Ti oxides are largely unaffected by the zeolite-facies metamorphism. Volcaniclastic rocks of unit Tvs are pervasively altered to clay minerals and zeolites.
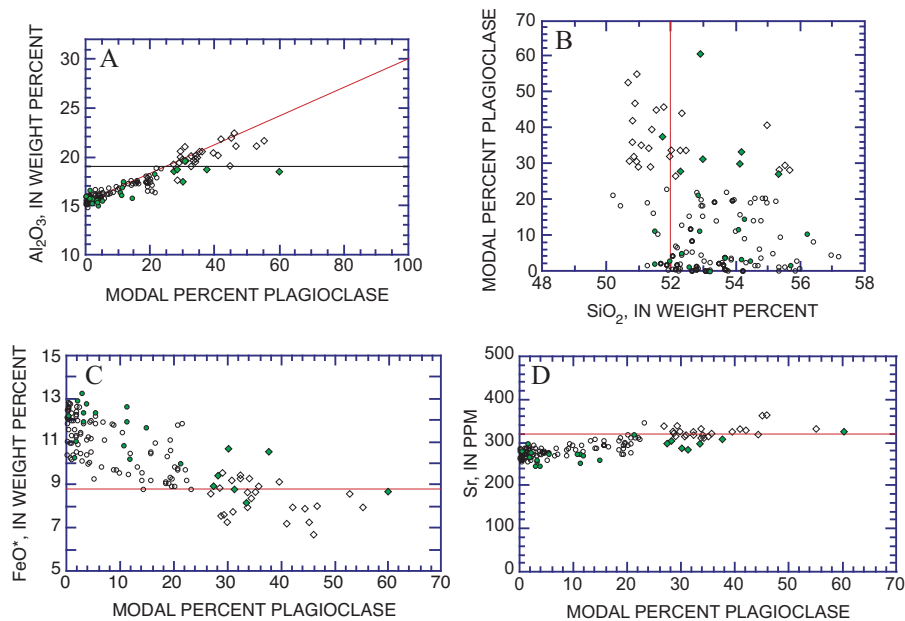
Figure 3. Chemical characteristics of lavas in the basaltic andesite of Elkhorn Mountain (Tbem), illustrating the effects of plagioclase accumulation. Filled symbols designate samples from Camas quadrangle, unfilled symbols designate samples from adjacent areas; strongly plagioclase-accumulative samples, shown as diamonds, contain more than 25 percent plagioclase phenocrysts. *A*, Al_2O_3 versus abundance of plagioclase phenocrysts, showing that the lavas plot along a plagioclase-accumulation line (shown in red) that projects to the composition of a calcic labradorite (about 30 wt percent Al_2O_3); *B*, SiO_2 versus abundance of plagioclase phenocrysts, showing that many basalts (SiO_2 less than 52 wt percent) are strongly plagioclase-accumulative lavas; *C*, FeO* versus abundance of plagioclase phenocrysts, showing that FeO* contents of most non-accumulative lavas (<10 percent plagioclase phenocrysts) are greater than 9.0 wt percent; FeO*, total Fe as FeO; *D*, Sr versus abundance of plagioclase phenocrysts, showing that Sr contents of non-plagioclase accumulative lavas are mostly less than 320 ppm.

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BASIN-FILL DEPOSITS[1]

As the Portland Basin gradually subsided during the late Miocene and Pliocene, 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. Previous workers (Wilkinson and others, 1946; Lowry and Baldwin, 1952; Trimble, 1957; Mundorff, 1964; Tolan and Beeson, 1984; Howard, 2002) have generally mapped this fill as the Troutdale Formation, which was named by Hodge (1938) for exposures near Troutdale, Oregon. Throughout most of the Portland Basin, the older part of this nonmarine section rests unconformably on Paleogene bedrock or the Miocene Columbia River Basalt Group, and consists predominantly of fine-grained beds quite different than the coarse-grained sandstone and conglomerate that typifies the Troutdale section in the type area. 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, while retaining the name Troutdale Formation for the overlying sandstone and conglomerate. He also noted that the youngest conglomeratic beds south of the Columbia River included volcanic debris flow deposits and consisted largely of clasts derived from the nearby Cascade Range rather than sediment transported from the east by the Columbia River. He mapped these beds as the Springwater Formation of probable Pleistocene age (Trimble, 1963). Similarly, on the basis of position and clast composition, Howard (2002) and Evarts (2004a, c, d, 2006b) distinguished a separate late Pliocene or Pleistocene conglomerate unconformably overlying the Troutdale Formation. These deposits, previously included in the Troutdale, are locally overlain by mafic volcanic rocks, the Boring Lava of Treasher (1942), which erupted from scattered local centers in Quaternary time.

Recent studies have shown that stratigraphic relations within the basin fill of the eastern Portland Basin are considerably more complex than portrayed by Trimble (1963) and Mundorff (1964). These complications are well illustrated in the vicinity of the Portla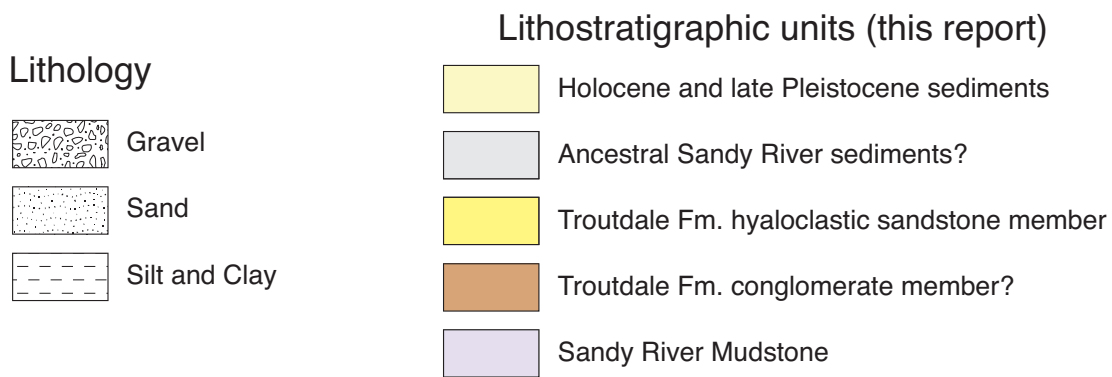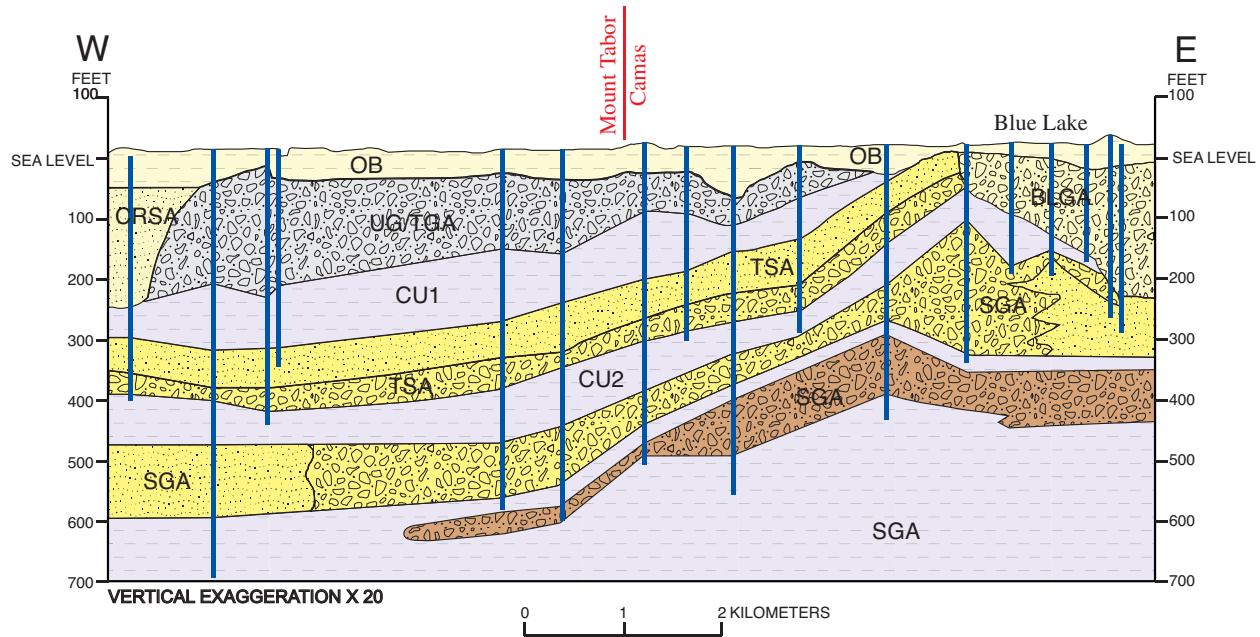nd Well Field (fig. 4), where it is evident that the stratigraphic intervals previously mapped as Troutdale Formation and Sandy River Mudstone are interbedded, and rapid facies changes related to alternating periods of deposition and incision and a general downstream fining of average grain size are apparent (Hogenson and Foxworthy, 1965; Hoffstetter, 1984; Swanson, 1986; Hartford and McFarland, 1989; Swanson and others, 1993; Bet and Rosner, 1993; Koreny and Fisk, 2000). Figure 5 shows a comparison of our nomenclature with the schemes employed by previous workers; these relationships are discussed in more detail below.

SANDY RIVER MUDSTONE

The Sandy River Mudstone 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 by 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 (Treasher, 1942; Chaney, 1944; Trimble, 1963; Tolan and Beeson, 1984). Trimble interpreted the Sandy River Mudstone as a lacustrine deposit but sedimentary structures indicate deposition in low-energy fluvial or overbank settings.

Strata lithologically similar to the Sandy River Mudstone crop out at several localities in the map area but are too small and discontinuous to map; they intertongue and are mapped with coarse-grain beds assigned to the hyaloclastic sandstone member of the Troutdale Formation (Ttfh). Well logs in the Portland Well Field (Hoffstetter, 1984; Hartford and McFarland, 1989; Swanson and others, 1993) show that several fine-grained intervals, forming aquitards or confining units, are interbedded with sandstone and conglomerate in the shallow subsurface (fig. 4). The fine-grained beds, which we consider tongues of the Sandy River Mudstone, become more abundant to the west and may be more than 300 m thick near the west boundary of map area (Swanson and others, 1993). The uppermost confining unit (CU1 in fig. 4) is probably equivalent to a 7–15-m-thick interval of leaf-bearing beds below Broughton Bluff that Trimble (1963) mapped as Troutdale Formation. A likely correlative section exposed at the mouth of Beaver Creek contains multiple paleosols developed in very fine felsic sand as well as a thin volcanic debris flow. A lower confining unit (CU2 in fig. 4) probably corresponds to the Sandy River Mudstone that Trimble (1963) mapped along the Sandy River southeast of the Camas quadrangle. Similar fine-grained sediments, not mapped separately due to limited exposure, are interbedded with

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[1] The distinction between basin-fill and surficial fluvial deposits is necessarily somewhat arbitrary. Deposits mapped as basin fill in this report are relatively widespread, voluminous, and typically bear no direct relation to modern drainage. Surficial deposits include unconsolidated late Quaternary sediments with distributions restricted to modern stream valleys (Qa, Qac, Qh, and terrace deposits) and the widespread but relatively thin cataclysmic-flood deposits (Qfg, Qfs).

Figure 4. Cross section along the south shore of the Columbia River, after Hartford and McFarland (1989), showing stratigraphic relations of basin-fill deposits in the Portland Well Field and correspondence between lithologic, hydrogeologic and lithostratigraphic nomenclature as discussed in text. Vertical blue lines denote wells along profile. Depth to basin floor is unknown; nearby wells penetrate 1100 ft of fine-grained beds without reaching bedrock. Note that the Troutdale gravel aquifer (TGA) consists of deposits that postdate the Troutdale Formation as defined in this report. The Blue Lake gravel aquifer (BLGA) probably consists of the gravel facies of Missoula-flood deposits. The Columbia River sand aquifer (CRSA) consists of Holocene sediments that fill the Pleistocene channel of the Columbia River (Gates, 1994; Pratt and others, 2001). Overbank deposits (OB) are modern Columbia River floodplain sediments. Correlations near east end of the profile are uncertain owing to vertical displacement on the Blue Lake Fault, which obliquely crosses the profile in this area.

hyaloclastic sandstone on Prune Hill and east of Lacamas Lake.

The only direct age information for the Sandy River Mudstone comes from late Pliocene paleofloras obtained from the upper part of the formation (Chaney, 1944; Treasher, 1942; Trimble, 1963; Tolan and Beeson, 1984); one of these sites is directly below Broughton Bluff (Trimble, 1963 and unpub. field notes). The unit largely postdates the Columbia River Basalt Group (Trimble, 1963; Tolan and Beeson, 1984; Madin, 1994, 2004; Mabey and Madin, 1995) although the lowest beds were invaded by the 15.6-Ma Grande Ronde Basalt near Woodland, Washington (Evarts, 2004a).

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 as mapped by Tolan and Beeson (1984) in the western Columbia River Gorge.

Conglomerate member

The conglomerate member (Ttfc) crops out only in the valley wall of Little Washougal River near the northeast corner of the map area but is widespread to the north and east (Evarts, 2004a, d, 2006a, b; R.C. Evarts, unpub. mapping). It is unconformably overlain by a younger but similar conglomerate (QTc); the location of the contact is inferred from relations in adjacent areas (Evarts, 2006b; R.C. Evarts, unpub. mapping). Water-well logs indicate the conglomerate member is underlain by the Sandy River Mudstone.

The Troutdale Formation conglomerate member consists of weakly to moderately cemented pebble and cobble conglomerate and 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 the massive to crudely stratified beds, clast-support, moderate to good sorting, and clast imbrication, are consistent with deposition during high flow in a large, perhaps braided, gravel-bed river system (Miall, 1977, 1996; Rust, 1978).

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 of basaltic hyaloclastic debris, called yellow grit, tuffaceous sandstone, or vitric sandstone by previous workers (Williams, 1916; Hodge, 1938; Lowry and Baldwin, 1952; Trimble, 1963; Tolan and Beeson, 1984). Similar strata underlie eastern Camas and are well exposed in lower Lacamas Creek, along the shores of Lacamas Lake, and south of the Columbia River near Blue Lake and along Interstate 84. Hyaloclastic sediment also constitutes prominent intervals at depth in the Portland Well Field (fig. 4) (Hoffstetter, 1984; Swanson, 1986; Hartford and McFarland, 1989; Swanson and others, 1993; Bet and Rosner, 1993). The hyaloclastic sediment is generally coarse 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 contain 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 interbedded with the hyaloclastic sandstone and locally, as in the type area along the Sandy River, are predominant. Many conglomerate beds are well sorted and consist largely of well-rounded cobbles and pebbles of dark gray to black 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 source areas in eastern Washington and Idaho are minor but persistent components. Rounded to subangular cobbles and boulders of variably vesicular olivine- and plagioclase-phyric basalt are abundant in some conglomerates. These beds tend to be lensoidal, poorly sorted, and possess a matrix of basaltic sand compositionally similar to the associated sandstone beds, and resemble hyperconcentrated flood-flow deposits as described by 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.
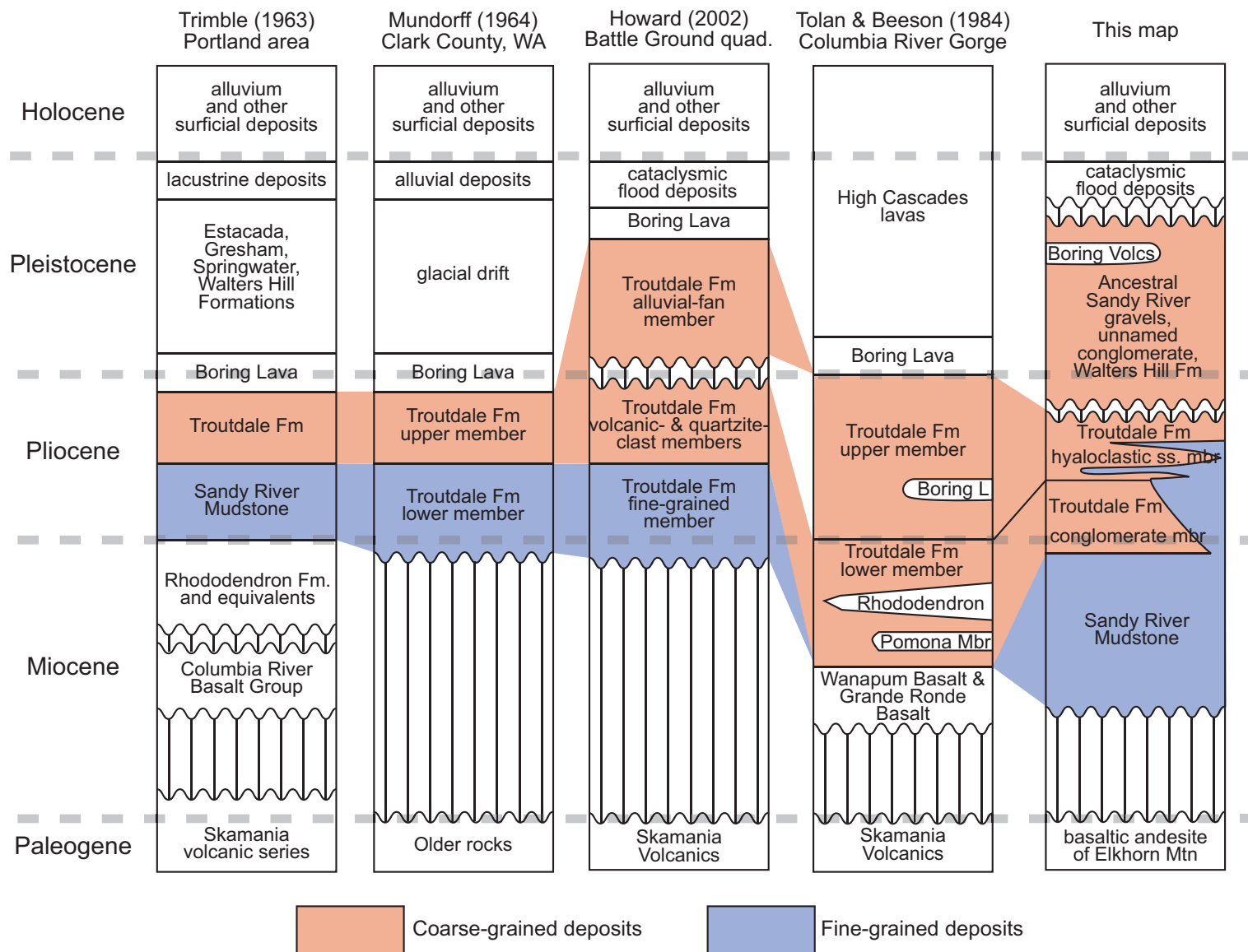
10

Figure 5. Comparison of stratigraphic nomenclature and age assignments for Neogene basin-fill units of the Portland Basin and vicinity.

However, the textural immaturity, poor sorting, and nearly monolithologic character of many beds suggest relatively short transport distances in a river system highly loaded with such sediment and rapid deposition. Following Trimble (1963), Tolan and Beeson (1984), and Swanson (1986; 1988), we interpret these sediments as hyaloclastic debris generated by basalt flows entering the ancestral Columbia River upstream from the map area. This voluminous debris was swept downstream and aggraded the eastern Portland Basin; its distribution (Swanson and others 1993) indicates that the ancestral western Columbia River valley was considerably wider than the present gorge. The north side of this paleovalley is visible in lower Lacamas Creek where hyaloclastic sandstone and conglomerate are banked against a steep wall of eroded Oligocene rocks. Paleocurrent directions inferred from steep foreset bedding and clast imbrication measured in the Sandy River (Cole, 1983) and Lacamas Creek valleys indicate transport to the north and north-northwest in the northern part of the paleovalley.

Tolan (1982) and Tolan and Beeson (1984) mapped a section of Troutdale Formation conglomerate and sandstone more than 335 m thick in the western Columbia River Gorge and observed that the distinctive hyaloclastic sandstone beds were restricted to the upper 75 m of the section, and on this basis divided the Troutdale Formation into informal upper and lower members (fig. 5). Their upper member is correlative with our hyaloclastic sandstone member (Ttfh). Tolan and Beeson (1984) also suggested that the contact between their members was equivalent to the Troutdale Formation–Sandy River Mudstone contact mapped by Trimble (1963, p. 34) along the Sandy River southeast of the Camas quadrangle. However, the fine-grained beds mapped as Sandy River Mudstone by Trimble can be traced in the subsurface to the Portland Well Field, where they overlie hyaloclastic sandstone and conglomerate (fig. 4) (Swanson, 1986; Hartford and McFarland, 1989; Swanson and others, 1993). Hence, as noted above, the Sandy River Mudstone mapped by Trimble is actually a tongue of fine-grained beds within the hyaloclastic sandstone-bearing sequence. This tongue (CU2 in fig. 4) separates two intervals dominated by hyaloclastic debris (TSA and upper part of SGA in fig. 4) 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 to the base of the lower hyaloclastite-rich interval (fig. 5). The total thickness of the hyaloclastite-bearing section in the Portland Well Field is approximately 125 m (fig. 4) (Swanson, 1986; Hartford and McFarland, 1989; Swanson and others, 1993) and is correlated with the 140-m-thick hyaloclastic sandstone member (Ttfh) mapped in the Prune Hill–Lacamas Lake area.

Chemical analyses (Swanson, 1986; Andrei Sarna-Wojcicki, written commun., 2005) show that the vitric clasts in the hyaloclastic sandstone and the olivine+plagioclase-phyric basalt cobbles in the associated conglomerate (table 1, no. 34) both possess a low-potassium tholeiite composition, similar to basalt flows in the Cascade Range but unlike locally erupted lavas in the Boring Volcanic Field (Swanson, 1986; R.C. Evarts and R.M. Conrey, unpub. data). Their chemistry thus suggests that the sediments are genetically related to the compositionally similar lava flows erupted to the east (Tolan and Beeson, 1984; Swanson, 1986; R.C. Evarts and R.M. Conrey, unpub. data), several of which have yielded late Pliocene radiometric ages (2.8 to 3.5 Ma; Conrey and others, 1996a, b; R.J. Fleck, written commun., 2006).

WALTERS HILL FORMATION

Trimble (1963) gave the name Walters Hill Formation to a sequence of deeply weathered, generally coarse-grained fluvial deposits that form a group of hills south of Gresham. The most northerly of these hills is Grant Butte at the southern quadrangle boundary. This unit (QTwh) is poorly exposed in the map area, but most clasts exposed in roadcuts ascending Grant Butte are deeply weathered porphyritic andesites of Cascadian provenance. Trimble (1963) described poorly indurated, weathered gravel and debris-flow deposits, locally interbedded with sandstone, as thick as 300 ft (90 m) south of the map area. Hill summits are between 650 and 1000 ft (200 and 300 m) elevation and the hills are probably erosional remnants of an alluvial fan or bajada extending west or northwest from the Cascade Range. These sediments were mapped as Springwater Formation by Madin, (1994) in the Damascus quadrangle to the south, but they grade to a distinctly higher level than the Springwater Formation in its type area (Trimble, 1963), although the elevation difference could reflect unrecognized structural deformation. The age of the Walters Hill Formation is poorly constrained but deposits that were mapped as Walter Hill Formation by Trimble (1963) in the Gladstone quadrangle to the southwest appear to be interbedded with basalts dated at about 1.6 to 1.4 Ma (R.J. Fleck, written commun., 2002).

UNNAMED CONGLOMERATE

Evarts (2004a, c, d, 2006b) mapped an unnamed conglomerate unit (QTc) north and northwest of the Camas quadrangle that is 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, is

commonly more poorly sorted, and forms an extensive geomorphic bench (mostly capped by Missoula Flood sediment) within the Portland Basin. Beds of weathered conglomerate that overlie the hyaloclastic sandstone member of the Troutdale Formation on Prune Hill and underlie much the area east of Lacamas Lake are assigned to this unit. The unnamed conglomerate unit is also present in the Portland Well Field (UG/TGA in fig. 4), where it overlies the Troutdale Formation (Ttfh) and Sandy River Mudstone (Tsr) along an erosional unconformity (Hartford and McFarland, 1989; Swanson and others, 1993; Bet and Rosner, 1993). In the map area, the unnamed conglomerate is as thick as 90 m. Except where severely eroded by Pleistocene cataclysmic floods, the upper several meters of the unit is deeply weathered. The unnamed conglomerate is probably of latest Pliocene to early Pleistocene age because it overlies the hyaloclastic sandstone member of the Troutdale Formation and is overlain by the basaltic andesite of Prune Hill, which is about 595 k.y. old (table 2). The elevation, age, and depositional setting of the unnamed conglomerate (QTc) and the unnamed fan gravel (QTfg) are similar, suggesting that both reflect periods of regional Columbia River aggradation coincident with widespread piedmont deposition of Cascadian volcaniclastic detritus.

UNNAMED FAN GRAVEL

The distal edge of a broad, west-northwest-sloping, moderately dissected piedmont extends into the southeasternmost part of the map area. Where exposed along Division Street west of Beaver Creek, the deposits (QTfg) beneath this surface consist of weathered fluvial gravel of Cascade Range provenance interbedded with lithic-rich sand and matrix-supported diamicts, which contain angular hornblende-andesite clasts up to 1m in diameter. These deposits are 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 associated with aggradation of an 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. The unnamed fan gravels therefore probably predate the basaltic andesite, which has an ^{40}Ar/^{39}Ar age of 1.28 Ma (R.J Fleck, written commun., 2003).

GRAVEL WEST OF GRESHAM

An isolated flat-topped hill 2 km west of Gresham along the southern map edge is underlain by fluvial gravel (Qgwg). Temporary construction excavations up to 4 m deep show cobble gravel overlain by less than 1 m of silt. Most clasts are rounded to well-rounded with maximum intermediate diameters less than 20 cm. Clasts are mostly andesites and other Cascade Range rock types. The clasts are relatively fresh; weathering rinds on fine-grained volcanic rocks are thinner than 5 mm. The matrix is strongly oxidized silt and clay.

The stratigraphic relation of this gravel to other fluvial deposits in the map area and surrounding terrain is uncertain. Clast composition and location suggest deposition by an ancient Sandy River, perhaps in conjunction with regional aggradation associated with Cascade Range alpine glaciation, but correlative surfaces are not evident. Its higher topographic position indicates a greater age than the youngest ancestral Sandy River gravel (Qaas) exposed in the MBI gravel pit 1 km northwest of the hill, although it may be a high-standing erosional remnant of one of the deeper gravel units exposed in the pit. Alternatively, the gravel of the hill may be equivalent to that in the pit and has been vertically displaced along faults buried beneath Missoula-flood deposits.

These deposits (Qgwg) were mapped by Trimble (1963) as Springwater Formation, but the minimal silt cover and lack of clast weathering and soil development suggest a much younger age than the deposits of the type area. Madin (1994) mapped the southern part of this hill in the Damascus quadrangle as coarse-grained Missoula Flood deposits, but the common 1-3 mm weathering rinds and lack of typical Columbia River provenance clasts such as Columbia River Basalt and quartzite, indicate instead that the hill is underlain by older deposits of Cascade Range provenance.

ALLUVIUM OF ANCESTRAL SANDY RIVER

A thick gravel section (Qaas) apparently underlies cataclysmic-flood deposits throughout much of the area south of Interstate 84 in Oregon. Although only minimally exposed along Beaver Creek south of Mount Hood Community College, more than 60m of cobbly gravel is well exposed in the large MBI gravel

pit 1 km north of Grant Butte. The gravel beds here are several meters thick, massive to crudely stratified, well sorted, and tabular to slightly west-tapering. Thin sand beds are scattered throughout the gravel but are laterally discontinuous and volumetrically minor. Sharp contacts within the sequence are planar and apparently conformable but are not associated with significant soil profiles, so apparently do not represent large time intervals. We interpret the coarse grain size, apparent rapid deposition, and absence of channel features to indicate deposition on an aggrading braid plain or fan. Clasts in the gravel and sand are dominated by volcanic rocks derived from the nearby Cascade Range, include likely Mt Hood andesites. By contrast, clasts of Columbia River provenance such as Columbia River Basalt Group, granitic rocks, quartzite, quartz and muscovite are uncommon. This composition indicates that the gravels were deposited by a tributary of the Columbia emanating from in the adjacent Cascade Range, most likely the ancestral Sandy River. Clast imbrication indicating deposition by west- to north-flowing currents is consistent with this interpretation.

In the MBI gravel pit, the ancestral Sandy River gravels are overlain by 15 m of cataclysmic flood gravel (Qfg). Where the contact is conformable, the upper part of the Sandy River deposits consists of a fining-up sequence of alternating sand and gravel surmounted by about 1 m of massive, pedogenically altered silt and very fine sand, probably loess. Cobbles directly below the loess(?) have weathering rinds ranging from 1 to 5 mm thick. The weathering characteristics are consistent with an exposure duration of 100 k.y., indicating late Pleistocene deposition, perhaps during a glacial period of enhanced sediment production in the ancestral Sandy River headwaters. The ancestral Sandy River alluvium corresponds in part with terraces that were mapped by Trimble (1963) as Estacada Formation along the Sandy River southeast of the map area (J.E. O'Connor, unpub. mapping).

VOLCANIC ROCKS OF THE BORING VOLCANIC FIELD

The Boring Volcanic Field (Fleck and others, 2002) consists of several dozen late Pliocene to Quaternary monogenetic vents and associated lava flows scattered throughout the greater Portland area (Treasher, 1942; Trimble, 1963; Allen, 1975). Lava compositions are diverse but predominantly mafic. The products of two Boring volcanoes are present in the Camas quadrangle (Qbph and Qbbb); both exhibit calc-alkaline compositions that are typical of volcanic-arc magmas (fig. 2).

Thick deposits of variably agglutinated scoria on the west flank of Prune Hill, associated with a strong positive aeromagnetic anomaly, mark a Quaternary volcanic vent. At approximately 595 ka (table 2), lava

flows of olivine-phyric basaltic andesite (Qbph) erupted from this center and flowed about 2 km to the north and west and an unknown distance to the south, burying unweathered gravel (presumably in the contemporary channel of the Columbia River) at an elevation of 150–170 ft (45–55 m). Late Pleistocene cataclysmic floods severely eroded the cinder cone and undercut and removed the southern part of the associated flow field.

An older basaltic andesite flow (Qbbb) crops out at the top of Broughton Bluff above the Sandy River. It overlies the hyaloclastic sandstone member of the Troutdale Formation and probably erupted from a vent located at Chamberlain Hill, about 3 km east of the bluff. A sample collected just east of the map area yielded an ^{40}Ar/^{39}Ar age of 1.282±0.014 Ma (R.J. Fleck, written commun., 2003). At 230–250 ft (70–75 m) elevation on Broughton Bluff, the pillowed base of this flow rests on unweathered micaceous sand; this contact presumably marks the position of the Columbia River channel at about 1 Ma.

QUATERNARY ALLUVIAL, EOLIAN, AND MASS WASTAGE DEPOSITS

Surficial deposits in the Camas quadrangle include sediment deposited by the cataclysmic Missoula floods, deposits along the Sandy River related to eruptions of Mount Hood, and various alluvial, eolian, and mass-wastage deposits.

TERRACE DEPOSITS

Sand and gravel deposits that record channel positions older and higher than modern levels border the Sandy, Washougal, and Little Washougal Rivers. Younger, probable late Pleistocene or early Holocene gravel deposits flank the lower Washougal and Sandy Rivers. Gravel deposits along the Washougal River (Qtdw$_l$) underlie a prominent and extensively quarried terrace tread at about 50 ft (15 m) above sea level. Gravel deposits along the lower Sandy River and Beaver Creek, (Qtds) underlie a prominent bench whose surface is between 170 and 190 ft (52 and 58 m) above sea level. In both areas, these deposits are scantly weathered and are not capped by Missoula flood deposits, so must be either latest Pleistocene or Holocene, although the high elevation of the Sandy River gravel suggests a late Pleistocene age is more likely. Both accumulations are thought to represent aggradation while the mouths of their source rivers were impounded by large and coarse Missoula-flood bars, and were left as terraces when the rivers incised the bars. Coarse boulder lags in the channels of both rivers where they pass the margins of Missoula flood bars (Qfg) may be the remnants of such blockages. The Sandy River gravel contains a 1-m-thick bed of gray,

silty gravelly sand bed interpreted as a lahar-runout deposit, indicating that Mount Hood was active at the time sediment was accumulating behind this blockage.

Thin (<5 m thick) gravel deposits (Qtdl) border the Little Washougal River near the northeast corner of the map area. They reflect aggradation in response to blockage of the river by landslides downstream to the east (R.C. Evarts and J.E. O'Connor, unpub. mapping). The ages of the landslides is unknown, but their relatively undissected morphology indicates they are probably late Pleistocene or Holocene.

CATACLYSMIC FLOOD DEPOSITS

During the last glacial maximum in late Pleistocene time, an ice dam at Pleistocene Lake Missoula in western Montana failed repeatedly, each breach generating enormous floods, commonly referred to as the Missoula floods, that coursed down the Columbia River and into the Portland Basin (Bretz, 1925, 1959; Bretz and others, 1956; 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 17 and 12 ka (Waitt, 1994; Benito and O'Connor, 2003; Clague and others, 2003).

The Camas quadrangle is located at the mouth of the Columbia River Gorge, which formed one of the most profound constrictions along the flood route. Because of this constriction, the largest floods achieved tremendous flow velocities in the western gorge, perhaps as great as 35 m/s (Benito and O'Connor, 2003). These high 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 gravel formed, including the prominent bar transected by the Washougal River at Camas, and the 6-km-long, 100-m-high bar extending southwest from Broughton Bluff. Hydrogeologic studies in east Portland also show correlative bouldery gravel up to 68 m thick and extending to 230 ft (70 m) below sea level in the area northeast of Blue Lake (Hoffstetter, 1984; Hartford and McFarland, 1989).

Within the map area, flood flow spread out from the Columbia River valley, sweeping through the Lacamas Lake trough in Washington and winding through remnants of older basin fill and terrace deposits in Oregon. Floodwaters scoured the landscape near Camas, completely denuding Paleogene bedrock and the Troutdale Formation of soil and other surficial material to elevations as high as 400 ft (120 m). On both sides of the river, the floods deposited multiple lenticular gravel sheets, at elevations as high as 370 ft (110 m), which have been extensively quarried for sand and aggregate. In conjunction with decreasing flow velocity, maximum clast diameter diminishes westward (Trimble, 1963), from greater than 7 m at Troutdale (where they provide a significant obstruction to grading and landscaping) to less than 1 m at the western edge of the map area. At Prune Hill, the floods undercut a Pleistocene lava flow (Qbph), leaving a talus-like lag deposit composed of huge (as large as 7 m across), angular, basaltic andesite boulders with interstices occupied by well-rounded pebbles and cobbles; the landslides at Camas may have a similar origin. Later Missoula floods were smaller than earlier ones (Benito and O'Connor, 2003) and were probably confined to the immediate Columbia River valley (the floor of which was about 90 m below modern sea level), but left thin onlapping sequences of sand and gravel on the margins of the older 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, slack-water deposits are found at Grass Valley and Gresham. Exposures in these areas are limited to shallow excavations, which 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 indicate 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). In the Portland Basin, slack-water silts and ice-rafted erratic boulders are found at elevations as high as 400 ft (120 m), and mappable deposits at elevations as high as 300 ft (90 m) (Minervini and others; 2003; Evarts, 2002, 2004a, b, c, d). At least 40 of these floods apparently achieved stages of 115 to 170 ft (35 to 50 m) in the Portland Basin and spilled southward into the northern Willamette Valley, where that many individual beds are preserved in that elevation range (Glenn, 1965; O'Connor and others, 2001).

ALLUVIAL AND LAHAR DEPOSITS DERIVED FROM MOUNT HOOD VOLCANO

The lower Sandy River has been episodically inundated by volcaniclastic debris generated at Mount Hood. Pleistocene terrace-gravel deposits (Qtds) along the Sandy River in the map area contain volcanic debris flow deposits. Additionally, older terrace deposits

along the Sandy River 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). Late Holocene eruptive activity is recorded by stratified sand and gravel and diamictons that crop out from near present Columbia River level (about 3 ft [1 m] above sea level at low flow) to 30-40 ft (9 to 12 m) elevation (Qh). These deposits were produced during the Timberline and Old Maid eruptive periods of Mount Hood (Crandell, 1980), both of which significantly affected the lower Sandy River and nearby Columbia River (Rapp, 2005; T.C. Pierson, unpublished mapping).

The Timberline eruptive period (Crandell, 1980) began about 1500 years ago 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 volcanic debris flows (lahars) that moved down several drainages (Cameron and Pringle, 1986; Scott and others, 1997). 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 an extensive lowland at the mouth of the Sandy River known locally as the Sandy River delta. Charcoal in Columbia River sediment beneath the oldest lahar indicates that all three lahars are younger than 1520±40 ^{14}C yr B.P. (A.D. 430-620; Rapp, 2005). 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 indicates that incision through Timberline-age deposits to near present levels, at least near the Columbia River confluence, was accomplished by 1240±40 ^{14}C yr B.P. (A.D. 690-890; Rapp, 2005).

Following a several-century-long hiatus, during which little sediment accumulated on the uneroded top of Timberline-age deposits but Columbia River overbank deposits filled channels and swales etched into Timberline deposits near the mouth of the Sandy River, renewed volcanic activity at Mount Hood triggered another period of Sandy River aggradation. The Old Maid eruptive period (Crandell, 1980), dated by dendrochronology, began in the 1760s or 1770s and lasted to as late as 1807 (Lawrence, 1948, Cameron and Pringle, 1986, 1987; T. C. Pierson, written commun., 2006). This was a smaller eruptive episode, producing only about one fifth of the clastic debris produced during the Timberline period. Several lahars flowed into and down the Sandy River (Cameron and Pringle, 1987), but none reached the map area. Downstream fluvial transport of Old Maid-age volcaniclastic debris, however, caused up to 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 and, where forming the banks of the present Sandy River, are subject to rapid bank erosion at high flows. Aggradation had probably ceased by the mid 19th century, since there have been no avulsions and little channel shifting in historical time.

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 370 ft (112 m) below present sea level at approximately 13,000 ^{14}C yr B.P. (about 15,000 cal yr B.P.; Baker, 2002). Consistent with this, well records and seismic-reflection profiles in the map area indicate that nearly 100 m of predominantly sand and silt fill a buried late Pleistocene paleochannel that trends eastward across the quadrangle from Government Island to the Portland-Troutdale Airport (Hoffstetter, 1984; Hartford and McFarland, 1989; Gates, 1994; Pratt and others, 2001; Rapp, 2005). Gates (1994) identified fluvially concentrated Mazama tephra (7700 cal yr B.P.) at 45 ft (14 m) below sea level in a boring near Blue Lake.

Sea level rise slowed in the late Holocene, and most deposits above present low-water elevation (about 3 ft [1 m] above sea level) are less than 2000 years old (table 3). 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 above 30 ft (10 m) elevation are too thin to map. 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. Lady Island is fringed by older bedrock, which has probably anchored accumulations of Columbia River overbank deposits since the river migrated to its present position after the Timberline eruptive period. Radiocarbon dates from lowermost stratigraphic units exposed along the banks of Government Island (table 3) indicate that this island has formed in the last 500 years. McGuire Island has

largely formed during historic time as a result of sand-dike construction.

Holocene alluvium of tributary streams

Thin, areally restricted alluvium and lacustrine deposits (Qa) flank small streams, Lacamas Lake, and small closed depressions in the map area. Although not directly dated, they almost certainly post-date the late Pleistocene Missoula floods. Some of these areas have been modified by diking and draining.

Landslide and talus deposits

Several landslides (Qls), composed largely of debris derived from the Troutdale Formation (Ttfh) and unnamed conglomerate (QTc), have descended the flanks of Prune Hill. Although none are dated, the landslides may have been triggered by undercutting of hillslopes during cataclysmic floods. Talus continues to accumulate below steep cliff faces along the southern edge of Prune Hill and at Broughton Bluff, where Quaternary volcanic rocks overlie weakly consolidated sedimentary rocks.

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 they are mapped only on Prune Hill and east of Gresham, where they are exceptionally thick. These deposits are equivalent to the Portland Hills Silt, a regionally extensive loess deposit found 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 distribution of the loess indicates deposition by easterly winds, which regularly occur in winter when atmospheric high pressure in the interior drives easterly airflow in the Columbia River 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).

STRUCTURAL FEATURES

The Camas quadrangle lies along the east margin of the Portland Basin, part of Puget-Willamette Lowland that separates the Cascade Range to the east from the Oregon and Washington Coast Ranges to the west (fig. 1). The basin began to form in middle Miocene time (Beeson and others, 1989). In contrast to the sharply defined southwest side of the basin (fig.1b), the east and north margins are topographically and structurally complex, reflecting the interplay between local tectonics and Columbia River erosion and deposition.

Oligocene bedrock east of Lacamas Creek dips about 25° southeast, whereas exposures to the north (Evarts, 2006b) and on Prune Hill exhibit lower dips. This suggests the bedrock east of Lacamas Lake forms a fault-bounded block that has been tilted relative to adjacent blocks. This deformation apparently predates deposition of the Troutdale Formation, which is not noticeably tilted in this area.

Neogene basin-fill strata in the Camas quadrangle generally dip about 1° to the west but have been disrupted by uplift of a Paleogene basement block in the Prune Hill area (Swanson, 1986; Swanson and others, 1993; Bet and Rosner, 1993). The Prune Hill uplift, located west of the main Portland Basin margin, is bounded by three faults, the Lacamas Lake Fault on the northeast, the Prune Hill Fault on the northwest, and the Blue Lake Fault on the south.

LACAMAS LAKE FAULT

Many previous workers have suggested that the northwest-trending, elongate basin occupied by Lacamas Lake is controlled by a major fault, which parallels several major northwest-striking structures in northwestern Oregon including the Portland Hills Fault that bounds the southwestern margin of the Portland Basin (fig. 1B; Mundorff, 1964; Davis, 1987; Beeson and others, 1989; Tolan and Reidel, 1989; Beeson and Tolan, 1990; Blakely and others, 1995, 2000). Mundorff (1964) reported slickensides and sheared zones of unspecified orientation in lower Lacamas Creek and inferred a west-side-down normal fault along the northeastern lakeshore. Davis (1987) modeled a gravity profile across the northwest projection of the Lacamas Lake Fault as reflecting a set of steep, down-to-the-west normal faults. Blakely and others (1995) noted an aeromagnetic gradient coincident with the Lacamas Lake Fault, which they interpreted as a dextral strike-slip structure. Beeson and Tolan (1990) consider the fault along Lacamas Lake to be a strand of a larger structure, the Sandy River Fault Zone, with both dextral and dip-slip displacement. The existence of this structure is also supported by the divergence in bedrock attitudes across it, as noted above.

The main trace of the Lacamas Lake Fault is not exposed but Oligocene bedrock in lower Lacamas Creek exhibits pronounced subvertical jointing oriented about N40°W, and minor faults cut bedrock along the northeast side of Lacamas Lake and in lower Lacamas Creek. The orientation of the minor faults suggests they are Riedel shears related to right-lateral movement on the major structure. Northwest of Lacamas Lake, bedrock may deepen to the southwest of the Lacamas Lake Fault (Swanson and others, 1993),

suggesting a component of dip slip, but wells in this area are too shallow to demonstrate this conclusively. We conclude that the Lacamas Lake Fault is primarily a dextral oblique-slip structure with possible minor(?) west-side-down normal(?) displacement.

The segment of the Lacamas Lake Fault east of Prune Hill appears to have a more complex kinematic history. The surface of the unnamed conglomerate (QTc) and the top of the hyaloclastic sandstone member of the Troutdale Formation are both about 100 m higher on Prune Hill than they are east of the fault. Paleogene bedrock (Tbem), however, crops out at about the same elevation, about 550–600 ft (167–182 m), on both sides of the fault. Restoring the inferred post-QTc throw places the surface bedrock approximately 100 m lower on Prune Hill than it is east of the fault, similar to relations observed in water wells north of the Lacamas Lake, as noted above. The relatively recent uplift of Prune Hill appears to have occurred in part along a reactivated segment of the Lacamas Lake Fault, reversing earlier normal offset of bedrock basement.

High-resolution seismic reflection profiles acquired by Pratt and others (2001) along the southeast projection of the Lacamas Lake Fault failed to yield evidence for late Pleistocene or younger deformation. They noted, however, that the fault may be a strike-slip structure with no detectable vertical displacement or that it has not moved significantly since late Pleistocene time.

PRUNE HILL FAULT

A relatively sharp and steep northwestern slope forms the northwest boundary of the Prune Hill block. This slope is in unlikely position to be an erosional scarp, leading us to infer a northeast-striking, northwest-side-down structure, the Prune Hill Fault along its base. The total vertical throw across the fault may exceed 300 m based on the elevation difference of the bedrock surface across it (approximately 600 ft (190 m) on the south side of Prune Hill compared to -420 ft (-130 m) in a well at Grass Valley). Apparent displacement of the unnamed conglomerate (QTc), however, is much less, about 100 m, indicating that considerable movement occurred prior to deposition of QTc or that part of the elevation difference reflects erosional topography rather than structure. The location of the vent of the Prune Hill volcano (Qbph) may owe to the Prune Hill Fault providing a pathway for injection of magma into the shallow crust.

BLUE LAKE FAULT

Several investigators have reported structural disruption of basin-fill sediments in and near the Portland Well Field. Swanson (1986) and Hartford and McFarland (1989) noted that hyaloclastic sandstone beds on the south shore of Blue Lake dip 10–15° southwestward, from which Swanson (1986) interpreted a northwest-trending monoclinal fold between the lake and Prune Hill. Swanson and others (1993) mapped a south-southwest-plunging anticline in the Troutdale Formation south of Blue Lake, whereas Bet and Rosner (1993) postulated an east-west-elongated structural dome in the same area. Bet and Rosner (1993) also suggested that the upturned beds at Blue Lake are truncated to the north by a north-northwest-striking, south-side-down fault with as much as 150 m of vertical separation. Swanson and others (1993) inferred a northwest-trending fault (not shown on their map) along the southwest side of Prune Hill, stating that Paleogene bedrock has been displaced vertically more than 480 m, and hyaloclastic sandstone as much as 150 m, on this structure. The variety of interpretations are not surprising given the difficulty of correlating strata between well logs in an area characterized by complex and rapid facies changes, but the indications of structural disruption are clear. We agree with Swanson and others (1993) and Bet and Rosner (1993) and infer that a major structure, the Blue Lake Fault, bounds the south side of the Prune Hill uplift and places uplifted Paleogene bedrock against the Sandy River Mudstone (Tsr) and the hyaloclastic sandstone member of the Troutdale Formation (Ttfh) (cross section B-B'). The fault is interpreted to extend just east and north of Government Island where seismic reflection experiments reveal a west-side-down offset of the basin floor and structural disruption of the uppermost basin-fill deposits (Pratt and others, 2001; L.B. Liberty, written commun., 2006). We speculate that, west of Prune Hill, this structure truncates the Prune Hill Fault and continues northwest of the map area along a trend marked by a pronounced aeromagnetic lineament (west edge of anomaly III) noted by Blakely and others (1995). The hyaloclastic sandstone beds near Blue Lake may correlate with similar beds located above 500 ft (150 m) elevation on Prune Hill, implying vertical throw of as much as 240 m. Bedrock crops out at sea level north of the fault but is not penetrated by a 335-m-deep well located 1 km west of Blue Lake (Bet and Rosner, 1993), suggesting that offset of the basin floor is even greater, although erosion by the Columbia River may partly account for the elevation difference.

SANDY RIVER FAULT

Beeson and others (1989), Beeson and Tolan (1990), and Blakely and others (1995) inferred the presence of a fault parallel to the Lacamas Lake Fault along the lower Sandy River. If it exists, recent displacement on this fault must be predominantly strike-slip because no vertical offset of Troutdale Formation sediments is apparent from well logs (Swanson and others, 1993). Working in the Sandy

quadrangle southeast 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 also found no evidence for deformation in the overlying sedimentary units. Possibly, the Sandy River Fault originated as a basin-bounding normal fault, but significant vertical motion ceased before deposition of the Pliocene sediment. Subsequent displacement, if any, has been lateral (no boreholes in the map area penetrate deep enough to determine if the bedrock basement floor is similarly offset here). In any case, such a structure cannot simply continue northwestward as previously inferred but must merge with or terminate against the Blue Lake Fault.

OTHER FAULTS

A buried, northwest-striking, unnamed fault is mapped northeast of Lacamas Lake. This fault is inferred from water-well logs indicating that the Oligocene bedrock surface has dropped about 200 m on the northeast (Evarts, 2006b). This fault, which may extend northwest to near Saint Helens, Oregon (Evarts, 2004c, d), forms the southwestern side of a graben-like structure in the bedrock basement (Evarts, 2006b) and, together with Lacamas Lake Fault, bounds a northwestward-narrowing block of uplifted basement rock.

The top of the Oligocene mafic volcaniclastic rocks unit (Tmv) is displaced at least 65 m vertically along a northeast-striking fault near Hassalo Rock. To the northeast, the basal contact of the unnamed conglomerate (QTc) may also be displaced to a lesser extent but exposures are insufficient to demonstrate this. Mundorff (1964) mapped a northeast-striking normal fault in the same area and extended it northeastward to beyond Round Lake. A fault on this alignment may extend along the gully east of Round Lake, as shown on this map, but we find no evidence that this structure links up the fault near Hassalo Rock.

AGE OF DEFORMATION

Subsidence of the Portland Basin and accumulation of its fluvial sedimentary fill occurred throughout late Neogene time. Some of this deformation may have taken place on northwest-striking structures like the Lacamas Lake Fault, which offsets Paleogene basement, and the inferred Sandy River Fault. Differential tilting of Paleogene bedrock across the Lacamas Lake Fault is not seen in the overlying basin-fill deposits, indicating that significant movement along this structure occurred prior to their deposition. In lower Lacamas Creek, the hyaloclastic sandstone member of the Troutdale Formation (Ttfh) is banked against the older rocks along a steep, west-facing, valley wall, the location of which may have been controlled by the Lacamas Lake Fault. The Prune Hill uplift, however, must be a younger feature because both the hyaloclastic sandstone member of the Troutdale Formation and the unnamed conglomerate (QTc) have been affected. The hyaloclastic sandstone is approximately 3–4 m.y. old and the unnamed conglomerate may be as young as early Pleistocene, so most uplift is probably post-Pliocene. The basaltic andesite of Prune Hill has not been noticeably displaced, however, so uplift was largely completed by about 600 ka.

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

GEOLOGIC EVOLUTION

Most Paleogene volcanic bedrock in the Camas 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 large shield volcano. Only one dike and no zones of hydrothermal alteration are present in the map area, indicating that the vent for this large volcano is located outside the quadrangle, probably to the northeast. Age determinations in this and adjacent quadrangles (table 2; Evarts, 2006a, b) show that this volcano was active in Oligocene time, about 27–25.5 Ma. The andesite and dacite flows that overlie 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. The south to southeastward dips of these strata may record mild deformation related to middle Miocene regional folding (Evarts and Swanson, 1994) and (or) to early subsidence of the Portland Basin (Beeson and others, 1989; Beeson and Tolan, 1990). Normal or oblique-slip on the northwest-striking Lacamas Lake Fault may have started at this time.

By late Miocene time, the Portland Basin was subsiding and accumulating mostly fine-grained sediments of the ancestral Columbia River. This sediment, the Sandy River Mudstone, was deposited in low-energy fluvial environments, probably near sea level. Maintenance of this setting throughout Sandy River time and onlap of sediment against eroded Oligocene bedrock indicate that subsidence and accumulation rates were roughly balanced.

In latest Miocene time, the sedimentary regime in the Portland Basin changed dramatically. The low-energy environment recorded by the Sandy River Mudstone was succeeded by progradation of a gravelly

braid plain across the basin. Clast compositions in these Troutdale Formation gravels (Ttfc) indicate transport from terranes east of Cascades by an ancestral Columbia River. This pronounced change in Columbia River sedimentation may record regional uplift and consequent erosion of the Columbia River Basalt Group east of the map area, integration of upstream basin areas, or climate changes resulting in a higher-energy gravel-rich river system. Later, the east side of the Portland Basin was raised and tilted, and the Troutdale gravels were eroded from much of the basin, leaving remnants preserved only on its uplifted eastern flank.

In late Pliocene time, about 4–3 Ma, voluminous basaltic lava flows erupted in the Cascade Range east of the map area (Tolan and Beeson, 1984; Conrey and others, 1996b). Some of these lavas entered the Columbia River and interacted explosively with river water to produce huge quantities of hyaloclastic sediment, which may have temporarily dammed the river. If so, such dams were probably short-lived and the loose hyaloclastic debris was rapidly flushed downriver and deposited in a rapidly aggrading valley bottom, considerably wider than modern gorge, that opened into the eastern Portland Basin (Tolan and Beeson, 1984). Part of the northern edge of this valley has been exhumed in lower Lacamas Creek where massive hyaloclastic sandstone is banked against Oligocene volcanic bedrock. There may have been at least two such events judging from relations in the Portland Well Field where two thick sequences of hyaloclastic sandstone and conglomerate are separated by a section of fine-grained, largely nonvolcanic strata similar to the Sandy River Mudstone. In the well field, the hyaloclastic sandstone beds are now located at depths as great as 150 m below sea level, indicating continuing subsidence of the basin depocenter.

Andesitic volcanism in the northern Oregon Cascade Range during Pliocene and early Pleistocene time generated voluminous debris that was carried westward by lahars in the ancestral Sandy River and Clackamas River drainages. These volcaniclastic flows and associated fluvial deposits built a suite of west-sloping piedmont surfaces along the western flank of the Cascade Range, locally preserved in the map area as the Walters Hill Formation (QTwh) and unnamed fan gravels (QTfg). The unnamed fan gravel may be broadly coincident with (and partly owe to) the aggradation of the Columbia River recorded by the unnamed conglomerate unit (QTc) to the north. Compared to the older Troutdale Formation conglomerate (Ttfc), the unnamed conglomerate contains a higher proportion of volcanic clasts derived from the adjacent Cascade Range. Sometime after deposition of the unnamed conglomerate, Prune Hill was uplifted along the Lacamas Lake, Prune Hill, and Blue Lake Faults.

Beginning about 2.5 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; Fleck and others, 2002). The Camas quadrangle is in the northern part of the volcanic field and contains volcanic rocks of two centers, one located on the west side of Prune Hill in Washington and the other at Chamberlain Hill, about 3 km east of the map area in Oregon. The basaltic andesite of Broughton Bluff erupted at about 1.28 Ma from the vent at Chamberlain Hill. The Prune Hill volcano west of Camas is younger, about 595 ka.

The Camas quadrangle lies beyond the limits of Pleistocene glaciers emanating from the Cascade Range (Crandell, 1980; Mundorff, 1984; Evarts, 2006a), although glacial outwash may be present in the Quaternary gravel deposits in the southern part of the map area and formed terraces flanking the Sandy River (QTfg, Qgwg, Qaas, Qtds), and loess episodically blanketed uplands during glacial periods. The map area was also profoundly affected by the latest Pleistocene glacier-outburst floods from Glacial Lake Missoula (Bretz, 1925; Trimble, 1963; Allison, 1978; Waitt, 1994, 1996; Minervini and others, 2003). Several dozen floods exited the Columbia River Gorge and spread out into the Portland Basin, spilling through the trough now occupied by Lacamas Lake and over the older basin-fill deposits in east Portland. The floods left thick bouldery gravel deposits in large bar complexes on uplands up to 370 ft (112 m) elevation, and deposited slack-water silt and sand in areas of lower flow velocity.

Since the last glacial sea-level low stand of about 370 ft (112 m) below present sea level at about 15,000 cal yr B.P. (Baker, 2002), the Columbia River has aggraded nearly 90 m in the map area to its present low-water elevation of about 3 ft (1 m) and formed the historic floodplain, beach deposits, and mid-channel islands (Qac). Coarse-grained volcaniclastic deposits generated by two late Holocene eruptions of Mount Hood constitute much of the Holocene sediment entering the Columbia River within the map area. Voluminous lahars and eruption-induced alluvium moved down the Sandy River and built out the Sandy River delta. Formation of this delta pushed the Columbia River northward, narrowing the main channel and placing it onto and against the older bedrock of Ione Reef and along the southern edge of Lady Island. Since the early 1900s, much of the historic 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 Columbia River flow regime.

GEOLOGIC RESOURCES

Known geologic resources available in the Camas quadrangle are limited to nonmetallic industrial

materials, chiefly aggregate for road construction and similar purposes (Johnson and others, 2005). Large blocks of the basaltic andesite of Prune Hill have been excavated at the Fisher Quarry for over a century and used to construct jetties, piers, bridge foundations, and roadbeds (Shedd, 1903; Darton, 1909; Landes and others, 1911; Glover, 1936). Both massive and scoriaceous basaltic andesite from this unit have been used for landscaping projects (Huntting, 1960; Trimble, 1963).

The abundant sand and gravel deposits in the Camas quadrangle have long been exploited (Darton, 1909). Several large gravel pits have been developed in the Mill Plain bar near the northwest corner of the map area (Johnson and others, 2005). Large pits between Grant Butte and Fairview in Oregon have excavated through Missoula-flood gravel (Qfg) and into underlying ancestral Sandy River gravel (Qaas) . Smaller operations scattered throughout the quadrangle have obtained sand and gravel from Quaternary alluvium along the Columbia, Sandy, and Washougal Rivers.

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Table 1. Chemical analyses of volcanic rocks, Camas 7.5' quadrangle

[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 $100Mg/(Mg+Fe^{2+})$ with Fe^{2+} set to $0.85x\ Fe^{total}$. Modal analyses, secondary minerals counted as primary mineral replaced. -, not present. 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-T50**	**03CM-T185**	**02CM-T41B**	**02CM-T53**	**02CM-T70A**	**02CM-T69C**	**02CM-T73**	**02CM-T102**	**03CM-T232**
Latitude (N)	45°35.87'	45°37.27'	45°34.69'	45°36.23'	45°37.19'	45°36.95'	45°36.89'	45°35.20'	45°34.92'
Longitude (W)	122°23.77'	122°24.95'	122°26.02'	122°23.67'	122°25.52'	122°25.15'	122°24.89'	122°25.68'	122°26.66'
Map unit	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem
Rock type	Basalt	Basalt	Basalt	Basalt	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite

Analyses as reported (wt percent)									
SiO_2	51.11	51.52	51.52	51.55	52.22	52.01	52.33	52.65	52.90
TiO_2	1.50	1.82	1.34	1.71	1.42	1.78	1.64	1.55	1.39
Al_2O_3	16.94	15.77	18.86	15.58	18.90	15.59	16.61	18.38	18.72
FeO*	12.44	12.98	10.47	13.07	9.43	12.21	10.21	9.93	9.39
MnO	0.19	0.24	0.19	0.27	0.18	0.24	0.20	0.19	0.15
MgO	4.32	4.75	3.90	4.35	3.77	4.46	4.84	3.79	3.77
CaO	9.08	9.22	9.54	8.78	10.39	9.24	10.04	9.15	9.76
Na_2O	3.09	3.33	3.12	3.14	3.02	3.24	3.18	3.30	3.16
K_2O	0.41	0.29	0.49	0.50	0.46	0.39	0.31	0.52	0.64
P_2O_5	0.14	0.19	0.15	0.16	0.14	0.18	0.17	0.17	0.18
Total	99.22	100.11	99.58	99.10	99.93	99.33	99.52	99.63	100.06

Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)									
SiO_2	51.51	51.46	51.74	52.02	52.26	52.36	52.58	52.85	52.86
TiO_2	1.51	1.82	1.35	1.72	1.42	1.79	1.65	1.56	1.39
Al_2O_3	17.07	15.75	18.94	15.72	18.91	15.69	16.69	18.45	18.70
FeO*	12.54	12.96	10.52	13.19	9.44	12.29	10.26	9.96	9.39
MnO	0.19	0.24	0.19	0.27	0.18	0.24	0.20	0.19	0.15
MgO	4.35	4.74	3.92	4.39	3.77	4.49	4.86	3.80	3.77
CaO	9.15	9.22	9.58	8.86	10.40	9.30	10.09	9.18	9.75
Na_2O	3.11	3.33	3.13	3.17	3.02	3.26	3.20	3.31	3.16
K_2O	0.41	0.29	0.49	0.50	0.46	0.39	0.31	0.52	0.64
P_2O_5	0.14	0.19	0.15	0.16	0.14	0.18	0.17	0.17	0.18
Mg#	42.1	43.4	43.9	41.1	45.6	43.4	49.9	44.5	45.7

Modes (volume percent)									
Plagioclase	11.1	1.9	37.4	2.8	28.1	5.2	1.4	21.2	60.2
Clinopyroxene	-	-	-	trace	-	-	-	-	18.4
Orthopyroxene	-	-	trace	-	-	-	-	-	-
Olivine	0.2	trace	2.5	0.2	0.3	0.3	0.2	0.5	1.2
Fe-Ti Oxide	-	-	-	-	-	-	-	trace	2.6
Hornblende	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Groundmass	88.7	98.1	60.1	97.0	71.6	94.5	98.4	78.3	interstit glass:
No. points counted	810.0	775.0	810.0	810	810	810	810.0	810	810
Texture (rock/ groundmass)	porphyritic/ trachytic	sparsely trachytic	porphyritic/ intergranular	sparsely trachytic	porphyritic/ intergranular	seriate/ trachytic	sparsely trachytic	porphyritic/ intergranular	seriate/ intersertal

Trace element analyses (ppm)									
Ba	133	149	138	139	113	173	139	142	177
Rb	5	3	12	12	10	6	2	11	18
Sr	275	277	308	245	306	275	298	318	312
Y	26	29	24	30	24	30	34	24	28
Zr	71	107	88	89	78	101	90	92	110
Nb	6.1	7.0	7.5	7.4	5.8	8.2	6.6	8.2	6.3
Ni	10	8	15	10	12	11	13	9	18
Cu	207	247	144	204	204	205	199	176	136
Zn	102	119	83	114	90	109	107	86	97
Cr	23	28	25	30	38	42	73	16	24

Table 1. Chemical analyses of volcanic rocks, Camas 7.5' quadrangle—Continued

Map No.	10	11	12	13	14	15	16	17	18
Field sample No.	00CM-T16	02CM-T57	02CM-T44	00CM-T02C	02CM-T58A	00CM-T01	03CM-T230	00CM-T17	02CM-T80
Latitude (N)	45°34.22'	45°35.76'	45°35.17'	45°34.78'	45°35.58'	45°34.85'	45°34.85'	45°34.68'	45°34.50'
Longitude (W)	122°24.99'	122°22.86'	122°24.76'	122°26.37'	122°23.00'	122°25.52'	122°25.52'	122°24.22'	122°26.57'
Map unit	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem	Tbem
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite

Analyses as reported (wt percent)

SiO_2	52.96	52.62	52.88	53.58	53.96	54.12	54.26	54.36	53.77
TiO_2	1.52	1.12	1.87	2.05	1.33	1.47	1.47	1.21	1.69
Al_2O_3	16.25	19.61	16.00	15.16	17.60	17.33	17.64	19.90	15.46
FeO*	12.02	8.67	12.11	12.73	10.18	10.75	10.74	8.29	12.16
MnO	0.22	0.18	0.23	0.25	0.21	0.21	0.20	0.17	0.23
MgO	4.41	3.49	3.80	3.73	3.50	3.34	3.10	2.99	3.43
CaO	8.75	9.78	8.23	7.78	8.76	8.71	8.65	9.15	8.09
Na_2O	3.38	3.21	3.57	3.55	3.50	3.50	3.60	3.61	3.55
K_2O	0.51	0.46	0.51	0.66	0.52	0.45	0.49	0.53	0.57
P_2O_5	0.18	0.16	0.17	0.32	0.17	0.15	0.15	0.20	0.20
Total	100.18	99.30	99.37	99.81	99.73	100.02	100.32	100.41	99.15

Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)

SiO_2	52.86	52.99	53.21	53.68	54.11	54.11	54.09	54.14	54.23
TiO_2	1.51	1.13	1.88	2.05	1.34	1.46	1.47	1.21	1.70
Al_2O_3	16.22	19.75	16.10	15.19	17.65	17.33	17.59	19.82	15.59
FeO*	11.99	8.73	12.19	12.75	10.20	10.74	10.71	8.26	12.27
MnO	0.22	0.18	0.23	0.25	0.21	0.21	0.20	0.17	0.23
MgO	4.40	3.51	3.82	3.74	3.51	3.34	3.09	2.98	3.46
CaO	8.73	9.85	8.28	7.80	8.78	8.71	8.62	9.11	8.16
Na_2O	3.37	3.23	3.59	3.56	3.51	3.50	3.59	3.60	3.58
K_2O	0.51	0.46	0.51	0.66	0.52	0.45	0.49	0.53	0.57
P_2O_5	0.17	0.16	0.18	0.32	0.17	0.15	0.15	0.20	0.20
Mg#	43.5	45.8	39.7	38.1	41.9	39.5	37.7	43.1	37.2

Modes (volume percent)

Plagioclase	11.2	31.2	0.2	3.6	11.7	44.5	30.0	33.3	3.2
Clinopyroxene	trace	0.1	-	-	0.3	0.6	0.5	-	0.1
Orthopyroxene	-	-	-	-	-	-	0.3	-	-
Olivine	1.6	1.9	0.1	0.1	0.7	1.9	1.6	1.8	0.5
Fe-Ti Oxide	trace	trace	trace	trace	trace	0.2	0.5	0.4	0.2
Hornblende	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Groundmass	87.2	66.8	99.7	96.3	87.3	52.8	67.1	64.5	96.0
No. points counted	810	810	810	810	810	810	810	810	810
Texture (rock/ groundmass)	seriate/ intergranular	porphyritic/ intergranular	seriate/ trachytic	seriate/ trachytic	glomerophyric/ intergranular	seriate/ intergranular	porphyritic/ intergranular	porphyritic/ intergranular	seriate/ trachytic

Trace element analyses (ppm)

Ba	143	115	143	186	127	147	136	147	152
Rb	12	9	11	13	10	11	11	12	13
Sr	252	284	280	247	270	277	287	300	257
Y	29	25	29	42	28	25	26	28	32
Zr	94	95	86	164	106	82	88	111	109
Nb	7.9	8.0	7.7	13.9	7.8	7.8	5.0	8.7	8.8
Ni	5	6	5	5	4	3	1	4	3
Cu	198	94	158	194	115	163	221	78	235
Zn	100	78	109	124	87	99	105	85	114
Cr	27	24	12	16	24	21	2	11	14

Table 1. Chemical analyses of volcanic rocks, Camas 7.5' quadrangle—Continued

Map No.	19	20	21	22	23	24	25	26	27
Field sample No.	02CM-T62	02CM-T42	02CM-T59	02CM-T66	02CM-T41A	02CM-T79	00CM-T15	99CM-T03	02CM-T24
Latitude (N)	45°34.99'	45°34.71'	45°35.65'	45°35.77'	45°34.66'	45°34.11'	45°34.39'	45°35.15'	45°35.37'
Longitude (W)	122°25.31'	122°25.65'	122°22.58'	122°23.09'	122°26.28'	122°24.56'	122°23.94'	122°28.70'	122°28.26'
Map unit	Tbem	Tbem	Tbem	Tbem	Tbem	Ta	Td	Qbph	Qbph
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Andesite	Dacite	Basaltic andesite	Basaltic andesite

Analyses as reported (wt percent)									
SiO_2	53.84	54.07	55.10	55.25	55.88	57.25	64.74	54.29	54.42
TiO_2	1.77	1.77	1.29	1.89	1.60	1.32	0.84	1.26	1.21
Al_2O_3	15.77	15.53	18.66	15.41	16.34	17.20	15.07	17.22	17.05
FeO*	11.50	11.76	8.90	10.85	10.68	8.51	7.37	7.82	7.43
MnO	0.23	0.23	0.20	0.30	0.23	0.18	0.21	0.13	0.13
MgO	3.60	3.58	2.62	3.09	2.58	2.66	1.24	6.05	6.04
CaO	8.04	7.86	8.23	7.61	7.08	7.17	3.90	7.80	7.70
Na_2O	3.58	3.63	3.90	3.77	4.04	4.04	5.16	3.85	3.91
K_2O	0.59	0.61	0.50	0.68	0.73	0.75	1.15	1.07	1.03
P_2O_5	0.23	0.23	0.18	0.27	0.22	0.25	0.31	0.34	0.32
Total	99.16	99.26	99.58	99.12	99.38	99.32	99.99	99.82	99.25

Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)									
SiO_2	54.30	54.47	55.33	55.74	56.23	57.64	64.75	54.39	54.84
TiO_2	1.79	1.78	1.30	1.90	1.61	1.33	0.84	1.26	1.22
Al_2O_3	15.90	15.65	18.74	15.55	16.44	17.32	15.07	17.25	17.18
FeO*	11.60	11.84	8.93	10.95	10.75	8.57	7.37	7.83	7.49
MnO	0.23	0.23	0.20	0.30	0.23	0.18	0.21	0.13	0.13
MgO	3.63	3.61	2.63	3.12	2.60	2.68	1.24	6.06	6.08
CaO	8.11	7.92	8.26	7.68	7.1	7.2	3.9	7.82	7.76
Na_2O	3.61	3.66	3.92	3.80	4.07	4.07	5.16	3.86	3.93
K_2O	0.60	0.61	0.50	0.69	0.73	0.76	1.15	1.07	1.04
P_2O_5	0.23	0.23	0.18	0.28	0.22	0.25	0.31	0.34	0.32
Mg#	39.6	39.0	38.2	37.4	33.6	39.6	26.1	61.9	63.0

Modes (volume percent)									
Plagioclase	14.6	3.1	27.2	1.7	10.5	18.0	0.9	0.1	trace
Clinopyroxene	0.3	trace	-	trace	-	-	trace	-	-
Orthopyroxene	-	-	-	-	-	0.1	-	-	-
Olivine	0.9	0.4	0.3	0.2	trace	-	0.1	5.0	5.2
Fe-Ti Oxide	0.1	0.1	0.3	trace	trace	trace	trace	-	-
Hornblende	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	trace apatite	-	-
Groundmass	84.1	96.4	72.2	98.1	89.5	81.9	99.0	94.9	94.8
No. points counted	810	810	796	810	810	810	800	800	800
Texture (rock/ groundmass)	seriate/ trachytic	seriate/ intergranular	porphyritic/ intergranular	seriate/ intergranular	porphyritic/ intergranular	seriate/ intergranular	sparsely phyric pilotaxitic	porphyritic/ trachytic	porphyritic/ trachytic

Trace element analyses (ppm)									
Ba	160	168	143	192	210	173	301	426	416
Rb	13	14	11	15	16	17	28	11	12
Sr	261	259	299	266	276	267	213	780	747
Y	35	34	29	42	35	37	52	21	20
Zr	119	120	99	141	118	158	217	151	147
Nb	9.4	10.4	7.8	11.3	9.0	12.6	15.7	10.8	11.7
Ni	7	5	1	2	3	4	7	125	131
Cu	213	134	77	184	95	73	40	55	55
Zn	112	110	89	126	112	94	103	93	92
Cr	12	13	13	12	13	9	0	197	215

Table 1. Chemical analyses of volcanic rocks, Camas 7.5' quadrangle—Continued

Map No.	28	29	30	31	32	33	34
Field sample No.	**02CM-T34B**	**02CM-T68**	**03CM-T247**	**03CM-T248**	**QV99-22**	**02CM-T34A**[†]	**02CM-T48A**[‡]
Latitude (N)	45°34.89'	45°35.79'	45°35.46'	45°35.46'	45°35.19'	45°34.88'	45°35.93'
Longitude (W)	122°26.90'	122°28.07'	122°28.75'	122°28.75'	122°29.00'	122°27.08'	122°24.09'
Map unit	Qbph	Qbph	Qbph	Qbph	Qbph	Qbph	Ttfh
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basalt

Analyses as reported (wt percent)							
SiO_2	53.58	54.44	53.35	53.66	54.18	54.90	50.09
TiO_2	1.29	1.21	1.27	1.26	1.21	1.22	1.47
Al_2O_3	17.18	17.12	17.02	17.06	17.05	17.11	17.32
FeO*	7.79	7.50	7.61	7.65	7.64	7.24	10.18
MnO	0.13	0.13	0.13	0.13	0.13	0.13	0.15
MgO	5.80	6.01	5.37	5.79	6.00	5.98	6.72
CaO	7.65	7.69	7.49	7.66	7.74	8.06	9.87
Na_2O	3.80	3.89	3.94	3.84	3.77	3.43	3.14
K_2O	1.10	1.03	1.01	1.11	1.00	1.26	0.35
P_2O_5	0.33	0.32	0.34	0.34	0.31	0.37	0.20
Total	98.65	99.33	97.51	98.50	99.03	99.70	99.49

Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)							
SiO_2	54.32	54.81	54.71	54.48	54.67	55.06	50.32
TiO_2	1.31	1.22	1.30	1.28	1.22	1.23	1.48
Al_2O_3	17.42	17.23	17.45	17.32	17.20	17.16	17.40
FeO*	7.90	7.55	7.80	7.77	7.78	7.26	10.27
MnO	0.13	0.13	0.13	0.13	0.13	0.13	0.15
MgO	5.88	6.05	5.51	5.87	6.05	6.00	6.75
CaO	7.75	7.74	7.68	7.77	7.81	8.08	9.92
Na_2O	3.85	3.91	4.04	3.90	3.81	3.44	3.15
K_2O	1.11	1.04	1.04	1.13	1.01	1.27	0.35
P_2O_5	0.34	0.32	0.35	0.34	0.31	0.37	0.20
Mg#	61.0	62.7	59.7	61.3	62.0	63.4	58.0

Modes (volume percent)							
Plagioclase	trace	trace	trace	trace	trace	trace	
Clinopyroxene	0.1	trace	trace	0.1	-	-	
Orthopyroxene	-	-	-	-	-	-	
Olivine	5.6	5.1	3.2	6.4	6.5	2.5	
Fe-Ti Oxide	-	-	-	-	-	-	
Hornblende	-	-	-	-	-	-	
Biotite	-	-	-	-	-	-	
Quartz	-	-	-	-	-	-	
K-feldspar	-	-	-	-	-	-	
Other	-	-	-	-	-	-	
Groundmass	94.3	94.9	96.8	93.5	93.5	97.5	
No. points counted	800.0	800.0	800	800	745	800	
Texture (rock/ groundmass)	porphyritic/ trachytic	porphyritic/ trachytic	porphyritic/ trachytic	porphyritic/ trachytic	porphyritic/ trachytic	porphyritic/ intergranular	

Trace element analyses (ppm)							
Ba	425	413	427	425	372	587	117
Rb	12	12	10	12	11	16	4
Sr	749	750	748	760	680	933	364
Y	21	22	22	21	20	21	28
Zr	151	148	151	151	131	170	94
Nb	11.4	10.7	11.3	11.3	8.2	12.3	7.5
Ni	118	128	108	113	139	129	115
Cu	56	52	51	52	59	35	44
Zn	94	89	95	94	86	83	95
Cr	187	212	181	185	221	191	206

[†] bomb in agglutinate

[‡] cobble in conglomerate

Table 2. Summary of K-Ar and $^{40}Ar/^{39}Ar$ incremental-heating age determinations, Camas 7.5' quadrangle

Field sample no.	Location Latitude (N)	Longitude (W)	Map unit	Rock type	Material dated	Method	Age (±1σ error)	Source
92TB-4*	45°34.88'*	122°27.33'*	Qbph	Basaltic andesite	Whole rock	K-Ar	590±50 ka	Conrey and others, 1996a
99CM-T03	45°35.15'	122°28.70'	Qbph	Basaltic andesite	Whole rock	$^{40}Ar/^{39}Ar$	596±47 ka	R.J. Fleck, written commun., 2001
02CM-T41A	45°34.66'	122°26.28'	Tbem	Basaltic andesite	Plagioclase	$^{40}Ar/^{39}Ar$	25.5±0.2 Ma	R.J. Fleck, written commun., 2001

*Location as given in source is incorrect; sample probably collected from roadcut on State Route 14 near 99CM-T03.

Table 3. Summary of radiocarbon age determinations, Camas 7.5' quadrangle

[Conventional corrected radiocarbon ages, referenced to A.D. 1950, calculated on basis of Libby half-life of 5568 years; 1-σ error based on combined measurements of sample, background, and modern reference standards. 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	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 probablity density function)	Source
1	9/13/01-4(1)	WW 3970	45°34.009'	122°29.214'	Within Qac, 7.5 m below surface, but stratigraphically below 9/13/01-4(3)	leaf fragments Douglas-fir	500±36	*	497-556 (0.95); 606-621 (0.05)	this report
1	9/13/01-4(3)	WW 3969	45°34.009'	122°29.214'	Within Qac, 7.5 m below surface	cone	386±38	*	422-512 (0.63); 317-399 (0.37)	this report
2	8/21/02-1(1)	WW 4355	45°33.756'	122°23.638'	Within Qac, above Timberline-age lahar (Qh)	charcoal organic fragments	1240±40	*	1063-1263 (1.0)	Rapp (2005; Reynolds Al/2 section)
2	8/21/02-1(2)	Beta 170603	45°33.756'	122°23.638'	Within Qac, above Timberline-age lahar (Qh)		1050±40	-26.2	917-1059 (1.0)	Rapp (2005; Reynolds Al/2 section)
2	8/21/02-1(8)	Beta 170604	45°33.756'	122°23.638'	Within Qac, above Timberline-age lahar (Qh)	wood	390±40	-24.5	422-513 (0.64); 317-399 (0.36)	Rapp (2005; Reynolds Al/2 section)
2	8/20/02-1(1)	Beta 170600	45°33.756'	122°23.638'	Within Qac, above Timberline-age lahar (Qh)	charcoal organic	140±40	-24.9	169-282 (0.45); 55-154 (0.38); 0-44 (0.18)	Rapp (2005; Reynolds Al/1 section)
2	8/20/02-1(2)	Beta 170601	45°33.756'	122°23.638'	Within Qac, above Timberline-age lahar (Qh)	fragments	1850±40	-24.8	1701-1876 (0.98)	Rapp (2005; Reynolds Al/1 section)
2	8/20/02-1(5)	Beta 170602	45°33.756'	122°23.638'	Within Qac, at contact with underlying Timberline-age deposits (Qh)	wood	1600±50	-25.0	1385-1572 (0.93)	Rapp (2005; Reynolds Al/1 section)
2	8/20/02-1(6)	WW 4682	45°33.756'	122°23.638'	Within Qac, above Timberline-age lahar (Qh)	charcoal	250±35	*	272-327 (0.54); 146-192 (0.22); 358-431 (0.21)	Rapp (2005; Reynolds Al/1 section)
2	8/26/02-1(2)	Beta 170605	45°33.756'	122°23.638'	Within Qac, above Timberline-age lahar (Qh)	charcoal	450±40	-26.1	439-545 (0.97)	Rapp (2005; Reynolds Al/4 section)
2	8/26/02-1(4)	Beta 170606	45°33.756'	122°23.638'	Within Qh, below Qac	charcoal	1870±140	-25.0	1510-2149 (0.99)	Rapp (2005; Reynolds Al/4 section)
3	TCP 930630-8	Beta 66187	45°33.250'	122°23.133'	Within Qh, 0.9 m below surface	charcoal	190±70	*	0-321 (0.96)	T.C. Pierson, written commun., 1993
3	TCP 930630-9	Beta 66188	45°33.250'	122°23.133'	Within Qac near contact with overlying Qh, 4.7 m below surface	charcoal	2060±60	-27.2	1879-2152 (0.98)	T.C. Pierson, written commun., 1993
4	4/19/02-1(4)	Beta 189662	45°33.477'	122°28.558'	Within Qac, 3.0 m below surface	charcoal	330±40	-24.1	304-478 (1.0)	this report
4	4/19/02-1(5)	Beta 189663	45°33.477'	122°28.558'	Within Qac, 3.5 m below surface	charcoal	470±40	-25.3	462-551 (0.99)	this report
4	4/19/02-1(6)	Beta 189663	45°33.477'	122°28.558'	Within Qac, 6.0 m below surface	charcoal	930±40	-28.3	759-928 (0.99)	this report
5	7/9/04-1(2)	WW 4937	45°33.386'	122°25.361'	Within thin, unmapped alluvial deposit above Qh, 1.2 m below surface	charcoal	180±40	*	131-230 (0.52); 245-300 (0.21); 0-37 (0.17); 67-122 (0.11)	Rapp (2005)
6	7/8/04-4(1)	WW 4938	45°33.322'	122°24.459'	Within Qh, at basal contact with underlying Qac	wood	1620±35	*	1413-1569 (0.96)	Rapp (2005)
7	6/24/02-1(7)	Beta 170588	45°33.159'	122°23.373'	Within Qh, near base of Timberline-age lahar, 7.8 m below surface	wood	1630±40	-25.7	1413-1611 (0.99)	Rapp (2005; shop well)
7	6/26/02-1(11)	WW 4354	45°33.159'	122°23.373'	Within Qac, below Qh, 9.3 m below surface	wood	1970±40	*	1858-1995 (0.92); 1824-1852 (0.08)	Rapp (2005; shop well)
7	6/26/02-1(15)	Beta 170591	45°33.159'	122°23.373'	Within Qac, below Qh, 12.5 m below surface	charcoal	4510±40	-25.3	5039-5306 (0.99)	Rapp (2005; shop well)
7	6/26/02-1(3)	Beta 170590	45°33.159'	122°23.373'	Within Qh, near base of Timberline-age lahar, 7.8 m below surface	wood	1640±40	-26.8	1414-1614 (0.96)	Rapp (2005; shop well)
7	TCP 030918-4	Beta 183680	45°33.159'	122°23.373'	Within Qac, below Qh, 13.8 m below surface	wood	4110±40	-26.9	4519-4732 (0.73); 4752-4818 (0.25)	Rapp (2005; shop well)
8	7/12/02-1(4)	Beta 171398	45°32.742'	122°23.093'	Within Qh, 0.4 m below surface	charcoal	1730±40	-25.2	1534-1723 (1.0)	Rapp (2005; Outhouse 10 section)
8	7/12/02-1(7)	Beta 170598	45°32.742'	122°23.093'	Within Qh, 0.3 m below surface	wood	130±40	-23.3	8-150 (0.58); 172-277 (0.41)	Rapp (2005; Outhouse 10 section)
8	7/12/02-1(8)	Beta 171399	45°32.742'	122°23.093'	Within Qh, 0.7 m below surface	charcoal	1740±40	-24.0	1540-1720 (1.0)	Rapp (2005; Outhouse 10 section)
8	7/9/02-1(10)	Beta 170594	45°32.742'	122°23.093'	Within Qac, beneath Qh, 6.2 m below surface	charcoal	1520±40	-25.0	1329-1517 (1.0)	Rapp (2005; Outhouse 2 section)
8	7/9/02-1(13)	Beta 170595	45°32.742'	122°23.093'	Within Qac, beneath Qh, 6.4 m below surface	wood	1650±40	-27.4	1477-1627 (0.82); 1418-1473 (0.12); 1670-1689 (0.06)	Rapp (2005; Outhouse 2 section)
8	7/9/02-1(3)	Beta 170592	45°32.742'	122°23.093'	Within Qh, between two Timberline-age lahars, 5.4 m below surface	wood	1570±40	-24.8	1368-1536 (0.98)	Rapp (2005; Outhouse 2 section)
8	7/9/02-1(6)	Beta 170593	45°32.742'	122°23.093'	Within Qh, in lower-most Timberline-age lahar, 5.7 m below surface	wood	1670±40	-29.3	1509-1634 (0.80); 1645-1694 (0.16)	Rapp (2005; Outhouse 2 section)
9	7/02/93-2	Beta 67082	45°32.537'	122°23.141'	Within Qac at contact with overlying Qh, 1.4 m below surface	detrital wood	1630±110	-25.5	1308-1739 (0.98)	this report
9	RBW-93-PV.30C	Beta 67082	45°32.537'	122°23.141'	Rooted stump within Qac at contact with underlying Qh, ~1.5 m below surface	wood	1510±50	*	1311-1516 (1.0)	R.B. Waitt, written commun., 1993
9	TCP 930630-4	Beta 67082	45°32.537'	122°23.141'	Within Qac near contact with overlying Qh, 1.4 m below surface	detrital wood	1540±50	*	1329-1529 (1.0)	T.C. Pierson, written commun., 1993

*^{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.