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Oregon Department of Geology and Mineral Industries
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OPEN-FILE REPORT O-12-02

LIDAR-BASED SURFICIAL GEOLOGIC MAP AND DATABASE OF THE GREATER PORTLAND AREA, CLACKAMAS, COLUMBIA, MARION, MULTNOMAH, WASHINGTON, AND YAMHILL COUNTIES, OREGON, AND CLARK COUNTY, WASHINGTON

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2012

NOTICE

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. government. The results and conclusions of this report are necessarily based on limited geologic and geophysical data. At any given site in any map area, site-specific data could give results that differ from those shown in this report. **This report cannot replace site-specific investigations.** The hazards of an individual site should be assessed through geotechnical or engineering geology investigation by qualified practitioners.

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TABLE OF CONTENTS

LIST OF FIGURES

PLATE

INTRODUCTION

Since 2003 the Oregon Department of Geology and Mineral Industries (DOGAMI) has been working with the U.S. Geological Survey (USGS) to develop modern digital geologic maps of the greater Portland urban area in Oregon (Figure 1). The maps are needed to support earthquake and landslide hazard and risk studies for the region. The USGS has provided considerable funding to DOGAMI from the National Earthquake Hazard Reduction Program (NEHRP) through assistance awards 03HQAG0013, 08AG0140, and G11AC20312. USGS and DOGAMI geologists have been collaborating on the regional mapping, with USGS work focused west of the Tualatin Mountains, and DOGAMI work focused to the east. Quadrangles published by DOGAMI to date include an initial regional compilation (Madin, 2004), Oregon City quadrangle (Madin, 2009), Dixie Mountain quadrangle (Madin and Niewendorp, 2008), and Linnton quadrangle (Madin and others, 2008). Oregon quadrangles published by the USGS include the Camas quadrangle (Evarts and O'Connor, 2008); numerous other quadrangles are in preparation.

The eventual goal of the collaborative project is a published digital geologic map and database and an accompanying paper map covering 54 quadrangles in Oregon and Washington (Figure 1).

An additional part of the project is the development by DOGAMI of a detailed surficial geologic map and a three-dimensional geologic model describing important geotechnical parameters. This report is an interim product on the way to a final three-dimensional model and a regional geologic map.

We started with Oregon geologic data compilation (OGDC) release 5 (Ma and others, 2009), DOGAMI's statewide digital geologic database. We then used high-resolution (nominal 1-m cell size) lidar topographic data to revise the locations of previously mapped contacts and units and to digitize new contacts for surficial geologic units that were expressed in the new topographic imagery. We viewed elevation, hillshade, and slopeshade images, singly and in combination, at scales from 1:24,000 to 1:4,000, and supplemented these images with digital orthophotogra-

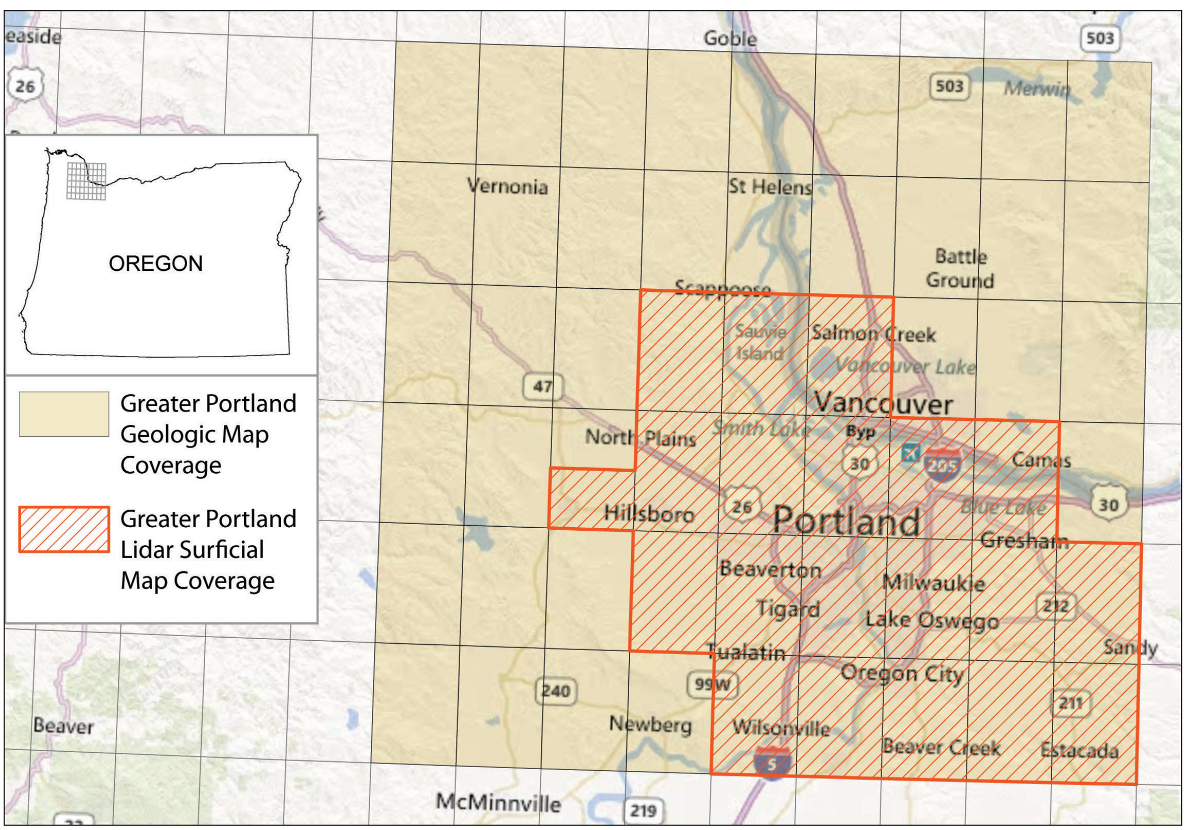

Figure 1. Location map showing bounds of the USGS-DOGAMI collaborative greater Portland urban area geologic map (tan area) and the area covered by this map and report (diagonal pattern).

phy, custom-made lidar-based contours, and driller's logs of approximately located water and geotechnical wells. Limited new field work was performed for this report, but the report incorporates field data collected by the authors over the last decade. Additional digital geologic data were drawn from Evarts and O'Connor (2008) and Simenstad and others (2011) (unit **Hfd**).

Our understanding of the regional geologic framework continues to evolve as regional mapping is completed (Figures 2 and 3). We are publishing the spatial database with sparse geologic unit descriptions in order to ensure that this detailed mapping is available in a timely manner. This publication includes a thematic map derived from the detailed work to provide the general product with a more easily understood description of the dynamic surficial processes at work in the area. We expect that the regional geologic map will provide a far more detailed and comprehensive description of units and discussion of structure, stratigraphic relationships, geochemistry, geochronology, and geologic history of the area.

The spatial database is provided in the form of a geodatabase for Esri ArcGIS® versions 9.3 and 10.0. Metadata are embedded in the geodatabase.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

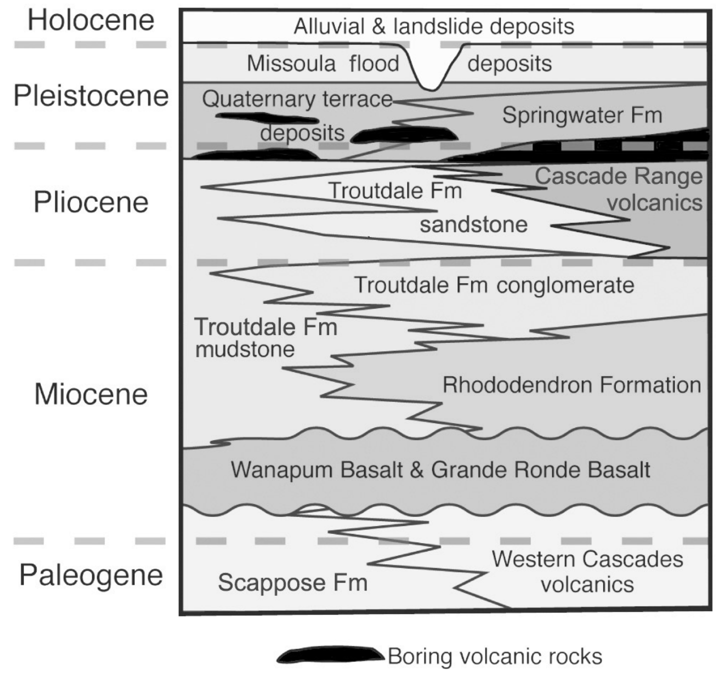

Figure 2. Schematic stratigraphic relationships in the Portland Basin (modified from Evarts and others, 2009). Fm is formation. The stratigraphic nomenclature in the figure differs from that of the original, reflecting both names preferred by the authors and the restriction of this map to the Oregon portion of the Portland Basin. Substitutions: Troutdale Formation sandstone for Troutdale Formation hyaloclastic sandstone member, Troutdale Formation mudstone for Sandy River mudstone, Cascade Range volcanics for low-potassium tholeiite flows, and Scappoose Formation for marine sedimentary rocks. Western Cascades volcanics are not discussed in this paper.

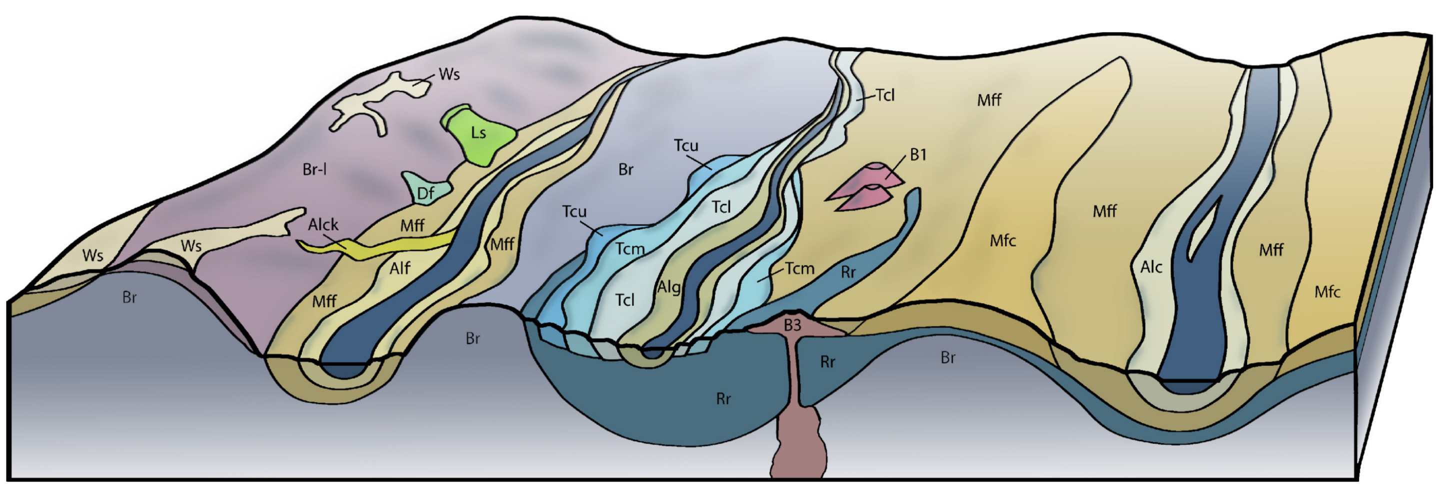

Figure 3. Generalized relationships of surficial geologic units in the Portland Basin. This block diagram shows the relative spatial and age relationships of selected geologic units on the thematic map plate map plate, as well as their depositional environments. The diagram is conceptual and not to scale; it does not represent any actual portion of the mapped area. See Thematic Map Unit and Geologic Unit Chart (p. 3) for unit names.

THEMATIC MAP UNIT AND GEOLOGIC UNIT CORRELATION

The thematic map derived from the detailed work described in this report combines 101 geologic units in the geodatabase into 23 process-oriented groups. The relationships of thematic map units to geologic units are shown below.

Names in **ALL CAPITAL** letters and preceded by a □ symbol are thematic map units; names in capital and lowercase letters are geologic units described in this text.

□ ARTIFICIAL FILL (Af)

- **Aaf** *Anthropocene* artificial fill

LANDSLIDES

□ LANDSLIDES (Ls)

- **Als** *Anthropocene* landslide deposits
- **Qls** *Quaternary* landslide deposits

□ MEGA-LANDSLIDES (Mls)

- **Qlww** *Pleistocene-Anthropocene* Wildwood landslide complex
- **Qld** *Pleistocene* Dutch Canyon landslide complex

DEBRIS FLOW FANS

□ DEBRIS FLOW FANS (Df)

- **Qf** *latest Pleistocene-Holocene* fans and flows

□ OLDER DEBRIS FANS (Of)

- **Qof** *Quaternary* older flow and fan deposits

ALLUVIUM

□ ALLUVIUM OF THE COLUMBIA RIVER (Alc)

- **Haco** *Holocene* alluvium of the Columbia River

□ COARSE ALLUVIUM (Alg)

- **Hacl** *Holocene* alluvium of the Clackamas River
- **Ham** *Holocene* alluvium of the Mollala-Pudding Rivers

□ FINE ALLUVIUM (Alf)

- **Htw** *Holocene* terraces of the Willamette River
- **Hat** *Holocene* alluvium of the Tualatin River
- **Haw** *Holocene* alluvium of the Willamette River

□ CREEK ALLUVIUM (Alck)

- **Hta** *Holocene* terraces of Abernethy Creek
- **Hal** *Holocene* alluvium of minor streams
- **Qal** *Quaternary* alluvium of minor streams
- **Qp** *Quaternary* pond deposits
- **Qtcx** *Quaternary* Clackamas River terraces, undifferentiated

□ VOLCANIC SEDIMENT OF THE SANDY RIVER (Vs)

- **Has** *Holocene* alluvium of the Sandy River
- **Hsd** *Holocene* Sandy volcanogenic delta
- **Qtsu** *Pleistocene* terraces of the Sandy River, undifferentiated

TERRACES OF THE CLACKAMAS RIVER

□ LOWEST CLACKAMAS TERRACE (Tcl)

- **Htce** *Holocene* Estacada terrace of the Clackamas River
- **Htcx** *Holocene* Estacada sub-terraces of the Clackamas River

□ MIDDLE CLACKAMAS TERRACE (Tcm)

- **Qtcm** *Pleistocene* middle Clackamas river terraces
- **Qtcmx** *Pleistocene* middle Clackamas River sub-terraces

□ UPPER CLACKAMAS TERRACE (Tcu)

- **Qtcu** *Quaternary* upper Clackamas river terraces

MISSOULA FLOOD DEPOSITS

□ FINE FLOOD DEPOSITS (Mff)

- **Qmf-c** *Pleistocene* colluvium on fine-grained Missoula flood deposits
- **Qmf** *Pleistocene* Missoula flood deposits, fine-grained

□ COARSE FLOOD DEPOSITS (Mfc)

- **Qmc** *Pleistocene* Missoula flood deposits, coarse-grained facies
- **Qmch** *Pleistocene* Missoula flood deposits, floodway deposits

WINDBLOWN SEDIMENT

□ WINDBLOWN SEDIMENT (Ws)

- **Hfd** *Holocene* floodplain dunes
- **Ql** *Pleistocene* loess
- **Qe** *Quaternary* eolian deposits
- **Qttm** *Quaternary* terrace deposits of the Tualatin Mountains

(table continued on next page)

(MAP UNIT AND GEOLOGIC UNIT CORRELATION, continued)

BORING VOLCANOES

YOUNGEST BORING VOLCANOES (B1)

Qbab *Pleistocene* basaltic andesite of Barnes Road
Qbrb *Pleistocene* basaltic andesite of Rocky Butte
Qbae-l *Pleistocene* basaltic andesite of Elk Point
Qbmt *Pleistocene* basalt of Mount Tabor
Qbkb *Pleistocene?* basalt of Kelly Butte

BORING HILLS VOLCANOES (B2)

Qbca *Pleistocene* basalt of Carver
Qvca *Pleistocene* volcanic sandstone and conglomerate
Qbr *Pleistocene* basalt of Borges Road
Qbrr-l *Pleistocene* basalt of Rodlun Road and loess
Qvrr *Pleistocene* tephra of Rodlun Road
Qbhs *Pleistocene* basalt of Hardscrabble
Qbw *Pleistocene* basalt of Winston Road
Qbs *Pleistocene* basalt of Mount Scott
Qbj *Pleistocene* basalt of Jenne
Qvj-l *Pleistocene* tephra of Jenne and loess
Qbp *Pleistocene* basalt of Powell Butte
Qba *Pleistocene* basaltic andesite of Anderson
QTbz *Pliocene-Pleistocene* basalt of Zion Hill
QTbt *Pliocene-Pleistocene* basalt of Tong Road

OLDER BORING VOLCANOES (B3)

Qbk-l *Pleistocene* basalt of Kaiser Road and loess
Qbd *Pleistocene* basalt of Douglass Ridge
Qbsy *Pleistocene* basalt of Mount Sylvania
Qbsy-l *Pleistocene* basalt of Mount Sylvania and loess
Qbo *Pleistocene* basaltic andesite of Outlook
Qvo *Pleistocene* Outlook tephra
Qbh *Pleistocene* basaltic andesite of Hunsinger
Qbbb *Pleistocene* basaltic andesite of Broughton Bluff
Qbm *Pleistocene* basalt of Mount Talbert
QTbb-l *Pliocene-Pleistocene* basaltic andesite of Bonny Slope and loess
QTb *Pliocene-Pleistocene* Undivided basalt and basaltic andesite

OLDEST BORING VOLCANOES (B4)

Tbr *Pliocene* basaltic andesite of Root Creek
Tvr *Pliocene* Root Creek tephra
Tbc *Pliocene* basalt of Canemah
Tvc *Pliocene* Canemah tephra
Tbf *Pliocene* basalt of Fallsview
Tvf *Pliocene* Fallsview tephra
Tbb *Pliocene* basaltic andesite of Beaver Creek
Tbh *Pliocene* Basaltic andesite of Highland Butte

ANCIENT RIVER ROCKS

ANCIENT RIVER ROCKS (Rr)

QTh *Miocene-Pleistocene* Hillsboro Formation
QTh-l *Miocene-Pleistocene* Hillsboro Formation and loess
QTs *Pliocene-Pleistocene* Springwater Formation
QTs-l *Pliocene-Pleistocene* Springwater Formation and loess
Ttm *Miocene-Pliocene?* Troutdale Formation, mudstone
Tts *Miocene-Pliocene?* Troutdale Formation, sandstone
Ttg *Miocene-Pliocene?* Troutdale Formation, conglomerate
Ttg-l *Miocene-Pleistocene* Troutdale Formation, conglomerate and loess

BEDROCK

BEDROCK (Br)

Tbcb *Miocene-Pleistocene?* basalt of Cook's Butte
Tr *Miocene-Pliocene* Rhododendron Formation
Tcr *Miocene* Columbia River Basalt, undifferentiated
Twfsg *Miocene* Wanapum Basalt, Basalt of Sentinel Gap
Twfsh *Miocene* Wanapum Basalt, Basalt of Sand Hollow
Twfg *Miocene* Wanapum Basalt, Basalt of Gingko
Tgsb *Miocene* Grande Ronde Basalt, Member of Sentinel Bluffs
Tgww *Miocene* Grande Ronde Basalt, Member of Winter Water
Tgu *Miocene* Grande Ronde Basalt, Member of Umtanum
Tgo *Miocene* Grande Ronde Basalt, Member of Ortley
Tgr *Miocene* Grande Ronde Basalt, undifferentiated
Ts *Miocene?* Scappoose Formation
Twh *Eocene* Basalt of Waverly Heights

BEDROCK AND LOESS (Br-l)

Tcr-l *Miocene* Columbia River Basalt, undifferentiated, and loess
Twfsh-l *Miocene* Wanapum Basalt, Basalt of Sand Hollow and loess
Twfg-l *Miocene* Wanapum Basalt, Basalt of Gingko and loess
Tgsb-l *Miocene* Grande Ronde Basalt, Member of Sentinel Bluffs and loess
Tgww-l *Miocene* Grande Ronde Basalt, Member of Winter Water and loess
Tgo-l *Miocene* Grande Ronde Basalt, Member of Ortley and loess
Tgwr-l *Miocene* Grande Ronde Basalt, Member of Wapshilla Ridge and loess
Twh-l *Eocene-Pleistocene* Basalt of Waverly Heights and loess

OVERVIEW OF GEOLOGIC UNITS

Please note that the stratigraphic order in this overview does not necessarily correlate with thematic map unit process-oriented groups.

QUATERNARY SURFICIAL DEPOSITS

Anthropocene surficial deposits

Aaf	artificial fill (Anthropocene*).
Als	recent or active landslide deposits (Anthropocene)

Holocene surficial units

Haco	alluvium of the Columbia River (Holocene)
Haw	alluvium of the Willamette River (Holocene)
Hacl	alluvium of the Clackamas River (Holocene)
Hat	alluvium of the Tualatin River (Holocene)
Ham	alluvium of the Mollala-Pudding Rivers (Holocene)
Hal	alluvium of lowland streams (Holocene)
Has	alluvium of the Sandy River (Holocene)
Hsd	Sandy River volcanogenic delta (Holocene)
Hfd	floodplain dune deposits (Holocene)
Htw	terrace deposits of the Willamette River (Holocene)
Hta	terraces of Abernethy Creek (Holocene)
Htce	Estacada terrace of the Clackamas River—(Holocene)
Htcx	subterraces of the Estacada terrace of the Clackamas River (Holocene)

Quaternary surficial deposits

Qf	debris flow fans (latest Pleistocene-Holocene)
Qlww	Wildwood landslide complex (Pleistocene-Anthropocene)
Qld	Dutch Canyon landslide complex (Pleistocene)
Qtcm	middle Clackamas River terrace (Pleistocene)
Qtcmx	subterraces of the middle terrace of the Clackamas River (Pleistocene)
Qtcu	upper Clackamas River terrace (Pleistocene)
Qtcx	Clackamas River terraces undifferentiated (Quaternary)
Qttm	terrace deposits of the Tualatin Mountains (Quaternary)
Qtsu	terrace deposits of the Sandy River (Quaternary)
Qal	alluvium of minor streams (Quaternary)
Qp	pond deposits (Quaternary)
Qls	landslide deposits (Quaternary)

Missoula flood deposits (Pleistocene)

Qmf-c	Missoula flood silt colluvium (Pleistocene)
Qmf	Missoula flood fine-grained deposits (Pleistocene)
Qmc	Missoula flood coarse-grained deposits (Pleistocene)
Qmch	Missoula flood channel deposits (Pleistocene)

Qof	older fan and colluvial deposits (Quaternary)
Ql	primary loess (Pleistocene)
Qe	eolian deposits (Quaternary)

NEOGENE VOLCANIC AND SEDIMENTARY ROCKS

Boring Volcanic Field

Qbab basaltic andesite of Barnes Road (Pleistocene)
Qbrb basaltic andesite of Rocky Butte (Pleistocene)
Qbae-l basaltic andesite of Elk Point and loess (Pleistocene)
Qbmt basalt of Mount Tabor (Pleistocene)
Qbkb basalt of Kelly Butte (Pleistocene?)
Qbca basalt of Carver (Pleistocene)
Qvca volcanic sandstone and conglomerate (Pleistocene)
Qbr basalt of Borges Road (Pleistocene)
Qbrr-l basalt of Rodlun Road and loess (Pleistocene)
Qvrr tephra of Rodlun Road (Pleistocene)
Qbhs basaltic andesite of Hardscrabble (Pleistocene)
Qbw basalt of Winston Road (Pleistocene)
Qbs basalt of Mount Scott (Pleistocene)
Qbj basalt of Jenne (Pleistocene)
Qvj-l tephra of Jenne and loess (Pleistocene)
Qbp basalt of Powell Butte (Pleistocene)
Qba basaltic andesite of Anderson (Pleistocene)
Qbk-l basalt of Kaiser Road and loess (Pleistocene)
Qbd basalt of Douglass Ridge (Pleistocene)
Qbsy basalt of Mount Sylvania (Pleistocene)
Qbsy-l basalt of Mount Sylvania and loess (Pleistocene)
Qbo basaltic andesite of Outlook (Pleistocene)
Qvo Outlook tephra (Pleistocene)
Qbh basaltic andesite of Hunsinger (Pleistocene)
Qbbb basaltic andesite of Broughton Bluff (Pleistocene)
Qbm basalt of Mount Talbert (Pleistocene)
QTbz basalt of Zion Hill (Pliocene-Pleistocene)
QTbt basalt of Tong Road (Pliocene-Pleistocene)
QTbb-l basaltic andesite of Bonny Slope and loess (Pliocene-Pleistocene)
QTb undifferentiated basalt and basaltic andesite (Pliocene-Pleistocene)
Tbr basaltic andesite of Root Creek (Pliocene)
Tvr Root Creek tephra (Pliocene)
Tbc basalt of Canemah (Pliocene)
Tvc Canemah tephra (Pliocene)
Tbf basaltic andesite of Fallsview (Pliocene)
Tvf Fallsview tephra (Pliocene)
Tbb basaltic andesite of Beaver Creek (Pliocene)
Tbh basaltic andesite of Highland Butte (Pliocene)
Tbcb basalt of Cooks Butte (Miocene-Pleistocene?)

QTh Hillsboro Formation (Miocene-Pleistocene)
QTh-l Hillsboro Formation and loess (Miocene-Pleistocene)
QTs Springwater Formation (Pliocene to Pleistocene)
QTs-l Springwater Formation and loess (Pliocene to Pleistocene)

(NEOGENE VOLCANIC AND SEDIMENTARY ROCKS, continued)

Troutdale Formation (Miocene-Pliocene)

Ttm Troutdale Formation mudstone and siltstone (Miocene-Pliocene?)
Tts Troutdale Formation volcaniclastic sandstone (Miocene-Pliocene?)
Ttg Troutdale Formation conglomerate (Miocene-Pliocene?)
Ttg-l Troutdale Formation conglomerate and loess (Miocene-Pleistocene?)

Tr Rhododendron Formation (Miocene-Pliocene)

Columbia River Basalt Group

Tcr undifferentiated Columbia River Basalt Group (middle Miocene)
Tcr-l undifferentiated Columbia River Basalt Group (middle Miocene)

Wanapum Basalt

Frenchman Springs Member

Twfsg Basalt of Sentinel Gap (middle Miocene)
Twfsh Basalt of Sand Hollow (middle Miocene)
Twfsh-l Basalt of Sand Hollow and loess (middle Miocene)
Twfg Basalt of Ginkgo (middle Miocene)
Twfg-l Basalt of Gingko and loess (middle Miocene)

Grande Ronde Basalt

Tgsb Member of Sentinel Bluffs (middle Miocene)
Tgsb-l Member of Sentinel Bluffs and loess (middle Miocene)
Tgww Member of Winter Water (middle Miocene)
Tgww-l Member of Winter Water and loess (middle Miocene)
Tgu Member of Umtanum (middle Miocene)
Tgo Member of Ortley (middle Miocene)
Tgo-l Member of Ortley and loess (middle Miocene)
Tgwr-l Member of Wapshilla Ridge and loess (middle Miocene)
Tgr undifferentiated Grande Ronde Basalt (middle Miocene)

Ts Scappoose Formation (Miocene?)
Twh Basalt of Waverly Heights and associated undifferentiated sedimentary rocks (Eocene)
Twh-l Basalt of Waverly Heights and loess (Eocene-Pleistocene)

EXPLANATION OF GEOLOGIC UNITS

UPPER CENOZOIC SURFICIAL DEPOSITS

Anthropocene surficial deposits

Aaf **artificial fill (Anthropocene*)**[*]— Man-made deposits of mixed gravel, sand, silt, clay, and other debris. Fill material ranges from completely uncontrolled mixtures of earth materials and woody debris like sawdust to modern engineered fill of crushed, graded rock. Most deposits are culvert fills, reservoir dams, and other roadway structures such as freeway and bridge embankments. Also mapped over large developed areas in the industrial and harbor areas along the lower Willamette River and the Columbia River just upstream of the Willamette. In these areas the entire surface has been modified to some extent, and little natural floodplain topography remains. Mapped from topographic features interpreted from 1-m bare-earth lidar DEM and aerial imagery. The boundaries of many bodies of fill are difficult to map, and in many areas fill may be only a meter or two thick, as foundation base for roads and buildings. Mapped only where boundaries could be accurately inferred; for example, many buildings on slopes have a prism of fill on the downslope side and a cut on the uphill side. In these cases it is not possible to accurately delineate the fill from the cut with the lidar topography. Age ranges from the mid-late 1800s to the present.

Als **recent or active landslide deposits (Anthropocene)**— Chaotically mixed, unconsolidated, and deformed masses of rock, soil, and colluvium that have moved downslope historically or are presently active. Notable active landslides include the Washington Park and Zoo landslides (Burns and Duplantis, 2011b), the Interstate Highway 205 (I-205) landslide (Burns, 2009b), and the Newell Creek Apartments and Beaver Lake landslides (Burns and Mickelson, 2010). Deposits occur throughout the map area as a result of numerous types of mass movement, including earthflow, slumping, translational slides, and rockfall. Age ranges from the mid-late 1800s to the present.

* Here defined as the period from 1792 to the present, as described in Wiley and others, 2011.

Detailed landslide inventories are being prepared for much of the study area as a separate study (Burns and others, in press). The inventory maps are based on methods and formats described by Burns and Madin (2009) and include far more detailed information about the geometry, age, and style of landslide deposits. To date, 22 landslide inventory maps and databases have been published for the Portland area (Figure 4). Should data in this publication differ from

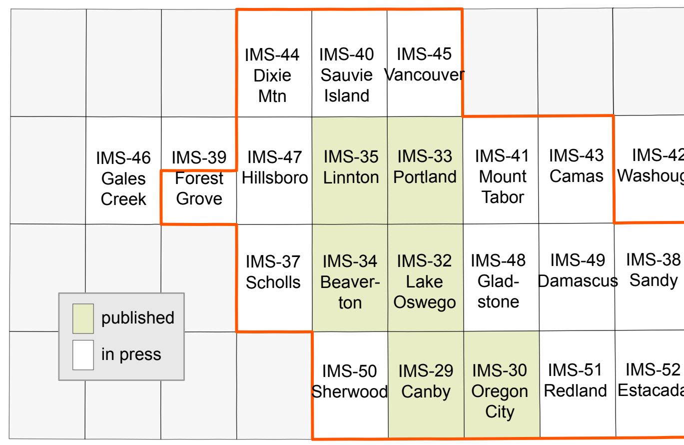

Figure 4. Published and in-press DOGAMI landslide inventory maps for the project area. The orange outline is the boundary of DOGAMI surficial map coverage for this project. IMS is Interpretive Map Series.

the inventory maps, the landslide inventories should be considered definitive.

Holocene surficial deposits

Haco **alluvium of the Columbia River (Holocene)**— Unconsolidated micaceous arkosic sand and silt, clay and minor disseminated organic material, peat, diatomite, and tephra deposited in the active channel and on the floodplain of the Columbia River. Missoula floods swept the area repeatedly from about 21,000 to 12,000 years ago (Waitt, 1985; Mullineaux and others, 1978; Benito and O'Connor, 2003; Madin and others, 2008), scouring out a channel graded to the sea level at the time, which was 112 m below modern sea level (Baker, 2002). After the floods ended, sea level rose rapidly. Sediment accumulated in the scoured Columbia River channel, filling it to the elevation of the modern floodplain. Numerous radiocarbon ages from the unit have been reported by Rapp (2005) and Evarts and O'Connor (2008) with the majority of calibrated ages less than 1,500 years for samples within 8 m of the surface. Ash from the eruption of Mount Mazama 7,700 years ago is commonly found in the unit at depths of about 14.5 m (Gates, 1994). The age of the deposits ranges from about 12,000 years to the present. The thickness of the unit is typically 60 to 70 m but, locally, can be up to 100 m (Madin, 1998; Gates, 1994).

Through much of the map area, unit **Haco** laps onto Missoula flood deposits (unit **Qmf**), and the boundary has little topographic expression. Because the Columbia River has been aggrading throughout the Holocene and part of the Anthropocene, we place the contact of unit **Haco** at the elevation of the highest recorded floods, approximately 10 m above sea level, which is very close to the elevation of the 500-year flood as modeled by the Federal Emergency Management Agency (FEMA, 2010).

Although much of the floodplain in the Portland urban area has been resurfaced by development, floodplain landforms like sloughs and lakes, and bar-and-scroll topography are locally preserved.

More detailed descriptions of the unit are given by Rapp (2005), Evarts and O'Connor (2008), Madin (1998), and Gates (1994).

Haw **alluvium of the Willamette River (Holocene)**— Mostly sand, silt, and clay with some gravel and minor organic material. Missoula floods swept the area repeatedly at the end of the Pleistocene, scouring out a channel graded to the sea level at the time, which was 112 m below modern sea level (Baker, 2002). As sea level rose rapidly during the last 12,000 years, sediment accumulated rapidly, filling the ancient channel near downtown Portland with up to 50 m of alluvium (Madin, 1998). Upstream at Oregon City, the river runs over bedrock at Willamette Falls, and bedrock is exposed in the channel upstream almost to Canby. In the reach from the Sellwood Bridge to the Columbia River, the Willamette River floodplain is incised into the older Missoula flood deposits; abandoned meander scars at Mocks Bottom, Oaks Bottom, University Park, and Doane Lake are the result of geologically recent channel migration. The scars at Oaks Bottom and Mocks Bottom end in bluffs that are prone to shallow landslides. The fact that these slopes remain uniformly steep despite frequent landslides suggests that the Willamette River recently occupied these old channels. Just downstream from the Sellwood Bridge, Ross Island is an anomalously large deposit of gravel, unique along the lower Willamette River. It covers 125 ha and extends to a depth of 40 m below sea level. The island has been extensively mined for aggregate. Upstream from the Sellwood bridge, the Willamette River is incised into bedrock, with little in the way of a floodplain, and alluvium is largely restricted to the channel.

Exposures are rare, but two excavations in the south waterfront district exposed several meters of Willamette alluvium beneath 2-3 m of hydraulic fill. The alluvium is micaceous, clayey, silty sand, in beds typically 10 to 20 cm thick. Most beds were capped with a dark organic and clay rich layer. The beds were blue, greenish blue, brown, or gray-brown in the lower exposures and tan or yellowish brown in the upper layers. Some well-developed brick red paleosols were observed.

The age of unit **Haw** extends from the end of the Missoula floods to the present. A ^{14}C age of 3,512 ± 36 ybp was obtained (Jim O'Connor, USGS, personal commun., 2006) on a sample of organic material from an exposure of **Haw** in the foundation excavation for the Oregon Health & Science University (OHSU) tram. The sample was collected from an elevation of 4-5 m above sea level and approximately 2-3 m below the historical floodplain surface.

Hacl **alluvium of the Clackamas River (Holocene)**— Predominantly well-rounded pebble to cobble gravel and minor sand and silt deposited in the channel and on the floodplain of the Clackamas River. Much of the unit takes the form of bars and islands. Along much of the river, alluvium in the active channel is thin or absent, and the river flows directly on bedrock. Clasts are mainly of volcanic origin, including basalt, andesite, and dacite from the nearby Cascade Range.

The modern Clackamas River floodplain is incised into older Holocene and Quaternary terraces and into bedrock, and cliff exposures of bedrock are common.

The modern floodplain is incised 12 to 30 m into the lower Clackamas River terrace, which has been dated at about 10,000 years, so the alluvium is probably only a few hundreds to a few thousands of years old.

Hat **alluvium of the Tualatin River (Holocene)**— Sand, silt, clay organic material, and minor gravel deposited in the channel and on the floodplain of the Tualatin River. The entire course of the Tualatin River in the map area was inundated by the Missoula floods, and in the intervening approximately 12,000 years the river has re-established a meandering course across the broad, flat Tualatin Valley. The floodplain is almost entirely incised into fine-grained Missoula flood deposits with the exception of a few locations where it cuts across Columbia River Basalt or coarse Missoula flood deposits. The age of the alluvium is Holocene. The thickness is very difficult to determine, because most boring logs do not clearly discriminate between fine-grained alluvium and the underlying fine-grained Missoula flood deposits.

Ham **alluvium of the Mollala-Pudding Rivers (Holocene)**— Gravel, sand, silt, and clay deposited on the floodplain of the Mollala River near its confluence with the Willamette River. Cobbles are predominantly andesite, dacite, and basaltic andesite clasts derived from the Cascade Range. Sand and silt are a combination of volcaniclastic material and micaceous quartz silt from the Pudding River, which largely drains areas of Missoula flood deposits. The floodplain is incised into Missoula flood deposits, making the unit Holocene in age. Boreholes in the unit typically record 18 to 24 m of sand and gravel overlying siltstone and claystone. It is difficult to determine how much of this thickness is unit **Ham** and how much is the coarse Missoula flood deposits that the unit incised.

Hal **alluvium of lowland streams (Holocene)**— Sand, silt, gravel, and clay deposited in the channels and on the floodplains of minor streams. **Hal** is mapped from lidar imagery and defined by areas along streams where the valley floor is mostly flat perpendicular to the stream for at least 5 to 10 m, suggesting that the landform is being shaped by stream processes rather than by slope processes. Streams below the approximately 130-m nominal Missoula floods high-water mark probably had their courses re-arranged during the flood through scour or burial. By definition, alluvium in these streams is younger than the floods and therefore Holocene and contains a large component of Missoula flood sediment. Thickness is poorly known and varies widely.

Has **alluvium of the Sandy River (Holocene)**— Sand, silt, and gravel deposited in the channel and on the floodplain of the Sandy River. Multiple volcanic eruptions of Mount Hood between 200 and approximately 1,500 years ago and again between 15,000 and 30,000 years ago (Scott and others, 1997) produced numerous lahars in the Sandy drainage, periodically choking the system with volcaniclastic debris. The alluvium of the Sandy River is therefore mostly composed of reworked material from these recent eruptions and is a few hundred to a few thousand years old. Detailed descriptions of the Sandy River alluvial and terrace system are given by Pierson and others (2009, 2011), Rapp (2005), and Evarts and O'Connor (2008).

Hsd **Sandy River volcanogenic delta (Holocene)**— Volcaniclastic sand and gravel complexly interbedded with Columbia River alluvium (**Haco**) that form a delta in the Columbia River at the mouth of the Sandy River. The volcaniclastic material consists of andesite and dacite lithic fragments; pumice; and feldspar, hornblende, and pyroxene crystals. The material is largely derived from the Old Maid Flat and Timberline eruptive periods, approximately 200 and 1,400 to 1,800 years ago, respectively (Rapp, 2005). The delta covers approximately 10 km^2 and is approximately 9 to 10 m thick. Detailed descriptions of the stratigraphy, mineralogy, and geochemistry of the unit are provided by Rapp (2005).

Hfd **floodplain dune deposits (Holocene)**— Sand dunes on the Columbia River floodplain at Sauvie Island (Simenstad and others, 2011). Defined by topography and to an extent by elevation, the dunes include an area of irregular hummocky terrain that is largely above the nominal 10- to 12-m maximum flood elevation and extends as high as 23 m. A second area of dune ridges parallel to the flow of the river is almost entirely below 12-m elevation and so must be periodically inundated by floods. Logs of wells drilled in the hummocky dune deposits describe brown sand 7 to 15 m thick over brown silt or sandy silt. This may represent the sandy dune deposits on top of Columbia River alluvium.

Htw **terrace deposits of the Willamette River (Holocene)**— Fluvial terraces that flank the Willamette River between the mouth of the Mollala River and the mouth of the Clackamas River. The terraces are 9 to 13 m above the modern river above Willamette Falls and 12 to 19 m above the modern river below the falls. No data are available about the lithology or thickness of the terrace deposits. Unit **Htw** is incised into Missoula flood deposits and is therefore Holocene in age.

Hta **terraces of Abernethy Creek (Holocene)**— Silt and sand (?) deposits capping terraces inset in Missoula flood deposits along Abernethy Creek near Oregon City. The terraces occur at three distinct elevations with respect to the modern floodplain of Abernethy Creek: at 10 m, 15 m, and 20 m. There are no field data to indicate the nature or thickness of any deposits on the terraces; they are defined exclusively on the basis of geomorphology interpreted from lidar imagery. Limited well log data suggest that the deposits are silt, sand, and clay. The terraces must be latest Holocene in age, as they postdate the Missoula flood deposits.

Htce **Estacada terrace of the Clackamas River (Holocene)**— Cut-and-fill terrace of cobble gravel that is well developed on both sides of the Clackamas River from the mouth to Estacada in the southeast corner of the map. This terrace is the lowest and youngest of three well-developed broad terraces and has been dated at approximately 10 ka by Wampler (2004). The terrace is typically 2 to 3 km wide and is approximately 18 to 24 m above the modern river. The average thickness of terrace gravel encountered in water wells is 13 m. A detailed discussion of the origin of the terrace is provided by Wampler (2004). Mapped as Estacada Formation by Trimble (1963).

Htcx **subterraces of the Estacada terrace of the Clackamas River (Holocene)**— Numerous small gravel terraces that occur between the **Htce** surface and the floodplain of the Clackamas River. Up to six stepped terraces occur in this position; Wampler (2004) ascribed a well-preserved sequence near Estacada to Holocene climate cycles. With high-resolution lidar topography this study maps 148 terrace remnants below the **Htce** surface with inconsistent patterns of relative elevation. These intermediate terraces simply may be remnants of a rapidly downcutting and laterally migrating river. Limited water well data indicate that the thickness of gravel on these terraces ranges from 5 to 20 m and averages 8 m.

Quaternary surficial deposits

Qf **debris flow fans (latest Pleistocene-Holocene)**— Mixed sand, silt, clay, gravel, and soil deposited by debris flows or earth flows, typically where minor streams and gullies enter larger valleys. These deposits are mapped entirely on the basis of subtle topography revealed by the lidar imagery. The deposits generally take one of two forms: fan-shaped deposits at the mouths of small gullies that may be separated from the area where the flow originated by some distance; or lobes on slopes that are more clearly connected to an arcuate hollow upslope where the flow originated. Hollows at the heads of many drainages are suggestive of debris flow initiation zones but are mapped as such only where clearly connected to a fan deposit. Earth and debris flows typically occur during periods of high rainfall and can be triggered by human activities that concentrate runoff on slopes. These flows can move rapidly down slopes and channels and may be life threatening. Flows and fans occur in drainages underlain by the full range of surficial materials in the area but are particularly common in drainages originating in units **Qmf** and **Ql** or in bedrock and loess units. The 1,570 mapped fans range in size from 30 m^2 to 10 ha and average 4,300 m^2 in area.

A detailed landslide inventory is being prepared for much of the study area as a separate study; see unit **Als** for more information.

Qlww **Wildwood landslide complex (Pleistocene-Anthropocene)**— Large complex of bedrock and surficial landslides that occupy the embayment in the northeast flank of the Tualatin Mountains between Rocky Point Road and Logie Trail Road. The landslide complex includes translational block slides, slumps, and earthflows and probably consists of dozens of independent landslides. Several sag ponds occupy depressions on the landslide surface. The complex covers more than 7 km^2. The primary headscarp extends for almost 6 km and is typically 50 to 100 m high. Close to the headscarp the landslide complex consists of large intact blocks separated by scarps, while the lower reaches flow down canyons as more homogenous masses. Geotechnical investigations were conducted on the landslide when the area was considered for a regional landfill (Kennedy, 1975). Deep borings revealed failure planes on siltstone layers within the Scappoose Formation at depths of 50 to 80 m beneath the landslide surface. No primary loess (**Ql**) was mapped within the boundaries of the Wildwood landslide complex, suggesting that most of the landslide has moved during the Holocene. However, given the size of the landslide, the amount of mass deficit represented by the huge headscarp, and the relatively deep incision of the mass of the landslide, it is likely that the complex is a long-lived feature that may extend back to the middle Pleistocene.

Depositional contacts between Columbia River Basalt flows and between Columbia River Basalt and Scappoose Formation occur in numerous blocks within the complex and are typically fairly flat lying. It is interesting to note that the basalt strata encountered in the blocks were invariably from the bottom of the section exposed in the head scarp, suggesting that there was little vertical displacement involved in the formation of the head scarp, which may have developed by calving successive translational blocks that then broke up and eroded away.

During the last glacial period the Columbia River was graded to sea levels much lower than today. This meant that at the foot of the Wildwood Complex there would have been a canyon as much as 50 to 100 m deeper than today; in fact, latest Pleistocene Missoula flood deposits are typically 50 to 60 m thick at the foot of the slide. The presence of the thick mass of Missoula deposits and Holocene alluvium on the Columbia River floodplain at the toe of the landslide may have a stabilizing effect. However, scour, elevated pore pressures, and vibration during the floods may have had the opposite effect.

Qld **Dutch Canyon landslide complex (Pleistocene)**—Large complex of bedrock and surficial landslides that occupy the embayment in the northeast flank of the Tualatin Mountains between Rocky Point Road and Scappoose Creek. The landslide complex includes translational block slides, slumps, and earthflows and probably consists of dozens of independent landslides. The complex covers approximately 25 km^2. The primary headscarp extends for over 8 km and is typically 100 to 200 m high. There is no information available about the thickness of the landslide deposits or the depth of the main failure plane, but either weak strata in the Scappoose Formation or the Columbia River Basalt–Scappoose Formation contact are obvious candidates. A spectacular exposure of a minor failure plane shows Scappoose Formation being thrust over Columbia River Basalt. In contrast to the smaller, more homogenous Wildwood Complex, the Dutch Canyon Complex consists of large areas of dissected blocky terrain that appear to be relatively stable interspersed with bedrock landslide complexes ranging in size from 5 ha to over 400 ha in area. Many of the stable regions are capped with thick, smooth primary loess deposits, suggesting stability for tens of thousands of years. From the presence of undeformed loess at one extreme and buckled pavement at the toe of one of the active slides within the complex, the age range is Pleistocene to recent. As with the Wildwood Complex, the size of the slide, the amount of mass deficit represented by the huge headscarp, and the relatively deep incision of the mass of the landslide suggest that the Dutch Canyon Complex is a long-lived feature that may extend back to the middle Pleistocene.

Depositional contacts between Columbia River Basalt flows and between Columbia River Basalt and Scappoose Formation were observed in numerous blocks within the Dutch Canyon Complex and, typically, are fairly flat lying. As with the Wildwood Complex, the basalt stratigraphy was invariably from the bottom of the section exposed in the head scarp, suggesting that there was little vertical displacement involved in the formation of the head scarp and that it may have developed by calving successive slices of translational blocks, which then broke up and eroded away.

During the last glacial period the Columbia River was graded to sea levels much lower than today. This means that at the foot of the Dutch Canyon Complex there would have been a canyon as much as 50 to 100 m deeper than today and, in fact, latest Pleistocene Missoula flood deposits are typically 50 to 60 m thick at the foot of the slide. The presence of the thick mass of Missoula deposits and Holocene alluvium on the Columbia floodplain at the toe of the landslide may have a stabilizing effect. However, scour, elevated pore pressures, and vibration during the floods may have had the opposite effect.

Qtcm **middle Clackamas River terrace (Pleistocene)**— Cut-and-fill terrace of cobble gravel that is well developed on both sides of the Clackamas River from a few kilometers upstream of Carver to Estacada. This terrace is middle in elevation and age of three well-developed broad terraces and has been dated at approximately 22.8 ka by Wampler (2004). The terrace is typically 3–5 km wide and is approximately 36 m above the modern river near Estacada and approximately 47 m above the river near Carver. The average thickness of terrace gravel encountered in water wells is 15 m. A detailed discussion of the origin of the terrace is provided by Wampler (2004). Mapped in part as Gresham Formation by Trimble (1963).

Qtcmx **subterraces of the middle terrace of the Clackamas River (Pleistocene)**— Numerous small gravel terraces that occur at elevations between the **Qtcm** terrace surface and the **Htce** surface. As with unit **Htcx**, numerous terrace remnants were mapped from lidar imagery, but a consistent pattern of elevation could not be determined. This similarity suggests continuity between the terrace polygons. These intermediate terraces may simply be remnants of a rapidly downcutting and laterally migrating river. No thickness data are available.

Qtcu **upper Clackamas River terrace (Pleistocene)**— Cut-and-fill terrace of cobble gravel that is well developed on the south side of the Clackamas River from about 1.5 km upstream of Carver to Estacada. This terrace is the highest in elevation and oldest of three well-developed broad terraces, and the age is probably Pleistocene, as the terrace is incised below the basalt of Douglass Ridge (**Qbd**). The terrace is typically 2 to 4 km wide, but the lack of preservation north of the river makes this a minimum estimate. The terrace is approximately 70 to 90 m above the modern river, and the average thickness of terrace gravel encountered in water wells is 15 m. Mapped in part as Gresham Formation by Trimble (1963).

Qtcx **Clackamas River terraces, undifferentiated (Quaternary)**— Numerous small gravel terrace remnants that occur on tributaries to the Clackamas River and that cannot be correlated to one of the larger terraces.

Qttm **terrace deposits of the Tualatin Mountains (Quaternary)**— Silt and sand (?) deposits that form flat surfaces flanking the upper reaches of minor streams in the Tualatin Mountains. The terraces appear to be remnants of a gently sloping floodplain and/or loess deposition surface that originated in a late Pleistocene landscape of much more gentle topography. This may represent a change from late Pleistocene peri-glacial conditions with rapid accumulation of loess to Holocene conditions with a reduction in loess deposition and re-arrangement of the lower reaches of the drainages by repeated Missoula floods. There are no field data to indicate the nature or thickness of any deposits on the terraces; they are defined exclusively on the basis of geomorphology interpreted from the lidar imagery. The terraces must be late Pleistocene to Holocene in age, as they postdate the Missoula flood deposits, and have been incised as much as 30 m by modern streams.

Qtsu **terrace deposits of the Sandy River (Quaternary)**— Volcaniclastic sand, silt, and gravel forming a series of terraces along the Sandy River. Multiple volcanic eruptions of Mount Hood between approximately 1,500 and 200 years ago and again between 30,000 and 15,000 years ago (Scott and others, 1997) produced numerous lahars in the Sandy drainage that periodically choked the system with volcaniclastic debris. Terraces were developed and then eroded repeatedly, and terrace surfaces and deposits are preserved at a variety of elevations above the modern channel. Detailed descriptions of the Sandy River terraces and terrace system are given by Pierson and others (2009, 2011).

Qal **Quaternary alluvium of minor streams (Quaternary)**— Sand, silt, gravel, and clay deposited in channels and on floodplains of minor streams. **Qal** is mapped from lidar imagery and defined by areas along streams where the valley floor is mostly flat perpendicular to the stream for at least 5 to 10 m, suggesting that the landform is being shaped by stream processes rather than by slope processes.

Streams above the nominal Missoula flood high-water mark did not have their courses re-arranged during the flooding. By definition, the alluvium in these streams does not contain significant Missoula flood sediment; the deposits may be older than the period of the floods and are therefore assigned a Quaternary age. Thickness is poorly known and varies widely.

Qp **pond deposits (Quaternary)**— Silt, sand, clay, and organic detritus accumulated in naturally occurring ponds. Deposits were not observed or sampled. Age is unknown but likely Holocene, as older natural depressions would have filled with loess during the late Pleistocene. All occurrences in the quadrangle are sag ponds on the surfaces of large landslides.

Qls **landslide deposits (Quaternary)**— Chaotically mixed and deformed masses of soil, sediment, and rock that have moved downslope in one or more landslide events. Landslide deposits are mapped almost exclusively by observation of typical geomorphic features (head and lateral scarps, irregular topography, bulging or lobate toes) in lidar imagery. Almost 3,000 landslide deposits are mapped in the study area. The deposits include small shallow slumps, earthflows, large slumps, translational slides, and complex slides involving bedrock. Almost half of the mapped deposits are less than 1 ha in size and are probably shallow landslides. These occur throughout the area but are particularly common in the loess-mantled bedrock slopes of the Tualatin Mountains. Of the mapped landslides 216 are 100 ha or larger and are deep-seated bedrock landslides. Large bedrock landslides are also found throughout the area but are particularly common in three geologic settings. In the Tualatin Mountains the failure planes are typically paleosol or sediment interbeds between Columbia River Basalt flows, or the contact between Columbia River Basalt and the underlying Scappoose Formation. In the Oregon City area the contact between Boring lava flows and the underlying Troutdale Formation mudstone is highly prone to landslides. In the Eagle Creek area the Troutdale Formation mudstone causes numerous large landslides. The surficial landslides range from a few tens to a few thousands of square meters and, rarely, exceed 5 ha. The deposits are typically less than 5 to 10 m thick, as inferred from the height of the head scarps.

A detailed landslide inventory is being prepared for much of the study area as a separate study; see unit **Als** for more information.

Missoula flood deposits

Missoula flood deposits (Pleistocene)— Silt, sand, and gravel, deposited by floods caused by the repeated failure of the glacial ice dam that impounded glacial Lake Missoula (Bretz and others, 1956; Allison, 1935; Waitt, 1985; Allen and others, 1986, Benito and O'Connor 2003). Dramatic scour features and giant bars throughout the map area emphasize the extent to which the Quaternary geomorphology of the region has been shaped by the floods. The age of the flood deposits has been estimated to be between 19,000 to 13,000 years B.P. (Mullineaux and others, 1978; Waitt, 1985; Benito and O'Connor, 2003) on the basis of tephra and ^{14}C ages from outside the map area. Recent optically stimulated luminescence (OSL) age determinations on flood silt samples from an exposure on U.S. Highway 26 in the Tualatin Valley were reported by Ray Wells and Shannon Mahan of the USGS (personal commun., 2007) as follows:

Sample	Location	Layer	Age, ka
RW05-0913-16:45	Hwy 26 (bottom)	Rhythmite 7	21.6 ± 2.14
RW05-0913-17:05	Hwy 26 (bottom)	Rhythmite 12	19.7 ± 2.51
RW05-0913-17:20	Hwy 26 (top)	Rhythmite 19	16.1 ± 1.28

Although these OSL ages have not been correlated to any tephra or ^{14}C ages, they are internally consistent and fit the ages established outside of the area fairly well. Benito and O'Connor (2003) considered that most of the floods postdate 19 ka and that as many as 13 may have occurred after 13 ka. Considering the OSL dates reported here and the likelihood of numerous floods after 13 ka, we assume the age range for Missoula flood deposits in the Portland Basin to be from approximately 21 ka to 12 ka.

We mapped three distinct facies of Missoula flood deposits: fine-grained facies, coarse-grained facies, and channel facies.

Qmf-c Missoula flood silt colluvium (Pleistocene)— Colluvium composed of micaceous silt and sand derived from Missoula flood deposits. This unit, along with the Missoula flood deposits, appears to be particularly susceptible to shallow landslides and debris flows. Differentiated from Missoula deposits by a typically abrupt change in geomorphology from relatively smooth flat surfaces to very irregular slopes and drainage networks with characteristically simple, steep-walled and steep-headed gullies. Mapped only in the Tualatin Valley.

Qmf Missoula flood fine-grained deposits (Pleistocene)— Silt, sand, and minor gravel deposited by slow-moving phases of Missoula floods. Micaceous quartzo-feldspathic silt, fine sandy silt, and fine to coarse sand typically deposited in fining-upward beds 10 to 40 cm thick, each inferred to represent a single flood event. The beds, called rhythmites, are commonly capped by zones of brown clay and iron oxide mottling 5 to 30 cm thick that are interpreted to be paleosols. The beds range from massive to laminated and in some instances are ripple cross-bedded. Extensive networks of liquefaction dikes up to 20 cm wide cut some exposures. Rare exotic (granitoid and metamorphic) glacial erratics up to 1 m across are found in the fine-grained facies at elevations up to 115 m.

Fine-grained flood deposits cover most of the floor of the Tualatin Valley, most of the Northern Willamette Valley, and extensive areas in the Portland Basin. Deposits in the Tualatin Valley are commonly 20 to 25 m thick and range up to 35 m thick. In the Portland Basin, deposits are typically 20 m thick and range up to 27 m.

Qmc Missoula flood coarse-grained deposits (Pleistocene)— Pebble to boulder gravel, some with silt and coarse sand matrix. The gravel is poorly sorted and subrounded to well rounded and ranges from openwork gravel to gravel with considerable fine-grained matrix material. Clasts are largely basalt, but other lithologies may dominate downstream from bedrock exposures. Clasts as large as several meters in diameter are common in the eastern part of the Portland Basin near the Columbia River Gorge. The largest body of coarse flood deposits is a huge fan that extends from the mouth of the Sandy River almost to the Willamette River, covering 123 km^2 in Oregon. The fan is composed of a series of overlapping sheets of gravel tens of meters thick, and the edges of the individual sheets are clearly visible in the lidar imagery. Smaller fans occur at the city of Durham, where floodwaters flowing west dumped gravel scoured from Oswego Lake. A larger fan occurs at Canby, where waters flowing into the Willamette Valley dumped gravel scoured from the narrow reach of the Willamette River between Oregon City and Canby. The coarse flood sediments are up to 60 m thick in the map area.

Qmch **Missoula flood channel deposits (Pleistocene)**— Complexly interlayered and variable silt, sand, and gravel deposited in major floodways and along the northeast foot of the Tualatin Mountains. Floodway channel deposits are typically 5 to 15 m thick. Along the northeast foot of the Tualatin Mountains, channel deposits 30 to 55 m thick are banked against the slope and form moderately sloping benches.

Qof **older fan and colluvial deposits (Quaternary)**— Sand, silt, clay, and minor gravel deposited on moderate slopes by debris flows, colluvial processes, and minor streams. Mapped on the basis of distinctive topography, with generally sharp upslope contacts against steeper bedrock slopes, and lobate lower contacts. In many areas individual fans coalesce. Older fans are typically incised by modern drainages, indicating that they are no longer active depositional surfaces. Many of the larger older fan deposits are built out onto either the **Qtcm** surface or the **Htce** surface, suggesting that these may have been active fans at the time the associated terrace surfaces were active. Assigned a Quaternary age on the basis of the association with the 10-ka **Htce** surface and the 22.8-ka **Qtcm** surface. Limited water well data indicate that the thickness of **Qof** is 5 to 8 m but is likely to be highly variable.

Ql **primary loess (Pleistocene)**— Micaceous eolian silt derived from glacial outwash transported down the Columbia River during Pleistocene glaciations. Primarily quartz and feldspar with minor mica. Typically tan, but color ranges from nearly white to brick red. Locally, the loess is indurated and jointed, and weathers to angular colluvium when dry. When saturated, the loess is notoriously weak and prone to landslides and debris flows. Where deeply weathered, the loess is mottled red-brown-orange and typically develops spherical accumulations of iron oxide 1 to 3 mm in diameter (pisolites) that locally weather out and occur as a lag on the ground surface.

Lentz (1977, 1981) suggested that loess was deposited between 34 ka and 700 ka B.P. from correlations of paleosols to glacial advances and stratigraphic relations with Boring Lava and catastrophic flood deposits. Recent OSL dating of loess samples by the USGS (Ray Wells and Shannon Mahan, personal commun., 2007) resulted in the following ages:

Sample	Location	Depth	Age, ka	Age, ka
RW05-0913-12:15	Beaverton/ Portland Hills	—	45.7 ± 5.05	47.0 ± 6.29
RW05-0913-14:00	Skyline Road/ Cornelius Pass	2 m below surface	—	38.7 ± 3.01
RW05-0913-14:30	Skyline Road/ Cornelius Pass	5.3 m below surface	—	>79

The Beaverton/Portland Hills sample is from the Linnton quadrangle (NAD 83 UTM coordinates 516,334 m E and 5,046,073 m N), and the two Skyline Road/Cornelius Pass Road samples are within the adjacent Dixie Mountain quadrangle.

Although loess at some point blanketed nearly all of the Tualatin Mountains to a depth of tens of meters, the loess is mapped only as a primary, undisturbed deposit on relatively low gradient slopes and capping ridges. In the conceptual model used for the surficial map, it was assumed that during the most recent glaciation, loess accumulation was rapid, and that a thick layer draped most of the topography, producing a smoothed landscape of moderate relief. When loess accumulation ceased, streams began to incise into the smooth surface and mass transport began to move loess as colluvium on steepening slopes. Loess as a primary deposit is therefore restricted to upper slopes generally less than about 10 degrees. As mapped, this deposit also generally coincides with a markedly smooth and consistent appearance to the land surface as seen in lidar imagery. Loess on slopes is mapped as bedrock and loess, with units for each of the underlying bedrock units. The thickness of loess encountered in wells in the Tualatin Mountains is variable but generally ranges from 10 to 30 m.

Another large body of loess occurs between Gresham and Boring. Originally mapped by Madin (1994) as fine-grained facies of the Springwater Formation, it was recognized as loess by Evarts and O'Connor (2008). This deeply weathered deposit was mined for brick clay at Hogan, and water well logs indicate that the deposit is typically 20 m thick.

Qe **eolian deposits (Quaternary)**— Brown sand and silt deposited by wind. Rare exposures show dipping laminae and some cross-bedding. Includes sheets of sand on the north faces of hills south of Gresham and elongate dune features on Powell Butte. Estimated thickness is 3 to 8 m.

NEOGENE VOLCANIC AND SEDIMENTARY ROCKS

Boring Volcanic Field

Numerous small volcanoes and associated basalt flows in the Portland area have been informally known as the Boring lava, named for exposures near the town of Boring, Oregon (Treasher, 1942). As increased geochemical and geochronological data for these volcanic rocks became available, Fleck and others (2002) proposed that they be considered part of the Boring Volcanic Field. As used in this study, the Boring Volcanic Field comprises all of the late Pliocene to Pleistocene mafic volcanoes and lava flows in the greater Portland basin. Throughout the greater Portland area these rocks can be distinguished on the basis of lithology, geochemistry, age, and spatial distribution into the units described below, which are ordered according to DOGAMI and the USGS have developed an extensive body of geochemical data for the Boring volcanoes. The data are part of the planned regional geologic map and are not included here.

Qbab **basaltic andesite of Barnes Road (Pleistocene)**— Massive gray basalt flow or flows. The unit is well exposed in road cuts along Barnes Road and at the intersection of Highway 26 and Highway 217, and a distinct geomorphic flow front is evident along the southwest edge of the unit at Cedar Hills. The unit covers approximately 395 ha. The exposed rock is relatively fresh, medium grained, and diktytaxitic and has common 1-2 mm iddingsitized olivine phenocrysts. The lava is typically massive to crudely columnar jointed, with some breccia zones and voids present between more massive parts. The vent for the flow is inferred to be a roughly circular depression 200 m in diameter and 7 m deep, located just north of Barnes Road and just east of Catlin Gabel High School, and occurs at the highest and easternmost part of the flows. Well logs indicate that the thickness ranges from 30 m to 110 m near the vent and averages 70 m. The estimated volume is approximately 0.28 km^3. Russell Evarts and Robert Fleck (personal commun., 2007) determined an $^{40}Ar/^{39}Ar$ radiometric age of 105 ± 6 ka for the flow, making it among the youngest flows in the area. All measured outcrops have normal magnetic polarity.

Qbrb **basaltic andesite of Rocky Butte (Pleistocene)**— Massive gray, diktytaxitic olivine bearing basaltic andesite. The Rocky Butte volcano, a single thick plug of lava, has been severely eroded by the Missoula floods, obscuring its original shape. A boring on the north side of the butte encountered the base of the lava at an elevation of approximately 3 m and the summit of the Butte is at 187 m, making the lava at least 184 m thick. Fleck and others (2002) reported an $^{40}Ar/^{39}Ar$ age of 125 ± 40 ka.

Qbae-l **basaltic andesite of Elk Point and loess (Pleistocene)**— Massive gray basalt flows, scoria, and breccia. The unit is poorly exposed in road cuts along the northwest edge of Elk Point and the unnamed hill to the northwest and at the western portal and within the western end of the TriMet light rail tunnel (tunnel data provided by Ray Wells and Russell Evarts (Walsh and others, 2011). The unit covers approximately 1,300 ha. The exposed rock is relatively fresh, medium grained, and diktytaxitic and has common 1-2 mm iddingsitized olivine phenocrysts. The lava is typically massive to crudely columnar jointed, with some breccia zones and voids present between more massive parts. Engineering borings for the light rail tunnel encountered complexly interlayered massive lava, breccia, and scoria.

The vents for the flows are inferred to be the dome-shaped hill named Elk Point, two unnamed conical hills just northwest of Elk Point, and Cornell Mountain, all of which retain the morphology of small cinder cones or shield volcanoes. Well logs indicate that the thickness ranges from 30 m to 100 m near the vents and is typically 50 to 70 m. The estimated volume is approximately 0.78 km^3.

Conrey and others (1996) reported a K/Ar radiometric age of 260 ± 110 ka for magnetically normal samples from the western tunnel portal, and Fleck and others (2002) reported an $^{40}Ar/^{39}Ar$ age of 120 ± 15 ka. Other dates reported by both sets of authors that are likely to be from the same unit range from 860 ± 40 ka to 1,221 ± 110 ka, consistent with measurements of reversed magnetic polarity from some samples from the unit.

Most of the area underlain by this unit is mantled with several meters of loess and basalt colluvia on steeper slopes.

Qbmt **basalt of Mount Tabor (Pleistocene)**— Basaltic scoria and bombs forming a small cinder cone and a small associated basalt lava flow on the north end of Mount Tabor. The cinder cone was quarried for scoria, removing the south half of the cone. The remaining excellent exposure has been preserved as a park. The volume of the cone is approximately 800,000 m^3. An $^{40}Ar/^{39}Ar$ age of 203 ± 5 ka was obtained by Russell Evarts and Robert Fleck of the USGS (personal commun., 2009).

Qbkb **basalt of Kelly Butte (Pleistocene?)**— Small flow of gray, diktytaxitic basalt or basaltic andesite on the west slope of Kelly Butte. No chemistry or age is available. The lava covers 27,000 m^2 and is approximately 7 m thick. Pleistocene age is based on the ages of other nearby Boring volcanoes. No vent is evident.

Qbca **basalt of Carver (Pleistocene)**— Basalt flows, scoria, and at least one dike form a small volcano north of the Clackamas River at Carver. The dike intrudes volcaniclastic sandstone and scoria conglomerate (unit **Qvca**), which is capped by basalt of Carver flows. Most exposures are too deeply weathered for radiometric dating. Samples of the dike were K/Ar dated at 427 ± 26 ka (Madin, 1994). The vent was probably in the modern Clackamas River channel just upstream of Carver. A moderately strong positive-polarity magnetic anomaly is associated with this unit.

Qvca **volcanic sandstone and conglomerate (Pleistocene)**— Well-lithified crudely bedded tuffaceous siltstone, sandstone, and pebble conglomerate. Restricted to the area immediately around the **Qbca** vent at Carver. Massive to well bedded and composed mostly of vitric silt and sand, angular to subrounded pebbles and cobbles of scoria, basalt, and rare quartzite, and feldspathic and lithic sand with some mica.

Qbr **basalt of Borges Road (Pleistocene)**— Flow or flows of basalt and associated scoria restricted to the hill just north of Borges Road in sec. 29, T. 2 S., R. 3 E. Maximum thickness penetrated in water wells is at least 145 m, but this section may be deformed. Magnetic polarity is normal. A K/Ar radiometric age of 510 ± 8 ka (Madin, 1994) was obtained from the only known exposure, located on Wooded Hills Road near the center of sec. 29, T. 3 E., R. 1 S. The vent may be located on the west flank of the hill described above, where there is a strong positive aeromagnetic anomaly.

Qbrr-l **basalt of Rodlun Road and loess (Pleistocene)**— Flow or series of flows of basalt or basaltic andesite up to 50 m thick covering large areas in the hills just south of Gresham. All measured outcrops have normal magnetic polarity. A K/Ar radiometric age of 544 ± 25 ka (Madin, 1994) was obtained from a sample taken from a road cut in the northwest corner of the southeast quarter of sec. 22, T. 1 S., R. 3 E. A possible vent is located at the small conical hill in the southwest corner of the northwest quarter of sec. 27 T. 1 S., R. 3 E., which is associated with a strong positive aeromagnetic anomaly.

Most of the area underlain by this unit is mantled with several meters of loess and basalt colluvium on steeper slopes.

Qvrr **tephra of Rodlun Road (Pleistocene)**— Red-brown weathered scoria and clay.

Qbhs **basaltic andesite of Hardscrabble (Pleistocene)**— Flow or series of flows of gray, diktytaxitic olivine bearing basaltic andesite forming a broad plateau south and southeast of Damascus. All measured outcrops have normal magnetic polarity. Excellent exposures in Hardscrabble quarry (sec. 17, T. 2 S., R. 3 E.) indicate that one flow was at least 45 m thick. A

K/Ar radiometric age of 612 ± 23 ka (Madin, 1994) was obtained at Hardscrabble quarry. One likely vent for these flows is a small conical hill in the northwest corner of sec. 15, T. 2 S., R. 3 E., which is associated with a strong positive aeromagnetic anomaly.

Qbw **basalt of Winston Road (Pleistocene)**— Flow or flows up to 110 m (360 ft) thick of diktytaxitic olivine basalt with associated scoria located to the west and north of Damascus. A K/Ar radiometric age of 646 ± 27 ka (Madin, 1994) was obtained from a cut on Winston Road just east of Foster Road. All measured outcrops have normal magnetic polarity. The likely vent is located in sec. 28, T. 1 S., R. 3 E., where a water well penetrated over 30 m of unit **Qbw** scoria. The unit is associated with a moderate positive aeromagnetic anomaly.

Qbs **basalt of Mount Scott (Pleistocene)**— Cinder cones and flows of gray, olivine-bearing basalt. There are at least three obvious vents in the unit. Mount Scott is a large cone with a clear summit crater. A second cinder cone vent with a beautifully preserved crater almost 300 m in diameter occurs in the northwest quarter of sec. 36, T. 1 S., R. 2 E. An eroded and breached cone occurs in the south half of sec. 35, T. 1 S., R. 2 E. One flow that directly underlies a flow of basalt of Jenne (**Qbj**) on the eastern flank of the hill in sec. 24, T. 1 S., R. 2 E. has a K/Ar radiometric age of 711 ± 20 ka (Madin, 1994). An $^{40}Ar/^{39}Ar$ age of 1,230 ± 390 ka was reported from the western edge of the volcano by Fleck and others (2002). Outcrops have both normal and reversed magnetic polarity (Madin, 1994).

Qbj **basalt of Jenne (Pleistocene)**— Basaltic scoria and at least one flow making up the hill south of the communities of Jenne and Linneman. The flow or flows are up to 18 m thick. At the eastern foot of the hill in sec. 24, T. 1 S., R. 2 E., a flow directly overlies a flow of basalt of Mount Scott. The flow is normally magnetically polarized and has a K/Ar radiometric age of 832 ± 128 ka (Madin, 1994). The vent is probably the bowl-shaped depression in the southeast corner of sec. 18, T. 1 S., R. 3 E. The vent area is associated with a modest positive aeromagnetic anomaly.

Qvj-l **tephra of Jenne and loess (Pleistocene)**— Ash, scoria, and basaltic bombs of basalt of Jenne (**Qbj**) composition deposited on and around vents. In most exposures the tephra is severely weathered to clay, tan, or brown. The tephra makes up the walls of the beautifully preserved breached cinder cone in sec. 18, T. 1 S., R. 3 E. and most of the hill immediately to the north. Most of the area underlain by this unit is mantled with several meters of loess and basalt colluvia on steeper slopes.

Qbp **basalt of Powell Butte (Pleistocene)**— Flow or flows of basalt mantle the northwest slopes of Powell Butte. The only measurable outcrop was found to have reversed magnetic polarity (Madin, 1994). No radiometric ages are available, but the age is inferred to be Pleistocene on the basis of the ages of surrounding volcanoes.

Qba **basaltic andesite of Anderson (Pleistocene)**— Poorly exposed and deeply weathered flows and tuff breccia of vesicular, olivine-microphyric basaltic andesite; erupted from conical hill east of Anderson (Russell Evarts, personal commun., 2011).

Qbk-l **basalt of Kaiser Road and loess (Pleistocene)**— Platy gray to gray brown olivine basalt flow or flows. The unit is exposed in only one small area of road cut along NW Kaiser Road near the intersection with NW Wismer Road, where the rock is medium grained, diktytaxitic, platy, and moderately weathered with abundant red-brown altered olivine phenocrysts 1-2 mm in diameter. From well log data this unit probably underlies about 1,400 ha in the area east of Bethany, bounded to the south by Branson Creek and roughly to the north by Germantown Road. The likely vent is the roughly conical hill located some 1,800 m southeast of the intersection of Kaiser Road and Springville Road. The thickness of the unit encountered in wells ranges from 10 to 75 m and is typically 25 to 50 m. The estimated volume is approximately 0.5 km^3. Russell Evarts and Robert Fleck of the USGS (personal commun., 2007) reported that the unit has provisional $^{40}Ar/^{39}Ar$ age of 960 ± 5 ka and is magnetically reversed.

Most of the area underlain by this unit is mantled with several meters of loess and basalt colluvia on steeper slopes.

Qbsy **basalt of Mount Sylvania (Pleistocene)**— Basalt or basaltic andesite tephra and lava flows making up the roughly conical Mount Sylvania. From limited exposure and well data, most of the mountain is tephra, with several lava flows extending out beyond the base of the mountain. The lava is gray and massive to platy, with abundant fresh or iddingsitized olivine phenocrysts 1 to 2 mm in diameter. The mountain stands 150 to 200 m above the surrounding terrain. A borehole located 120 m below the summit of the mountain penetrated 85 m of interbedded lava and tephra. The diameter of the base of the volcano is roughly 5 km, so the approximate volume of the volcano is 1.4 km^3. The USGS has determined $^{40}Ar/^{39}Ar$ radiometric ages of 1,129 ± 5, ka 1,125 ± 6 ka, and 1,121 ± 7 ka (Russell Evarts and Robert Fleck, personal commun., 2009) for the basalt of Mount Sylvania.

Qbsy-l **basalt of Mount Sylvania and loess (Pleistocene)**— Basalt of Mount Sylvania with a mantle of loess and basalt colluvia several meters thick.

Qbo **basaltic andesite of Outlook (Pleistocene)**— Flow or flows of fine-grained, gray, diktytaxitic olivine basaltic andesite that occur about 5 km northeast of Oregon City. Rarely exposed but generally massive, with jointing restricted to crude columns 0.6 to 1.5 m in diameter. Weathered lava is typically gray or purplish and soft, with relict igneous textures preserved. Several vents, some of which are mostly composed of tephra (unit **Qvo**), occur around the community of Outlook. Two radiometric ages are available for this unit. Madin (1994) reported a conventional K/Ar date of 3,146 ± 62 ka for the basalt of Outlook near Carver, approximately 1.6 km north of the northeast corner of the map. A more recent $^{40}Ar/^{39}Ar$ age on the same outcrop at Carver yielded an age of 1,220 ± 50 ka (Russell Evarts, personal commun., 2005). An $^{40}Ar/^{39}Ar$ age from this study gave an well-constrained plateau age of 1,280 ± 40 ka. All measured outcrops were found to have reversed magnetic polarity (Madin, 1994, 2009).

The basaltic andesite of Outlook is typically 15 to 60 m thick and has a volume of approximately 0.2 km^3.

Qvo **Outlook tephra (Pleistocene)**— Ash, scoria, bombs, and breccia of basaltic andesite of Outlook composition deposited on and around vents. In most exposures the tephra is severely weathered to clay and brightly colored in shades of tan, pink, red, orange, yellow, white, and black. At the vent in sec. 25, T. 2 S., R. 2 E., the tephra is interbedded with thin vesicular lava flows, sandstone, and mudstone and includes cobbles from the underlying Springwater Formation (**QTs**).

The tephra are about 45 m thick in the northeast corner and about 70 m thick at the small cinder cone.

Qbh **basaltic andesite of Hunsinger (Pleistocene)**— Flow or flows of gray, fine-grained, diktytaxitic olivine basaltic andesite. This unit is exposed a few kilometers east of Oregon City; the lava was erupted from a vent in sec. 2, R. 3 S., T. 2 E. The basaltic andesite of Hunsinger is typically massive with widely spaced planar joints. Weathered surfaces are typically littered with subangular blocks up to 1 m across. A sample of the basaltic andesite of Hunsinger from Maple Lane yielded an $^{40}Ar/^{39}Ar$ age of 1,217 ± 89 ka and a sample from Potter Creek had an $^{40}Ar/^{39}Ar$ age of 1,190 ± 10 ka (Russell Evarts, personal commun., 2005). All measured outcrops were found to have reversed magnetic polarity (Madin, 2009).

The basaltic andesite of Hunsinger is typically 45 to 75 m thick, and the estimated volume of lava remaining in the area is 0.24 km^3.

Qbbb **basaltic andesite of Broughton Bluff (Pleistocene)**— Gray, olivine-bearing basaltic andesite flow that caps the eastern bluff above the Sandy River at its mouth (Evarts and O'Connor, 2008). Only about the westernmost 2.5 ha of the flow are exposed in the extreme northeast corner of the map. The flow has reversed magnetic polarity and an $^{40}Ar/^{39}Ar$ age of 1,282 ± 14 ka (Evarts and O'Connor, 2008). The likely vent is Chamberlain Hill, about 3 km east of the outcrop on the map (Evarts and O'Connor, 2008).

Qbm **basalt of Mount Talbert (Pleistocene)**— Flow or flows of basalt and associated scoria exposed in Rock Creek in sec. 6, T. 2 S., R. 3 E. These exposures are the eastern edge of a thin sheet that extends in the subsurface to the west for approximately 3 km. The western edge of the unit is marked by Mount Talbert, a conical hill composed of basalt and tephra. Most of the measured outcrops were found to have reversed magnetic polarity (Madin, 1994). Conrey and others (1996) reported K/Ar radiometric ages of 1,590 ± 170 ka and 1,260 ± 290 ka. The unit has no clear aeromagnetic signature. Mount Talbert is the likely vent.

QTbz **basalt of Zion Hill (Pliocene-Pleistocene)**— Flow or flows of basalt and associated scoria mantling the hills immediately north of Boring and in the subsurface along the eastern edge of Sunshine Valley. The basalt is up to 61 m thick. Magnetic polarity measured on one poor outcrop was normal; however, there is a significant negative magnetic anomaly associated with this basalt (Madin, 1004). No samples were sufficiently fresh for radiometric dating. No radiometric ages are available, so the Pliocene-Pleistocene age is assigned from ages of surrounding volcanoes.

QTbt **basalt of Tong Road (Pliocene-Pleistocene)**— Flow or flows of basaltic andesite or andesite forming a small body north of the Clackamas River and west of Tong Road (secs. 8 and 18, T. 2 S., R. 3 E.). The basalt may be as much as 61 m thick but covers only about 60 ha. The chemistry, with relatively high Al_2O_3 and SiO_2 and low TiO_2 and MgO, is significantly different from other analyzed Boring lava units. There is no obvious vent and no strong aeromagnetic signature. No radiometric ages are available, so the Pliocene-Pleistocene age is assigned from ages of surrounding volcanoes.

QTbb-l **basaltic andesite of Bonny Slope and loess (Pliocene-Pleistocene)**— Massive gray basalt flow or flows. The unit is poorly exposed in road cuts near Thompson and Saltzman roads and in Cedar Mill Creek, and a has muted geomorphic expression. The unit covers approximately 830 ha between Bonny Slope and Cedar Mill, and Cedar Mill Creek and Bronson Creek. The vent for the flow is inferred to be a crudely conical hill just west of Bonny Slope. Well logs indicate that the thickness ranges from 10 m to 50 m and is typically 25 m. The estimated volume is approximately 0.2 km^3. Russell Evarts (personal commun., 2008) reported that one exposure has reversed magnetic polarity.

Most of the area underlain by this unit is mantled with several meters of loess and basalt colluvium on steeper slopes.

QTb **undifferentiated basalt and basaltic andesite (Pliocene-Pleistocene)**— Flows of olivine-bearing diktytaxitic calc-alkaline basalt and basaltic andesite and coarse-grained tholeiitic basalt that make up the eastern rim of the Sandy River canyon in the northeast corner of the map (Russell Evarts, personal commun., 2011). Includes the Pleistocene age basalt of North Fork Gordon Creek and basaltic andesite of Trout Creek and the Pliocene age low-potassium tholeiite unit (Russell Evarts, personal commun., 2011).

Tbr **basaltic andesite of Root Creek (Pliocene)**— Flow or flows of fine-grained gray basaltic andesite. The basaltic andesite occurs only in the southeast corner of the map, along Root Creek, after which the unit is named. The unit is rarely exposed but is typically strongly platy. Olivine is absent, making this unit unusual among Boring volcanic field flows in the map area. The basaltic andesite of Root Creek was erupted from a conical hill in sec. 31, T. 3 S., R. 3 E.

Russell Evarts of the USGS (personal commun., 2005) reported an $^{40}Ar/^{39}Ar$ total fusion age of 2,470 ± 20 ka. The unit has normal remnant magnetism on the basis of fluxgate magnetometer data from a single site. Russell Evarts (personal commun., 2005) reported that more sophisticated measurements indicated that the unit has reversed remnant magnetism.

Limited well data suggest that the basaltic andesite of Root Creek is 90 m thick and that the volume of the unit is approximately 0.4 km^3.

Tvr **Root Creek tephra (Pliocene)**— Ash, scoria, bombs, and breccia of basaltic andesite of Root Creek composition. The tephra is exposed in road cuts where Carus Road crosses Root Creek and makes up the vent cone in sec. 31, T. 3 S., R. 3 E. The tephra is severely weathered and consists of red-brown ash matrix with yellow, soft-weathered scoria and black bombs up to 80 cm across. The bombs typically have a scoriaceous crust; some larger bombs have relatively fresh cores. Bomb fragments were geochemically analyzed from the tephra deposits and correlate geochemically with the basaltic andesite of Root Creek. The tephra is Pliocene from correlation with flows of the basaltic andesite of Root Creek.

The thickness of the tephra is poorly constrained but is estimated to be 3 to 9 m at Root Creek and 50 -60 m at the vent.

Tbc **basalt of Canemah (Pliocene)**— Flow or flows of gray, fine-grained, diktytaxitic olivine basaltic andesite, that cover most of the plateau south of Oregon City.

The basalt of Canemah was probably erupted from vents 2-3 km south of the community of Beaver Creek. Flows advanced at least 15 km from the vents to reach the Willamette River in the northwest corner.

Several radiometric ages are available for the basalt of Canemah. Conrey and others (1996) reported a conventional K/Ar date of 2,440 ± 180 ka. Russell Evarts (personal commun., 2005) reported an $^{40}Ar/^{39}Ar$ age from the adjacent Colton quadrangle (southeast) of 2,530 ± 40 ka. All measured outcrops of the basalt of Canemah have reversed remnant magnetic polarity.

From the mapped extent of the unit the basalt of Canemah is typically 15 to 40 m thick and the volume is approximately 1.4 km^3. Erosion has probably removed a similar amount from the original volume of this unit within the quadrangle.

The weathered top of the basalt of Canemah is locally overlain by massive red-brown to brown, sandy to silty clay. The material is apparently sedimentary in origin, comprising a matrix of red-brown to brown clay with variable amounts of rounded heterogeneous lithic sand, silt, fine lithic and feldspathic sand, and rare angular quartz sand. The material is clearly distinct from the severely weathered basalt it overlies; in the rare locations where the contact is observed, it is sharp. The sandy, silty clay deposit has a patchy distribution and, from water well log data, is probably never more than 1 to 3 m thick; therefore it is not mapped separately. The origin of the deposits may include air-fall tephra from later Boring eruptions, windblown sediment, and an alluvial component from the earliest drainages that were established on the surface of the basalt of Canemah.

Tvc **Canemah tephra (Pliocene)**— Ash- to bomb-sized tephra with minor basalt flows inferred from water well logs. The tephra caps the hill in sec. 35, T. 3 S., R. 2 E. and forms an irregular cone around an inferred basalt of Canemah vent located just off the map at Massinger's Corner. No outcrops of the tephra were observed, but water well logs in the area suggest that the tephra is mixed with thin flows of lava. Well log descriptions suggest that much of the tephra is largely weathered to clay. Well logs indicate that the deposit is approximately 35 m thick at the vent in sec. 35, T. 3 S., R. 2 E. and at least 54 m thick near Massinger's Corner.

Tbf **basaltic andesite of Fallsview (Pliocene)**— Flow or flows of gray to black, fine to medium grained, diktytaxitic olivine basaltic andesite. The flows occur only along the map boundary south of Oregon City, where they are interbedded with tephra of Fallsview, but they are widespread to the south on the Mollala quadrangle, where they are named for outcrops near the community of Fallsview (Russell Evarts, personal commun., 2005). The basaltic andesite of Fallsview typically has widely spaced joints, and the ground surface on the unit is typically littered with subangular boulders.

Several vents for the basalt of Fallsview occur a few kilometers south of Beaver Creek. Two vents occur in the west half of sec. 2, T. 4 S., R. 2 E. One is a small conical hill underlain by the highest local flows of the unit; the other is a roughly circular depression 180 m across that is inferred to be an eroded crater. A third vent in sec. 3, T. 4 S., R. 2 E. is spectacularly exposed in a cut 75 m long. The majority of the cut consists of tephra that is cut by a central feeder dike of lava about 6 m wide and capped by a thin, highly vesicular lava flow.

The basalt of Fallsview has been radiometrically dated, yielding an $^{40}Ar/^{39}Ar$ age of 2,540 ± 80 ka, and has reversed remnant magnetism (Russell Evarts, personal commun. 2005).

The thickness of the basalt of Fallsview is variable, ranging from 81 m thick near the vents to 3–12 m thick in distal flows. The volume of lava remaining in the area is difficult to estimate, given the complex interbedding with tephra, but is probably on the order of 0.08 km^3. There is substantial additional volume on the adjacent Mollala quadrangle.

Tvf **Fallsview tephra (Pliocene)**— Ash, scoria, bombs, and breccia interbedded with the basaltic andesite of Fallsview. The tephra is severely weathered and consists of red-brown ash matrix with white and yellow soft-weathered scoria and black bombs up to 40 cm across. The bombs typically have scoriaceous crusts; some larger bombs have relatively fresh cores. In one exposure, the tephra is horizontally bedded, with layers ranging from 0.6 to 60 cm.

The deposits are correlated to the basaltic andesite of Fallsview on the basis of their interbedded relationship. The tephra is therefore Pliocene from the radiometric age of the basaltic andesite flows.

The thickness of the tephra is poorly constrained, but water well logs suggest that it is as much as 36 m thick near the vents.

Tbb **basaltic andesite of Beaver Creek (Pliocene)**— Flow or flows of gray, fine-grained, weakly diktytaxitic olivine basaltic andesite. The flows cover a few square kilometers at and to the east of the community of Beaver Creek. The basaltic andesite of Beaver Creek typically has strong platy jointing. In some exposures, weathering proceeds along the platy joints, converting the rock into a soft, white, gray, or tan mass of clay that superficially resembles a bedded sedimentary rock, although relict igneous textures are preserved.

The vents for the basaltic andesite of Beaver Creek are located 1 km west of the community of Four Corners in secs. 8 and 17, T. 3 S., R. 3 E.

The basaltic andesite of Beaver Creek was radiometrically dated (Madin, 2009) and yielded a well-constrained $^{40}Ar/^{39}Ar$ plateau age of 2,660 ± 50 ka. All measured outcrops were found to have reversed magnetic polarity (Madin, 2009).

The basaltic andesite of Beaver Creek is typically 60 to 80 m thick, with a maximum of 214 m recorded in well logs. The estimated volume of lava is 1.7 km^3.

Tbh **basaltic andesite of Highland Butte (Pliocene)**— Flows and tephra of basaltic andesite erupted from the conical hill called Highland Butte, located on the Colton quadrangle 2 km south of the map area. The basaltic andesite of Highland Butte covers 16 km^2 in the map area with an average thickness of 45 m and a maximum thickness of 130 m. The unit covers an additional 104 km^2 on the adjacent quadrangles to the south (Ma and others, 2009). The extent implies an approximate volume of 5.4 km^3, making the Highland Butte volcano one of the largest in the Boring volcanic field. Conrey and others (2009) reported a poorly constrained $^{40}Ar/^{39}Ar$ age of between 2.4 and 2.6 Ma.

Tbcb **basalt of Cooks Butte (Miocene-Pleistocene?)**— Diktytaxitic olivine basalt flows and tephra that cap the ridge south of Oswego Lake and make up cones at Cooks Butte and an unnamed butte to the south. (Beeson and others, 1989a). Russell Evarts (personal commun., 2011) reported three radiometric ages of approximately 13 Ma. This age is dramatically older than any other Boring volcanic field rocks. The degree of preservation of vent cones and the moderate weathering of the lava flows argue for a much younger age.

Hillsboro Formation

QTh **Hillsboro Formation (Miocene-Pleistocene)**— Fluvial sandstone, siltstone, claystone, and rare conglomerate that underlie much of the southwest half of the quadrangle. The Hillsboro Formation is everywhere buried by surficial units or Boring volcanic field rocks; no exposures are known. In the quadrangle the unit is known entirely from driller's logs, where it is typically described as blue, green, gray, or brown silt, sand, or clay. The type section of the formation is a core hole from the adjacent Hillsboro quadrangle that was described by Wilson (1997, 1998).

The unit is banked against the southwest slope of the Tualatin Mountains, where the unit rests on Columbia River Basalt, and thickens to the southwest, reaching a maximum thickness of 268 m in the southwest corner of the quadrangle.

Wilson (1998) reported the age to range from late Miocene to Pleistocene on the basis of diatoms, pollen, and paleomagnetism. Wilson reported that on the basis of heavy minerals and trace element geochemistry the unit is derived from rocks exposed in the surrounding highlands and stated that there is little evidence of a Columbia River sediment source for the formation. Previous maps have called this unit Sandy River Mudstone, Sandy River Mudstone equivalent, and Helvetia Formation (Trimble, 1963; Schlicker and Deacon, 1967; Madin, 1990). The Sandy River Mudstone is a fluvial deposit of Columbia River Provenance (Madin, 1990, 1994) deposited in the Portland Basin and is clearly distinct from the Helvetia Formation, although it occupies the same general stratigraphic position.

QTh-l **Hillsboro Formation and loess (Miocene-Pleistocene)**— Hillsboro Formation mantled with loess and loess, sandstone, siltstone, and claystone colluvia on steeper slopes.

Springwater Formation

QTs **Springwater Formation (Pliocene-Pleistocene)**— Fluvial conglomerate, volcaniclastic sandstone, siltstone, and volcanic mud flow breccia derived from the Cascade Range. The conglomerate is moderately indurated and typically consists of well-rounded pebbles, cobbles, and boulders of basalt, andesite, and dacite with rare exotic metamorphic and plutonic rocks. The sand and silt conglomerate matrix contains varying amounts of feldspathic and volcanic lithic and vitric sediment. The conglomerate is commonly massive and profoundly weathered. Weathered conglomerates are strongly varicolored in reds, browns, gray-greens, and oranges. Fresh material is more typically gray and brown. Mud flow breccia consists of angular to rounded clasts of basalt, andesite and dacite lava, scoria, and pumice in a matrix of clay, ash, and sand. Sandstone ranges from fine to coarse and is composed of volcanic lithic, vitric, and feldspathic sand, rarely micaceous. Siltstones and mudstones consist of quartzo-feldspathic silt, ash, and clay. The basal contact is probably conformable with the underlying Troutdale Formation and may be gradational. South of the Clackamas River the top of the Springwater Formation appears to be part of a deeply weathered bajada surface that is well developed to the south and east of the Clackamas River and rises eastward to the foothills of the Cascade Range. This surface was originally noted by Trimble (1963). Springwater Formation rocks are interbedded with or underlie numerous Boring lava flows, so the age of the Formation is late Pliocene and Pleistocene. Includes rocks mapped by Trimble (1963) as Gresham, Troutdale, and Walters Hill Formations, and rocks mapped by Evarts and O'Connor (2008) as Walter's Hill Formation and gravel west of Gresham.

The Springwater Formation is typically 30 to 45 m thick.

QTs-l **Springwater Formation and loess (Pliocene to Pleistocene)**— Springwater Formation mantled with loess and loess, sandstone, siltstone, and claystone colluvia on steeper slopes.

Troutdale Formation (Miocene-Pliocene)

Troutdale Formation (Miocene-Pliocene)— Moderately to poorly indurated mudstone, siltstone, sandstone, and conglomerate. This unit includes coarse- and fine-grained fluvial sedimentary rocks with varied provenance ranging from sediments with exotic origins presumably carried by the ancestral Columbia River and sediments of Cascade Range origin. Part of the Troutdale Formation was shown by Tolan and Beeson (1984) to be Miocene to Pliocene age in the Columbia River Gorge east of the map area. The Troutdale Formation is overlain by the upper Pliocene and Pleistocene flows of the Boring Volcanic Field; this relationship suggests a late Pliocene upper limit. Ashes interbedded with Troutdale Formation mudstone near the mouth of Eagle Creek have ages of 3.27 ± 0.15 Ma and 3.92 ± 0.11 Ma (Jeff Benowitz and Paul Layer, personal commun., 2011), but the stratigraphic position of the samples within the formation is not known. The stratigraphic and facies relationships between these lithologies are complex, and the unit is poorly exposed over much of its range.

The Troutdale Formation is more than 345 m thick at Oregon City and 390 m thick at the Portland airport.

The formation is mapped as the following units, which are based on the dominant lithology.

Ttm **Troutdale Formation mudstone and siltstone (Miocene-Pliocene(?))**— Mudstone and siltstone with sandstone, rare conglomerate, and water-laid tuff. Includes micaceous arkosic or feldspathic siltstone and tuffaceous mudstone. Blue-green to gray where fresh, weathering gray-green to brown. Siltstone and sandstone are typically thin bedded or laminated and mudstone is typically massive. Organic material, wood fragments, and logs are locally common. This unit was mapped by Trimble (1963) as the lacustrine Sandy River Mudstone, but common ripple, channel, and trough cross-bedding indicate fluvial origin. Correlates with the Lower Troutdale member (Sandy River Mudstone) (unit Ttl) of Lite (1992) and Sandy River Mudstone (Tsr unit) of Evarts and O'Connor (2008). More than 345 m of **Ttm** were encountered in a well near Oregon City that did not reach the base of the unit.

Tts **Troutdale Formation volcaniclastic sandstone (Miocene-Pliocene(?))**— Massive to well-bedded volcanic-lithic and vitric sandstone composed mostly of glassy fragments of olivine-bearing basalt. Correlates to the Upper Troutdale member vitric and lithic sand (Ttus unit) of Lite (1992) and the Troutdale Formation hyaloclastic sandstone member (Ttfh unit) of Evarts and O'Connor (2008). Evarts and O'Connor showed at least 90 m of the sandstone at Broughton Bluff.

Ttg **Troutdale Formation conglomerate (Miocene-Pliocene(?))**— Massive pebble and cobble conglomerate composed mostly of well-rounded Columbia River Basalt clasts with a significant percentage of metamorphic quartzite, granitoids, and schist. Feldspathic and arkosic micaceous sand matrix and interbeds are common. At the Portland airport near the Columbia River the gravel forms a sheet that is up to 120 m thick (Mabey and Madin, 1995). The gravel thins to the south, and along the Clackamas River it is restricted to scattered channel fill deposits in Troutdale Formation mudstone.

Ttg-l **Troutdale Formation conglomerate and loess (Miocene-Pleistocene(?))**— Troutdale Formation conglomerate mantled by loess and loess-conglomerate colluvium.

Rhododendron Formation

Tr **Rhododendron Formation (Miocene-Pliocene)**— Trimble (1963) described the Rhododendron Formation as andesitic mudflow breccia with subordinate andesite flows, conglomerate, and sandstone, commonly with uncarbonized wood fragments. Lava blocks up to 2 m are common. Flows and lava blocks are hypersthene andesite, and the unit is commonly deeply weathered and capped with a saprolite. Thickness is estimated at about 180 m. The Rhododendron Formation overlies Columbia River Basalt outside the map area and is overlain by the mudstone facies of the Troutdale Formation within the map area.

Columbia River Basalt Group

Bedrock in most of the map area is the middle Miocene Columbia River Basalt Group (CRBG). CRBG units in the map area make up but a small part of the approximately 164,000 km^2 of the Pacific Northwest underlain by Columbia River Basalt flows. Many individual flows are known to be huge, covering thousands to tens of thousands of square kilometers in area, with volumes up to thousands of cubic kilometers (Tolan and others, 1989, 2009). These enormous flows erupted from vents in eastern Oregon and Washington and western Idaho and flowed through the Portland region. Individual Columbia River Basalt Group units are defined on the basis of stratigraphic position, geochemistry, magnetic polarity, and petrography following the work of Swanson and others (1979), Reidel and others (1989), Beeson and others (1985, 1989b), and Tolan and others (2009).

CRBG units exposed in the map area include the Sentinel Gap, Sand Hollow, and Ginkgo basalts of the Frenchman Springs Member of the Wanapum Basalt, and the Sentinel Bluffs, Winter Water, Ortley, Umtanum, and Wapshilla Ridge rocks of the Grande Ronde Basalt.

Tcr **undifferentiated Columbia River Basalt Group (middle Miocene)**— Lava flows of the Columbia River Basalt Group in areas for which no more detailed mapping was available at the time this map was completed.

Tcr-l **undifferentiated Columbia River Basalt Group (middle Miocene)**— Undifferentiated Columbia River Basalt Group mantled with loess and loess-basalt colluvium.

Wanapum Basalt

Frenchman Springs Member

Twfsg **Basalt of Sentinel Gap (middle Miocene)**— Consists of a single, blocky- to columnar-jointed flow within the map area. Fresh exposures are dark gray; weathered surfaces are typically brownish gray to dark gray. Fine to medium grained microphyric basalt but can contain rare plagioclase phenocrysts <1 cm in size. Thickness of unit is variable, ranging from 8 to 15 m. Compositionally similar to older Ginkgo flows but can be differentiated on the basis of stratigraphic position, lithology (lack of abundant plagioclase phenocrysts), and normal paleomagnetic polarity (Beeson and others, 1985).

Twfsh **Basalt of Sand Hollow (middle Miocene)**— Black basalt flows weathering to dark gray or greenish gray. Plagioclase phenocrysts up to 3 mm in length occur sparsely in some flows. The flows typically are columnar jointed. The age of the basalt of Sand Hollow is middle Miocene, from a K-Ar date of 15.3 Ma reported by Beeson and others (1985). The maximum reported thickness of the unit is approximately 90 m (Madin and Niewendorp, 2008).

Twfsh-l **Basalt of Sand Hollow and loess (middle Miocene)**— Basalt of Sand Hollow mantled with loess and loess-basalt colluvium.

Twfg **Basalt of Ginkgo (middle Miocene)**— Flow or flows of lava that is typically dark gray or black where fresh, weathering to gray with a purplish brown surface. Plagioclase phenocrysts up to 15 mm and plagioclase glomerocrysts up to 20 mm in length are common. The flows typically are blocky to columnar jointed, with columns 1 to 1.75 m in diameter common. The age of the basalt of Gingko is middle Miocene, with an isotopic age of 15.6 Ma (Tolan and others, 2009) The maximum thickness of the unit inferred in the map area is approximately 75 m.

Twfg-l **Basalt of Gingko and loess (middle Miocene)**— Basalt of Ginkgo mantled with loess and loess-basalt colluvium.

Grande Ronde Basalt

Tgsb **Member of Sentinel Bluffs (middle Miocene)**— Flow or flows of basaltic andesite. The lava typically is dark gray or black where fresh, weathering to grayish brown. Sparse plagioclase phenocrysts up to 10 mm occur. The flows typically are blocky to platy jointed and typically are highly vesicular near the flow tops with horizontal bands of flattened vesicles and vugs. The lava weathers to form rounded core-stones up to 0.5 m in diameter. The age of the Sentinel Bluffs basalt is middle Miocene, with an $^{40}Ar/^{39}Ar$ date of approximately 15.6 Ma for the youngest flows of this unit on the Columbia Plateau (Long and Duncan, 1982). The typical thickness of the unit in the map area is approximately 40 m.

Tgsb-l **Member of Sentinel Bluffs and loess (middle Miocene)**— Member of Sentinel Bluffs mantled with loess and loess-basalt colluvium.

Tgww **Member of Winter Water (middle Miocene)**— Several thick flows of fine-grained, gray basaltic andesite. The lava is glassy to fine grained and phyric to abundantly phyric with small (< 3 mm) plagioclase glomerocrysts that often display a distinctive radial habit. Outcrops typically display columnar jointing, with well-developed 1- to 2-m diameter columns common. Entablature jointing is also common, and some flows display strong platy jointing. The age of the Member of Winter Water is middle Miocene on the basis of its stratigraphic position below the 15.6 Ma Member of Sentinel Bluffs. The Member of Winter Water is typically 50 to 70 m thick.

Tgww-l **Member of Winter Water and loess (middle Miocene)**— Member of Winter Water mantled with loess and loess-basalt colluvium.

Tgu **Basalt of Umtanum (middle Miocene)**— Within the map area, two flows that were designated as "N3 low-MgO flows" by Beeson and Moran (1979) are present. Umtanum flows commonly display entablature/colonnade jointing style. Fresh surfaces are dark gray to black; weathered surfaces are gray-green to dark gray. Flows are commonly glassy to very fine grained and abundantly plagioclase microphyric, with small (<2 mm) acicular microphenocrysts. The age of the basalt of Umtanum is middle Miocene on the basis of its stratigraphic position below the 15.6 Ma Member of Sentinel Bluffs. The unit is typically 50 m thick.

Tgo **Member of Ortley (middle Miocene)**— Several thick flows of fine-grained black basaltic andesite. The lava is glassy to fine grained and aphyric and commonly displays entablature jointing.

The age of the Member of Ortley is middle Miocene on the basis of its stratigraphic position below the 15.6 Ma Sentinel Bluffs Member. The unit is typically 40 to 60 m thick.

Tgo-l **Member of Ortley and loess (middle Miocene)**— Member of Ortley mantled with loess and loess-basalt colluvium.

Tgwr-l **Basalt of Wapshilla Ridge and loess (middle Miocene)**— Flow or flows of gray to black aphyric to abundantly plagioclase phyric basalt. Outcrops of the unit range from severely weathered entablature to basalt fragment and pelagonite breccia to well-formed pillows where the basalt lies directly on top of the Scappoose Formation and in most cases suggested that the flowing lava interacted with water. Some of the basalt is abundantly phyric with equant 0.5-mm plagioclase phenocrysts in a fine-grained groundmass. The age of the basalt of Wapshilla Ridge is middle Miocene on the basis of its stratigraphic position below the 15.6 Ma Member of Sentinel Bluffs. The unit is typically 20 to 30 m thick. Everywhere mantled with loess and loess-basalt colluvium.

Tgr **undifferentiated Grande Ronde Basalt (middle Miocene)**— Lava flows of the Grande Ronde Basalt in areas for which no more detailed mapping was available at the time this map was completed.

Scappoose Formation

Ts **Scappoose Formation (Miocene?)**— Tuffaceous marine sandstone, siltstone, and claystone. Scappoose Formation rocks are poorly exposed in the northern part of the map. The sandstone is typically white, yellow, or tan, moderately to poorly bedded, and well sorted. Composition is arkosic with varying amounts of mica. Siltstone is gray-tan or white and typically micaceous and tuffaceous. Claystone is white to gray to tan. Cross-beds are common in the sandstone, as are bivalve and gastropod fossils. The Kappler 1 well, located within the Wildwood landslide complex, penetrated 200 m of sedimentary rock likely to be Scappoose Formation. The age of the Scappoose Formation is late Oligocene to middle Miocene on the basis of fossils (Warren and others, 1945) and the presence of Columbia River Basalt clast conglomerate in the upper parts of the formation in other areas (Kelty, 1981).

Twh **Basalt of Waverly Heights and associated undifferentiated sedimentary rocks (Eocene)**— Consists of a sequence of subaerial basaltic lava flows and associated sediments that unconformably underlie flows of the Columbia River Basalt Group. The top of unit **Twh** is typically marked by a deeply weathered zone (probably >10 m thick), except where it has been scoured away either by catastrophic floodwaters or by normal river downcutting. Consequently, the best exposures of this unit are found adjacent to the Willamette River in the Waverly Heights area. Flows of unit **Twh** are typically blocky to columnar jointed and have well-developed vesicular flow tops and bottoms. Vesicles and vugs within flow tops, as well as some joints, are commonly filled with secondary minerals. Flow morphology and the absence of intraflow structures (pillow complexes and hyaloclastites) suggest that the lava flows were emplaced subaerially. Fresh flow surfaces are typically brownish gray to black; weathered surfaces are dark gray to brownish black. In hand sample, the flows are commonly fine to medium grained and range from sparsely to abundantly plagioclase phyric, with phenocrysts and glomerocrysts that are usually <0.5 cm in size. Unit **Twh** flows are basaltic in composition and are similar in composition to those of the Columbia River Basalt Group (Table 1). However, unit **Twh** flows can be distinguished from Columbia River Basalt Group flows because they do not precisely match any specific compositional type within the Columbia River Basalt Group. Two flows have yielded K-Ar dates of about 40 Ma (Beeson and others, 1989a). Sediments associated with unit **Twh** flows are not exposed, but borehole data suggest a marine depositional environment and further suggest that these sediments underlie much of the Tryon Creek area. Thickness of this unit is not known but is assumed to extend to considerable depth in the map area.

Twh-l **Basalt of Waverly Heights and loess (Eocene-Pleistocene)**— Basalt of Waverly Heights mantled with loess and loess-basalt colluvium.

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