Geologic map of the Deer Island quadrangle, Columbia County, Oregon and Cowlitz County, Washington

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INTRODUCTION

GEOGRAPHIC AND GEOLOGIC SETTING

The Deer Island 7.5' quadrangle is situated in the Puget-Willamette Lowland of southwestern Washington and northwestern Oregon, approximately 50 km north of Portland (fig. 1). The lowland, which extends from Puget Sound southward into western Oregon, is a complex structural and topographic trough that separates two major physiographic and geologic provinces: the Coast Range to the west and the Cascade Range to the east. Since late Eocene time, the Cascade Range has been the locus of a discontinuously 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 complex assemblage of Eocene to Miocene volcanic and marine sedimentary rocks.

The Deer Island quadrangle is located at the northern end of the Portland Basin (fig. 1), a roughly 2000-km^2 topographic and structural depression that is the northernmost of several sediment-filled structural basins which collectively constitute the Willamette Valley segment of the 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. Its northern boundary coincides with the lower Lewis River, which drains a large area in the southern Washington Cascade Range and joins the Columbia River approximately 6 km south of Woodland (see index map on map sheet). Northwest of Woodland, the Columbia River exits the broad floodplain of the Portland Basin and flows northward at an elevation near sea level through a relatively narrow bedrock valley which is less than 2.5 km wide at a point about 2 km north of the Deer Island quadrangle. The flanks of the basin consist of Eocene through Miocene volcanic and sedimentary rocks that rise to elevations exceeding 2000 ft (610 m). Lithologic logs of water wells drilled throughout the basin indicate that as much as 550 m of upper Miocene and younger sediments have accumulated in the deepest part of the basin near Vancouver (Swanson and others, 1993). Most of this basin fill was transported from the east by the Columbia River but contributions from streams draining the adjacent highlands are locally important.

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 and dextral shear within the forearc in response to oblique subduction of the Pacific plate beneath the North America 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 bounded on its northeast flank by the Portland Hills Fault (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 broad, partially buried, zone of dextral offset and extension, referred to as the Frontal Fault Zone, has been inferred from topography, microseismicity, potential field-anomalies, and reconnaissance geologic mapping (Yelin and Patton, 1991; Beeson and others, 1989; Blakely and others, 1995). Another dextral structure may control the north-northwest-trending reach of the Columbia River north of Portland (Blakely and others, 1995). If it exists, this structure may merge in some fashion with the Frontal Fault Zone in the vicinity of the Deer Island quadrangle.

The greater Portland-Vancouver metropolitan area, home to more than 1.75 million people, occupies much of the low-lying central area of the Portland Basin. The Deer Island quadrangle lies outside the heavily urbanized core and includes all or parts of the small cities of Woodland in Cowlitz County, Washington and Columbia City and Saint Helens in Columbia County, Oregon. Historically, the economic base of the local area has been agriculture, silviculture, and, to a lesser extent, production of industrial minerals. Recently, these and other areas at the margins of the Portland-Vancouver metropolitan region have been experiencing accelerated population growth. In the past decade, residential and associated commercial development expanded significantly within the Columbia River floodplain and extended into the adjacent foothills of the Coast and Cascade Ranges. Greater development increases vulnerability to substantial economic losses from earthquakes and landslides (Madin and Wang, 1999; Burns, 1999) and stresses water and sewage systems.

Geologic hazards in the Deer Island quadrangle are of regional concern. The Puget-Willamette Lowland is relatively narrow here, providing a natural corridor within which utility lines serving the Pacific Northwest have become concentrated. Interstate Highway 5 in Washington, U.S. Route 30 in Oregon, and rail lines on both sides of the Columbia River are the major north-south ground transportation routes for the heavily populated western parts of

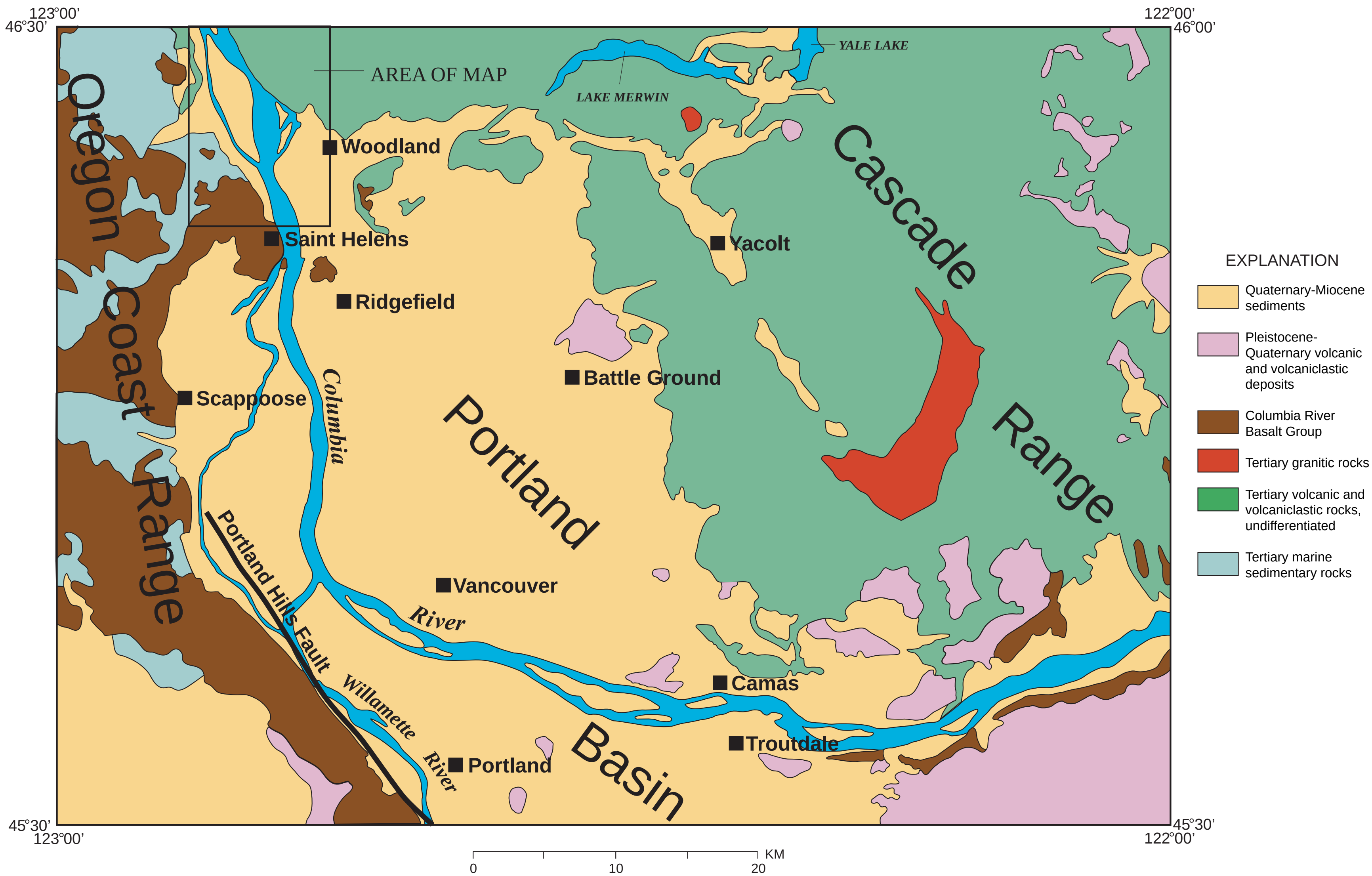

Figure 1. Simplified geologic map of the Vancouver 30' x 60' quadrangle, modified from Phillips (1987a).

these two states. The Columbia River itself is, of course, the vital maritime trade route for the Portland Basin and the inland region to the east. Natural gas and petroleum pipelines, electrical-power transmission lines, and fiber-optic communications cables also pass through the quadrangle. In recent years these utilities have been, and will continue to be, impacted by natural events.

This map is a contribution to a U.S. Geologic Survey program designed to improve the geologic database for the Portland Basin part 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 of the basin and its surrounding area is needed to refine assessments of seismic and ground-failure hazards and resource availability in this rapidly growing region. Although the risk posed by earthquakes generated in the shallow crust of the Portland area is widely recognized, it is difficult to quantify because mapped faults are few and seismicity is diffusely distributed (Yelin and Patton, 1991; Bott and Wong, 1993; Wong and others, 2001). Geologic mapping of the basin margins can provide clues to the structure of the Portland Basin and help to constrain the types, sizes, and frequency of earthquakes that may be anticipated there. Likewise, knowledge of the location of past landslides and of the distribution of landslide-prone geologic materials can be used to guide development and avoid disasters such as the one suffered by the Aldercrest neighborhood in Kelso, Washington, about 15 km north of the Deer Island quadrangle (Burns, 1999; Wegmann and Walsh, 2001).

PREVIOUS GEOLOGIC INVESTIGATIONS

The geology of the Deer Island 7.5' quadrangle was first mapped and described by Wilkinson and others (1946) in their report on the Saint Helens 15' quadrangle. Their representation of the geology at a scale of 1:62,500 is much simplified but does portray the general distribution of the major geologic units of the area: Paleogene volcanic and sedimentary rocks, Miocene Columbia River Basalt 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. Wilkinson and others (1946) introduced the name Goble Volcanic Series for the thick section of Eocene volcanic and volcaniclastic rocks of the area, named for the village of Goble, Oregon about 1.5 km north of the northwestern corner of the Deer Island quadrangle.

Phillips (1987a) compiled a geologic map of the Vancouver 30'x60' sheet, which includes the Deer Island 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 the map of Wilkinson and others (1946), he attempted to define informal stratigraphic units within the Tertiary volcanic section based largely on reconnaissance mapping east of the Deer Island quadrangle. Phillips also presented chemical analyses for some of the Paleogene volcanic rocks as well as several new whole-rock K-Ar age determinations.

Several topical investigations of regional extent also provide limited information on the geology of the Deer Island quadrangle. These include the reports of Yancey and Geer (1940) on coal, Libbey and others (1945) on ferruginous bauxite, Lowry and Baldwin (1952) on late Cenozoic deposits, Mundorff (1964) and Swanson and others (1993) on water resources, Beck and Burr (1979) on remanent magnetism of the Goble Volcanics, and Harp and others (1997) on landslides.

ACKNOWLEDGMENTS

Access granted by the many landowners in the Deer Island quadrangle was essential to the work described herein. Blake Rowe, Robert Ross, Dennis Mohan, and Larry Hurley of the Longview Fibre Co. provided access to its timberlands. Randy Baker, manager of the Columbia Road and Driveway quarry west of Saint Helens, and Brian Gray, manager of the Morse Brothers quarry in Columbia City, offered access to their quarries for chemical and paleomagnetic sampling. The Burlington Northern - Santa Fe Railroad allowed me to examine railroad-cut exposures along their tracks near Martin Bluff, accompanied by track inspector Perry Lee. Several U.S. Geological Survey colleagues provided important data: David Siems (analytical chemistry), Jonathan Hagstrum (paleomagnetic measurements), Richard Blakely (aeromagnetic anomaly maps), and Robert Fleck (^{40}Ar/^{39}Ar ages). Andrei Sarna-Wojcicki, Kenneth Bishop, Judith Fierstein, and Michael Clynne made available essential laboratory facilities. Ellen J. Moore graciously identified the marine fossils found in the Pittsburg Bluff Formation. Kevin Anderson gave able field and laboratory assistance in 1997. Debra Hunemuller and Stephanie Abraham of the Washington Department of Ecology Southwest Regional Office in Lacey, Wash., provided access to their files of water-well drillers' reports as well as space to examine them. Connie Manson, librarian at the Washington Division of Geology and Earth Resources in Olympia, Wash., has been a continuing and enthusiastic source of information from that agency's files. I have benefited immensely from discussions and field conferences with Roger Ashley, Marvin Beeson, Michael Clynne, Paul Hammond, Keith Howard, Alan Niem, William Phillips, James O'Connor, Charles Powell, William

Scott, James Smith, Donald Swanson, Terry Tolan, Karl Wegmann, and Ray Wells on various aspects of the regional geology of the Portland Basin and environs. O'Connor and Wegmann provided valuable information on alluvial deposits and landslides, respectively, that has been incorporated into the map. The presentation and content were improved substantially as a result of formal reviews by Niem and Wells.

SYNOPSIS OF GEOLOGY

The geology of the Deer Island quadrangle is dominated by four main packages of deposits separated by regional unconformities: Paleogene bedrock, Miocene flood-basalt flows of the Columbia River Basalt Group, late Miocene and Pliocene alluvial deposits of the ancestral Columbia River, and Quaternary deposits of the modern river and its tributaries. The latter two packages constitute the thick sedimentary fill of the Portland Basin, a Neogene structural depression developed in the older rocks. Late Eocene volcanic and volcaniclastic rocks and rare small intrusions, early products of the Cascade volcanic arc, underlie the dissected, southwest-sloping surface on the Washington side of the river. In Oregon, similar volcanogenic rocks of the Goble Volcanics and unconformably overlying Oligocene marine sedimentary strata are sporadically exposed beneath a mantle of younger deposits. Following mild folding, faulting, and erosion, the bedrock units formed a low-relief terrain that was inundated by some of the areally extensive lava flows of the Columbia River Basalt Group. These lavas erupted from fissures in eastern Washington and Oregon, traversed the Cascade Range via an ancestral Columbia River valley, and spread out to cover large areas of the Coast Range province. After the basaltic eruptions ceased, fluvial silt, sand, and gravel of Columbia River provenance were deposited on the subhorizontal surface of the flows within and adjacent to the subsiding Portland Basin. Owing partly to late Neogene regional uplift, the Columbia River has cut through the Miocene and Pliocene deposits into the subjacent bedrock. In addition to fluvial sediments transported by the Columbia River, the fill of the modern river valley includes strata of colossal late Pleistocene glacier-outburst floods and volcanic debris carried down the Lewis River following eruptions of Mount St. Helens.

A relatively mild, wet climate prevailed in the western Pacific Northwest throughout most of the Cenozoic era (Wolfe and Hopkins, 1967; Wolfe, 1978) and promoted intense chemical weathering of the geologic units. Saprolitic soil horizons locally as much as 10 meters thick are commonly developed on both Paleogene bedrock and Neogene basin-fill deposits, and flows of the Columbia River Basalt Group have locally been converted into laterites in which all primary rock textures have been destroyed. Natural outcrops are generally limited to steep cliff faces, landslide scarps, and streambeds except along the Columbia River, where massive floods during the last glacial maximum stripped surficial deposits from bedrock below elevations of 150 to 200 ft (45 to 60 m). Many exposures encountered during the mapping were found in roadcuts and quarries. The surface information was supplemented with lithologic data from water-well logs provided by the Oregon Department of Water Resources and the Washington Department of Ecology; well locations were used as described in the driller's reports and were not field checked.

PALEOGENE BEDROCK

The Paleogene bedrock that underlies the west-sloping terrain between the Columbia River and Green Mountain in Washington consists of subaerially emplaced mafic lava flows interbedded with less abundant volcaniclastic rocks. Similar volcanic rocks, the Goble Volcanics, crop out across the river in Oregon, where they are unconformably overlain by nearshore marine and nonmarine sedimentary rocks of the Pittsburg Bluff Formation. ^{40}Ar/^{39}Ar age determinations (R.J. Fleck, written commun., 1999) indicate that the volcanic rocks exposed in the Deer Island quadrangle erupted during a relatively short time span (ca. 36-38 Ma) in late Eocene time; fossil evidence indicates the unconformably overlying Pittsburg Bluff Formation sedimentary section is probably Oligocene. Almost all the lava flows in the quadrangle are sparsely to abundantly plagioclase + olivine + augite-phyric basaltic andesites (table 1, Map nos. 1-22; fig. 2). Andesites and dacites, common in the region to the east and northeast (Phillips, 1987a, b; Evarts and Ashley, 1990a, b, 1991, 1992; Smith, 1993; R.C. Evarts, unpub. mapping) are rare here, as are intrusive bodies. The volcaniclastic rocks are chiefly intermediate to silicic pumiceous and lithic lapilli tuff and tuff breccia. Small intrusive bodies of glassy porphyritic andesite and dacite are found only east of the Columbia River.

STRATIGRAPHIC NOMENCLATURE: THE GOBLE PROBLEM

All Paleogene volcanic and volcaniclastic rocks in the Deer Island quadrangle were assigned to the Goble Volcanic Series by Wilkinson and others (1946); the name was later revised to Goble Volcanics by Livingston (1966) to conform to the then-current North American Code of Stratigraphic Nomenclature. The formation was named for volcanic and volcaniclastic rocks exposed near the village of Goble, Oregon, located along U.S. Route 30 about 1.5 km north of the northwest corner of the Deer Island quadrangle. Wilkinson and others (1946) included within the Goble a 1500-m-thick, south-dipping section of lava flows and breccias exposed along the Washington side of the Columbia River from near Woodland north to Kelso. Near Kelso, the lowest part of this volcanic section interfingers with and overlies fossiliferous, shallow marine to nonmarine, arkosic sandstones assigned to the middle to late Eocene Cowlitz Formation. The top of the formation was defined as the unconformity with the overlying

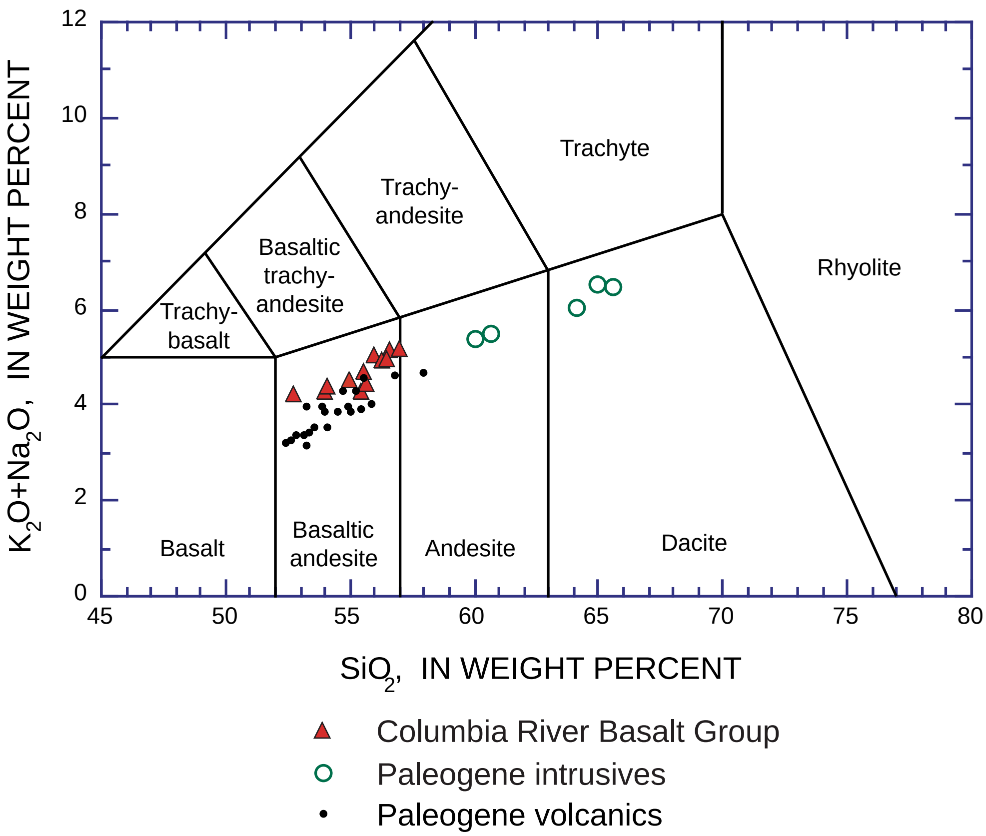

Figure 2. K_2O+Na_2O versus SiO_2 (recalculated volatile-free) for volcanic and intrusive rocks from the Deer Island 7.5' quadrangle showing IUGS classification (Le Bas and Streckeisen, 1991).

Oligocene sedimentary rocks (Pittsburg Bluff Formation of this map). Wilkinson and others (1946) stated that the formation “extends eastward from the northeast corner of the Saint Helens [15'] quadrangle to the Lake Merwinarea,” which is about 20 km east of Woodland (fig. 1). West of the Deer Island quadrangle, exploration wells and seismic data indicate that subaerial flows and volcaniclastic rocks, presumably contiguous with the Goble Volcanicsof Wilkinson and others (1946), form a westward-thinning wedge sandwiched between and interfingering with late Eocene marine sedimentary beds of the Cowlitz and Keasey Formations (Niem and others, 1992, 1994.

The difficulty with employing the Goble Volcanics as a formal lithostratigraphic unit in Washington is that the superjacent marine sedimentary rocks do not extend east of the Columbia River. As a result, it is impossible to locate the top of the unit as originally defined. Instead, the rocks that Wilkinson and others (1946) mapped as Goble Volcanics east of the river merely constitute the lower part of a thick pile of Paleogene to early Neogene volcanic rocks that underlie most of the western slope of the southern Washington Cascade Range (see Evarts and Swanson, 1994, and references therein). This heterogeneous but essentially conformable sequence includes many flows and volcaniclastic beds lithologically indistinguishable from the rocks exposed near Goble. No pronounced lithologic break correlative with the top of the Goble Volcanics in Oregon is apparent in Washington. In reconnaissance 1:100,000-scale mapping of the Vancouver and Mount St. Helens 30' x 60' quadrangles, Phillips (1987a, b) recognized this problem and suggested several informal revisions to the Goble Volcanics of Wilkinson and others (1946). He showed that the lowermost part of the unit near Kelso consists of chemically distinctive high-Ti tholeiitic basalts which he separated from the Goble Volcanics and informally named the Grays River volcanics (see also

Phillips and others, 1989). His Grays River volcanics includes most of the Eocene rocks that had been mapped in Washington as the Goble Volcanics by Livingston (1966), Wells (1981), Wells and Coe (1985), and Henriksen (1956). Phillips (1987a, b) retained the name Goble Volcanics for the basaltic andesite-dominated sections stratigraphically above the Grays River volcanics and the Cowlitz Formation, including most of the Paleogene volcanic rocks in the Deer Island quadrangle. However, he assigned the pyroclastic rocks exposed near Martin Bluff to an overlying unnamed volcaniclastic unit, Tvc_1. Furthermore, he asserted that these superjacent volcaniclastic rocks could be traced as a persistent horizon to the east and northeast, and used their presence to define the top of the Goble Volcanics on his map. More recent detailed mapping in the region (Evarts and Ashley, 1990a, b, 1991, 1992; R.C. Evarts, unpub. mapping) reveals stratigraphic relations that are considerably more complex than those portrayed by Phillips. The area he mapped as Tvc_1 is actually underlain by laterally discontinuous volcaniclastic strata intercalated with numerous lava flows. Age determinations (R.J. Fleck, written commun., 1999, 2000) confirm that the rocks of Phillips' unit Tvc_1 represent several stratigraphic levels. Furthermore, no substantive differences in the nature of volcanic activity or the chemistry of volcanic rocks are apparent across his inferred contact. The Goble Volcanics appears to be a valid lithostratigraphic unit in the Oregon Coast Range where it is confined between marine sedimentary strata. In the southern Washington Cascade Range, however, the lack of a clear lithologic marker for defining its upper contact renders the formation untenable there. On this map, therefore, the Goble Volcanics is restricted to rocks west of the Columbia River that are contiguous with those exposed at Goble. Only informal or lithologic names are applied to the Paleogene volcanic rocks in Washington, although I recognize that they are correlative with the Goble Volcanics across the river.

LATE EOCENE VOLCANIC, VOLCANICLASTIC, AND INTRUSIVE ROCKS

Basaltic andesite

The basaltic andesites of units Tgvb and Tba typically form blocky to platy jointed flows 3 to 6 m thick that display flow-brecciated tops and bottoms. Abundant zeolite- and clay-filled vesicles and reddish colors produced by oxidation during cooling or Eocene weathering characterize upper flow-breccia zones. Where well exposed, as in several roadcuts along Interstate Highway 5, on U.S. Route 30 north of Tide Creek, and on Martin Bluff Road north of Mill Creek, the flows are seen to be lobate in form. Younger flows fill irregularities on the surfaces of underlying flows, resulting in undulose flow contacts whose orientations may not accurately track regional structural trends. Sparse interflow sedimentary rocks generally consist of massive, reddish brown, tuffaceous siltstone or sandstone intervals less than 0.5 m thick. The red coloration probably reflects soil development, possibly enhanced by baking by the overlying flow; in either case this is evidence for a subaerial eruptive environment. Nowhere were pillow lavas or other indications of subaqueous emplacement observed.

Most basaltic andesite flows are conspicuously porphyritic, with phenocrysts of plagioclase, olivine, and, in many samples, augite. Groundmass textures range from intergranular to trachytic. In general, the chemistry of the lava flows in the Deer Island quadrangle resembles that of mafic flows exposed to the east and northeast (Evarts and Ashley, 1990a, b, 1991, 1992; R.C. Evarts, unpub. data). They are low- to moderate-K_2O basaltic andesites (figs. 2, 3) that straddle the dividing line between tholeiitic and calc-alkaline compositions according to the classification of Miyashiro (1974; fig. 4). Because the west dip of the basaltic andesites in Washington is similar to the slope of the land surface, only a relatively thin stratigraphic section, perhaps 200 m thick, is exposed there. The petrographic and chemical uniformity of these basaltic andesites suggests that they were all derived from the same volcanic center. The location of the source vent(s) is unknown but must reside outside the Deer Island quadrangle because basaltic andesite dikes are rare here. $^{40}Ar/^{39}Ar$ ages indicate eruption of the basaltic andesites at about 37 Ma (table 2).

Volcaniclastic rocks

Various types of volcaniclastic rocks (units Tgvt and Tt) are interbedded with the basaltic andesite flows on both sides of the Columbia River. Excellent exposures are found along the east bank of the Columbia River in the vicinity of Martin Bluff and in nearby railroad cuts. Massive beds of andesitic, dacitic, and rhyolitic lapilli tuff and tuff breccia, typically 3 to 10 m thick, dominate the volcaniclastic sections. These coarse-grained beds are very poorly sorted, matrix-supported, pyroclastic-flow and lahar deposits composed of varying proportions of lithic and pumiceous lapilli and blocks in an ashy matrix. Thin intervals (≤1-2 m) of stratified, clast-supported, volcanic sedimentary rocks and tuff commonly separate the thick massive beds; these strata probably consist largely of debris reworked from underlying pyroclastic deposits shortly after emplacement. Pumiceous beds exhibit no significant compaction or welding; some contain globular pumice blocks as large as 30 cm in diameter. Carbonized logs occur locally at or near the base of some pyroclastic units. The locations of source vents for the pyroclastic rocks are unknown, although a silicic dome complex exposed to the east on Schumaker Mountain in the Woodland quadrangle (R.C. Evarts, unpub. mapping) is likely of similar age. Plagioclase from an ash-flow tuff in the Goble Volcanics yielded a $^{40}Ar/^{39}Ar$ age of 36.1±0.3 Ma (table 2).

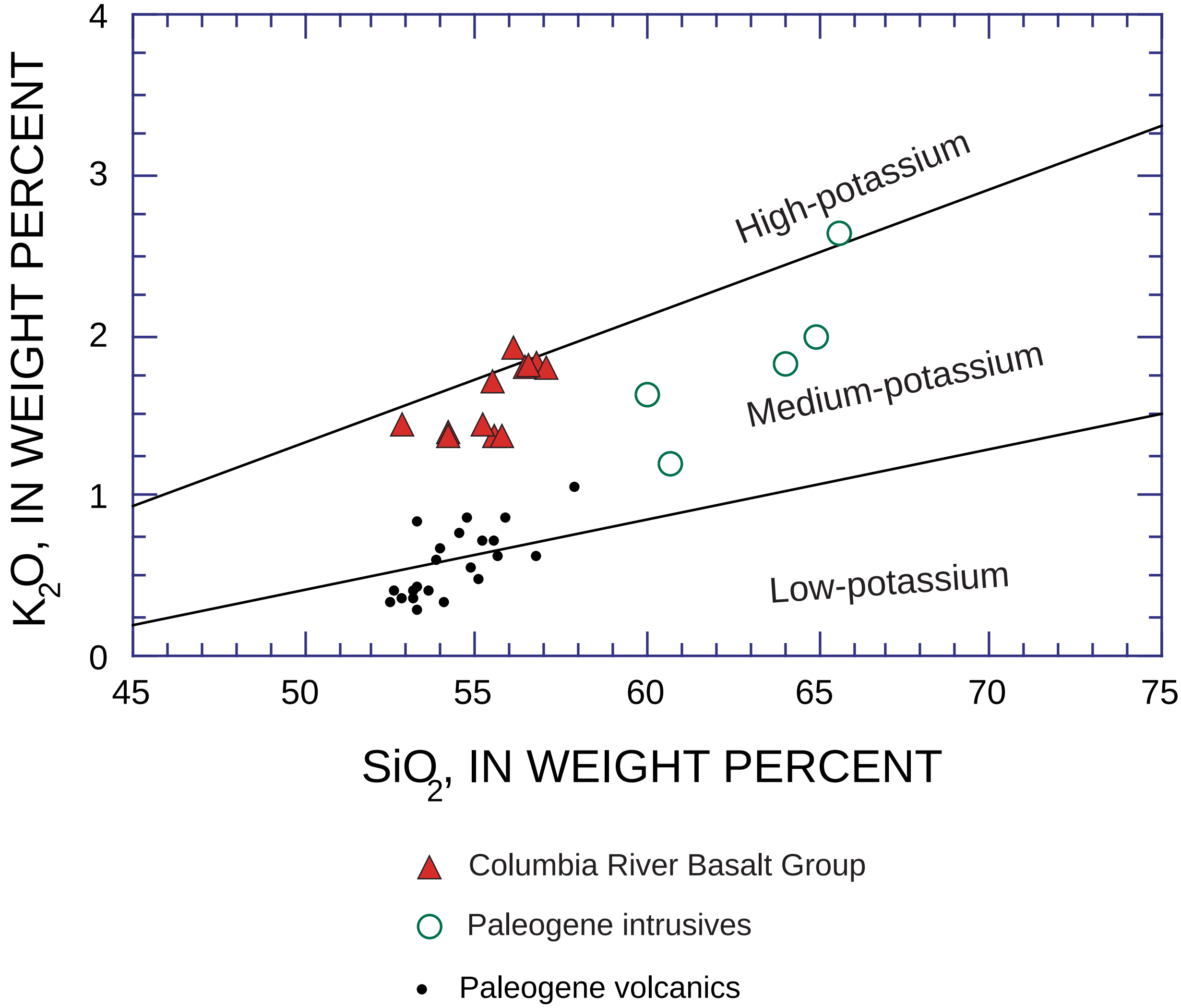

Figure 3. K_2O versus SiO_2 (recalculated volatile-free) for volcanic and intrusive rocks from the Deer Island 7.5' quadrangle. Low-, medium-, and high-potassium fields from Gill (1981, p. 6).

Other volcanic rocks

The only flow rock mapped in the Deer Island quadrangle that is not a basaltic andesite is an andesite distinguished in the field by small mafic xenoliths that are scattered throughout it. The flow is platy, commonly microvesicular, and sparsely phyric, with small phenocrysts and microphenocrysts of plagioclase, augite, and altered olivine. The streaky, cryptocrystalline groundmass is charged with finely crystalline Fe-Ti oxides. The xenoliths are relatively coarse-grained, variably recrystallized, porphyritic basaltic andesites or microdiorites. They range from angular to ovoid in shape and rarely exceed 1 cm in diameter. The chemical analysis (table 1, Map no. 22) of a sample freed of xenoliths shows it to be a mafic andesite (fig. 2).

A massive, unsorted, monolithologic breccia composed of angular clasts of seriate basaltic andesite crops out on a south-facing slope at the edge of the quadrangle about 2.5 km north of Woodland. Its texture is strikingly similar to that of the 1980 debris-avalanche deposit at Mount St. Helens. Wilkinson and others (1946) interpreted the deposit as a volcanic breccia interbed within the Miocene to Pliocene Troutdale Formation (the strata shown as Sandy River Mudstone on this map), but its petrographic similarity to some Eocene basaltic andesite flows and a plagioclase $^{40}Ar/^{39}Ar$ age of 37.3±0.3 Ma (table 2) shows it to be a late Eocene unit.

A poorly sorted monolithologic dacite breccia forms the top of a sharp-crested ridge near the mouth of Canyon Creek. The breccia consists of very angular clasts, as large as 1 m across, of black to red dacite in a matrix of comminuted dacite. The dacite clasts contain sparse small phenocrysts of plagioclase and augite in a cryptocrystalline groundmass; some clasts are flow banded. The breccia and an underlying matrix-rich debris-flow(?) deposit are weakly indurated, and slumping of these units on the flanks of the ridge seems to be responsible for the sharpness of its crest. The monolithologic breccia may be a block-and-ash deposit of the kind produced by lithic pyroclastic flows resulting from gravitational collapse of a silicic dome. No vestige of such a dome or its feeder dike was found in the immediate vicinity of the breccia outcrop, but lithic pyroclastic flows can travel many kilometers from their source (Fisher and Schmincke, 1984, p. 227), and a petrographically similar dacite plug-dome complex crops out about 4 km to the southeast in the Woodland quadrangle (R.C. Evarts, unpub. mapping).

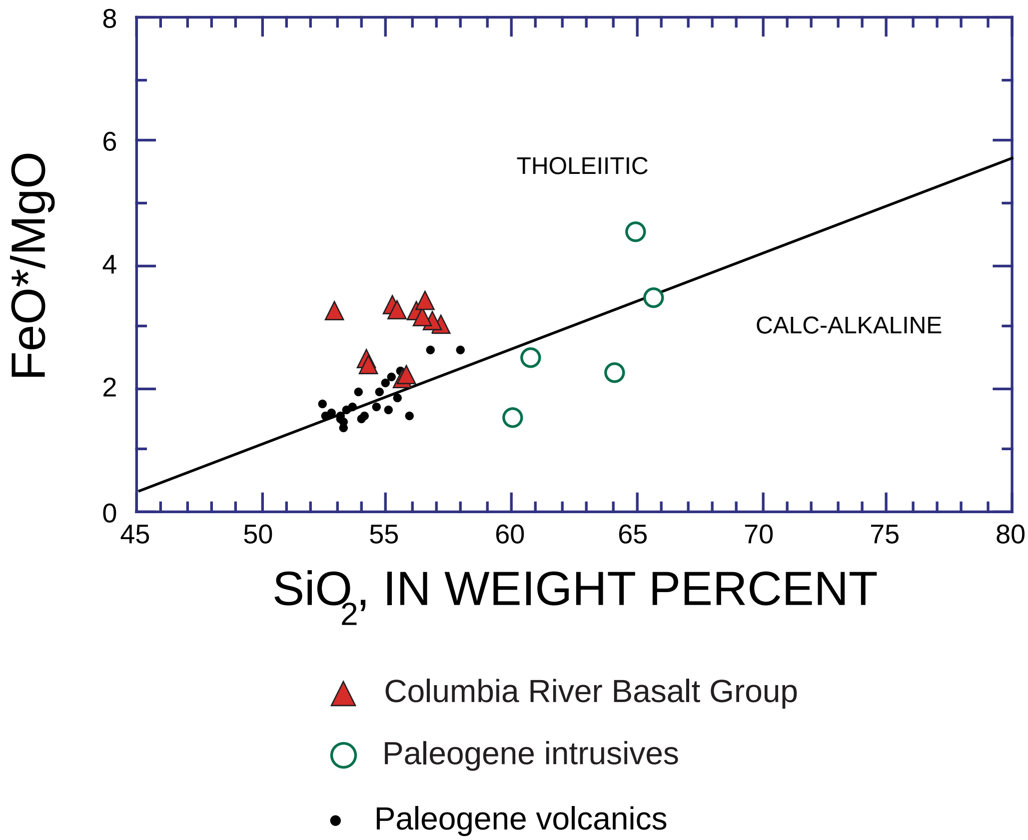

Figure 4. FeO*/MgO (wt. percent ratio) versus SiO_2 (recalculated volatile-free) for volcanic and intrusive rocks from the Deer Island 7.5' quadrangle showing classification into tholeiitic and calc-alkaline rocks according to Miyashiro (1974). FeO*, total Fe as FeO.

Intrusive rocks

A few small glassy intrusions of porphyritic pyroxene andesite and dacite are scattered throughout the extrusive sequence east of the Columbia River. These include dikes, sills, and irregular bodies, most of which display well-developed columnar jointing. Compositionally, the intrusions are chiefly medium-potassium calc-alkaline andesites and dacites readily distinguished from their mafic host rocks (table 1, nos. 23-27; figs. 2, 3, and 4). Although chemically distinct, the intrusions do not appear to be significantly younger than their host rocks. An $^{40}Ar/^{39}Ar$ age of 36.8±0.2 Ma was obtained from plagioclase in one of these intrusions (table 2). The intrusions may mark the source vents for flows of similar composition that crop out on Goose Hill in the Woodland quadrangle east of this map (R.C. Evarts, unpub. mapping). The scarcity of intrusions in the Deer Island quadrangle contrasts with areas to the east, reflecting the distal location of this area relative to the axis of the Paleogene volcanic arc in late Eocene time.

PITTSBURG BLUFF FORMATION

The poorly exposed sequence of sandstones and siltstones that unconformably overlie volcanic rocks west of the Columbia River was mapped as Oligocene sediments by Wilkinson and others (1946). They tentatively correlated a macrofossil assemblage recovered from several localities west of the map area with the Oligocene Gries Ranch fauna of southwestern Washington and with fauna from the Pittsburg Bluff Formation of Warren and Norbisrath (1946) in the upper Nehalem Basin. The Gries Ranch fauna falls within the late Eocene to early Oligocene Galvinian molluscan stage of Armentrout (1981). An $^{40}Ar/^{39}Ar$ age of approximately 30 Ma (McKnight and others, 1995) and magnetostratigraphy (Prothero and Hankins, 2000; Hankins and Prothero, 2001) from the type area of the Pittsburg Bluff Formation indicate the unit is largely of early Oligocene age, although the basal part of the formation may be latest Eocene (A.R. Niem, written commun., 2001). Poorly preserved mollusks collected from coarse-grained sandstone beds about 1.5 km southeast of Maple Hill are consistent with an Oligocene age (E.J. Moore, written commun., 1999). These strata are assigned herein to the Pittsburg Bluff Formation on the basis of their lithologic and faunal similarities to rocks of the type area to the west. As mapped, the upper part of the unit may include strata correlative with the early Miocene to late Oligocene Scappoose Formation of Warren and Norbisrath (1946).

Pittsburg Bluff Formation strata in this quadrangle consist of bedded fine- to coarse-grained tuffaceous and micaceous arkosic sandstone, siltstone, and mudstone deposited in nearshore marine to deltaic or nonmarine environments. As noted by Wilkinson and others (1946), the poorly consolidated sedimentary rocks are prone to severe creep and landsliding, so reliable primary structural attitudes are difficult to obtain. In rare undisturbed outcrops, the beds display variable strikes and low (<10°) dips. The regional distribution of the formation indicates that it dips generally southwestward, lapping onto the paleohighland of subaerial volcanic rocks to the north and east. It appears to be approximately 200 m thick in this quadrangle and increases in thickness to the west (Wilkinson and others, 1946). The poorly preserved molluscan fossils in tuffaceous sandstone and grit southeast of Maple Hill suggest a shallow continental shelf depositional environment (E.J. Moore, written commun., 1999). A lignite seam reported by Yancey and Geer (1940) occurs less than 30 m below the fossil-bearing horizon according to the map of Wilkinson and others (1946). Niem and others (1994) observed similar interbedded deltaic sandstone and shallow marine facies in the type Pittsburg Bluff Formation southwest of this quadrangle.

The framework composition of the Pittsburg Bluff Formation sedimentary rocks indicates contributions from both volcanic and nonvolcanic sources. The sandstones contain angular to subangular clasts of a variety of volcanic and metamorphic rocks and grains of quartz, plagioclase, and orthoclase. Heavy-mineral suites include muscovite, biotite, green hornblende, pyroxene, epidote, and garnet. Most of these heavy minerals, as well as the quartz and potassium feldspar, are inconsistent with a Cascade volcanic-arc source and most likely were eroded from pre-Tertiary terranes to the north or east of the arc.

METAMORPHISM AND HYDROTHERMAL ALTERATION

The late Eocene volcanic rocks and Oligocene sedimentary rocks in the Deer Island quadrangle have been pervasively affected by zeolite-facies regional metamorphism. The metamorphic effects are similar to, but generally less intense than, those described in Tertiary volcanogenic rocks elsewhere in the southern Washington Cascade Range (Fiske and others, 1963; Wise, 1970; Evarts and others, 1987; Evarts and Swanson, 1994). This regional-scale metamorphism reflects burial of the late Eocene rocks by younger volcanics within the relatively high-heat-flow environment of an active volcanic arc. The lower intensity of alteration in this quadrangle presumably relates to its position on the western fringe of the Paleogene volcanic arc, as shown by the scarcity of intrusions, and to shallower depths of burial. The age of metamorphism is poorly constrained but must predate emplacement of the unaltered flows of the early to middle Miocene Grande Ronde Basalt that unconformably overlie the Paleogene strata.

The main effect of the very low grade metamorphism in the lava flows is the nearly universal development of various clay minerals and zeolites that replace labile interstitial glass, fill vesicles, and are deposited on joint surfaces. Feldspar is incipiently to moderately replaced by clay minerals and (or) zeolites, and olivine is almost universally replaced by smectite with or without hematite and calcite. Augite and Fe-Ti oxides, however, are generally unaffected. Alteration tends to be more advanced in the volcaniclastic rocks and flow breccias because of their permeable character. Uncollapsed pumice clasts in some silicic pyroclastic rocks have been totally replaced by zeolites of the heulandite-clinoptilolite series and minor kaolinitic clay, although plagioclase phenocrysts within them remain relatively fresh. More commonly, abundant vitric debris in volcaniclastic rocks is altered to iron-rich smectite that gives these rocks their characteristic green colors. The widespread presence of heulandite and clinoptilolite in pyroclastic rocks of this quadrangle indicates that metamorphic temperatures did not exceed 180°C (Cho and others, 1987) and may have been considerably lower.

Sedimentary rocks of the Pittsburg Bluff Formation exhibit less intense development of zeolites. This probably reflects the lower abundance of unstable volcanic detritus in Pittsburg Bluff Formation sandstones, but alternatively it may indicate that zeolitization of the older volcanic rocks took place before deposition of the overlying sedimentary rocks in Oligocene time. Volcanic rock and mineral grains in Pittsburg Bluff Formation sandstones and siltstones display considerable replacement by clay minerals, but these may be diagenetic rather than metamorphic in origin. Early cementation by sparry calcite in some sandstone beds seems to have protected framework grains from further diagenesis. Dissolution of the carbonate cement under the current weathering regime is largely responsible for the friable nature and consequent poor exposure of the Pittsburg Bluff Formation.

Metasomatic hydrothermal alteration is uncommon in the Deer Island quadrangle, as expected from the near absence of intrusive rocks. Small zones of argillized rock associated with sparse chalcedony or quartz veins are found in and near the small andesitic and dacitic intrusions mapped in Washington, but the fact that the intrusions still contain abundant fresh glass demonstrates that they were too small to induce significant hydrothermal systems. Similar alteration along some faults indicates that at least minor amounts of slightly heated water did move through the strata during and after faulting. These altered zones are composed entirely of poorly crystallized kaolinitic clay minerals with or without quartz and minor limonite; no relict sulfides have been detected in any of them. In other localities, such as the bedrock outcrops along the east bank of the Columbia River north of Martin Island, zeolites have been deposited on fault planes, but this mineralization is probably related to the regional zeolite-facies metamorphism rather than deposition from heated fluids.

COLUMBIA RIVER BASALT GROUP

In Miocene time, between 16.5 and 6 Ma, huge volumes of tholeiitic flood basalts erupted from fissures in southeastern Washington and adjacent areas of Oregon and Idaho, forming the Columbia River Basalt Group. Some of the largest flows moved down an ancestral Columbia River valley all the way to the Pacific Ocean (Snavely and others, 1973; Tolan and others, 1989). West of the Cascade Range, thick flows buried large areas of low-relief terrain in the Coast Range (Beeson and others, 1989). Dissected remnants of these flows now blanket the upland areas west of the Columbia River in the Deer Island and adjacent quadrangles (Wilkinson and others, 1946). The majority of the flood-basalt flows were erupted during a brief period between 16.5 and 15.6 Ma and constitute the voluminous Grande Ronde Basalt; these flows were succeeded during the next 1 million years by flows of the Wanapum Basalt (Tolan and others, 1989). In the field, the Miocene flows are readily distinguished from Paleogene volcanic rocks by their distinctive, glass-rich, intersertal and microvesicular texture and generally unaltered condition. They also differ from the older rocks in chemical composition (table 1). Although both the Miocene and Eocene flows plot chiefly as basaltic andesites on figure 2, all the Columbia River Basalt flows are tholeiites (fig. 4) that contain less Al_2O_3 and more FeO*, TiO_2, and K_2O than the Eocene flows, and their range of MgO contents is more limited (figs. 3, 4, and 5). Certain trace-element abundances, particularly that of Ba, also serve to differentiate between the two rock groups (fig. 6). Nearly all of the Miocene basalt exposed in the Deer Island quadrangle belongs to the Grande Ronde Basalt, but a small flow remnant on the west slope of Maple Hill belongs to the Frenchman Springs Member of the Wanapum Basalt. Grande Ronde Basalt flows can be distinguished from other Columbia River Basalt Group units by lower TiO_2 contents (Swanson and others, 1979; Mangan and others, 1986; Beeson and others, 1989; Reidel and others, 1989; Hooper, 2000).

In the Deer Island quadrangle, the Grande Ronde Basalt crops out west of the Columbia River between Merrill Creek and the southern quadrangle boundary. The lowest flow in the section generally rests directly and unconformably on Paleogene volcanic and sedimentary rocks except on the northeast side of Maple Hill where a thin lens of basalt-cobble conglomerate intervenes. Similar conglomerate beds have been found locally at or near the base of the Grande Ronde Basalt elsewhere in the lower Columbia valley (Lowry and Baldwin, 1952; Van Atta and Kelty, 1985). In the southernmost part of the quadrangle, a thin, poorly exposed sedimentary section (see below) overlies deeply weathered basalt. The total thickness of the Grande Ronde Basalt in the map area generally increases southward and probably exceeds 200 m at the southern boundary of the quadrangle. Exposures are inadequate to determine precisely how many flows are present but at least four can be distinguished from the chemical and paleomagnetic data. A driller's log of a water well drilled about 0.5 km west of Columbia City records at least 172 m of basalt with two claystone intervals that presumably mark interflow sedimentary horizons or weathered vesicular flow tops.

Using lithologic, chemical, and paleomagnetic criteria, Reidel and others (1989) divided the Grande Ronde Basalt on the Columbia Plateau into several informal members that they called units but were later referred to as members by Reidel (1998), the terminology followed here. Beeson and others (1989) and Wells and others (1989) employed these criteria to trace a number of these units into the Portland Basin and westward into the Coast Range, in some cases as far as the Pacific Ocean. Three of these informal members are recognized in the Deer Island quadrangle (fig. 7) based on chemical, petrographic, and paleomagnetic similarities to the informal members described by these authors.[1]

The youngest and most widespread informal member in the map area is the member of Sentinel Bluffs, which is also the youngest member of the Grande Ronde Basalt on the Columbia Plateau. It is distinguished by relatively high MgO contents (4.5 to 4.7 wt. percent; table 1, no. 38; table 3) and normal magnetic polarity. Several large quarries have been excavated in the member of Sentinel Bluffs near Columbia City. All appear to be developed in a single flow, which displays a blocky to columnar jointing pattern. Exposures are rare north of McBride Creek but the flow probably forms the pronounced escarpment that extends north-northwestward from Columbia City.

Several basalt flows with distinctly lower MgO contents (<3.95 wt percent; table 1, no. 37; table 3) underlie the member of Sentinel Bluffs in the Deer Island quadrangle. The basalt section thins to the north, apparently banked against a Miocene paleovalley wall eroded into the Pittsburg Bluff Formation. Poor exposure

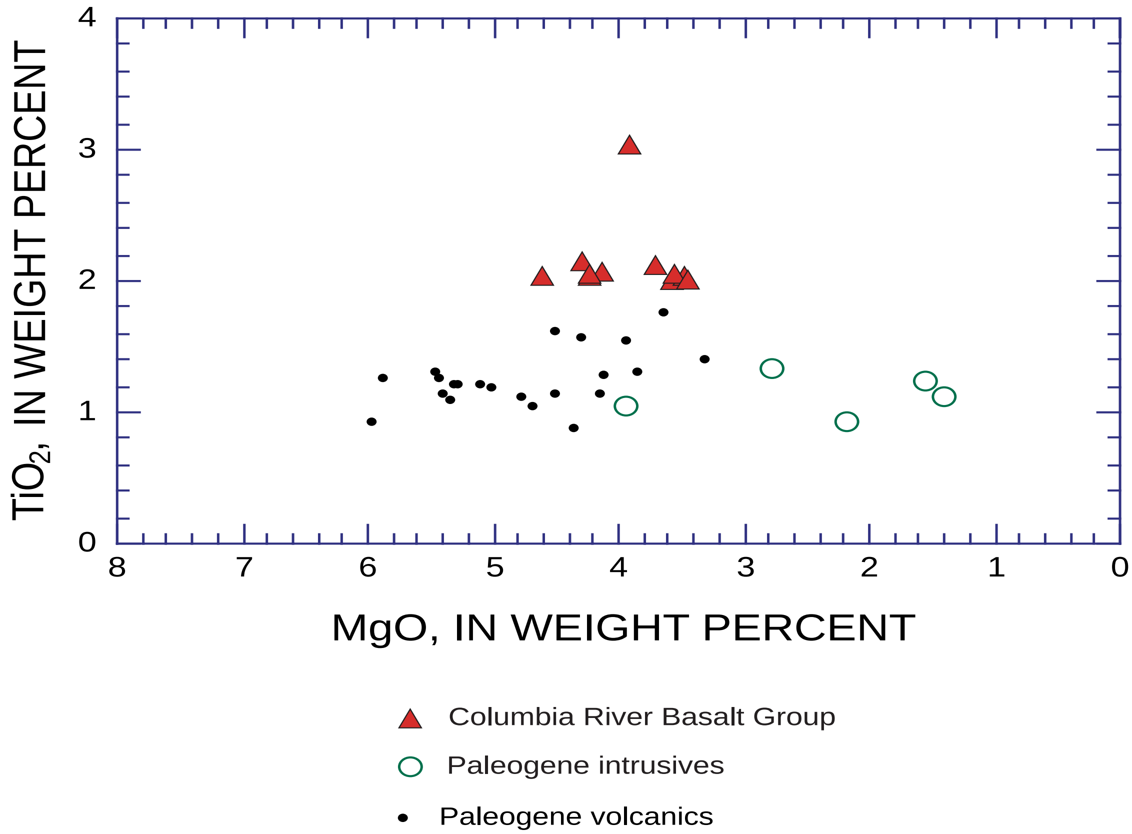

Figure 5. MgO versus TiO_2 (recalculated volatile-free) for volcanic and intrusive rocks from the Deer Island 7.5' quadrangle

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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.

prevents determination of the number of flows in the map area, but chemical and paleomagnetic data (R.C. Evarts, unpub. data; J.T. Hagstrum, written commun, 1999, 2001) indicate that three low-MgO flows crop out in the city of Saint Helens and extend northward into this quadrangle. The uppermost flow exhibits a colonnade/entablature jointing pattern, contains sparse phenocrysts and glomerocrysts of plagioclase, and has a distinctive shallow northwest paleomagnetic direction that contrasts with the steep northeast directions that typify most Grande Ronde Basalt flows. Based on these characteristics, this flow is tentatively assigned to the member of Winter Water (Winter Water unit of Reidel and others, 1989), although its TiO_2 content of 2.03 to 2.10 wt. percent is lower than reported for that unit elsewhere.

An aphyric basalt flow that underlies the member of Winter Water flow is assigned to the member of Ortley. Compared to the member of Winter Water flow, this flow is distinguished by its slightly lower MgO and CaO and higher K_2O and Ba concentrations and a steep northeast paleomagnetic direction (table 1, nos. 32-35; table 3).

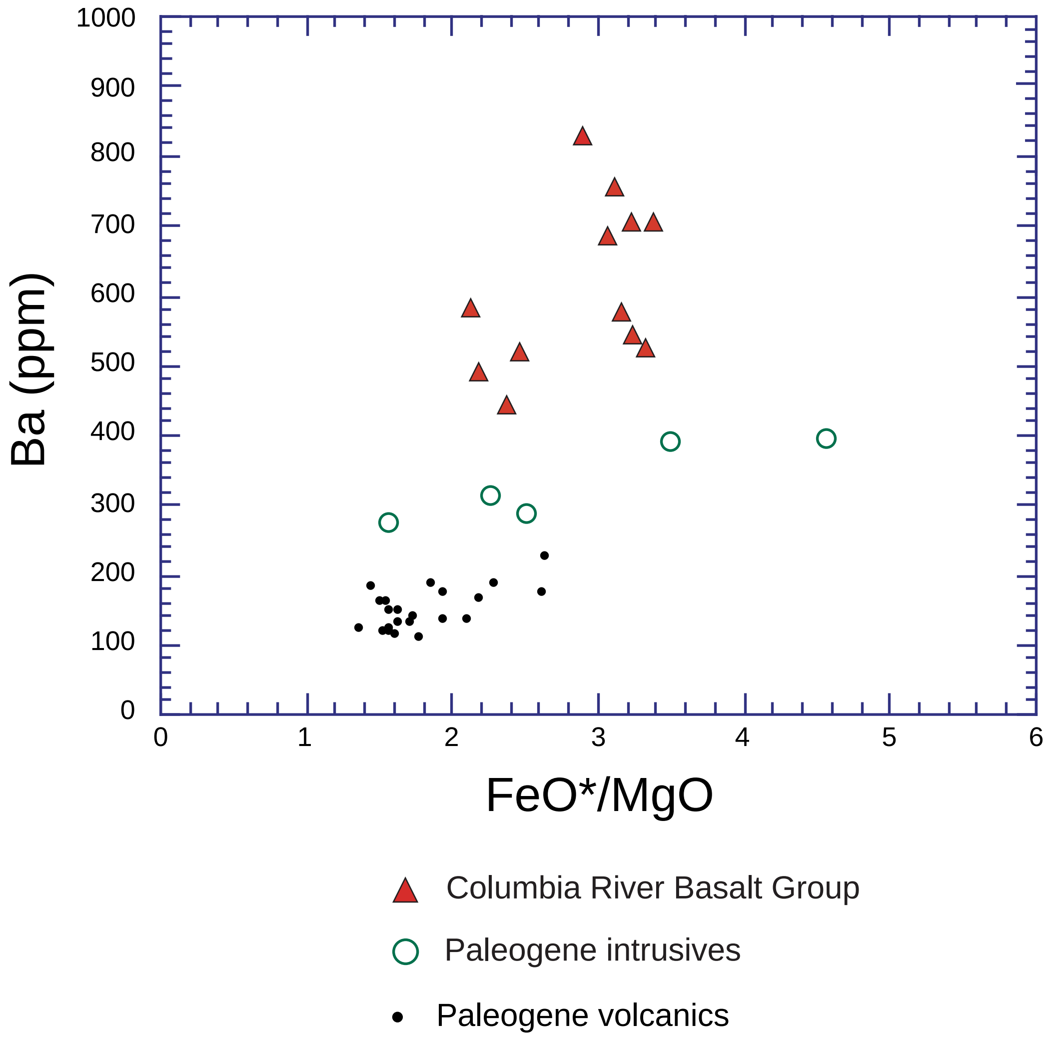

Figure 6. Ba versus FeO*/MgO (wt. percent ratio) for volcanic and intrusive rocks from the Deer Island 7.5' quadrangle.

Reversely magnetized, generally intermediate MgO (4.1 to 4.2 wt. percent; table 1, nos. 28-31; table 3) basalt constitutes the bulk of Maple Hill. Chemical and paleomagnetic data suggest the presence of two flows there. The correlation of these flows is uncertain because their chemistry does not match any published data, displaying lower FeO* and higher CaO contents than most Grande Ronde flows (Reidel and others, 1989; Beeson and others,

Geologic age		Group		Formation	Series	Age (Ma)	Magnetic Polarity
Miocene	upper	Columbia River Basalt Group	Yakima Basalt Subgroup of Swanson and others (1979)	Saddle Mountains Basalt	**Lower Monumental Member**	6	N
					Erosional Unconformity		
					Ice Harbor Member	8.5	
					Basalt of Goose Island		N
					Basalt of Martindale		R
					Basalt of Basin City		N
					Erosional Unconformity		
					Buford Member		
	middle				**Elephant Mountain Member**	10.5	N, T
					Erosional Unconformity		
					Pomona Member	12	R
					Erosional Unconformity		
					Esquatzel Member		N
					Erosional Unconformity		
					Weissenfels Ridge Member		
					Basalt of Slippery Creek		N
					Basalt of Tenmile Creek		N
					Basalt of Lewiston Orchards		N
					Basalt of Cloverland		N
					Asotin Member	13	
					Basalt of Huntzinger		N
					Local Erosional Unconformity		
					Wilbur Creek Member		
					Basalt of Lapwai		N
					Basalt of Wahluke		N
					Local Erosional Unconformity		
					Umatilla Member		
					Basalt of Sillusi		N
					Basalt of Umatilla		N
					Local Erosional Unconformity		
				Wanapum Basalt	**Priest Rapids Member**	14.5	
					Basalt of Lolo		R
					Basalt of Rosalia		R
					Local Erosional Unconformity		
					Roza Member		T, R
					Frenchman Springs Member		
					Basalt of Lyons Ferry		N
					Basalt of Sentinel Gap		N
					Basalt of Sand Hollow	15.3	N
					Basalt of Silver Falls		N, E
					Basalt of Ginkgo	15.6	E
					Basalt of Palouse Falls		E
					Eckler Mountain Member		
					Basalt of Shumaker Creek		N
					Basalt of Dodge		N
					Basalt of Robinette Mountain		N
					Local Erosional Unconformity		
				Grande Ronde Basalt	**Member of Sentinel Bluffs**	15.6	N_2
					Member of Slack Canyon		
					Member of Fields Spring		
					Member of Winter Water		
	lower				**Member of Umtanum**		
					Member of Ortley		
					Member of Armstrong Canyon		
					Member of Meyer Ridge		R_2
					Member of Grouse Creek		
					Member of Wapshilla Ridge		
					Member of Mt. Horrible		
					Member of China Creek		N_1
					Member of Downy Gulch		
					Member of Center Creek		R_1
					Member of Rogersburg		
					Teepee Butte Member		
					Member of Buckhorn Springs	16.5	
				Imnaha Basalt			R_1
							T
							N_0
						17.5	R_0

Figure 7. Stratigraphic nomenclature of the Columbia River Basalt Group, after Tolan and others (1989). Terminology for informal members of the Grande Ronde Basalt described by Reidel and others (1989) is that of Reidel (1998). Magnetic polarity designations are N, normal; R, reversed; T, transitional; E, excursional; subscripts refer to magnetostratigraphic units of Swanson and others (1979). Units present in the Deer Island 7.5'quadrangle are highlighted.

1989; Mangan and others, 1986). Although the MgO contents are intermediate, the relatively high CaO and Cr contents indicate an affinity to high-MgO chemical groups (M. Beeson and T. Tolan, oral commun., 2001). Reversely magnetized Grande Ronde Basalt flows with intermediate MgO contents have not been described in the literature, thus basalt of this character in the Deer Island quadrangle is not assigned to any of the informal members of Reidel and others (1989).

A roadcut on the western flank of Maple Hill exposes spheroidally weathered basalt with scarce scattered plagioclase phenocrysts as large as 2 cm. The chemical composition (table 1, no. 39) indicates it belongs to the Frenchman Springs Member of the Wanapum Basalt; it most closely resembles the basalt of Sand Hollow (Beeson and others, 1985, 1989; Hooper, 2000), which was erupted about 15.3 Ma (Reidel and others, 1989). The topographically low position of this flow remnant relative to the older Grande Ronde flows atop Maple Hill suggests that the Sand Hollow flow filled a channel eroded into the Grande Ronde Basalt during the roughly 300,000 years separating emplacement of the two units (Tolan and others, 1989). Alternatively, the basalt of Sand Hollow flow may be downfaulted against the Grande Ronde Basalt. Exposures are insufficient to determine which geometry is correct, but the Frenchman Springs Member includes canyon-filling flows south of Portland (Beeson and others, 1985), so this alternative is preferred.

NEOGENE SEDIMENTARY ROCKS

Development of the Portland Basin may have begun in middle Miocene time, shortly before eruption of the Columbia River Basalt Group (Beeson and others, 1989; Beeson and Tolan, 1990). As the basin continued to subside during the late Miocene and Pliocene, it filled with fluvial and lacustrine sediments transported through the Cascade Range by the ancestral Columbia River as well as locally derived detritus contributed by tributaries draining the surrounding highlands. These deposits have been mapped from the Columbia River Gorge westward and northward along the Columbia River to Kelso, Washington, 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 schistose metamorphic rocks. These rock types are foreign to western Oregon and Washington and must have been transported from terranes composed of pre-Tertiary granitic and metamorphic rocks in the upper Columbia River Basin by the ancestral Columbia River. The arkosic sandstone consists largely of quartz, plagioclase, potassium feldspar, and felsic lithic clasts and contains minor but conspicuous muscovite and biotite. Its composition, like that of the conglomerate, points to source terranes east of the Cascade Range. The vitric sandstone consists of poorly sorted, relatively coarse-grained, variably palagonitized hyaloclastic debris. The petrography and chemistry of the vitric sandstone resemble those of olivine-phyric, high-alumina basalt and basaltic andesite flows erupted in the Columbia Gorge 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) refer to these locally derived deposits as 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 in 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. Subsequently, Trimble (1963) raised the lower, fine-grained, member to formational rank and formally named it the Sandy River Mudstone. More recent work by Swanson and others (1993), drawing on a large database of subsurface information, reveals that stratigraphic relations of the basin-fill sediments are considerably more complex than portrayed in these earlier studies. They show that predominantly coarse-grained strata at the west end of the Columbia River Gorge grade laterally westward into predominantly fine-grained deposits, and complex interbedding of coarse- and fine-grained intervals is common throughout much of the Portland Basin.

Because of likely facies changes and the lack of dateable beds in the northern part of the Portland Basin, correlations between the scattered outcrops of Neogene sediments in the Deer Island quadrangle and those of the type areas of the Troutdale Formation and Sandy River Mudstone in Oregon are uncertain. On this map, these deposits are divided into three units based on lithology and stratigraphic position. Sections dominated by relatively fine-grained sediments are tentatively assigned to the Sandy River Mudstone (unit Tsr). The conglomeratic deposits are divided into two units because work in the area to the southeast of the Deer Island quadrangle (Howard, 2002; R.C. Evarts, unpub. mapping) indicates that the deposits previously mapped as Troutdale Formation consist of two lithologically similar units separated by an erosional unconformity. The older conglomerate crops out at higher elevations, conformably overlies the Sandy River Mudstone, and is assigned to the Troutdale Formation. The younger conglomerate crops out at lower elevations and forms a sheetlike deposit that occupies a valley incised into the older sediments; it is mapped here as an informal unnamed conglomerate (unit QTc).

SANDY RIVER MUDSTONE AND TROUTDALE FORMATION

Deposits of interbedded micaceous arkosic sandstone and siltstone with thin lenticular beds of pebble conglomerate, mapped here as Sandy River Mudstone, rest unconformably on Paleogene bedrock on both sides of the Columbia River. In Oregon, outcrops of Neogene sedimentary rocks are scarce, and their distribution is based largely on lithologic logs of water-well records. Drillers' logs from the area north of Tide Creek report that the surficial deposit, which is as thick as 100 m, consists largely of clay with little or no conglomerate. The clay could be thoroughly decomposed conglomerate, but this is considered unlikely because sandstone and pebble conglomerate in a recent slump-scarp exposure where a power transmission line crosses Tide Creek Road are iron stained and somewhat weathered but not saprolitic. In contrast, most drillers' logs from the vicinity of Adams and Merrill Creeks record abundant gravel horizons, and this area is consequently mapped as Troutdale Formation.

In the southwestern part of the Deer Island quadrangle, poorly exposed sediments that were mapped as Troutdale Formation by Wilkinson and others (1946) are finer grained than the deposits to the north. Overburden in a quarry excavated in the member of Sentinel Bluffs of the Grande Ronde Basalt immediately south of the quadrangle consists of interbedded mudstone, siltstone, and minor basalt-pebble conglomerate. Some beds contain fragments of carbonized wood and they may include a substantial tuffaceous component. Micaceous arkosic and quartzose sandstones are absent. The rocks are intensely weathered to clay and are commonly iron stained; limonite occurs as cement in the conglomerate beds and as veins about 1 cm wide that generally parallel bedding planes. About 3 m of strata are exposed in the quarry but the maximum thickness of the claystone-dominated section is uncertain. Drillers' logs from the Perry Creek area report that as much as 75 m of clay overlies basalt bedrock, but it is impossible to ascertain how much of this clay is laterized basalt rather than claystone. However, the listing in some logs of gray, blue, and light brown clays, in contrast to the reddish-brown to yellow clays typical of weathered basalt, suggests these wells intersected sedimentary beds. Few drillers' logs report conglomerate intervals, and no residual quartzite pebbles were seen on the surface or in the alluvium of the local creeks. Judging from the elevations of basalt-sediment contacts in quarry walls, there may be as much as 50 m of fine-grained beds above the basalt. These beds are overlain by massive, light brown, micaceous silt. The silt was included in the Troutdale Formation by Wilkinson and others (1946), but subsequent work has shown it to be Pleistocene loess (Lentz, 1981).

In Washington, scattered deposits previously mapped as Troutdale Formation (Wilkinson and others, 1946; Phillips, 1987a, b) consist largely of fine-grained micaceous arkosic sandstone that is here assigned to the Sandy River Mudstone. In a small area east of Interstate Highway 5 about 2 to 4 km north of Woodland, sandstone and siltstone grade abruptly upward into weathered basalt-clast conglomerate that contains conspicuous pebbles and cobbles of quartzite. As noted by Mundorff (1964), this outcrop exposes the top of his lower member of the Troutdale Formation, which is equivalent to Trimble's (1963) Sandy River Mudstone. The overlying conglomerate is similar to conglomerate in the type area of the Troutdale Formation. Outcrops of the weathered deposits extend to elevations as high as 550 ft (170 m), but the original top of the unit was apparently much higher because scattered quartzite pebbles are present in the soil at elevations as high as 1,200 ft (365 m).

Wilkinson and others (1946) discussed at length a cliff-forming volcanic breccia exposed in the lower part of this section. Because micaceous sandstones and siltstones that contain Neogene plant fossils crop out in roadcuts topographically below outcrops of the breccia, they mapped it as a bed within the Troutdale Formation. However, as discussed above, the breccia (unit Tbb) is actually Eocene bedrock, hence the sedimentary rocks exposed at the base of the breccia cliff are only thin remnants of fill plastered against the steep wall of the late Neogene Columbia River paleovalley.

Scant data suggest that the Sandy River Mudstone and Troutdale Formation range from middle to late Miocene or early Pliocene in age. The only direct age information in the Deer Island quadrangle comes from leaf fossils of late Miocene or early Pliocene age collected by Wilkinson and others (1946) north of Woodland. The conformably overlying conglomerate is presumably also no younger than early Pliocene. The deposits that rest directly on the approximately 15.6-Ma Sentinel Bluffs flow near the southern edge of the quadrangle may be older, possibly correlative with a thin but widespread section of fluvial and lacustrine sediments commonly found between the Grande Ronde Basalt and Wanapum Basalt and referred to informally as the Vantage interbeds (Beeson and others, 1985, 1989; Beeson and Tolan, 1990). However, relationships in the quarry indicate that considerable time may have elapsed between emplacement of the basalt flow and deposition of the sediments. In most places the upper several meters of the underlying basalt are thoroughly weathered to structureless red-brown clay, but locally the sediments rest directly on fresh basalt and clearly occupy small channels incised into previously laterized basalt. Because no contacts between conglomeratic and fine-grained facies are exposed in Oregon, the stratigraphic and age relationships of these Neogene strata with those across the Columbia River are unclear. All of the fine-grained beds in the quadrangle may be roughly equivalent in age and older than any of the conglomerates mapped here as Troutdale Formation. Alternatively, the distribution of sedimentary facies in the quadrangle may reflect late Miocene and early Pliocene fluvial architecture rather than temporal changes in the nature of the sediment supply, in which case some of the fine-grained sediments may be overbank deposits coeval with the channel-fill conglomerates.

UNNAMED CONGLOMERATE

A nearly undissected terrace slopes uniformly northward from Columbia City at a gradient of about 1.75 m/km. This feature, informally named the Deer Island terrace, consists largely of massive, thick-bedded, poorly to moderately well sorted, framework-supported, pebble and cobble conglomerate that is less intensely weathered than typical Troutdale Formation conglomerate. The clast population is dominated by rocks eroded from the Columbia River Basalt Group and Tertiary volcanic rocks of the Cascade Range; quartzite pebbles and olivine-phyric basalt are minor but persistent components. Pronounced clast imbrication and crude foreset bedding both indicate deposition from north-flowing currents. Similar conglomerate crops out near Scappoose, about 14 km south of the Deer Island quadrangle, and underlies a broad plain called Fourth Plains to the southeast in western Clark County, Washington (Trimble, 1963; Mundorff, 1964; R.C. Evarts, unpub. mapping). These deposits apparently constitute the remains of a continuous sheet laid down as a gravelly braid-plain prograded across the northern Portland Basin. The Columbia River subsequently eroded through the gravel sheet but the beds of the Deer Island terrace were preserved in the lee of the bedrock platform that projects into the river at Columbia City.

The age of the conglomerate unit is poorly constrained. In the Deer Island terrace it is overlain by a thin mantle of unweathered, very poorly sorted gravel probably deposited by a late Pleistocene glacier outburst flood (see below). Southeast of this quadrangle, the lithologically similar conglomerate beneath Fourth Plains appears to occupy a broad valley incised into more deeply weathered strata of the Troutdale Formation. The sparse olivine-phyric basalt clasts suggest correlation with the informal upper member of the Troutdale Formation mapped by Tolan and Beeson (1984) in the Columbia River Gorge, which they inferred to be largely of Pliocene age. Farther east it may grade into deposits of possible outwash origin (Howard, 2002; R.C. Evarts, unpub. mapping) indicating that deposition may have continued into Pleistocene time.

QUATERNARY DEPOSITS

DEPOSITS OF THE COLUMBIA RIVER VALLEY

The floodplain of the Columbia River constitutes nearly one-half of the area of the Deer Island quadrangle. Sediment carried by the modern river consists largely of silt and sand eroded from pre-Tertiary terranes east of the Cascade Range as well as from the adjacent Cascade Range and Coast Range (Whetten and others, 1969). Similar sediment has apparently been transported by the river throughout the Holocene (Gates, 1994). The primary control on the sedimentary regime of the lower Columbia River during this time was the cyclical variation in base level in response to climate-induced sea level fluctuations. In latest Pleistocene time, the depositional system was perturbed by massive influxes of sediment transported into the Portland Basin by cataclysmic jökulhlaups originating in Idaho and Montana (Bretz, 1925, 1929, 1969; Allison, 1978). Repeated episodes of glacial melting and eruptions of Mount St. Helens have triggered alluviation events in the Lewis River system that have also impacted the Columbia River near Woodland (Major and Scott, 1988). Much of this material has been carried downstream into the Pacific Ocean, but erosional remnants of outwash and volcanogenic deposits are locally preserved along the margins of the modern floodplain.

GLACIAL OUTWASH DEPOSITS

East of the Deer Island quadrangle, valley walls above the Lewis River contain patches of alluvial gravels that record aggradational events before the birth of Mount St. Helens. Most of these gravels are probably outwash deposits associated with one or more episodes of Pleistocene glaciation (Mundorff, 1964, 1984; Crandell, 1987; R.C. Evarts, unpub. mapping). A similar deposit (unit Qo) crops out in the upper parts of the steep slopes that border Interstate Highway 5 about 2 to 3 km north of Woodland. This deposit overlies micaceous arkosic sands and fine-grained gravels of the Sandy River Mudstone and Troutdale Formation (units Tsr and Ttf) and was included within the Troutdale by Wilkinson and others (1946) and by Phillips (1987a). However, in contrast to the underlying conglomerate, the clasts of this unit are composed entirely of Cascadian volcanic rocks like those exposed in the Lewis River valley to the east, whereas quartzite and Columbia River Basalt Group clasts are absent. This deposit is also more weakly cemented and less weathered than the underlying Troutdale Formation conglomerate. For these reasons it is interpreted as ancient alluvium deposited by the Lewis River, most likely glacial outwash of early or middle Pleistocene age.

DEPOSITS OF MOUNT ST. HELENS VOLCANO

The southern slope of Mount St. Helens stratovolcano drains into the Lewis River about 50 km northeast of the Deer Island quadrangle. Lahars and pyroclastic flows generated during episodes of intense eruptive activity transported huge amounts of volcaniclastic debris into the river (Crandell, 1987). These events triggered periods of aggradation in the lower Lewis system as the river reworked and transported the large quantities of fresh volcanic debris downstream and into the Columbia River at the site of Woodland (Major and Scott, 1988). Remnants of the alluvial fills produced by these events are found as terrace fragments distributed throughout the Lewis valley (Major and Scott, 1988; R.C. Evarts, unpub. mapping).

A borrow pit and roadcuts about 1.5 km northwest of the village of Deer Island expose sandy pebble and cobble gravel that contains well-rounded clasts that can only have come from Mount St. Helens. These clasts are light gray to white coarsely porphyritic dacites that stand out against the darker Tertiary volcanic clasts that dominate the deposit. The dacites contain phenocrysts of blocky milky plagioclase, globular vitreous quartz, and hexagonal brown biotite as large as 1 cm across, along with smaller phenocrysts of hornblende and cummingtonite. The sandy component of the deposit consists largely of these same minerals. The presence of cummingtonite is diagnostic of a Mount St. Helens source (Mullineaux, 1996). Biotite-bearing dacite magma erupted from the ancestral volcano only during its earliest activity, the Ape Canyon eruptive stage (Crandell, 1987; Mullineaux, 1996). The age of the Ape Canyon eruptive stage was considered to be 50 to 36 ka by Crandell (1987) but recently acquired evidence suggests it may have begun earlier, perhaps before 100 Ma (Berger and Busacca, 1995; Whitlock and others, 2000; M.A. Clynne, oral commun., 2001; R.C. Evarts, unpub. mapping). The west-dipping orientation of crossbedding in this deposit is consistent with a Lewis River source. This vestige of a Mount St. Helens-derived fluvial deposit about 40 m above and west of the modern Columbia River indicates that, at least once during latest Pleistocene time, an alluvial fan was constructed at the mouth of the Lewis River that was large enough to extend entirely across and temporarily block the Columbia River valley. Holocene eruptions of Mount St. Helens built a similar but smaller delta at the mouth of the Lewis River, pushing the main course of the Columbia River westward against the bedrock valley wall near Columbia City (Gates, 1994).

CATACLYSMIC FLOOD DEPOSITS

Several times during the last glacial maximum, an ice dam impounding Lake Missoula in Idaho and Montana failed. Each collapse generated enormous jökulhlaups, commonly referred to as the Missoula floods, that coursed down the Columbia River and into the Portland Basin (Bretz, 1925, 1929, 1969; Trimble, 1963; Allison, 1978; Baker and Bunker, 1985; Waitt, 1985, 1994, 1996). The sediment-laden floodwaters were hydraulically dammed by the relatively narrow constriction of the Columbia River valley in and just north of the Deer Island quadrangle, ponded in the Portland Basin to elevations of as high as 120 m, and backed up into tributary valleys. Radiocarbon ages and tephrochronologic data cited by Waitt (1994) indicate that these floods occurred chiefly between about 15.5 and 12.7 ka, although there is accumulating evidence for older episodes of cataclysmic flooding (McDonald and Busacca, 1988; Zuffa and others, 2000; Bjornstad and others, 2001). Missoula-flood-related deposits in the Deer Island quadrangle consist of two distinct facies: coarse gravel transported as bedload (unit Qfg) and laminated silt and fine sand that settled out of suspension in temporarily ponded floodwaters (unit Qfs).

The silt and sand facies in the Deer Island quadrangle forms deposits as thick as 30 m that underlie flat surfaces between 200 and 250 ft (60 and 75 m) elevation along the western side of the modern Columbia River floodplain and in the lower reaches of Merrill Creek. Small unmapped patches of similar composition are found at elevations up to 350 ft (105 m). The silt and fine sand are light brown, micaceous, and consist largely of quartz and feldspar, indicative of a Columbia River basin provenance. Rare fresh exposures show that the sediments are well laminated with graded bedding. Widespread evidence of depositional hiatuses between beds indicates that they are the deposits of multiple floods, perhaps as many as 100 (Waitt, 1994). Angular to subrounded boulders as large as 3 m across, composed of rock types foreign to the region, locally rest on top of or within the fine-grained flood deposits (Wilkinson and others, 1946; Allison, 1935). They were apparently carried into the Portland Basin within icebergs transported by floodwaters.

The gravel facies of the cataclysmic flood deposits forms a thin mantle, generally less than 3 m thick, on the Deer Island terrace. It is distinguished from the underlying conglomerate of late Pliocene or Pleistocene age by its very poor sorting and lack of weathering. The gravel facies evidently postdates deposition of some slackwater silts and sands because it unconformably overlies micaceous silts interpreted as slackwater beds along Smith Road west of Columbia City. The steep margin of the fine-grained deposits along the west edge of the Deer Island terrace may be an erosional scarp created by stripping of slackwater beds by the late flood or floods that deposited the gravel facies. Alternatively, the scarp may mark a hydrologic boundary within the floodwaters between energetic downstream flow concentrated near the river channel and marginal zones of recirculation in which deposition of fine-grained suspended sediment could occur, in which case some of the fine-grained beds would be coeval with the gravel facies.

HOLOCENE AND PLEISTOCENE ALLUVIAL DEPOSITS

Unconsolidated sediments beneath the Columbia River floodplain are as thick as 100 m near the mouth of the Kalama River, about 5 km north of this quadrangle, and more than 65 m thick in the area west of Woodland (Gates, 1994). These Holocene and latest Pleistocene (at depth) sediments are chiefly light brown silt and fine sand composed of detritus transported from pre-Tertiary plutonic and metamorphic terranes east of the Cascade Range mixed with sediment eroded from the adjacent Cascade and Coast Ranges (Whetten and others, 1969; Gates, 1994). Riverbank outcrops and well logs indicate that pumice-bearing sand and fine gravel eroded from eruptive deposits of Mount St. Helens volcano are important components of this alluvial fill in and near the Deer Island quadrangle. According to Gates (1994), these sediments occupy a narrow paleovalley incised into older fluvial deposits and bedrock during the latest Pleistocene glacial maximum, when sea level was about 120 m lower than at present (Warne and Stanley, 1995). During the subsequent rapid marine transgression, aggradation in the lower Columbia River valley generally kept pace with the rise in sea level, filling the ice-age valley with fine sand and silt. These predominantly fluvial deposits are locally interbedded with lacustrine, aeolian, and organic-rich marsh deposits that accumulated in floodplain lakes and point-bar swales.

Small tributaries that flow into the Columbia River occupy bedrock-floored channels with thin local accumulations of sand and gravel derived largely from erosion of Eocene volcanic bedrock. Some sandy alluvium, particularly in Oregon, consists of debris recycled from nonresistant Tertiary sedimentary units (units Tsr and Tpb) and loess.

LOESS

Most of the relatively gentle upland surface west of the Columbia River is covered by massive, light-brown micaceous silt, as much as several meters thick, which was not mapped. This surface-mantling deposit is quartzofeldspathic in composition, lithologically similar to the cataclysmic flood deposits, but is found at higher elevations. It also resembles some beds in the Troutdale Formation and was considered to be an upper silty phase of the Troutdale by Wilkinson and others (1946) and by Lowry and Baldwin (1952), who named the unit the Portland Hills Silt Member of the Troutdale Formation. However, its distribution suggests the silt is a younger deposit unrelated to the Troutdale Formation and, recognizing this, Baldwin (1964) raised the unit to formational rank. A detailed examination of the Portland Hills Silt in the type area was conducted by Lentz (1981), who concluded that the unit is loess composed of material blown off the Columbia River floodplain during Pleistocene glacial episodes.

LANDSLIDE DEPOSITS

Landslides are common in the Deer Island quadrangle. Sedimentary units are particularly prone to failure, and many areas underlain by them display evidence of slumps and debris flows that are too small or poorly developed to show at the scale of this map. Wilkinson and others (1946) noted the difficulty in obtaining reliable structural attitudes in the Oligocene marine sedimentary rocks in Oregon, mapped here as the Pittsburg Bluff Formation, because of widespread slumping. Clay-rich Eocene pyroclastic beds are also vulnerable to failure, especially at higher elevations where they tend to be deeply weathered. Numerous slides have developed on steep slopes underlain by weakly consolidated Neogene sedimentary rocks and along terraces formed by unconsolidated cataclysmic flood deposits. During a series of storms in February 1996, a section of Sandy River Mudstone sediments approximately 4 km north of Woodland collapsed and buried all lanes of Interstate Highway 5 as well as the adjacent railroad line (Harp and others, 1997).

STRUCTURAL FEATURES

Late Eocene subaerial volcanic rocks on both sides of Columbia River in the Deer Island quadrangle generally strike northwesterly and dip to the west at less than 20°. Deviations from this trend, such as the north-dipping section of lava flows north of Woodland, are believed to reflect faulting rather than folding as inferred by Phillips (1987a). Reliable measurements of bedding attitudes in the unconformably overlying Pittsburg Bluff Formation in Oregon are sparse owing to poor exposure and mass wasting, but measured dips are mostly less than 10° (see Wilkinson and others, 1946).

Grande Ronde Basalt flows, widespread units with originally horizontal surfaces, potentially provide excellent datums for detecting post-15 Ma deformation (Beeson and Tolan, 1990). The Grande Ronde Basalt flows in the Deer Island quadrangle dip uniformly southward from Maple Hill to Columbia City at less than 2°. According to Wilkinson and others (1946), these flows are on the northern flank of a northwest-trending, southeast-plunging syncline whose axis runs parallel to Milton Creek near the village of Yankton, immediately southwest of this quadrangle.

Owing to the limited outcrops in this quadrangle, compelling evidence for the existence of faults is sparse. Some faults shown on this map are projected from structures observed in roadcuts or natural exposures. Others have been inferred from apparent discontinuities in distinctive units either at the surface or in well records, from topographic lineaments, from abrupt changes in bedding trends, or from aeromagnetic anomalies. Northeast- to east-west-striking, high-angle normal and oblique-slip faults dominate the fault pattern in the quadrangle.

Excellent exposures along the east bank of the Columbia River northwest of Martin Island show Paleogene volcaniclastic rocks broken into a series of small horsts and grabens by east-northeast-striking faults. Slickensides record normal, left-lateral strike-slip, and oblique-slip motions; vertical offsets rarely exceed 3 meters. Secondary minerals, including heulandite, calcite, and quartz, were deposited on most fault surfaces, indicating that the faults were formed prior to late Eocene or Oligocene regional zeolite-facies metamorphism. These secondary minerals are typically smeared, however, so some movement on these structures is younger.

Several northeast-striking faults with dip-slip offsets appear to cut the Columbia River Basalt Group in the southwest part of the quadrangle. All are inferred from apparent offsets of basal contacts with the Pittsburg Bluff Formation and (or) from topographic lineaments; none were observed in outcrop. Because the oldest basalt flows were emplaced on a dissected terrain, some of the inferred fault offsets may simply reflect topographic relief on the pre-basalt surface. East of the Columbia River, northeast-striking faults, some of which are exposed in outcrop, cut Paleogene strata. Like the similarly oriented faults in Oregon these may postdate the middle Miocene basalts.

KALAMA STRUCTURAL ZONE

Structural attitudes in the Paleogene bedrock in the Deer Island quadrangle and adjacent areas indicate that an important north-northwest-trending structure, referred to here as the Kalama Structural Zone, transects the crust beneath the Columbia River valley. The northwest strikes and southwest dips of strata in the northeastern part of the map area contrast with the east-west strikes and south dips of the section west of the river and with the northeast strikes and southeast dips of beds in the Cascade Range to the east (fig. 8). Attitudes east of the Columbia River outline a south-plunging anticlinal axis located immediately east of the quadrangle boundary. The north-south orientation of this fold is anomalous for the southwestern Washington Cascade Range, which typically strikes northwest to north-northwest (Beeson and others, 1989; Evarts and Swanson, 1994). The northwest-striking domain between Woodland and Kalama may have rotated clockwise in response to right-lateral shear on the inferred structure, generating what is essentially a large drag fold. Alternatively, or in addition, the Paleogene section may have been tilted westward owing to localized differential uplift of the Cascade Range relative to the Oregon Coast Range along the Kalama Structural Zone. The small section of north-dipping strata immediately north of Woodland may be a fault sliver tilted along a subsidiary structure within the structural zone. Regionally, the Kalama Structural Zone appears to be one of a dispersed set of complex north-south to northwest dextral shear structures at the northern margin of the Portland Basin (Evarts and others, 2002) that accommodate northward Cenozoic translation of the Oregon Coast Range crustal block relative to the Cascade volcanic arc (Pezzopane and Weldon, 1993; Blakely and others, 1995; Wells and others, 1998).

GEOLOGIC EVOLUTION

It is clear from previous regional studies that 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) suggested 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). Data from the Deer Island quadrangle provide some constraints on the nature and timing of basin evolution.

The oldest rocks exposed in this quadrangle are subaerially emplaced lava flows and pyroclastic deposits interbedded with fluvial and lacustrine volcaniclastic sedimentary rocks derived from reworking and erosion of the primary volcanic deposits. These rocks were emplaced about 36-37 Ma, early in the history of the Cascade volcanic arc (Duncan and Kulm, 1989; Evarts and Swanson, 1994). The scarcity of intrusive rocks and relatively mild

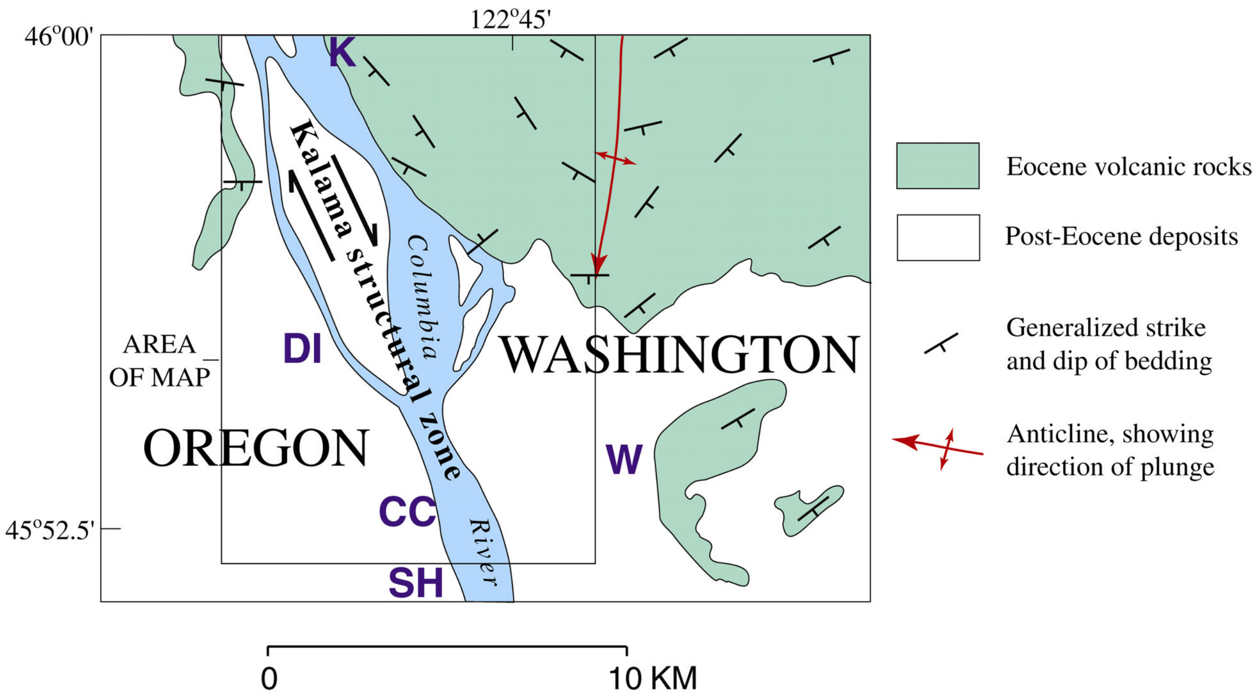

Figure 8. Sketch map showing major structural features in late Eocene volcanic rocks of the Deer Island 7.5'quadrangle and vicinity as inferred from variations in bedding attitudes (R.C. Evarts, unpub. mapping). K, Kalama; W, Woodland; DI, Deer Island; CC, Columbia City; SH, Saint Helens.

zeolite-facies burial metamorphism, combined with regional stratigraphic relations, indicate that the area of Deer Island quadrangle was located in a setting near the west margin of the late Eocene arc, immediately east of the marine forearc basin of the Oregon Coast Range. A period of erosion followed by subsidence below sea level is recorded by the unconformity at the base of the shallow marine to nonmarine Pittsburg Bluff Formation. The normal faults and associated zeolite veins in the Eocene volcanic section along the east bank of the Columbia River may reflect this subsidence, which possibly corresponds to a late Eocene extensional episode observed in forearc strata to the west (Niem and others, 1992, 1994). The absence of volcanic flows in the Oligocene Pittsburg Bluff Formation indicates that arc volcanism in southern Washington had decreased in vigor or that its focus shifted eastward to a more distal location during this time.

By late early Miocene time the eastern part of the forearc had been uplifted and eroded because the first flows of the Columbia River Basalt Group to reach western Oregon flowed onto a topographically subdued subaerial terrain developed on the older Tertiary rocks (Beeson and others, 1989). Wilkinson and others (1946) inferred pre-basalt surface relief of about 150-180 m in the area of this quadrangle. The low dips in the Pittsburg Bluff Formation indicate that only mild folding accompanied this uplift. The local course of the ancestral Columbia River prior to emplacement of the Columbia River Basalt Group was probably determined by a combination of structural control and differential resistance to erosion of the Paleogene volcanic and sedimentary strata. The river channel was located along the southern margin of a highland of resistant Paleogene volcanic rocks and was filled with the reversely magnetized, intermediate-MgO Grande Ronde Basalt lavas and basalt-clast gravels now exposed on Maple Hill. The river then shifted its course to the south, eroding a broad valley into weakly resistant Pittsburg Bluff Formation sandstones that was later occupied by the members of Wapshilla Ridge, Ortley, and Winter Water.

Restriction of the members of Wapshilla Ridge and Ortley to the southern part of the map area indicates that the northeastern part of the Deer Island quadrangle remained topographically elevated into late Grande Ronde time. The last of the Grande Ronde Basalt flows, belonging to the widespread member of Sentinel Bluffs, entered the Portland Basin shortly thereafter, covering the older basalt flows as well as much of the surrounding terrain. The river then carved a new channel into this Grande Ronde Basalt section, which was subsequently occupied by the basalt of Sand Hollow flow of the Wanapum Basalt.

A period of northeast-southwest-directed compressional deformation accompanied and followed emplacement of the Grande Ronde Basalt in the Deer Island area. The member of Sentinel Bluffs flow dips southward at 1° to 2°, forming the northeastern limb of a broad, northwest-striking, southeast-plunging syncline whose axis passes immediately southwest of the Deer Island quadrangle (Wilkinson and others, 1946; R.C. Evarts, unpub. mapping). Similarly oriented folds are present in the western Cascade Range east of this quadrangle (Phillips, 1987a, b; R.C. Evarts, unpub. mapping) and west of Portland (Beeson and others, 1989; Beeson and Tolan, 1990), suggesting this compressive event was regional in scale. Northeast-southwest compression is also consistent with dextral movement along the Kalama Structural Zone, which therefore also may have been active at this time. The timing and duration of folding in the Deer Island quadrangle are uncertain. Involvement of the member of Sentinel Bluffs demonstrates post-15.6 Ma-deformation, but folding may have begun before its emplacement. Evarts and Swanson (1994) cite evidence that folding in the southern Washington Cascade Range was largely confined to the late early to middle Miocene, about 15-20 Ma, whereas development of northwest-striking folds and associated faults in northwestern Oregon seems to have occurred discontinuously throughout the Neogene (Beeson and others, 1989; Beeson and Tolan, 1990).

By late Miocene time an area of localized northwest-southeast extension within a broad, northwest-trending zone of dextral shear had evolved into a major pull-apart structure, the Portland Basin (Beeson and others, 1989; Beeson and Tolan, 1990). The northeast-striking normal and oblique-slip faults in the Deer Island quadrangle, at the north end of the basin, may be related to this transtensional event. North of the basin, some of the dextral shear was probably taken up along the north-northwest striking Kalama Structural Zone. Subsidence of the Portland Basin apparently controlled the course of the lower Columbia River throughout late Neogene time, resulting in the deposition of as much as 500 m of fluvial and lacustrine sediments in the Vancouver area (Swanson and others, 1993). The Kalama Structural Zone and other north- to northwest-striking faults inferred from aeromagnetic anomalies in the Portland Basin (Blakely and others, 1995; Evarts and others, 2002) are believed to partially accommodate rotation and northward translation of the Oregon Coast Range crustal block relative to the Cascade Range, a process ultimately driven by oblique subduction of the Pacific plate beneath the North America plate along the Cascadia Subduction Zone (Pezzopane and Weldon, 1993; Wells and others, 1998).

Although seismicity in the northern Portland Basin (Yelin and Patton, 1991) implies active deformation, evidence for specific Pliocene and younger structures in the Deer Island quadrangle is based chiefly on topographic arguments because no faults have been observed to cut the basin-fill units. Wilkinson and others (1946, p. 25) stated that a “steep reverse fault” cuts “Troutdale sediments” north of Woodland but did not otherwise describe this structure. On the Washington side of the Columbia River, quartzite pebbles that are presumably residual from weathering of Troutdale Formation conglomerate are found at elevations as high as 1200 ft (365 m). If these thoroughly weathered deposits are correlative with Troutdale Formation conglomerate in Oregon, there may be as much as 240 m of differential uplift across the Kalama Structural Zone since late Miocene time. Similarly, the presence of probable early to middle Pleistocene Lewis River outwash deposits north of Woodland, presumably graded to the contemporaneous Columbia River, at elevations of 500-600 ft (150-180 m) suggests possible uplift of that magnitude within the past 1 to 2 million years.

The reach of the Columbia River that passes through the Deer Island quadrangle has experienced a complex Quaternary depositional history. Dramatic fluctuations in sea level, inundation by cataclysmic jökulhlaups, major alluviation events in response to repeated melting of Lewis River glaciers and eruptions of Mount St. Helens, and tectonic activity have resulted in alternating episodes of deposition and erosion in the Columbia River valley. Following deposition of the Troutdale Formation, the Columbia River cut down through the conglomerate into underlying fine-grained beds of the Sandy River Mudstone, possibly in response to late Pliocene regional uplift. Subsequently, in latest Pliocene or early Pleistocene time, a gravel sheet (unit QTc) prograded northward across the basin floor. The abruptness of the sedimentological change indicates an environmental rather than tectonic cause, perhaps reflecting glaciation in the headwaters of the Columbia River. The outwash deposits north of Woodland (unit Qo) may be of similar age. Later, most likely in response to lowering of sea level during glacial maxima, the gravel sheet itself was incised, leaving the Deer Island terrace as a relict surface, and the Columbia became localized near its present course. After major eruptive episodes at Mount St. Helens in late Pleistocene and Holocene time, alluvial fans were constructed at the mouth of the Lewis River, at times extending entirely across the Columbia River valley. These fans were probably short lived, however, and only a small remnant of an early fan (unit Qsh) survives west of the river. In latest Pleistocene time, sediment carried in suspension by multiple cataclysmic glacier outburst floods settled out and blanketed terrain in the map area below 300 ft (90 m) elevation with micaceous silt and fine sand. Except for patches along the lower valley walls of the Columbia River and its tributaries, most of this sediment was subsequently removed by later floods, one of which left a thin veneer of gravel on the surface of the Deer Island terrace.

Detection of neotectonic structures in this environment is difficult because the high sediment loads and constant fluvial reworking of valley-bottom sediments rapidly obliterates fault scarps and other surficial evidence of recent deformation. Ryan and Stephenson (1995) collected high-resolution seismic reflection data on the Columbia River, seeking evidence for recent faulting. Although no offset of river bottom sediments was detected, they did record the presence of dipping and truncated reflectors in the shallow subsurface near Columbia City that may reflect disruption of basin-fill deposits as young as Holocene along the Kalama Structural Zone.

GEOLOGIC RESOURCES

Geologic resources available in the Deer Island quadrangle are largely limited to nonmetallic industrial materials; no metallic deposits or significant hydrothermal alteration associated with such deposits have been found. Paleogene lava flows on both sides of the Columbia River have been quarried for crushed aggregate, but the Columbia River Basalt Group has more desirable engineering properties for most uses, and large quarries have been developed in the Grande Ronde Basalt near Columbia City (see Gray and others, 1978). Abundant sand and gravel are available from unconsolidated alluvial deposits adjacent to the Columbia River; gravels correlative with those that underlie the Deer Island terrace are being excavated immediately east of Deer Island and at Scappoose, about 15 km south of Columbia City.

Intense weathering under warm humid conditions produced weathering profiles more than 40 m thick on the Grande Ronde Basalt. Typical profiles consist of a lower saprolitic horizon, wherein the basalt has been totally replaced by kaolinite, halloysite, and goethite, overlain by massive red-brown laterite largely leached of alkalies and silica. The residual laterite consists largely of gibbsite and goethite, forming the well-known ferruginous bauxite deposits of the region, which have been discussed by Libbey and others (1945), Wilkinson and others (1946), Lowry and Baldwin (1952), Trimble (1963), Livingston (1966), and others. Libbey and others (1945) noted ferruginous bauxite occurrences north of Dart Creek in the vicinity of the intersection of Dart and Smith Roads.

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Table 1. Chemical analyses of volcanic and intrusive rocks, Deer Island 7.5' quadrangle

[X-ray fluorescence analyses. Rock-type names assigned in accordance with IUGS system (Le Bas and Streckeisen, 1991) 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.	97SH-X05	97SH-X30	97SH-X37	97SH-X07	97SH-X45A	97SH-X63	97SH-X16B	97SH-X35	97SH-X65
Latitude (N)	45°57.42'	45°59.76'	45°58.08'	45°57.12'	45°58.68'	45°59.88'	45°58.20'	45°58.26'	45°59.58'
Longitude (W)	122°46.74'	122°50.04'	122°48.36'	122°45.00'	122°51.96'	122°50.58'	122°48.30'	122°46.56'	122°45.18'
Map unit	Tba	Tba	Tba	Tba	Tgvb	Tba	Tba	Tba	Tba
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	51.03	51.19	51.67	52.04	52.11	52.39	52.04	52.29	52.40
TiO_2	1.09	1.11	1.20	1.19	1.07	1.25	0.92	1.18	1.11
Al_2O_3	18.23	17.65	17.43	17.49	17.86	16.97	17.60	17.65	18.52
Fe_2O_3	9.25	9.30	9.44	9.10	8.93	9.34	8.93	9.01	8.50
FeO	---	---	---	---	---	---	---	---	---
MnO	0.14	0.15	0.15	0.18	0.16	0.15	0.18	0.15	0.13
MgO	4.66	5.27	5.20	5.17	5.24	5.77	5.84	4.91	4.41
CaO	10.41	10.22	10.11	10.07	10.02	9.09	9.74	10.12	9.81
Na_2O	2.84	2.79	2.96	2.98	2.94	3.11	2.82	2.96	3.09
K_2O	0.33	0.40	0.35	0.36	0.40	0.83	0.29	0.43	0.42
P_2O_5	0.21	0.21	0.24	0.24	0.19	0.32	0.18	0.25	0.25
LOI	1.85	1.29	1.09	1.06	1.35	1.03	1.49	0.65	1.48
Total	100.04	99.57	99.84	99.87	100.25	100.27	100.04	99.59	100.12
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt. percent)									
SiO_2	52.46	52.58	52.83	53.15	53.17	53.30	53.29	53.34	53.59
TiO_2	1.12	1.14	1.22	1.22	1.09	1.27	0.94	1.20	1.14
Al_2O_3	18.75	18.13	17.82	17.86	18.22	17.27	18.02	18.01	18.93
FeO	8.56	8.60	8.69	8.36	8.20	8.55	8.23	8.27	7.82
MnO	0.14	0.15	0.15	0.18	0.16	0.15	0.18	0.15	0.14
MgO	4.79	5.41	5.32	5.28	5.35	5.87	5.98	5.01	4.51
CaO	10.70	10.50	10.34	10.28	10.22	9.24	9.98	10.32	10.03
Na_2O	2.92	2.87	3.03	3.04	3.00	3.17	2.88	3.01	3.16
K_2O	0.34	0.41	0.35	0.37	0.41	0.85	0.29	0.44	0.42
P_2O_5	0.22	0.21	0.24	0.24	0.19	0.33	0.18	0.26	0.25
Mg#	54.4	57.3	56.5	57.3	58.0	59.2	60.7	56.2	55.1
Modes (volume percent)									
Plagioclase	22.1	22.9	12.4	9.9	13.6	26.3	7.7	16.6	32.0
Clinopyroxene	-	-	-	-	0.2	0.9	-	-	1.0
Orthopyroxene	-	-	-	-	-	0.3	-	-	-
Olivine	3.5	3.3	0.9	1.2	1.5	2.6		1.1	1.4
Fe-Ti Oxide	-	-	-	-	-	-	0.9	-	-
Hornblende	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	amygdules: 0.7	-	-	-
Groundmass	74.4	73.8	86.7	88.9	84.7	69.9	91.4	82.3	65.6
No. points counted	800	805	766	761	822	800	737	800	825
Texture (rock/ groundmass)	porphyritic/ intergranular	seriate/ intergranular	seriate/ intergranular	seriate/ intergranular	porphyritic/ trachytic	porphyritic/ intergranular	seriate/ trachytic	seriate/ intergranular	porphyritic/ intergranular
Trace element analyses (ppm)									
Ba	111	119	115	125	119	186	124	134	132
Rb	<10	<10	<10	<10	<10	21	<10	<10	<10
Sr	393	382	404	399	380	491	393	402	431
Y	14	14	20	25	14	22	16	23	19
Zr	87	86	123	121	87	144	94	123	122
Nb	<10	<10	14	13	12	15	10	12	10
Ni	53	45	34	35	47	67	40	27	43
Cu	139	107	134	161	132	169	114	148	126
Zn	81	68	74	77	71	85	70	80	75
Cr	---	---	---	---	---	---	---	---	---

Table 1. Chemical analyses of volcanic and intrusive rocks, Deer Island 7.5' quadrangle—Continued

Map No.	10	11	12	13	14	15	16	17	18
Field sample No.	97SH-X57A	97SH-X19A	97SH-X28	97SH-X52	97SH-X15	97SH-X33	97SH-X44A	97SH-X08	97SH-X41
Latitude (N)	45°58.80'	45°55.86'	45°59.64'	45°58.32'	45°57.54'	45°59.40'	45°58.26'	45°57.18'	45°55.92'
Longitude (W)	122°45.96'	122°45.24'	122°49.68'	122°48.90'	122°46.14'	122°47.94'	122°51.96'	122°45.60'	122°51.36'
Map unit	Tba	Tba	Tba	Tba	Tba	Tba	Tgvb	Tba	Tba
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	52.87	53.27	52.98	53.68	53.69	53.81	54.10	54.24	53.49
TiO_2	1.26	1.29	1.23	1.04	1.58	1.29	1.19	1.54	1.11
Al_2O_3	18.40	17.11	16.83	17.63	16.61	17.78	16.53	15.96	17.54
Fe_2O_3	8.76	9.00	9.20	8.88	9.62	8.82	9.14	10.25	8.41
FeO	---	---	---	---	---	---	---	---	---
MnO	0.14	0.15	0.15	0.13	0.16	0.14	0.14	0.18	0.17
MgO	4.04	5.38	5.33	4.60	4.43	3.77	5.01	4.21	4.01
CaO	9.45	9.28	9.36	9.31	8.35	9.13	9.06	8.37	8.51
Na_2O	3.33	3.21	3.17	3.06	3.43	3.38	3.34	3.55	3.11
K_2O	0.59	0.65	0.32	0.76	0.85	0.54	0.47	0.71	0.68
P_2O_5	0.23	0.27	0.34	0.21	0.34	0.24	0.25	0.26	0.21
LOI	1.00	0.61	0.95	0.92	0.71	0.90	0.64	0.75	2.61
Total	100.07	100.22	99.86	100.20	99.77	99.80	99.86	100.02	99.86
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt. percent)									
SiO_2	53.85	53.97	54.07	54.55	54.73	54.90	55.03	55.21	55.48
TiO_2	1.28	1.31	1.26	1.05	1.61	1.31	1.21	1.57	1.15
Al_2O_3	18.74	17.34	17.18	17.92	16.93	18.14	16.81	16.24	18.19
FeO	8.03	8.20	8.44	8.12	8.83	8.10	8.36	9.39	7.85
MnO	0.14	0.16	0.15	0.13	0.17	0.15	0.14	0.18	0.18
MgO	4.11	5.45	5.44	4.68	4.52	3.84	5.10	4.29	4.16
CaO	9.63	9.40	9.55	9.46	8.51	9.31	9.22	8.52	8.82
Na_2O	3.39	3.25	3.23	3.11	3.50	3.45	3.40	3.61	3.23
K_2O	0.60	0.66	0.33	0.77	0.86	0.55	0.48	0.73	0.71
P_2O_5	0.23	0.28	0.35	0.21	0.35	0.25	0.25	0.26	0.22
Mg#	52.0	58.3	57.7	54.9	52.0	50.1	56.3	49.1	53.3
Modes (volume percent)									
Plagioclase	31.7	4.7	1.3	17.2	6.8	28.3	2.1	0.1	21.1
Clinopyroxene	0.3	-	-	-	-	1.0	-	0.1	1.4
Orthopyroxene	-	-	-	-	-	-	-	0.1	-
Olivine	2.0	0.1	0.3	0.9	0.6	1.0	0.5	-	1.6
Fe-Ti Oxide	-	-	-	-	-	-	-	-	-
Hornblende	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Groundmass	66.0	95.2	98.4	81.9	92.6	69.7	97.4	99.7	75.9
No. points counted	816	798	799	791	812	810	787	825	811
Texture (rock/ groundmass)	porphyritic/ intergranular	seriate/ subophitic	porphyritic/ trachytic	porphyritic/ trachytic	seriate/ trachytic	seriate/ intergranular	sparsely phyric/ pilotaxitic	seriate/ trachytic	seriate/ intersertal
Trace element analyses (ppm)									
Ba	137	164	163	141	176	136	150	167	188
Rb	10	<10	<10	15	14	<10	<10	14	17
Sr	416	353	375	381	393	415	375	384	372
Y	18	23	16	18	25	23	18	24	25
Zr	112	150	178	112	185	124	133	131	161
Nb	10	12	16	14	19	10	13	13	12
Ni	25	46	34	47	29	13	43	19	32
Cu	162	219	156	147	128	150	120	170	131
Zn	74	82	83	79	89	81	75	96	86
Cr	---	530	285	---	---	---	---	---	---

Table 1. Chemical analyses of volcanic and intrusive rocks, Deer Island 7.5' quadrangle—Continued

Map No.	19	20	21	22	23	24	25	26	27
Field sample No.	97SH-X40A	97SH-X17	97SH-X56	98SH-X88	97SH-X09	97SH-X12B	97SH-X16C	97SH-X23	97SH-X21
Latitude (N)	45°57.78'	45°58.44	45°58.68'	45°57.72'	45°56.58'	45°57.42'	45°58.22'	45°59.22'	45°58.92'
Longitude (W)	122°52.08'	122°47.04'	122°46.08	122°46.08'	122°45.90'	122°47.28'	122°48.21'	122°46.86'	122°47.58'
Map unit	Tgvb	Tba	Tba	Txa	Tid	Tid	Tid	Tid	Tid
Rock type	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite	Andesite	Andesite	Andesite	Dacite	Dacite	Dacite
Analyses as reported (wt. percent)									
SiO_2	54.65	54.84	55.84	56.68	58.81	59.04	62.18	63.29	63.01
TiO_2	1.52	0.87	1.74	1.37	1.02	1.30	0.90	1.10	1.20
Al_2O_3	16.43	18.48	15.39	15.89	16.08	15.63	15.78	14.58	14.37
Fe_2O_3	9.91	7.51	10.52	9.54	6.85	7.74	5.48	7.00	6.01
FeO	---	---	---	---	---	---	---	---	---
MnO	0.17	0.13	0.18	0.17	0.11	0.15	0.10	0.14	0.10
MgO	3.87	4.28	3.59	3.23	3.87	2.72	2.13	1.36	1.49
CaO	7.89	8.63	7.20	7.02	6.36	5.84	4.93	3.91	3.89
Na_2O	3.90	3.14	4.00	3.61	3.72	4.20	4.09	4.45	3.70
K_2O	0.61	0.86	0.61	1.03	1.59	1.16	1.78	1.93	2.54
P_2O_5	0.35	0.18	0.32	0.30	0.23	0.30	0.21	0.39	0.37
LOI	0.74	1.20	0.70	0.70	1.18	1.68	2.06	2.02	2.99
Total	100.02	100.14	100.08	99.53	99.82	99.77	99.64	100.16	99.67
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt. percent)									
SiO_2	55.60	55.85	56.79	57.91	60.04	60.67	64.09	64.95	65.58
TiO_2	1.54	0.89	1.77	1.40	1.04	1.34	0.93	1.13	1.25
Al_2O_3	16.71	18.82	15.65	16.23	16.41	16.06	16.26	14.97	14.96
FeO	9.07	6.89	9.62	8.77	6.29	7.16	5.08	6.46	5.63
MnO	0.17	0.13	0.18	0.17	0.11	0.16	0.11	0.15	0.11
MgO	3.94	4.36	3.65	3.30	3.95	2.79	2.19	1.39	1.55
CaO	8.02	8.79	7.33	7.17	6.50	6.00	5.08	4.01	4.04
Na_2O	3.97	3.20	4.07	3.69	3.80	4.32	4.22	4.57	3.86
K_2O	0.62	0.87	0.62	1.06	1.62	1.19	1.83	1.98	2.64
P_2O_5	0.35	0.19	0.33	0.30	0.24	0.30	0.22	0.40	0.38
Mg#	47.9	57.3	44.4	44.4	57.2	45.5	48.1	31.5	37.5
Modes (volume percent)									
Plagioclase	0.4	18.5	5.4	1.2	8.2	9.9	12.8	6.6	4.6
Clinopyroxene	0.1	0.4	1.0	0.3	5.2	1.6	1.4	0.7	1.0
Orthopyroxene	-	4.8	trace	-	3.9	1.7	2.5	1.2	0.3
Olivine	trace	-	-	0.1	0.4	-	-	-	-
Fe-Ti Oxide	trace	---	0.1	-	0.4	0.1	0.4	0.6	0.8
Hornblende	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Groundmass	99.5	76.3	93.5	98.4	81.9	86.7	82.9	90.9	93.3
No. points counted	801	775	779	789	776	808	814	802	826
Texture (rock/ groundmass)	seriate/ trachytic	seriate/ intergranular	porphyritic/ intergranular	sparsely phyric/ microgranular	seriate/ intersertal	porphyritic/ hyalopilitic	porphyritic/ hyalopilitic	porphyritic/ hyalopilitic	porphyritic/ hyalopilitic
Trace element analyses (ppm)									
Ba	190	151	178	229	277	289	313	396	390
Rb	16	16	19	23	35	31	39	39	49
Sr	401	587	360	365	448	305	299	259	224
Y	23	13	25	26	23	32	30	41	42
Zr	185	99	170	177	231	291	320	422	407
Nb	19	<10 (8)	15	17	16	21	20	23	25
Ni	25	38	24	22	54	18	16	<10	<10
Cu	166	86	205	157	97	137	69	40	51
Zn	80	68	85	94	72	84	73	91	76
Cr	---	---	---	---		---	---	---	---

Table 1. Chemical analyses of volcanic and intrusive rocks, Deer Island 7.5' quadrangle—Continued

Map No.	28	29	30	31	32	33	34	35	36
Field sample No.	97SH-X69A*	97SH-X69B*	97SH-X71*	97SH-X72*	99SH-X95B*	97SH-X43*	98SH-X80*	00SH-X112A*	01SH-X120A*
Latitude (N)	45°55.26'	45°55.26'	45°55.32'	45°54.90'	45°52.66'	45°53.40'	45°52.86'	45°52.62'	45°52.73'
Longitude (W)	122°51.54'	122°51.66'	122°51.72'	122°52.26'	122°48.26'	122°49.38'	122°48.48'	122°48.00'	122°48.43'
Map unit	Tgru	Tgru	Tgru	Tgru	Tgo	Tgo	Tgo	Tgo	Tgo
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	54.80	54.53	53.60	55.00	56.45	55.16	56.01	55.08	56.15
TiO_2	2.11	2.04	1.95	2.03	2.05	1.97	2.01	2.01	1.99
Al_2O_3	14.82	14.36	14.01	14.55	14.14	13.57	13.92	13.70	13.74
Fe_2O_3	---	---	---	---	---	---	---	---	
FeO	9.20	10.09	11.31	9.25	10.42	11.56	10.76	11.10	11.65
MnO	0.20	0.21	0.21	0.21	0.18	0.19	0.19	0.19	0.19
MgO	4.25	4.09	4.73	4.17	3.53	3.52	3.44	3.47	3.43
CaO	8.82	8.89	8.66	8.92	7.04	7.22	7.14	7.15	7.05
Na_2O	2.94	3.09	3.02	3.08	3.14	3.13	3.30	3.12	3.12
K_2O	1.33	1.41	1.33	1.32	1.74	1.86	1.78	1.73	1.77
P_2O_5	0.34	0.35	0.33	0.33	0.34	0.34	0.35	0.34	0.33
LOI	---	---	---	---	---	---	---	---	
Total	98.81	99.06	99.13	98.86	99.02	98.51	98.89	97.88	99.42
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt. percent)									
SiO_2	55.46	55.05	54.07	55.64	57.01	55.99	56.64	56.27	56.48
TiO_2	2.14	2.06	1.96	2.05	2.07	2.00	2.03	2.05	2.00
Al_2O_3	15.00	14.50	14.13	14.72	14.28	13.77	14.08	14.00	13.82
FeO	9.31	10.19	11.40	9.35	10.52	11.73	10.88	11.34	11.72
MnO	0.20	0.22	0.21	0.21	0.18	0.20	0.19	0.19	0.19
MgO	4.30	4.13	4.77	4.22	3.56	3.57	3.48	3.55	3.45
CaO	8.93	8.97	8.74	9.02	7.11	7.33	7.22	7.30	7.09
Na_2O	2.98	3.12	3.05	3.12	3.17	3.18	3.34	3.19	3.14
K_2O	1.35	1.42	1.34	1.34	1.76	1.89	1.80	1.77	1.78
P_2O_5	0.35	0.35	0.33	0.34	0.34	0.34	0.35	0.34	0.33
Mg#	49.5	46.2	47.0	48.9	41.8	39.3	40.4	40.1	38.3
Modes (volume percent)									
Plagioclase	-	-	-	-	-	-	-	-	-
Clinopyroxene	-	-	-	-	-	-	-	-	-
Orthopyroxene	-	-	-	-	-	-	-	-	-
Olivine	-	-	-	-	-	-	-	-	-
Fe-Ti Oxide	-	-	-	-	-	-	-	-	-
Hornblende	-	-	-	-	-	-	-	-	-
Quartz	-	-	-	-	-	-	-	-	-
K-feldspar	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
Groundmass	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
No. points counted	---	---	---	---	---	---	---	---	---
Texture (rock/ groundmass)	aphyric/ intersertal	aphyric/ intersertal	aphyric/ intersertal	aphyric/ intersertal	aphyric/ intersertal	aphyric/ intersertal	aphyric/ intergranular	aphyric/ intersertal	aphyric/ intersertal
Trace element analyses (ppm)									
Ba	582	526	447	494	838	705	688	755	704
Rb	30	31	28	32	50	46	45	48	49
Sr	335	325	306	324	322	316	307	321	311
Y	50	37	33	39	38	37	34	38	37
Zr	174	171	160	170	183	181	181	184	181
Nb	2.3	13.5	12.37	12.45	14.0	13.5	13.7	12.3	14.2
Ni	11	9	9	14	8	6	4	9	7
Cu	30	29	27	29	19	23	14	20	9
Zn	137	122	113	124	124	120	116	122	115
Cr	48	50	48	52	26	23	28	25	21

Table 1. Chemical analyses of volcanic and intrusive rocks, Deer Island 7.5' quadrangle—Continued

Map No.	37	38	39
Field sample No.	01SH-X117*	97SH-X47A*	98SH-X81*
Latitude (N)	45°53.47'	45°53.16'	45°55.38'
Longitude (W)	122°49.12'	122°48.84'	122°52.14'
Map unit	Tgww	Tgsb	Twfs
Rock type	Basaltic Andesite	Basaltic Andesite	Basaltic Andesite
Analyses as reported (wt. percent)			
SiO_2	54.78	52.98	51.81
TiO_2	2.05	2.00	2.99
Al_2O_3	13.65	13.80	13.46
Fe_2O_3		---	---
FeO	11.77	11.35	12.64
MnO	0.20	0.22	0.25
MgO	3.68	4.52	3.84
CaO	7.73	8.67	8.55
Na_2O	2.97	2.86	2.78
K_2O	1.67	1.33	1.40
P_2O_5	0.31	0.34	0.58
LOI		---	---
Total	98.81	98.07	98.29
Analyses recalculated volatile-free and normalized to 100% with all Fe as FeO (wt. percent)			
SiO_2	55.44	54.02	52.71
TiO_2	2.07	2.04	3.04
Al_2O_3	13.81	14.07	13.69
FeO	11.91	11.57	12.86
MnO	0.20	0.22	0.25
MgO	3.72	4.61	3.91
CaO	7.82	8.84	8.70
Na_2O	3.01	2.92	2.83
K_2O	1.69	1.36	1.42
P_2O_5	0.32	0.34	0.59
Mg#	39.90	46.0	39.3
Modes (volume percent)			
Plagioclase	trace	-	-
Clinopyroxene	-	-	-
Orthopyroxene	-	-	-
Olivine	-	-	-
Fe-Ti Oxide	-	-	-
Hornblende	-	-	-
Quartz	-	-	-
K-feldspar	-	-	-
Other	-	-	-
Groundmass	100.0	100.0	100.0
No. points counted	---	---	---
Texture (rock/ groundmass)	sparsely phyric/ intergranular	aphyric/ intersertal	aphyric/ intersertal
Trace element analyses (ppm)			
Ba	574	521	544
Rb	41	30	36
Sr	314	313	318
Y	37	37	41
Zr	173	161	187
Nb	14.4	11.6	15.78
Ni	5	13	18
Cu	2	29	28
Zn	122	120	147
Cr	24	43	64

Table 2. Summary of isotopic age determinations, Deer Island 7.5' quadrangle

Field sample no.	Location		Map unit	Rock type	Material dated	Method	Age (Ma) (±1σ error)	Source
	Latitude (N)	Longitude (W)						
97SH-X19B	45°55'52"	122°45'22"	Tbb	Basaltic andesite	Plagioclase	$^{40}Ar/^{39}Ar$	37.3±0.3	R.J. Fleck, oral commun., 1999
97SH-X46	45°59'31"	122°52'26"	Tgvt	Pumice-lapilli tuff	Plagioclase	$^{40}Ar/^{39}Ar$	36.1±0.3	R.J. Fleck, oral commun., 1999
97SH-X23	45°59'22"	122°46'86"	Tid	Pyroxene andesite	Plagioclase	$^{40}Ar/^{39}Ar$	36.8±0.2	R.J. Fleck, oral commun., 1999

Table 3. Comparison of selected chemical and paleomagnetic characteristics of Grande Ronde Basalt flows in the Deer Island and Saint Helens quadrangles (R.C. Evarts, unpub. data; J.T Hagstrum, written commun., 1999, 2000, 2001)

[Magnetic polarity: N, normal; R, reversed. Paleomagnetic direction: terminology is that of Wells and others (1989). Ranges in chemical composition based on analyses recalculated volatile-free and normalized to 100% with all Fe as FeO]

Member	Tgsb	Tgww	Tgo	Tgru
Magnetic polarity	N	N	N	R
Paleomagnetic direction	north	northwest shallow	northeast	northeast
MgO (wt. %)	3.83-4.90	3.65-3.93	3.41-3.61	4.13-4.77
TiO_2 (wt. %)	1.94-2.15	2.03-2.10	1.95-2.07	1.96-2.14
P_2O_5 (wt. %)	0.32-0.35	0.31-0.33	0.33-0.35	0.33-0.35
CaO (wt. %)	8.41-9.48	7.65-7.83	7.05-7.34	8.74-9.02
K_2O (wt. %)	0.96-1.36	1.42-1.67	1.73-2.01	1.34-1.42
Ba (ppm)	447-1019	530-759	668-838	447-582
Cr (ppm)	39-49	21-30	17-28	48-52

APPENDIX

DIGITAL DATABASE DESCRIPTION FOR THE GEOLOGIC MAP OF THE DEER ISLAND QUADRANGLE, COLUMBIA COUNTY, OREGON AND COWLITZ COUNTY, WASHINGTON

Database by Robert W. Givler and Philip A. Dinterman

INTRODUCTION

This appendix serves to introduce and describe the digital files that are included in this publication, available for downloading at *http://geopubs.wr.usgs.gov*. These files include a set of ARC/INFO geospatial databases containing the geologic information as well as Adobe Acrobat Portable Document Format (PDF) and PostScript plot files containing images of the geologic map sheet and the text of an accompanying pamphlet that describes the geology of the area. For those interested only in a paper plot of the map and pamphlet, please see the section entitled "Obtaining paper plots" below.

This digital map publication, generated from new mapping by the author, shows the general distribution of bedrock and surficial deposits in the Deer Island 7.5' quadrangle. Together with the accompanying geologic description pamphlet, it presents current knowledge of the geologic structure and stratigraphy of the area covered. The database identifies map units that are classified by general age and lithology following the stratigraphic nomenclature of the U.S. Geological Survey. The scale of the source map limits the spatial resolution (scale) of the database to 1:24,000 or smaller. The content and character of the digital publication, as well as methods of obtaining the digital files, are described below.

The databases in this report were compiled in ARC/INFO, a commercial Geographic Information System by Environmental Systems Research Institute (ESRI) in Redlands, California, with version 3.0 of the menu interface ALACARTE (Fitzgibbon and Wentworth, 1991; Fitzgibbon, 1991; Wentworth and Fitzgibbon, 1991). The files are in either GRID (ARC/INFO raster data) format or COVERAGE (ARC/INFO vector data) format. Coverages are stored in uncompressed ARC export format (ARC/INFO version 8.1.2 for Unix). ARC/INFO export files (files with the .e00 extension) can be converted into ARC/INFO coverages in ARC/INFO (see below) and can be read by some other Geographic Information Systems, such as MapInfo, via ArcLink and ESRI's ArcView (version 1.0 for Windows 3.1 to 3.11 is available for free from ESRI's web site: *http://www.esri.com*). The digital compilation was done in version 8.1.2 of ARC/INFO for Unix.

MF-2392 DIGITAL CONTENTS

The digital data for the Miscellaneous Field Studies Map consist of three separate packages. Choosing the most appropriate package will depend on the resources available. The **Encapsulated PostScript (EPS) package** consists of Encapsulated PostScript files of the geologic map with explanation and a geologic description pamphlet with figures and tables. The **Portable Document Format (PDF) package** contains the same map and pamphlet as the first package as PDF files The **Digital Database package** contains ARC/INFO files that comprise the geologic map database itself and supporting data, including base map, map explanation, geologic description, and references. Those who have computer capability can access the plot file packages in any of the three ways described below. However, it should be noted the plot file packages do require gzip and tar utilities or winzip to access the plot files. Therefore additional software, available free on the Internet, may be required to use the plot files (see section "Tar files"). In addition, the map sheet is large and requires large-format color plotters to produce a plot of the entire image, although smaller plotters can be used to plot portions of the images using the PDF plot files.
Those without computer capability can obtain plots of the map files through U.S. Geological Survey print on demand service for digital geologic maps (see section "To obtain paper plots from the U.S. Geological Survey, pg. 38) or from an outside vendor (see section "To obtain plots from a commercial vendor").

ENCAPSULATED POSTSCRIPT PACKAGE

For those interested in the geology of the Deer Island 7.5' quadrangle who do not use an ARC/INFO compatible GIS system we have included an Encapsulated PostScript (EPS) plot file created with Adobe Illustrator 8.0. This package contains:

di.eps	An EPS plottable file containing an image of the geologic map, base map, cross sections, correlation of map units, description of map units, and index map of the Deer Island 7.5' quadrangle The file contains a color plot of the geologic map sheet at 1:24,000 scale. The PostScript image of the map sheet is 36 by 55 inches, so it requires a large plotter to produce paper copies at the intended scale
geol.pdf	A PDF file of the geologic description pamphlet with figures and an appendix containing the readme file (digital database description)

The PostScript plot files for maps were produced by the PostScript command using the uncompressed option in ARC/INFO version 7.2.1 for Unix. Encapsulated PostScript files, as well as the layout (di.eps) contain a color plot of the geologic map, cross sections, correlation of map units, description of map units, and index map.

PORTABLE DOCUMENT FORMAT PACKAGE

Adobe Acrobat PDF files are similar to PostScript plot files in that they contain all the information needed to produce a paper copy of a map and they are platform-independent. PDF files allow printing of portions of a map image on a printer smaller than that required to print the entire map without the purchase of expensive additional software. The PDF files were created from the PostScript files using Adobe Acrobat Distiller. In test plots we have found that paper maps created with PDF files contain almost all the detail of maps created with PostScript plot files. We would, however, recommend that users with the capability to print the larger PostScript files use them in preference to the PDF files. This package contains the images described here in PDF 5.0 format:

di.pdf	A PDF file containing an image of the geologic map, base map, cross sections, correlation of map units, description of map units, and index map of the Deer Island 7.5' quadrangle
geol.pdf	A PDF file of the geologic description pamphlet with figures and an appendix containing the readme file (digital database description)

To use PDF files, the user must get and install a copy of Adobe Acrobat Reader. This software is available free from the Adobe website (*http://www.adobe.com*). Please follow the instructions given at the website to download and install this software. Once installed, the Acrobat Reader software contains an online manual and tutorial.

There are two ways to use Acrobat Reader in conjunction with the Internet. One is to use the PDF reader plug-in with your Internet browser. This allows interactive viewing of PDF file images within your browser. This is a very handy way to quickly look at PDF files without downloading them to your hard disk. The second way is to download the PDF file to your local hard disk and then view the file with Acrobat Reader. **We strongly recommend that large map images be handled by downloading to your hard disk, because viewing them within an Internet browser tends to be very slow.**

To print a smaller portion of a PDF map image using Acrobat Reader, use the crop tool to show the desired print area. This crop tool will not remove any area that is not printing, but masks the parts and can be later be changed to show the entire map or any other part of it for printing or viewing.

DIGITAL DATABASE PACKAGE

The database package includes geologic map database files for the Deer Island 7.5' quadrangle. ARC/INFO compatible Geographic Information System (GIS) software is required to use the files of this package. The digital maps, or coverages, and associated INFO directory have been converted to uncompressed ARC/INFO export files. ARC export files promote ease of data handling and are usable by some Geographic Information Systems in addition to ARC/INFO (see below for a discussion of working with export files). Raster data are stored in ARC grid format rather than export format to reduce file size. The ARC export files and associated ARC/INFO coverages, grids, and directories, as well as the additional digital material included in the database, are described below:

ARC/INFO export file	Resultant Coverage	Description of Coverage
di_geo.e00	di_geo	Faults, contacts, and rock units in the quadrangle
di_stx.e00	di_stx	Geologic attitudes as points; include pttype, strike, and dip fields, dip values as annotation, and cross section lines
di_anno.e00	di_anno	Unit labels and leaders
di_geochron.e00	di_geochron	Radiometric age localities as points; include age, sample number, and map plot number
di_chm.e00	di_chm	Geochemistry localities as points; include sample number, map plot number, and major and trace element XRF analysis
fnt032.e00	fnt032	ARC/INFO font used with markerset
fnt034.e00	fnt034	ARC/INFO font used with markerset
fnt035.e00	fnt035	ARC/INFO font used with markerset
fnt038.e00	fnt038	ARC/INFO font used with markerset
fnt039.e00	fnt039	ARC/INFO font used with markerset
fnt040.e00	fnt040	ARC/INFO font used with markerset
fnt339.e00	fnt339	ARC/INFO font used with markerset
geologykrg.mrk.e00	geologykrg.mrk	ARC/INFO markerset (custom)
droid.lut.e00	droid.lut	ARC/INFO marker look up table (internal)
di_poly.lut.e00	di_poly.lut	ARC/INFO line look up table for polygons (internal)
di_ln.lut.e00	di_ln.lut	ARC/INFO line look up table for lines and fold arcs (internal)
di_lo.lut.e00	di_lo.lut	ARC/INFO line look up table for lines and fold arcs (internal)
di_lm.lut.e00	di_lm.lut	ARC/INFO line look up table for fold and fault markers (internal)

ARC/INFO grid	Description of Grid
di_grd	Deer Island color geology grid merged with grid of topographic base

The digital database package also includes the following files:

metadata.txt	The metadata as a text file
geol.pdf	Geology pamphlet including readme as a PDF file with figures
geol.doc	Geology pamphlet including readme as a MSWord 2000 document with figures

import.aml	ASCII text file in ARC Macro Language (AML) used to convert ARC export files to ARC coverages in ARC/INFO
di.eps	Adobe Illustrator 8.0 Encapsulated PostScript file of the Deer Island quadrangle
di_plot.aml	AML that uses the coverages and grid to generate an uncompressed PostScript file of the Deer Island geologic map at 600 dpi., which can be combined with the other files in Adobe Illustrator to produce the entire map sheet layout
di.gra	ARC Graphics Metafile for the Deer Island quadrangle (geologic map only)
di.ps	Postscript file of Deer Island quadrangle (geologic map only) uncompressed
geol61r1.lin	Custom ARC lineset
johanna.txt	Custom ARC textset
uncom	Parameter file in di_plot.aml to uncompress PostScript file
di.tab	ARC/INFO grid remap table for colors
info	ARC/INFO directory
log	ARC/INFO log file
alc1.shd	ARC/INFO shadeset (custom)

The following supporting directory is not included in the database package, but is produced in the process of reconverting the export files into ARC coverages:

info/	INFO directory containing files supporting the databases

CONVERTING ARC EXPORT FILES

ARC export files for coverages are converted to ARC coverages using the ARC command IMPORT with the option COVER. To ease conversion and maintain naming conventions, we have included an ASCII text file in ARC Macro Language that will convert all of the export files in the database into coverages, import the fonts, markersets, and lookup tables, and create the associated INFO directory. From the ARC command line type:

```
Arc: &run import.aml
```

ARC export files can also be read by some other Geographic Information Systems. Please consult your GIS documentation to see if you can use ARC export files and the procedure to import them.

TAR FILES

The two data packages described above are stored in tar (UNIX tape archive) files. A tar utility is required to extract the database from the tar file. This utility is included in most UNIX systems and can be obtained free of charge over the Internet from Internet Literacy's Common Internet File Formats Webpage (http://www.matisse.net/files/formats.html). The tar files have been compressed and may be uncompressed with **gzip**, which is available free of charge over the Internet via links from the U.S. Geological Survey Public Domain Software page (http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/public.html). When the tar file is uncompressed and the data is extracted from the tar file, a directory is produced that contains the data in the package as described above. If you are using a PC, a software package called cygwin will provide a UNIX-like environment on a PC. Using this software these files maybe untared and uncompressed. Download this software for free at *http://sources.redhat.com/cygwin/*. The specifics of the tar files are listed below:

Name of compressed tar file (size)	Size of uncompressed tar file	Directory produced when extracted from tar file	Data package contained
2392ps.tar.gz (9.92 Mb)	27.1 Mb	2392ps/	Emcapsulated PostScript package
2392pdf.tar.gz (23.7 Mb)	27.3 Mb	2392pdf/	Portable Document Format package
2392db.tar.gz (34.2 Mb)	212 Mb	2392db/	Digital Database package

OBTAINING THE DIGITAL DATA

The digital data for this map can be obtained in any of three ways:

A. Western Region Geologic Information Web Page
B. Anonymous ftp over the Internet
C. Request for the data on a compact disk (CD)

A. TO OBTAIN TAR FILES FROM THE U.S. GEOLOGICAL SURVEY WEB PAGES

The U.S. Geological Survey supports a set of graphical pages on the World Wide Web. Digital publications (including this one) can be accessed via these pages. The location of the main Web page for the entire U.S. Geological Survey is http://www.usgs.gov. The Web server for digital publications from the Western Region is http://geopubs.wr.usgs.gov. To access files for the Deer Island quadrangle, go to *http://pubs.usgs.gov/mf/2002/2392/*.

B. TO OBTAIN TAR FILES ON A CD

The database files, EPS files, and PDF files can be obtained on a CD by sending a request and return address:

Russ Evarts, Ray Wells, or Karen Wheeler
U.S. Geological Survey
345 Middlefield Road, M/S 975
Menlo Park, CA 94025

or by email: *revarts@usgs.gov*, *rwells@usgs.gov* or *kwheeler@usgs.gov*
The compressed tar file will be returned on a CD.

OBTAINING PAPER PLOTS

TO OBTAIN PLOTS FROM A COMMERCIAL VENDOR

Those interested in the geologic map of the Deer Island 7.5' quadrangle, but who use neither a computer nor the Internet, can still obtain the information by providing the PostScript plot files to a commercial vendor who can make large-format plots. To obtain a CD with the compressed tar file, send a request and return address:

Russ Evarts, Ray Wells, or Karen Wheeler
U.S. Geological Survey
345 Middlefield Road, M/S 975
Menlo Park, CA 94025

or by email: revarts@usgs.gov, rwells@usgs.gov, or kwheeler@usgs.gov

Make sure your vendor is capable of reading CDs and PostScript files; be certain to provide a copy of this document to your vendor.

TO OBTAIN PAPER PLOTS FROM THE U.S. GEOLOGICAL SURVEY

The U.S. Geological Survey provides a print on demand service for digital maps such as this report. To obtain plots, contact the U.S. Geological Survey:

USGS Information Services
Box 25286
Denver Federal Center
Denver, CO 80225-0046

(303) 202-4200
1-800-USA-MAPS
FAX: (303) 202-4695
e-mail: infoservices@usgs.gov

Be sure to include with your request the Miscellaneous Field Studies Map number, MF-2392.

DIGITAL COMPILATION

Several different coverages were generated during the construction of the Deer Island quadrangle geologic map. The topographic base map remains as an image and then is converted to a grid, and is merged at the last step with the colored geology polygrids. The image was merged with the geology grid to give an apparent transparent color image of both combined. The raster geology grids were converted to vector coverages with ARC/INFO's gridline routine. Alacarte and some custom menus and AMLs (ARC Macro Language) were used to project, transform, edit, tag, and build lines, polygons, and points in the map. A digital layout or map collar was made with Adobe Illustrator. The plot AMLs run in ARC/INFO and call the coverages, grids, and Adobe Illustrator EPS files to make uncompressed PostScript files. The map is in UTM projection, zone 10, meters, and 1:24,000 scale. The pamphlet that describes the geology and readme was saved to PDF from Microsoft Word.

Base Map

The base map for the digital compilation is a Digital Raster Graphic (DRG) of the U.S. Geological Survey, 1:24,000-scale topographic map of the Deer Island 7.5' quadrangle (1990), which has a 20-foot contour interval. The image inside the map neatline is georeferenced to the Universal Transverse Mercator projection. The horizontal positional accuracy and datum of the DRG matches the accuracy and datum of the source map. These base map/geology layers are digital images but no information other than location is attached to the lines. The base/geology maps are provided for reference only.

Spatial Resolution

Uses of this digital geologic map should not violate the spatial resolution of the data. Although the digital form of the data removes the constraint imposed by the scale of a paper map, the detail and accuracy inherent in map scale are also present in the digital data. The fact that this database was edited at a scale of 1:24,000 means that higher resolution information is not present in the dataset. Plotting at scales larger than 1:24,000 will not yield greater real detail, although it may reveal fine-scale irregularities below the intended resolution of the database. Similarly, where this database is used in combination with other data of higher resolution, the resolution of the combined output will be limited by the lower resolution of these data.

Annotation

Annotation coverages were used to label desired information to show when the map is printed. These coverages do not hold any information other than the information attached to the lines or polygons. Within the structural coverage (di_stx) is an annotation showing dip amount associated with each attitude. An annotation coverage (di_anno) was also used to label map units within the geology polygons. These annotation layers are called by the plot AML (di_plot.aml) used by ARC/INFO, using a custom ARC textset, johanna.txt. The plot AML converts all coverages into a PostScript file (di.ps).

DATABASE SPECIFICS

The map databases consist of ARC coverages and supporting INFO files, which are stored in a UTM (Universal Transverse Mercator) projection (table 1). Digital tics define a 7.5' grid of projected latitude and longitude in the coverages corresponding with quadrangle corners and internal tics.

Table 1 - *Map Projection*

The map is stored in UTM projection

PROJECTION UTM	
UNITS METERS	-on the ground
ZONE 10	-UTM zone
PARAMETERS	
END	

The content of the geologic database can be described in terms of the lines, areas, and points that compose the map. Descriptions of the database fields use the terms explained in table 2.

Table 2 - *Field Definition Terms*

ITEM NAME	name of the database field (item)
WIDTH	maximum number of digits or characters stored
OUTPUT	output width
TYPE	B-binary integer, F-binary floating point number, I-ASCII integer, C-ASCII character string
N. DEC.	number of decimal places maintained for floating point numbers

Lines

The lines (arcs) are recorded as strings of vectors and are described in the arc attribute table (table 3). They define the boundaries of the map units, faults, and the map boundaries. These distinctions, including the geologic identities of the unit boundaries, are recorded in the LTYPE field according to the line types listed in table 4.

Table 3 - *Content of the Arc Attribute Tables*

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC.	Description
FNODE#	4	5	B		starting node of arc (from node)
TNODE#	4	5	B		ending node of arc (to node)
LPOLY#	4	5	B		polygon to the left of the arc
RPOLY#	4	5	B		polygon to the right of the arc
LENGTH	4	12	F	3	length of arc in meters
<coverage>#	4	5	B		unique internal control number
<coverage>-ID	4	5	B		unique identification number
LTYPE	35	35	C		line type (see table 4)
SEL	1	1	I		user-defined field used to save a selected set
SYMB	3	3	I		user defined field used to save symbol assignments (such as color)

Table 4 - *Line Types recorded in the LTYPE Field (listed by coverage name, LTYPE ending with "m" or "_" is for cartographic plotting purposes to cause a symbol to plot at a specific location on that line)*

di_geo
contact, approx. located
contact, certain
contact, concealed
contact, inferred
fault, concealed

fault, inferred
fault, inferred, queried
map boundary
normal fault, concealed
normal fault, inferred
normal fault, inferred _m
s.s. fault, l.l., inferred
water boundary

di_stx
dike
xsec

di_anno
none

Areas

Map units (polygons) are described in the polygon attribute table (table 5). The identities of the map units from compilation sources are recorded in the PTYPE field by map label (table 6). Note that ARC/INFO coverages cannot contain both point and polygon information, so only coverages with polygon information will have a polygon attribute table, and these coverages will not have a point attribute table. More complete descriptions of the various rock units can be found in the geologic report (geol.doc or geol.pdf) that accompanies the dataset.

Table 5 - *Content of the Polygon Attribute Table*

ITEM NAME	**WIDTH**	**OUTPUT**	**TYPE**	**N.DEC.**	**Description**
AREA	4	12	F	3	area of polygon in square meters
PERIMETER	4	12	F	3	length of perimeter in meters
<coverage>#	4	5			unique internal control number
<coverage>-ID	4	5	B		unique identification number
PTYPE	35	35	C		unit label
SEL	1	1	I		user defined field used to save a selected set
SYMB	3	3	I		user defined field used to save symbol assignments (such as color)

Table 6 - *Map Units*
(See geol.doc or geol.pdf for descriptions of units)

di_geo
QTc
Qa
Qfg
Qfs
Qls
Qoo
Qsh
Tba
Tbb
Tbc
Tdb
Tgo
Tgru
Tgsb
Tgvb
Tgvt
Tgww
Tid
Tpb
Tsr
Tt

Ttf
Tvs
Twfs
Txa
af
water

Points

Data gathered at a single locality (points) are described in the point attribute table (table 7). The identities of the points from compilation sources are recorded in the PTTYPE field by map label (table 8). Map units are described more fully in the text file geol.doc or geol.pdf. Note that ARC/INFO coverages cannot contain both point and polygon information, so only coverages with point information will have a point attribute table, and these coverages will not have a polygon attribute table.

Table 7 – *Content of the Point Attribute Table*

di_stx
Geologic attitudes

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC.
AREA	4	12	F	3
PERIMETER	4	12	F	3
DI_STX#	4	5	B	
DI_STX-ID	4	5	B	
PTTYPE	35	35	C	
DIP	3	3	I	
STRIKE	3	3	I	
SEL	1	1	I	
SYMB	3	3	I	

di_chem
Sample locality for chemical analysis with major and trace element data contained in database.

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC
AREA	4	12	F	3
PERIMETER	4	12	F	3
DI_SAMPLE#	4	5	B	-
DI_SAMPLE-ID	4	5	B	-
MAP_NO	4	7	B	-
SAMPNO	13	13	C	-
LATITUDE	8	13	F	5
LONGITUDE	8	13	F	5
LATITUDE1	8	10	F	3
LONGITUDE1	8	11	F	3
MAP_UNIT	7	7	C	-
ROCK_TYPE	14	14	C	-
SIO2	4	7	F	2
TIO2	4	6	F	2
AL2O3	4	7	F	2
FE2O3	4	7	F	2
FEO	7	7	C	-
MNO	4	6	F	2
MGO	4	6	F	2
CAO	4	7	F	2
NA2O	4	6	F	2
K2O	4	6	F	2
P2O5	4	6	F	2
LOI	4	6	F	2
TOTAL	8	8	F	2

R_SIO2	8	12	F	2
R_TIO2	8	12	F	2
R_AL2O3	8	12	F	2
R_FEO	8	12	F	2
R_MNO	8	12	F	2
R_MGO	8	12	F	2
R_CAO	8	12	F	2
R_NA2O	8	12	F	2
R_K2O	8	12	F	2
R_P2O5	8	12	F	2
PLAGIOCLASE	8	9	F	2
CLINOPYROX	12	12	C	-
ORTHOPYROX	12	12	C	-
OLIVINE	4	6	F	2
FE_TI_OXID	10	10	C	-
GROUNDMASS	8	10	F	2
NO_POINTS	8	14	F	2
TEXTURE	20	20	C	-
MG_	8	12	F	2
BA	4	4	B	-
RB	4	4	C	-
SR	4	4	B	-
Y	4	3	B	-
ZR	4	4	B	-
NB	7	7	C	-
NI	4	4	B	-
CU	4	4	B	-
ZN	4	4	B	-
CR	3	3	C	-

di_geochron
Sample location for radiometric age determination

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC.
AREA	4	12	F	3
PERIMETER	4	12	F	3
DI_GEOCHRON#	4	5	B	-
DI_GEOCHRON-ID	4	5	B	-
DATE	10	10	C	-

ACKNOWLEDGMENTS

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