Geologic Map of the Ridgefield Quadrangle, Clark and Cowlitz Counties, Washington

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INTRODUCTION

GEOGRAPHIC AND GEOLOGIC SETTING

The Ridgefield 7.5' quadrangle is situated in the Puget-Willamette Lowland approximately 35 km north of Portland, Oregon (fig. 1). The lowland, which extends from Puget Sound into west-central Oregon, is a complex structural and topographic trough that lies between the Coast Range and the Cascade Range. Since late Eocene time, the Cascade Range has been the locus of an active volcanic arc associated with underthrusting of oceanic lithosphere beneath the North American continent along the Cascadia subduction zone. The Coast Range occupies the forearc position within the Cascadia arc-trench system and consists of a structurally complex assemblage of Eocene to Miocene volcanic and marine sedimentary rocks.

The Ridgefield quadrangle lies in the northern part of the Portland Basin, a roughly 2000-km^2 topographic and structural depression in the central Puget-Willamette Lowland (Beeson and others, 1989; Swanson and others, 1993; Yeats and others, 1996). The rhomboidal basin is approximately 70 km long and 30 km wide, with its long dimension oriented northwest. The flanks of the basin consist of Eocene through Miocene volcanic and sedimentary rocks that rise to elevations exceeding 2000 ft (610 m). Seismic reflection profiles (L.M. Liberty, written commun., 2003) and lithologic logs of water wells (Swanson and others, 1993; Mabey and Madin, 1995) indicate that as much as 550 m of late Miocene and younger sediments have accumulated in the deepest part of the basin near Vancouver. Most of this basin-fill material was carried in from the east by the Columbia River, which flows northward just west of the Ridgefield quadrangle.

The physiography of the Ridgefield quadrangle is dominantly a nearly flat, modestly dissected surface of elevation 275 to 300 ft (90 to 100 m) developed on the basin-fill sediments. The top of this surface declines gradually westward to about 250 ft (80 m) near the town of Ridgefield. The surface is interrupted by low hills in the south and truncated to the west and north by erosional scarps overlooking the Columbia River floodplain and the East Fork Lewis River valley, respectively. Remnants of the same surface are present north of the East Fork Lewis River near La Center. The East Fork Lewis River enters the quadrangle from the east, and meanders across a 1 to 1.5 km-wide trenchlike valley cut into older alluvial deposits. Just west of La Center the river passes through a straight, 2-km-long bedrock gorge before joining the Lewis River. The terrain north of the river rises to elevations approaching 600 ft (200 m), forming the southern margin of a pronounced bench.

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; Beeson and Tolan, 1990; Yelin and Patton, 1991; Blakely and others, 1995, 2000). These fault zones are thought to reflect regional transpression and dextral shear within the forearc in response to oblique subduction 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; Liberty and others, 2003). The nature of the corresponding northeastern margin of the basin is less clear, but a poorly defined and partially buried dextral extensional fault zone has been hypothesized from topography, microseismicity, potential field-anomalies, and reconnaissance geologic mapping (Beeson and others, 1989; Beeson and Tolan, 1990; Yelin and Patton, 1991; Blakely and others, 1995). Another dextral structure, the Kalama Structural Zone of Evarts (2002), may underlie the north-northwest-trending reach of the Columbia River north of Woodland (Blakely and others, 1995).

This map is a contribution to a U.S. Geological Survey (USGS) program designed to improve the geologic database for the Portland Basin region of the Pacific Northwest urban corridor, the populated forearc region of western Washington and Oregon. Better and more detailed information on the bedrock and surficial geology of the basin and its surrounding area is needed to refine assessments of seismic risk (Yelin and Patton, 1991; Bott and Wong, 1993), ground-failure hazards (Madin and Wang, 1999; Wegmann and Walsh, 2001) and resource availability in this rapidly growing region.

PREVIOUS GEOLOGIC INVESTIGATIONS

Previous geologic mapping in the Ridgefield area, generally carried out as part of broad regional reconnaissance investigations, established the basic stratigraphic framework and distribution of geologic units in the quadrangle. The earliest published observations on the geology of the map area are those of Diller (1916), who noted exposures of fine-grained sediments and columnar-jointed basalt in the railroad cuts north of Ridgefield. The geology of the area west of the Ridgefield quadrangle was first mapped and described by Wilkinson and others (1946). Their representation of the geology at a scale of 1:62,500 portrays the general distribution of the major geologic units of the area: Paleogene volcanic and sedimentary rocks, Miocene Columbia River Basalt Group flows, Miocene and Pliocene basin-fill sediments of the Troutdale Formation, and post-Troutdale unconsolidated deposits. Geologic structures were discussed in the accompanying text but not shown on the map.

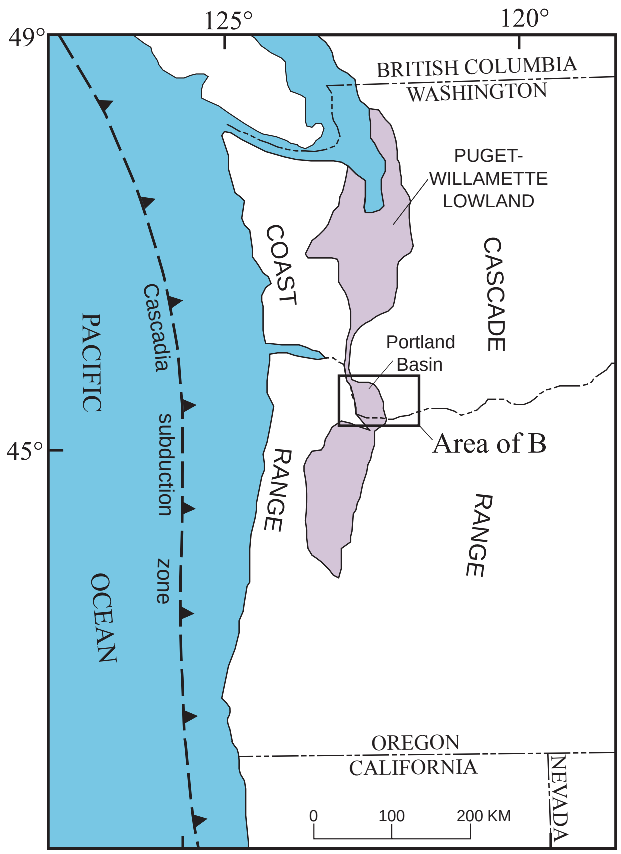

Figure 1A. Regional setting of the Ridgefield quadrangle showing major tectonic and physiographic features of the Pacific Northwest.

The first systematic geologic investigation to include the area of the Ridgefield quadrangle was that of Mundorff (1964), who conducted a hydrogeologic study of Clark County. His map, at a scale of 1:48,000, accurately portrays contacts between Tertiary bedrock and the basin-fill units, but he did not map stratigraphic units within the Tertiary sequence. He proposed a two-fold division of the Troutdale Formation into a lower fine-grained member and an upper coarse-grained member, but did not show their distribution on his map. Mundorff (1964) also described Pleistocene drift in the East Fork Lewis River valley and the glacier-outburst flood deposits that cover most of the quadrangle. Mundorff (1984) elaborated further on glacial deposits in the Lewis River system.

Swanson and others (1993) updated Mundorff's (1964) Clark County work as part of an investigation of ground-water resources in the entire Portland Basin. The focus of their work was on the basin-fill units, and their map shows hydrogeologic rather than lithostratigraphic units, although there is substantial equivalence between the two. 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 3-dimensional view of the subsurface stratigraphy of the basin fill.

Phillips (1987a) compiled a geologic map of the Vancouver 30'x60' quadrangle, which includes the Ridgefield 7.5' quadrangle, at 1:100,000 scale as part of the state geologic map program of the Washington

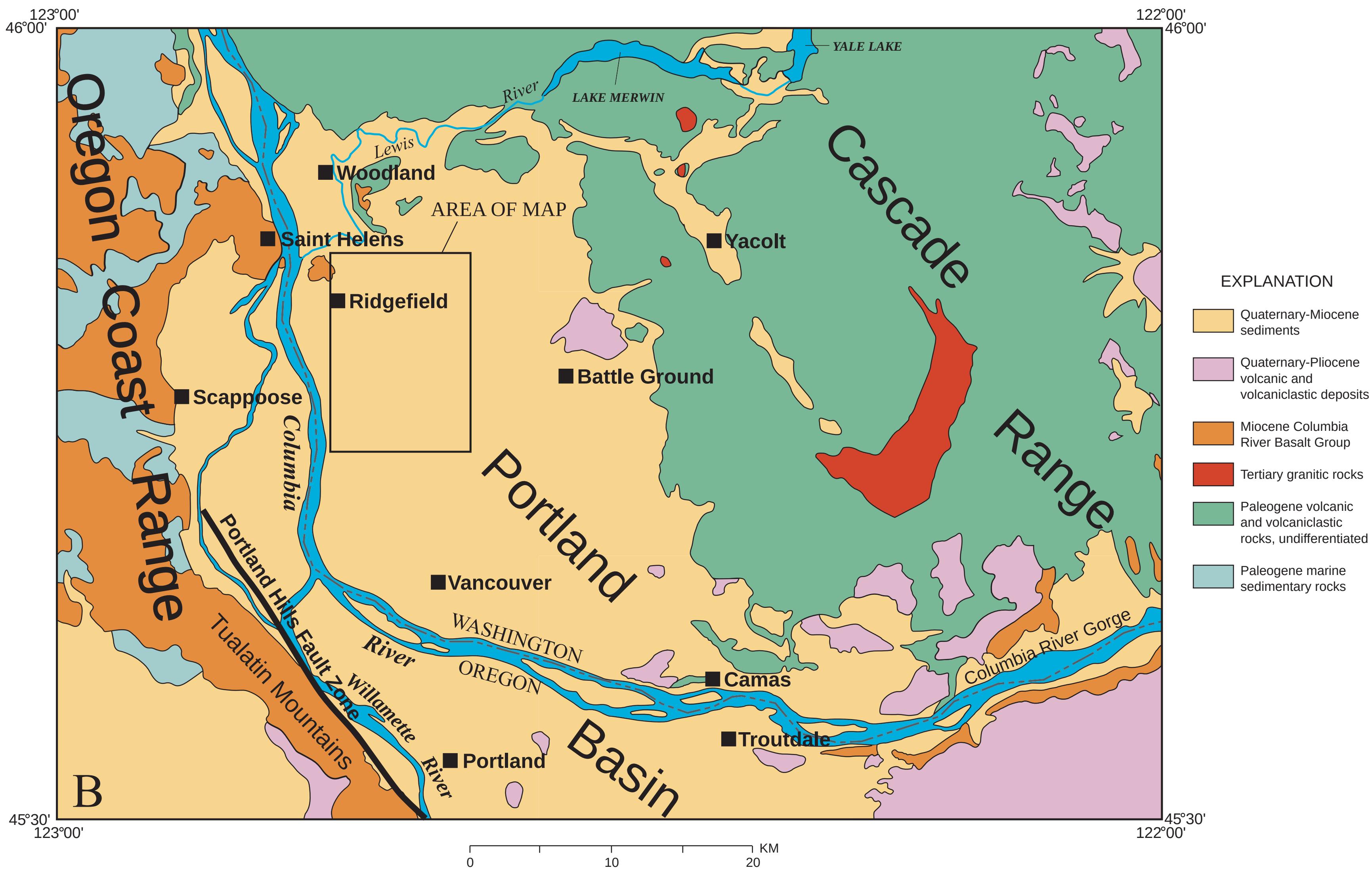

Figure 1B. Simplified geologic map of the Vancouver 30' x 60' quadrangle, modified from Phillips (1987a).

Division of Geology and Earth Resources (Walsh and others, 1987). He relied heavily on Mundorff's work and did not undertake any new mapping in the Ridgefield quadrangle. Most recently, adjoining 7.5-minute quadrangles to the west, north, and east were mapped by Evarts (2002, 2004a, b, c) and Howard (2002).

ACKNOWLEDGMENTS

Access granted by landowners was essential for mapping in the Ridgefield quadrangle. Jonathan Hagstrum (USGS) provided paleomagnetic data and David Siems (USGS) and Diane Johnson (Washington State University) performed chemical analyses necessary for interpreting local stratigraphy in the Columbia River Basalt Group. Aeromagnetic maps compiled by Richard Blakely (USGS) were used to interpret buried structures. Bradley Reid and Christopher DuRoss gave able field assistance in 1998 and 2000, respectively. Andrei Sarna-Wojcicki, Kenneth Bishop, Judith Fierstein, and Michael Clynne provided laboratory facilities. Stephanie Abraham of the Washington Department of Ecology Southwest Regional Office in Lacey, Washington provided access to their files of water-well logs. Connie Manson helped obtain unpublished information from the library at the Washington Division of Geology and Earth Resources in Olympia, Washington. I have benefited from discussions on various aspects of the regional stratigraphy and structure of the Portland Basin with Marvin Beeson, Keith Howard, Lee Liberty, Ian Madin, Jim O'Connor, Stephen Reidel, Terry Tolan, and Ray Wells. Reviews by Richard Waitt and Terry Tolan helped sharpen the logic and improve the language of this report.

SYNOPSIS OF GEOLOGY

The geology of the Ridgefield quadrangle consists essentially of four major groups of deposits: Paleogene bedrock, middle Miocene lava flows of the Columbia River Basalt Group, late Miocene to Pliocene alluvial sedimentary rocks that previous workers have assigned to the Troutdale Formation, and Quaternary deposits. Paleogene bedrock in this quadrangle crops out only along the East Fork Lewis River near Paradise Point. It consists of late Eocene andesitic lava flows and volcaniclastic rocks transected by dikes similar in character to the flows, all early products of the Cascade volcanic arc. After mild folding, faulting, and erosion, these strata formed a low-relief terrain within which the Portland Basin began to develop during the early Neogene (Beeson and others, 1989). About 15 to 16 Ma, the basin was inundated by huge flood-basalt flows of the Grande Ronde Basalt of the Columbia River Basalt Group. These lavas erupted from fissures in eastern Washington and Oregon, traversed the Cascade Range through a 60-km-wide structural lowland (Beeson and others, 1989; Beeson and Tolan, 1990), and spread out to cover large areas of the Coast Range province. In the Portland Basin, the basalt flows were buried by late Miocene to Pliocene fluvial deposits (Sandy River Mudstone and Troutdale Formation) deposited by the ancestral Columbia River and its tributaries. Continuing development of the Portland Basin gently warped the originally flat-lying basalt flows and overlying sediments. In the map area, basalt flows near the basin axis were preserved beneath the sedimentary cover, whereas basalt along the elevated basin margins was eroded, leaving only remnants plastered against Paleogene rocks north of the East Fork Lewis River. During Pleistocene and Holocene time, alluvial processes in the northern Portland Basin were strongly influenced by fluctuations in sea level, glaciation in the Cascade Range, and the cataclysmic Missoula Floods triggered by the failure of ice dams at Glacial Lake Missoula in Montana.

The relatively mild and wet climate in the western Pacific Northwest throughout most of the Cenozoic era (Wolfe and Hopkins, 1967; Wolfe, 1978) promoted intense chemical weathering of geologic deposits of the region. Because of this intense weathering and the dense vegetation of the region, natural outcrops are generally limited to cliff faces, landslide scarps, and streambeds; most exposures are at roadcuts and quarries. Because thick surficial deposits cover most of the map area, the surface information was supplemented with lithologic data extracted from several hundred water-well logs in the files of the Washington Department of Ecology. Well locations were taken as described in the drillers' reports and not field checked; only wells considered reliably located were used to infer the distribution and thicknesses of units in the subsurface.

PALEOGENE BEDROCK

The only outcrops of Paleogene rocks in the Ridgefield quadrangle are along the East Fork Lewis River at and above Paradise Point. They are more widely exposed to the north (Evarts, 2004a). In this quadrangle they consist primarily of subaerially erupted intermediate to silicic lava flows interbedded with various volcaniclastic rocks (Ta, Tvb, Tvs). These are cut by several dikes petrographically similar to the flows, which may be the remains of a subvolcanic feeder system. Rocks of this type are broadly typical of the strata that underlie much of the western slopes of the southern Washington Cascade Range (Evarts and others, 1987; Smith, 1993; Evarts and Swanson, 1994). Sparse structural data indicate that the Paleogene rocks of this quadrangle strike generally east-west to east-northeast and dip about 20° south. No radiometric dates exist for rocks in the Ridgefield quadrangle, but $^{40}Ar/^{39}Ar$ ages from nearby areas indicate the rocks here are probably late Eocene, about 35 Ma (R.J. Fleck, written commun., 2000).

Chemical analyses of Paleogene extrusive rocks in the Ridgefield quadrangle show them to be medium-potassium andesite and dacite of transitional tholeiitic to calc-alkaline character (fig. 2A–C), similar to Tertiary volcanic rocks sampled elsewhere in the southern Washington Cascade Range (Evarts and Ashley, 1990a,b, 1991, 1992; Evarts and Bishop, 1994; Evarts and Swanson, 1994; Evarts, 2001, 2002, 2004a, b; R.C. Evarts, unpub. data). They exhibit low TiO_2 contents (fig. 2D), typical of volcanic-arc magmas (Gill, 1981).

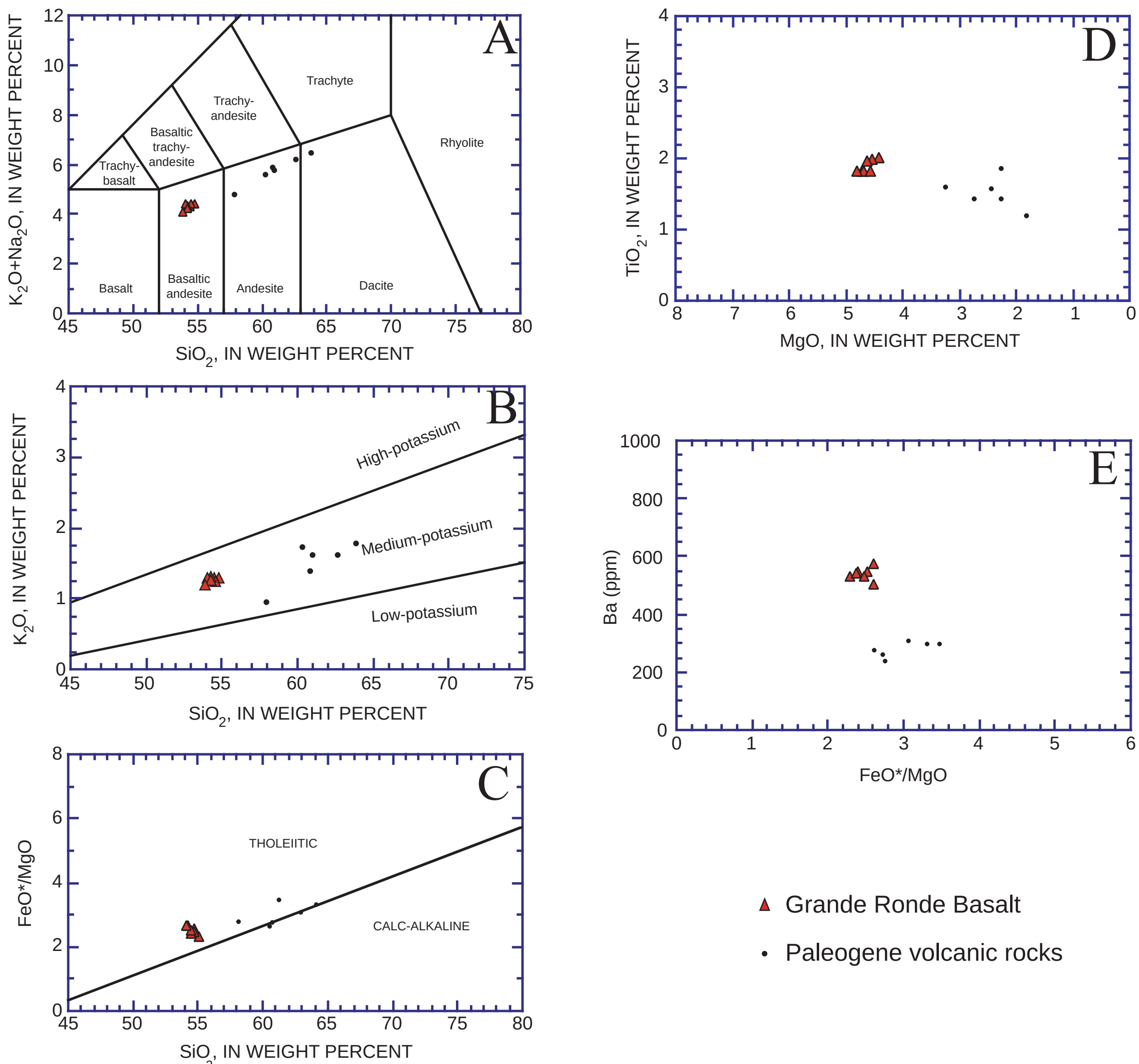

Figure 2. Chemical characteristics of volcanic rocks from the Ridgefield 7.5' quadrangle (analyses recalculated volatile-free). *A*, K_2O+Na_2O versus SiO_2, showing IUGS classification (Le Maitre, 2002); *B*, K_2O versus SiO_2, showing low-, medium-, and high-potassium fields extrapolated from Gill (1981, p. 6); *C*, FeO*/MgO versus SiO_2, showing classification into tholeiitic and calc-alkaline rocks according to Miyashiro (1974), *D*, TiO_2 versus MgO; *E*, Ba versus FeO*/MgO. FeO*, total Fe as FeO.

The Paleogene rocks in the quadrangle have been subjected to zeolite-facies regional metamorphism similar to that described from elsewhere in the southern Washington Cascade Range (Fiske and others, 1963; Wise, 1970; Evarts and others, 1987; Evarts and Swanson, 1994; Evarts, 2001, 2002, 2004a, b). This region-scale metamorphism reflects shallow burial of the late Eocene rocks by younger volcanic rocks within the relatively high-heat-flow environment of an active volcanic arc. It is manifested by incipient to complete replacement of igneous minerals by secondary phases. Glass-rich, permeable, silicic volcaniclastic rocks and vesicular flow breccia are the most susceptible. Feldspar typically displays partial alteration to calcite, clay minerals, and (or) zeolites. Primary augite and Fe-Ti oxides are largely unaffected. Hypersthene phenocrysts in pyroxene andesite flows commonly exhibit minor replacement by dark brown smectite. Alteration tends to pervade the volcaniclastic rocks and flow breccias because of their permeability. Smectitic clay minerals and zeolites replace framework grains and fill pore spaces; the development of iron-rich smectites gives these rocks their characteristic green colors. Widespread stilbite, heulandite, and clinoptilolite in pyroclastic rocks of this quadrangle indicates that metamorphic temperatures did not exceed about 150°C (Cho and others, 1987; Liou and others, 1991).

NEOGENE FILL OF THE PORTLAND BASIN

The Portland Basin is a structural depression floored by late Eocene and Oligocene rocks and filled with Neogene deposits. As described in previous studies, most of the fill comprises three stratigraphic units: the Columbia River Basalt Group, the Sandy River Mudstone, and the Troutdale Formation (Trimble, 1963; Mundorff, 1964; Swanson and others, 1993).

COLUMBIA RIVER BASALT GROUP

In Miocene time between 16.5 and 6 Ma, huge volumes of tholeiitic flood basalt erupted from fissures in southeastern Washington and adjacent regions of Oregon and Idaho, forming the Columbia River Basalt Group. Some of the largest flows crossed the Cascade Range through a broad lowland and ultimately reached the Pacific Ocean (Tolan and others, 1989; Beeson and others, 1989; Wells and others, 1989). West of the Cascade Range, thick sequences of lava flows buried large parts of low-relief terrain in the areas of the present Coast Range and Willamette Valley (Beeson and others, 1989). They are readily distinguished from Paleogene volcanic rocks by their distinctive, glass-rich, intersertal and microvesicular textures, general absence of alteration, and chemical compositions (table 1; fig. 2).

In the map area, eroded remnants of Columbia River Basalt Group flows crop out along the north valley wall of the East Fork Lewis River between Paradise Point and La Center and along the east edge of the Columbia River floodplain north of Ridgefield. All belong to the Grande Ronde Basalt, the most voluminous formation of the Columbia River Basalt Group (Tolan and others, 1989), which erupted during a relatively brief interval between 16.5 and 15.6 Ma. Grande Ronde flows can be distinguished from other Columbia River Basalt Group units by their relatively low TiO_2 contents (Swanson and others, 1979; Mangan and others, 1986; Beeson and others, 1989; Reidel and others, 1989; Hooper, 2000).

Using lithologic, chemical and paleomagnetic criteria, Reidel and others (1989) divided the Grande Ronde Basalt on the Columbia Plateau into several informal members. Beeson and others (1989) and Wells and others (1989) traced some of these members into the Portland Basin and westward into the Coast Range. Chemical and laboratory paleomagnetic data from basalt outcrops in this quadrangle show that all are normally magnetized, high-MgO (4.4–4.8 wt percent) basaltic andesite correlative with the member of Sentinel Bluffs of Reidel (1998; equivalent to the Sentinel Bluffs unit of Reidel and others, 1989) [1]. This is the youngest and most widespread member of the Grande Ronde Basalt on the Columbia Plateau. Mapping in this and adjacent quadrangles (Evarts,

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[1] Comparison of chemical analyses obtained for this report with older data in the literature (Reidel and others, 1989; Beeson and others, 1989), all of which were performed in the same laboratory at Washington State University, suggested that systematic biases were present. Reanalysis of a suite of 38 Columbia River Basalt Group samples, originally analyzed in 1983, confirmed this suspicion. The reasons for the discrepancies are unclear but probably relate to a change in instrumentation in the laboratory in 1986 (D.M. Johnson, written commun., 2001). Among the elements most useful in discriminating between Grande Ronde Basalt flows, the newer data exhibit consistently higher contents of TiO_2 (3.5%) and P_2O_5 (8.0%) and lower MgO (2.5%)(percentages are average relative differences between the datasets). These differences were taken into account in evaluating the data for correlation purposes.

2002, 2004a, c; Evarts and others, 2002) indicates that at least three flows of the member of Sentinel Bluffs reached the northern Portland Basin. Two of these flows are found in the map area. One flow, distinguished by a relatively low TiO_2 content (1.81–1.82 wt percent), crops out along the East Fork Lewis River; another flow, characterized by a higher TiO_2 content (1.96–1.99 wt percent), is exposed north of Ridgefield.

SANDY RIVER MUDSTONE AND TROUTDALE FORMATION

The Portland Basin may have begun to form in late early Miocene time, shortly before emplacement of the Grande Ronde Basalt (Beeson and others, 1989; Beeson and Tolan, 1990). As the basin continued to subside during the late Miocene and Pliocene, it filled with continental fluvial sediment transported through the Cascade Range by the ancestral Columbia River as well as with locally derived detritus carried in by tributaries draining the surrounding highlands. These deposits have been mapped from the Columbia River Gorge west and north along the Columbia River to Kelso, Washington, about 25 km north of the map area (Wilkinson and others, 1946; Lowry and Baldwin, 1952; Livingston, 1966; Trimble, 1957, 1963; Mundorff, 1964; Tolan and Beeson, 1984; Phillips, 1987a, b). Most workers have assigned these post-Grande Ronde Basalt nonmarine sedimentary beds to the Troutdale Formation of Hodge (1938). In its type area near the west end of the Columbia River Gorge, the Troutdale Formation is composed of three characteristic sedimentary rock types: basalt-clast conglomerate, arkosic sandstone, and vitric sandstone. The conglomerate consists chiefly of well-rounded pebbles and cobbles eroded from flows of the Columbia River Basalt Group, but its most distinctive components are well-rounded, light-colored but commonly iron-stained pebbles of quartzite, granite, and foliated metamorphic rocks. These rock types are foreign to western Oregon and Washington and must have been transported from terranes of pre-Tertiary granitic and metamorphic rocks in northeastern Washington, Idaho, and British Columbia by the ancestral Columbia River. The arkosic sandstone consists largely of quartz, plagioclase, potassium feldspar, and felsic lithic clasts, and it contains minor but ubiquitous muscovite and biotite. Its composition, like that of the conglomerate, indicates source terranes east of the Cascade Range. The vitric sandstone consists of poorly sorted, sandy to pebbly, and variably palagonitized hyaloclastic debris. The petrography and chemistry of the vitric sandstone resemble those of olivine-bearing, high-alumina basalt and basaltic andesite flows erupted from volcanic centers flanking the Columbia River in the Cascade Range during Pliocene time (Tolan and Beeson, 1984; Swanson, 1986). Near the margins of the Portland Basin, the Troutdale Formation contains debris eroded from adjacent volcanic highlands. Tolan and Beeson (1984) call these locally derived deposits the Cascadian stream facies of the Troutdale Formation, which they distinguish from the more typical ancestral Columbia River facies.

Scattered outcrops and abundant subsurface data from water-well drillers' logs show that a conglomeratic section as much as 120 m thick overlies a sequence of finer grained strata throughout most of the Portland Basin. This observation prompted Trimble (1957) and Mundorff (1964) to divide the Troutdale Formation into informal upper and lower members based on the pronounced difference in grain size. Trimble (1963) later formally named the lower, fine-grained member the Sandy River Mudstone.

In the Columbia River Gorge east of the Portland Basin, Tolan and Beeson (1984) mapped as Troutdale Formation a thick section of conglomerate and sandstone above (and locally beneath) the approximately 12-Ma Pomona flow of the Columbia River Basalt Group. They informally divided the Troutdale into a lower member characterized by quartzite-bearing conglomerate and arkosic sandstone and an upper member dominated by basaltic vitric sandstone and conglomerate that contains clasts of distinctive, olivine-phyric, high-alumina basalt. From the presence of early Pliocene fossil floras near the base of their upper member, Tolan and Beeson inferred the contact between their two members to have an age near the Miocene-Pliocene boundary, 5.32 Ma; (Berggren and others, 1995). According to Trimble (1963), these fossil localities are in the lower part of the Troutdale Formation, about 30 m above the contact with the Sandy River Mudstone. Therefore Tolan and Beeson's (1984) upper member corresponds to Trimble's (1963) Troutdale Formation and their lower member is a coarse-grained correlative of the Sandy River Mudstone.

More recently, Howard (2002) mapped the Battle Ground quadrangle directly east of the map area and employed lithologic and geomorphic criteria to subdivide Mundorff's (1964) Troutdale Formation. Following Mundorff (1964), Howard (2002) assigned most of the conglomerate that underlies the terrain north of the East Fork Lewis River to the Troutdale Formation. However, he noted that coarse-grained deposits found at lower elevations along and south of the East Fork, also mapped as Troutdale Formation by Mundorff, are younger and were derived primarily from the adjacent Cascade Range rather than from the Columbia River Basin. Howard (2002) mapped these deposits as an informal alluvial-fan member of the Troutdale Formation, which he suggested may include early Pleistocene outwash.

On this map, sedimentary deposits previously assigned to the Troutdale Formation (Mundorff, 1964; Phillips, 1987a) are divided by lithology and stratigraphic position into three units. These units generally correspond to those distinguished by Howard (2002) although the names and some interpretations of their correlations and ages differ (fig. 3). The fine-grained sedimentary rocks, equivalent to the informal lower member of the Troutdale Formation of Mundorff (1964) and the informal fine-grained member of the Troutdale Formation of Howard (2002) are assigned to the Sandy River Mudstone (Tsr). The older of the two overlying conglomeratic deposits underlies the high, gently south-sloping terrain near the northeast corner of the map area, which is part of a dissected bench along the north and east margins of the Portland Basin. These deposits disconformably overlie the Sandy River Mudstone and are assigned to the Troutdale Formation (Ttf) . They are stratigraphically and lithologically equivalent to Howard's (2002) informal quartzite-clast and volcanic-clast members of the Troutdale Formation. The younger conglomerate forms an extensive sheet inset against the Sandy River Mudstone and Troutdale Formation; it is contiguous with Howard's (2002) alluvial fan member of the Troutdale Formation and is mapped here as an informal unit of unnamed conglomerate (QTc).

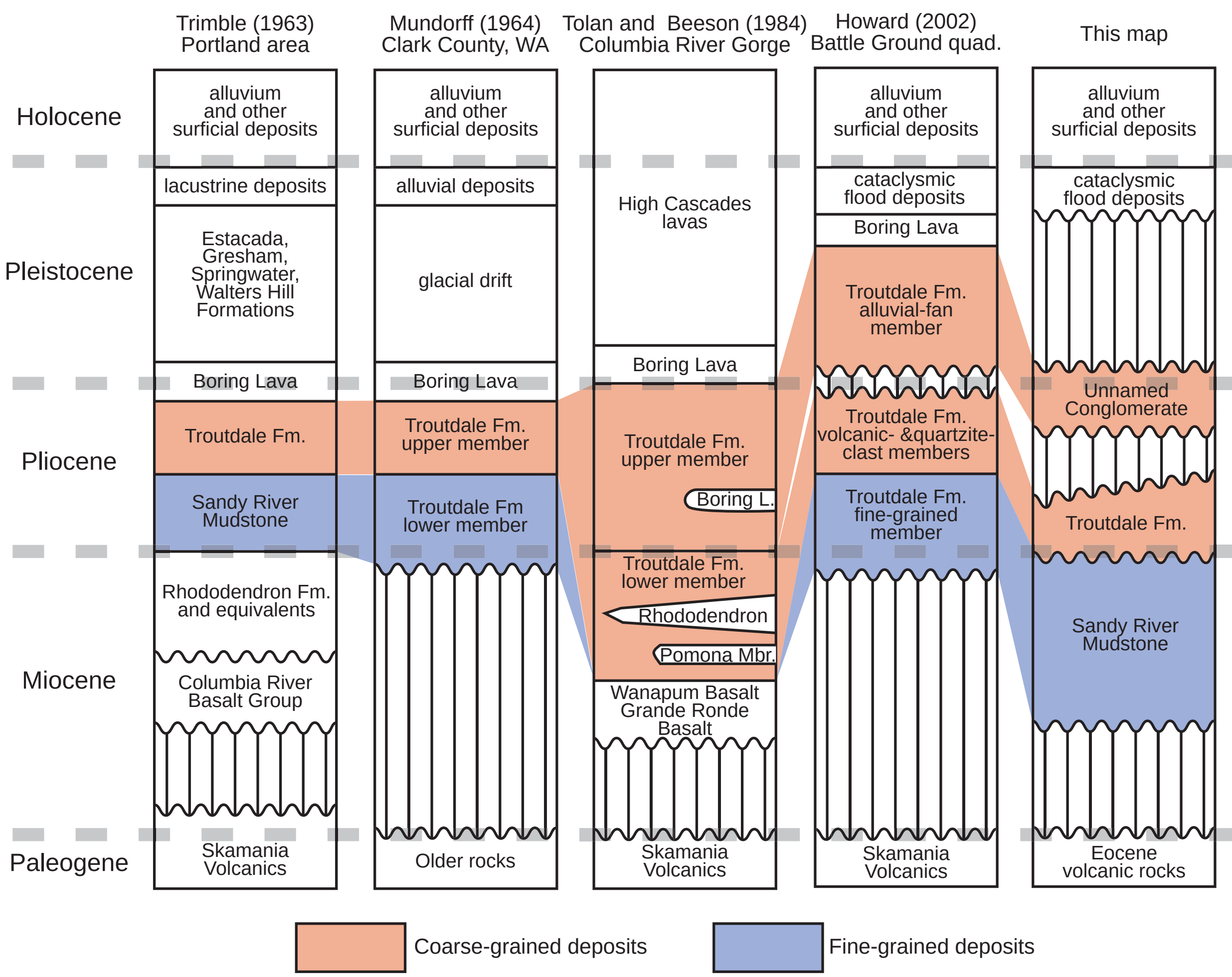

Figure 3. Comparison of stratigraphic nomenclature and age assignments for Neogene basin-fill units of the Portland Basin and vicinity.

Surface exposures and numerous water-well logs indicate that the Neogene sediments were deposited on an eroded bedrock surface of considerable relief. The bedrock-altitude map of Swanson and others (1993) shows a pronounced northwest-trending paleovalley about 3 km northeast of La Center that is filled with as much as 175 m of fine-grained sedimentary rocks assigned to the Sandy River Mudstone. The Paleogene bedrock surface beneath most of the map area slopes east and southeast and may be as deep as 1200 ft (365 m) below sea level near the southwest corner.

Fine-grained strata of the Sandy River Mudstone (Tsr) apparently constitute most of the sedimentary fill of the northern Portland Basin, but are largely buried by conglomerate and thus sparsely exposed (Swanson and others, 1993). In the Ridgefield quadrangle, rocks of this unit crop out locally beneath conglomerate (QTc) on the lower slopes of the valley walls along the East Fork Lewis River and its tributaries; to the north, in Lockwood, Riley, and Brezee Creeks, the Sandy River Mudstone underlies the Troutdale Formation (Ttf). The Sandy River Mudstone consists chiefly of coarse micaceous, quartzose and arkosic sandstone and thin-bedded, tuffaceous and carbonaceous claystone, mudstone, and siltstone. Beds are bluish gray to light green in fresh exposures but oxidize to light brown or tan; some are cemented by limonite. Planar and trough crossbedding, cut-and fill structures, and lenticular beds of pebbly sandstone and small-pebble conglomerate are common locally, suggesting deposition in fluvial channels. Current indicators give northward and westward flow directions, like those observed to the northeast (Howard, 2002). Thin-bedded siltstones and claystones are more common to the northeast and appear to increase in abundance downward. They were probably deposited in overbank environments on a broad floodplain. The composition of the sandstone, with abundant quartz and conspicuous mica, requires an extrabasinal source and indicates transport and deposition in an ancestral Columbia River.

As much as 70 m of Troutdale Formation conglomerate (Ttf) overlies the Sandy River Mudstone north of the East Fork Lewis River. It is intensely weathered to depths exceeding 30 m. Most exposures consist only of red-brown clayey soil with no vestige of original clastic textures. Better exposures in adjacent quadrangles show that the Troutdale Formation consists of thick-bedded, weakly cemented conglomerate and rare thin lenses of basaltic sandstone and grit (Mundorff, 1964; Howard, 2002; Evarts, 2004a). Well-rounded cobbles of aphyric basalt eroded from the Columbia River Basalt Group constitute most of the unit; the remainder includes light-colored granitic and quartzofeldspathic metasedimentary rocks, Fe-oxide stained quartzite, and variable but minor proportions of volcanic rocks eroded from the Cascade Range. Most of these components, like those of the Sandy River Mudstone, must have been transported from pre-Tertiary terranes east of the Cascade Range by the ancestral Columbia River. Sedimentologic characteristics of the conglomerate, such as their massive to crudely stratified appearance, clast-supported nature, openwork and sand-matrix textures, moderate to good sorting, and clast imbrication, are consistent with deposition during flood stage in a gravelly braided river system (Miall, 1977, 1996; Rust, 1978; Ramos and Sopeña, 1983). Crossbedding in a sandstone interbed above Riley Creek indicates deposition by north-northwest-flowing currents.

The contact between the Sandy River Mudstone and the Troutdale Formation is exposed in the valleys of Riley and Brezee Creeks near the northeast corner of the map area. Although the upper part of the Sandy River Mudstone contains a few pebble-conglomerate interbeds, suggesting a sedimentological transition, the contact itself is a low-relief erosional surface. Well data indicate relatively little relief, perhaps 100 ft or less, on the surface of the Sandy River Mudstone in the map area. The amount of time represented by the erosional unconformity is unknown.

No dateable beds were found in the Sandy River Mudstone and Troutdale Formation in the map area. Wilkinson and others (1946) recovered late Miocene or early Pliocene fossil leaves from fine-grained strata about 3 km northwest of Woodland that are lithologically similar to, not contiguous with, the Sandy River Mudstone in this quadrangle (Mundorff, 1964; Evarts, 2004a). Fossil floras in the Sandy River Mudstone of northern Oregon have been assigned an early Pliocene age (Trimble, 1963). In all localities the fossils derive from horizons interpreted to be near the top of the unit (Trimble, 1963; Mundorff, 1964). In the few places where the base of the Sandy River Mudstone is exposed along the edge of the Portland Basin, it rests unconformably on rocks ranging in age from late Eocene to late Miocene, and the formation has conventionally been considered to postdate the 15.6–14.5-Ma Wanapum Basalt of the Columbia River Basalt Group (Trimble, 1963; Swanson and others, 1993). Near Woodland, however, strata lithologically indistinguishable from the Sandy River Mudstone overlie and are invaded by both normally and reversely magnetized flows of the Grande Ronde Basalt (Evarts, 2004a), which shows that the lowest part of the formation is at least 1 m.y. older than previously inferred.

The Troutdale Formation in the map area lacks clasts of distinctive olivine-bearing, high-alumina basaltic rocks that erupted within the gorge mainly after 3.5 Ma (Conrey and others, 1996a, b). This indicates that it is probably equivalent to the informal lower member of the Troutdale Formation of Tolan and Beeson (1984; see fig. 3). Tolan and Beeson considered their lower member to be of Miocene age because the top of the member lies below strata that bear an early Pliocene flora. Given the complex facies changes in the Portland basin (Bet and Rosner, 1993; Swanson and others, 1993) and the poor age resolution of plant fossils, however, the Troutdale Formation in the Ridgefield quadrangle may be as young as earliest Pliocene.

The meager evidence thus indicates that the Sandy River Mudstone in the Portland Basin ranges in age from late early Miocene to early Pliocene. The eroded top of the unit in the Woodland quadrangle to the north (Evarts, 2004a) suggests that only the older, Miocene part of the formation is preserved here. The age of the Troutdale Formation in the map area is considered to be late Miocene to earliest Pliocene.

UNNAMED CONGLOMERATE

Conglomeratic beds (QTc) that are thought younger than the Troutdale Formation form a sheetlike body that underlies most terrain south of the East Fork Lewis River. The conglomerate is largely covered by silt deposited by late Pleistocene glacier-outburst floods (see below) but crops out where streams have incised into the surface, as at the south edge of the East Fork Lewis River floodplain, in Allen Canyon, along Gee Creek, and along the railroad grade south of Ridgefield. It ranges from 20 to 40 m thick throughout most of western Clark County but is as thick as 60 m beneath the low hills near the south boundary of the map area (Trimble, 1963; Mundorff, 1964; Swanson and others, 1993). Well logs indicate that the conglomerate abruptly overlies the Sandy River Mudstone along a subhorizontal contact, but it laps out with slight discordance against older Neogene sedimentary strata and Paleogene bedrock north of the East Fork Lewis River.

The conglomerate is texturally similar to, but less deeply weathered than the older Troutdale Formation. It is characterized by coarse grain size, moderate to good sorting, openwork and sand matrix, well-developed clast imbrication, and crude stratification. These properties reflect deposition in a fluvial setting similar to that of the Troutdale. In exposures near Ridgefield, this unit, like the Troutdale Formation, is dominated by cobbles of aphyric basalt of the Columbia River Basalt Group accompanied by varying proportions of plutonic and metamorphic rocks. To the east along the East Fork Lewis River, however, the conglomerate contains a large proportion of clasts eroded from Tertiary volcanic rocks of the western Cascade Range, in contrast to nearby outcrops of the Troutdale Formation that consist almost exclusively of Columbia River Basalt Group clasts. The compositional change corresponds to a shift in transport direction from north to northwest inferred from clast imbrication. Further east, inferred transport directions are west to southwest (Howard, 2002). The unnamed conglomerate is also distinguished from the Troutdale Formation by the presence of scattered clasts of high-alumina olivine-bearing basalt, and in Allen Canyon, by a lens of reworked basaltic hyaloclastite. The presence of olivine-basalt clasts and hyaloclastite indicate that the unnamed conglomerate is the same age as or younger than the informal upper member of the Troutdale Formation of Tolan and Beeson (1984) in the Columbia River Gorge, and the unit may be correlative, in part, to the Springwater Formation of Trimble (1963) east of Portland. It is probably no older than late Pliocene.

QUATERNARY DEPOSITS

ALLUVIAL DEPOSITS

The main factors that influenced Quaternary alluvial sedimentation in the Ridgefield quadrangle are all facets of climatic variation: (1) episodes of mountain glaciation; (2) changes in base level owing to sea-level fluctuation; and (3) inundation by great Missoula Floods. Several times during the Pleistocene epoch, icecaps covered the Washington Cascade Range and spawned glaciers that moved down all of the major river valleys (Crandell and Miller, 1974). Drift is widespread in the region east and northeast of this quadrangle (Mundorff, 1964, 1984), but apparently no glaciers reached the Portland Basin. A few terrace remnants in the quadrangle may be distal parts of outwash trains. During glacial maxima, sea level was as much as 120 m lower than at present (Warne and Stanley, 1995; Clark and Mix, 2002). The Columbia River in response deeply incised its bed, flowing through a narrow valley about 2 km west of the map area (Gates, 1994). The Lewis and East Fork Lewis Rivers presumably also adjusted to lower base level at these times. Late in the last glacial period, huge glacier-outburst floods from Glacial Lake Missoula coursed down the Columbia River valley and hydraulically ponded in the Portland Basin; silt and fine sand that settled out of this temporary lake now cover much of the map area. As sea level rose during the late Pleistocene and Holocene, the late Pleistocene valleys gradually filled with sediment.

Cataclysmic-flood deposits

During the last glacial maximum in late Pleistocene time, an ice dam impounded Glacial Lake Missoula in western Montana. The dam failed repeatedly, releasing 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 constricted by the narrow reach of the Columbia River valley north of (downstream from) the Ridgefield quadrangle. The constriction caused temporary ponding in the Portland Basin and tributary valleys to levels as high as 400 ft (120 m). Radiocarbon ages, paleomagnetic measurements, and tephrochronologic data indicate that the last-glacial episode of floods occurred chiefly between about 17,000 and 13,000 ^{14}C years B.P. (Waitt, 1985, 1994; Atwater, 1986; Clague and others, 2003). Similar episodes of cataclysmic flooding probably occurred earlier in the Quaternary (McDonald and Busacca, 1988; Zuffa and others, 2000; Bjornstad and others, 2001).

During each flood, the suspended load of fine sand and silt settled out of the temporarily ponded floodwaters. In the northern Portland Basin, multiple floods (Waitt, 1994, 1996) collectively built up deposits of laminated micaceous sediments as thick as 30 m. These slack-water deposits (Qfs), which grade almost imperceptively northward from fine sand to silt, now mantle the entire surface of the Ridgefield quadrangle south of the East Fork Lewis River. Partly eroded flood deposits lie north of the river between 200 and 300 ft (60 and 75 m) elevation, and local unmapped patches of micaceous silt are found at elevations up to 400 ft (120 m). An exotic, presumably ice-rafted, boulder of coarse-grained gneiss was excavated from the flood deposits east of Mud Lake. The laminated character of the flood deposits is obvious only in fresh slump-scarp outcrops because oxidation colors exposures light brown and obscures bedding. They are dominated by grains of quartz and feldspars and contain conspicuous muscovite, which confirms their Columbia River provenance.

Late Pleistocene and Holocene alluvial deposits

Remnants of a terrace with surface elevations of 110 to 140 ft (33 to 43 m) lie along the south bank of the Lewis River directly downstream from its confluence with the East Fork Lewis River. The terrace deposits (Qtd) consist of unconsolidated, poorly sorted sandy pebble gravel and lithic sand overlain by micaceous silt of Missoula-floods origin (Qfs). Terrace-gravel clasts are chiefly Tertiary volcanic rocks eroded from the Cascade Range, indicating that the terrace sediment was carried by the Lewis River rather than the Columbia. Similar but higher terraces about 3 km upstream (Evarts, 2004a) contain ash beds probably deposited between 300 and 400 ka (A.M. Sarna-Wojcicki, written commun., 2000). Evarts (2004a) suggests these terrace deposits are erosional remnants of a thick outwash apron formed at the mouth of the Lewis River during the Wingate Hill glaciation of Crandell and Miller (1974).

Along the northeast margin of East Fork Lewis River floodplain near River Mile 5, small terrace remnants with surfaces ≤20 m above the floodplain are underlain by deposits of poorly sorted pebble and cobble gravel and minor sand (Qoa) that are lithologically similar to modern alluvium. The terrace surfaces are not mantled by cataclysmic-flood deposits (Qfs), so must be younger than 14 to 13 ^{14}C yrs B.P.

Holocene alluvium (Qa) of the Columbia River floodplain consists largely of silt and fine sand with local concentrations of organic debris. The sand is dominated by quartz, feldspar, and lithic fragments eroded from pre-Tertiary nonvolcanic terranes east of the Cascade Range (Whetten and others, 1969; Gates, 1994), but near the northwest corner of the map area the unit contains a substantial proportion of pumice and other volcanic clasts derived from Mount St. Helens and carried to the Columbia River floodplain by the Lewis River. Floodplain alluvium of the East Fork Lewis River ranges from gravel to silt. Drill holes and gravel pits upstream from River Mile 7 near the east edge of the Ridgefield quadrangle reveal about 10 m of boulder to cobble gravel of probable glacial origin resting on the sandstone and siltstone facies of the Troutdale Formation (Norman and others, 1998; Howard, 2002). The river downstream from here is tidally influenced and has a significantly lower gradient (approximately 0.25 m/km) than that upstream (approximately 4.1 m/km). The upper part of the alluvial fill in this reach consists of silt and fine to medium sand with conspicuous muscovite flakes; these sediments are probably reworked cataclysmic-flood deposits.

LANDSLIDE DEPOSITS

Owing to the overall gentle relief, most areas in the Ridgefield quadrangle are not prone to the formation of large, deep-seated landslides (Fiksdal, 1975). Small slides and slumps commonly form on steep streambanks and terrace margins due to failure of weakly consolidated Sandy River Mudstone (Tsr) and unconsolidated cataclysmic-flood deposits (Qfs). Most of the mapped landslides (Qls) are vegetated and appear to have stabilized, but some are active, like those along the railroad tracks south of Ridgefield. Many areas underlain by Quaternary and Neogene sediments include small slumps and debris-flow deposits too small to portray at map scale.

STRUCTURAL FEATURES

The Ridgefield quadrangle is in the north part of the Portland Basin (fig. 1). Most of the quadrangle is underlain by weakly consolidated, subhorizontal, basin-fill sediments of Neogene age that rest on an eroded basement composed of Paleogene bedrock and Columbia River Basalt Group flows. Late Eocene basement rocks that crop out in the northeastern part of the map area belong to a generally east-northeast-striking, gently south-southeast-dipping (15 to 30°) section of volcanic and volcaniclastic rocks that is well exposed in highlands to the north (Evarts, 2004a). These strata are early products of the Cascade volcanic arc; in the subsurface they must grade westward to coeval sedimentary rocks exposed in the Oregon Coast Range (Niem and others, 1992, 1994). Near Jenny Creek and north of the map area near Woodland, the tilted Eocene rocks are overlain by nearly flat-lying lava flows of the Grande Ronde Basalt, which indicates that most deformation of the older strata occurred before about 16 Ma. This is consistent with regional relations that constrain major folding in the southern Washington Cascade Range to early middle Miocene time (Evarts and Swanson, 1994).

The low hills southeast of Ridgefield may reflect an underlying structure. Water-well drillers' logs show that the upper contact of the Sandy River Mudstone beneath the hills is elevated relative to surrounding areas. Mundorff (1964) and Swanson and others (1993) also recognized this feature, and interpreted it as evidence for a north-northwest-trending anticline roughly parallel to a gentle syncline delineated by Grande Ronde Basalt flows to the west and northwest (Wilkinson and others, 1946; Evarts, 2004c). A high-resolution aeromagnetic survey of the Portland Basin (Snyder and others, 1993) suggests an alternative explanation. Each of the hills coincides with prominent domelike magnetic highs like those commonly associated with Quaternary volcanic centers in the Portland area (Blakely and others, 1995). Intrusion of mafic magma into the Sandy River Mudstone as sills or small laccoliths could account for the aeromagnetic anomalies and the observed uplift. A few kilometers north, the Benedict No. 1 well (McFarland, 1983) intersected rock identified as basalt within sedimentary strata at 25 to 60 m depth.

Deep weathering of bedrock and thick cover of young sediment obscures evidence of faulting in the Ridgefield quadrangle, so faults shown on the map are largely inferred from indirect evidence. Mapped relations, however, suggest some largely buried faults. One underlies the East Fork Lewis River valley and runs through the linear bedrock-confined reach near the river's mouth. Evidence for this structure consists of the highly fractured andesite outcrops along the riverbank near Paradise Point and, to the southeast, an apparent offset of south-dipping Paleogene stratigraphy across the river. Such a fault may explain curious relations in that area. Water-well logs show that the bedrock basement drops steeply to below sea level within 1 km south of the outcrops near Paradise Point. Yet the river, after traversing easily eroded basin-fill sediments for more than 12 km, has cut a northwest-trending notch directly through bedrock rather than excavating the weakly consolidated sediments just to the south. Furthermore, in the Battle Ground quadrangle to the east, the East Fork Lewis River adopts this northwest course abruptly, after following a west to southwest route out of the Cascade Range. This suggests that the lower reach of the river was diverted by the rising south side of a fault. The distribution of Paleogene strata east of Paradise Point is also consistent with south-side-up offset along this inferred structure.

Along the railroad north of Ridgefield, a fault juxtaposes slightly warped Sandy River Mudstone to the north against Grande Ronde Basalt to the south. It is inferred to continue at least 2 km to the southeast, where water-well data indicate that the top of the Grande Ronde Basalt drops off steeply to the northeast. The northwest trend parallels a pronounced aeromagnetic lineament (Snyder and others, 1993; Evarts and others, 2002) that extends several kilometers to the northwest and southeast. It projects southeastward along the northeast flank of the inferred anticline described above to a fault mapped by Mundorff (1964) at Lacamas Lake, 20 km to the southeast. The position of this fault along the northeast flank of an anticlinal axis is analogous to that of the parallel Portland Hills Fault Zone, a major oblique-slip reverse structure that forms the margin of the Portland Basin to the southwest (Balsillie and Benson, 1971; Beeson and others, 1991; Blakely and others, 1995).

GEOLOGIC EVOLUTION

The Portland Basin and its bounding structures have a long and complex tectonic history (Beeson and others, 1989; Blakely and others, 1995; Yeats and others, 1996). Beeson and Tolan (1990) suggest that development of the structure that evolved into the present basin began in middle Miocene time, shortly before eruptions of the Grande Ronde Basalt. Considerable evidence also exists for older regional deformation (Snavely and Wells, 1996; Niem and others, 1992, 1994).

The general character of Paleogene bedrock in the map area is similar to that which underlies most of the southern Washington Cascade Range. Regional relations indicate that this area was near the western margin of the active Cascade volcanic arc during Paleogene time. Age determinations in nearby quadrangles (R.J. Fleck, written commun., 2000, 2001, 2002, 2003) indicate that the extrusive rocks here probably were erupted during late Eocene time, early in the history of the arc (Duncan and Kulm, 1989; Evarts and Swanson, 1994). Volcanic rocks continued to accumulate in a gradually subsiding Cascade-arc trough until middle Miocene time, when a major compressional event effectively terminated the early phase of arc development (Evarts and Swanson, 1994). The most intense phase of this event was largely over by 16 Ma because south-dipping Paleogene rocks in the Ridgefield and adjacent quadrangles are unconformably overlain by nearly flat-lying semi-consolidated sedimentary strata and Grande Ronde Basalt flows of about that age.

In early to middle Miocene time, when the Portland Basin began to form (Beeson and Tolan, 1990; Beeson and others, 1989), western Washington and Oregon constituted a terrain of modest relief eroded into mildly deformed Paleogene volcanic and sedimentary rocks (Wilkinson and others, 1946; Beeson and others, 1989). Largely nonmarine fine-grained sedimentary deposits that rest unconformably on Paleogene bedrock throughout western Oregon and Washington (Van Atta and Kelty, 1985; Beeson and others, 1989; Tolan and Beeson, 1999; Evarts 2004a) reflect deposition in low-energy fluvial, lacustrine, paludal, estuarine, and shallow-marine environments. The absence of coarse-grained volcaniclastic debris signifies that the middle Miocene Cascade arc was low in elevation and volcanically quiescent compared to earlier times.

Starting about 16.5 Ma, flood-basalt flows of the Grande Ronde Basalt entered the incipient Portland Basin and spread widely throughout the region, burying the topographically subdued terrain (Beeson and others, 1989). The position of flood-basalt remnants banked against Paleogene rocks east of La Center marks the east margin of the middle Miocene Columbia River valley.

Fine-grained sediment (Sandy River Mudstone) deposited on top of the Columbia River Basalt Group in the northern Portland Basin resembles deposits that locally underlie the lava flows. Aside from temporary and local perturbations imposed by the flows, the regional sedimentary regime therefore remained little changed into the late Miocene. The floor of the Portland Basin must have gradually subsided as these fine-grained upper Miocene sediments accumulated, for as much as 500 meters of fluvial sediments underlie Vancouver (Swanson and others, 1993; Mabey and Madin, 1995). To the southeast, near the west end of the Columbia River Gorge, these beds grade laterally and upward into conglomeratic fluvial deposits of the Troutdale Formation (Tolan and Beeson, 1984; Swanson and others, 1993). These gravelly beds are dominated by clasts eroded from flows of the Miocene Columbia River Basalt Group, but they also contain clasts of granitic, metamorphic, and quartzite rocks derived from pre-Tertiary terranes east of the Cascade Range. In the Ridgefield quadrangle and nearby areas, the contact between the Sandy River Mudstone and Troutdale Formation is disconformable, which suggests a period of mild uplift and erosion preceded deposition of the latter.

In Pliocene time, uplift of the Cascade Range tilted the surface of the Troutdale Formation southwest. As the eastern margin of the Portland Basin rose, the Columbia River cut through the Troutdale Formation and into the underlying Sandy River Mudstone; the pronounced break in slope north and east of La Center is an erosional scarp produced at this time. A gravel sheet (QTc) then prograded northward across the basin floor. The sedimentology of this deposit implies deposition by torrential floods in a braided stream environment (Miall, 1977, 1996; Rust, 1978; Ramos and Sopeña, 1983). Clasts eroded from flows of the Columbia River Basalt Group predominate, indicating deposition chiefly by the ancestral Columbia River, but Tertiary volcanic rocks eroded from the uplifted Cascade Range are abundant in conglomerate near the east margin of the Portland Basin. The widespread presence of cobbles of Cascadian high-alumina basalt indicates the conglomerate was deposited mostly during middle and late Pliocene time (Tolan and Beeson, 1984). During the Quaternary, the Columbia River incised the gravel sheet and became localized near its present course.

Mountain glaciers in the Cascade Range never reached the Portland Basin. The most pronounced impact of Pleistocene glaciation in the map area was inundation by huge floods originating from Glacial Lake Missoula. The hydraulically dammed floodwaters filled the basin to a depth of 400 ft (120 m) and deposited many layers of fine-grained slack-water deposits totaling as much as 30 m thick. North of Ridgefield, flood deposits are absent from parts of a surface, at an elevation of about 200 ft (70 m), underlain by the unnamed conglomerate (QTc). This surface is far above the reach of Holocene flooding on the Columbia River. It may be an exhumed surface from which slack-water beds were stripped by late Missoula Floods, or an area where fine-grained sediment was never deposited owing to swift currents in floodwaters near the main river channel. In the southeast part of the Ridgefield quadrangle and in adjacent areas, the slack-water deposits exhibit a pronounced, north-south, fluted morphology, which Howard (2002) interpreted as cataclysmic-flood erosion features.

Sea level during the last glacial maximum was about 120 m lower than at present (Warne and Stanley, 1995; Clark and Mix, 2002), and both the Columbia and Lewis River systems had correspondingly lowered base levels. The base level of the East Fork Lewis River may have been higher, constrained by the bedrock gorge at Paradise Point, and the river possibly terminated in a cataract. During the subsequent rapid marine transgression, aggradation in the lower Columbia valley generally kept pace with the rise in sea level, filling the latest Pleistocene channel with silt and fine sand (Gates, 1994).

GEOLOGIC RESOURCES

Geologic resources available in the Ridgefield quadrangle are limited to nonmetallic industrial materials, chiefly sand and gravel used for construction purposes. Abundant sand and gravel resources are available from unconsolidated alluvial deposits along the East Fork Lewis River, and large gravel pits have been excavated in the reach of the river above River Mile 7 (Norman and others, 1998). Just north of the map, area, flows of the Grande Ronde Basalt, especially the highly jointed entablatures, were quarried for aggregate used primarily as roadbase material. A 786-m-deep test hole drilled east of Ridgefield by the Adams-Benedict Oil Company in 1959 was dry (McFarland, 1983).

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

[X-ray fluorescence analyses. Rock-type names assigned in accordance with IUGS system (Le Maitre, 2002) applied to recalculated analyses. LOI, loss on ignition. 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; ---, no data. Analyses by D.F. Siems at USGS, Lakewood, Colo. using methods described in Taggart and others, (1987), Johnson and King (1987), and King and Lindsay (1990). *, analyses by D.M. Johnson 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.	97LC-Q62B2	98LC-Q281C	98LC-Q281B	00LC-Q459C*	00LC-Q422B*	97LC-Q61B	97LC-Q70*	99LC-Q304*	99LC-Q310*
Latitude (N)	45° 52.44'	45° 52.20'	45° 52.20'	45° 52.26'	45° 52.44'	45° 52.44'	45° 52.38'	45° 50.70'	45° 51.90'
Longitude (W)	122° 42.66'	122° 42.30'	122° 42.24'	122° 41.94'	122° 42.24'	122° 42.54'	122° 41.82'	122° 44.76"	122° 41.22'
Map unit	Ta	Ta	Ta	Ta	Ta	Ta	Tgsb	Tgsb	Tgsb
Rock type	Andesite	Andesite	Andesite	Andesite	Andesite	Dacite	Basaltic andesite	Basaltic andesite	Basaltic andesite
Analyses as reported (wt percent)									
SiO_2	56.31	57.64	58.03	59.33	62.17	62.13	54.04	54.06	54.03
TiO_2	1.55	1.37	1.76	1.54	1.41	1.15	1.80	1.98	1.80
Al_2O_3	15.58	15.77	14.59	15.51	15.31	15.46	14.02	14.07	14.06
Fe_2O_3	9.86	7.92	8.71	---	---	6.62	---	---	---
FeO	---	---	---	7.34	6.95	---	10.86	11.20	11.29
MnO	0.21	0.16	0.18	0.17	0.10	0.11	0.20	0.24	0.20
MgO	3.17	2.62	2.17	2.37	2.26	1.77	4.65	4.39	4.64
CaO	6.65	5.30	4.73	5.56	4.68	4.18	8.45	8.81	8.45
Na_2O	3.79	3.74	4.00	4.55	4.55	4.59	3.05	2.96	3.10
K_2O	0.92	1.65	1.53	1.26	1.60	1.71	1.25	1.26	1.22
P_2O_5	0.29	0.32	0.44	0.65	0.34	0.35	0.35	0.33	0.35
LOI	1.14	3.05	3.15	---	---	1.86	---	---	---
Total	99.46	99.53	99.29	98.28	99.37	99.94	98.66	99.30	99.14
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)									
SiO_2	57.85	60.24	60.91	60.37	62.56	63.78	54.77	54.44	54.50
TiO_2	1.59	1.44	1.85	1.57	1.42	1.18	1.82	1.99	1.82
Al_2O_3	16.01	16.48	15.32	15.78	15.41	15.87	14.21	14.17	14.18
FeO*	9.11	7.44	8.23	7.47	7.00	6.12	11.01	11.28	11.39
MnO	0.21	0.17	0.19	0.17	0.10	0.12	0.20	0.24	0.20
MgO	3.25	2.74	2.28	2.41	2.27	1.82	4.71	4.42	4.68
CaO	6.84	5.54	4.96	5.66	4.71	4.29	8.56	8.87	8.52
Na_2O	3.89	3.91	4.20	4.63	4.58	4.71	3.09	2.98	3.13
K_2O	0.94	1.72	1.60	1.28	1.61	1.76	1.27	1.27	1.23
P_2O_5	0.30	0.33	0.46	0.66	0.34	0.36	0.35	0.33	0.35
Mg#	38.9	39.6	33.1	36.5	36.7	34.6	43.3	41.1	42.3
Modes (volume percent)									
Plagioclase	0.7	10.4	0.1	0.9	11.4	5.2	-	-	-
Clinopyroxene	0.1	1.2	trace	0.2	1.3	0.8	-	-	-
Orthopyroxene	-	0.8	-	0.1	1.4	1.2	-	-	-
Olivine	-	-	-		-	-	-	-	-
Fe-Ti Oxide	trace	trace	trace	0.2	0.4	0.2	-	-	-
Hornblende	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Groundmass	99.2	87.6	99.9	98.6	85.5	92.6	100.0	100.0	100.0
No. points counted	800	811	777	800	845	750	---	---	---
Texture (rock/ groundmass)	sparsely phyric/ pilotaxitic	porphyritic/ intersertal	sparsely phyric/ intersertal	sparsely phyric/ hyalopilitic	porphyritic/ pilotaxitic	porphyritic/ pilotaxitic	aphyric/ intersertal	microhyric/ intersertal	aphyric/ intersertal
Trace element analyses (ppm)									
Ba	238	272	297	261	305	297	526	542	545
Rb	27	25	31	28	29	28	33	28	34
Sr	328	317	292	331	294	283	307	317	308
Y	26	31	33	36	32	32	34	36	35
Zr	186	227	264	203	247	290	164	162	163
Nb	16	19	20	16.6	16.4	20	13.0	12.0	12.1
Ni	13	17	11	2	6	---	9	11	11
Cu	110	102	75	32	67	---	26	29	29
Zn	90	79	92	98	88	---	116	115	111
Cr	---	---	---	1	7	---	49	47	51

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

Map No.	10	11	12
Field sample No.	00LC-Q447*	01LC-Q469A*	01LC-Q469B*
Latitude (N)	45° 51.60'	45° 50.87'	45° 50.80'
Longitude (W)	122° 40.32'	122° 44.95"	122° 44.96"
Map unit	Tgsb	Tgsb	Tgsb
Rock type	Basaltic andesite	Basaltic andesite	Basaltic andesite
Analyses as reported (wt percent)			
SiO_2	53.48	53.79	53.61
TiO_2	1.79	1.97	1.95
Al_2O_3	13.93	14.01	14.00
Fe_2O_3	---	---	---
FeO	11.47	11.33	12.10
MnO	0.21	0.25	0.22
MgO	4.76	4.51	4.60
CaO	8.46	8.85	8.68
Na_2O	2.98	2.94	2.88
K_2O	1.26	1.23	1.16
P_2O_5	0.34	0.32	0.32
LOI	---	---	---
Total	98.68	99.19	99.53
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt percent)			
SiO_2	54.20	54.23	53.87
TiO_2	1.82	1.98	1.96
Al_2O_3	14.12	14.12	14.07
FeO*	11.62	11.42	12.16
MnO	0.21	0.25	0.22
MgO	4.82	4.55	4.62
CaO	8.57	8.92	8.72
Na_2O	3.02	2.96	2.89
K_2O	1.28	1.24	1.17
P_2O_5	0.35	0.32	0.32
Mg#	42.5	41.5	40.4
Modes (volume percent)			
Plagioclase	-	-	-
Clinopyroxene	-	-	-
Orthopyroxene	-	-	-
Olivine	-	-	-
Fe-Ti Oxide	-	-	-
Hornblende	-	-	-
Quartz	-	-	-
K-feldspar	-	-	-
Other	-	-	-
Groundmass	100.0	100.0	100.0
No. points counted	---	---	---
Texture (rock/ groundmass)	aphyric/ intersertal	microphyric/ intersertal	microphyric/ intersertal
Trace element analyses (ppm)			
Ba	537	527	502
Rb	30	26	27
Sr	311	313	312
Y	36	35	36
Zr	164	160	161
Nb	11.4	11.4	12.1
Ni	11	11	9
Cu	25	19	25
Zn	117	113	116
Cr	47	41	44