State of Oregon
Department of Geology and Mineral Industries
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**Open-File Report O-07-15**

# PRELIMINARY GEOLOGIC MAP OF THE UMATILLA BASIN, MORROW AND UMATILLA COUNTIES, OREGON

By

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2007

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Oregon Department of Geology and Mineral Industries Open-File Report O-07-15
Published in conformance with ORS 516.030

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## INTRODUCTION

The Umatilla Basin is a large region of northeastern Oregon bounded generally by the Blue Mountains to the south and east and the Columbia River to the north. This is a generally arid region, with an extensive agricultural base and a few rapidly growing urban centers. Large portions of the area have been labeled critical groundwater areas by the Oregon Water Resources Department and are closed to new drilling. It is largely the concern over falling groundwater levels that prompted the Oregon Geologic Map Advisory Committee to make the Umatilla Basin a top priority for new geologic mapping. This map is meant to be an initial compilation and digitization of existing data that can serve to guide and focus future in depth studies and detailed mapping. This geologic map was funded in part by the U.S. Geological Survey (USGS) National Cooperative Geologic Mapping Program under award 01HQAG0044.

The study area (Figure 1) comprises all of the Umatilla River drainage basin within Umatilla and Morrow counties and covers an area of 11,250 km$^2$ (4,345 mi$^2$). The major urban areas in the study area are Pendleton (2001 pop. 16,600), Hermiston (2001 pop. 13,560), Milton-Freewater (2001 pop. 6,560) and Boardman (2001 pop. 2,940). Most of the highlands along the southern and eastern margin of the study area are private and U.S. Department of Agriculture (USDA) Forest Service timberland, while the lower elevations of the basin support cattle ranching, dry land wheat farming, and intensive irrigated agriculture and silviculture. The study area also includes the U.S. Army Umatilla Weapons depot, one of two chemical weapons storage and incineration sites, and the lands of the Confederated Tribes of the Umatilla Indian Reservation.

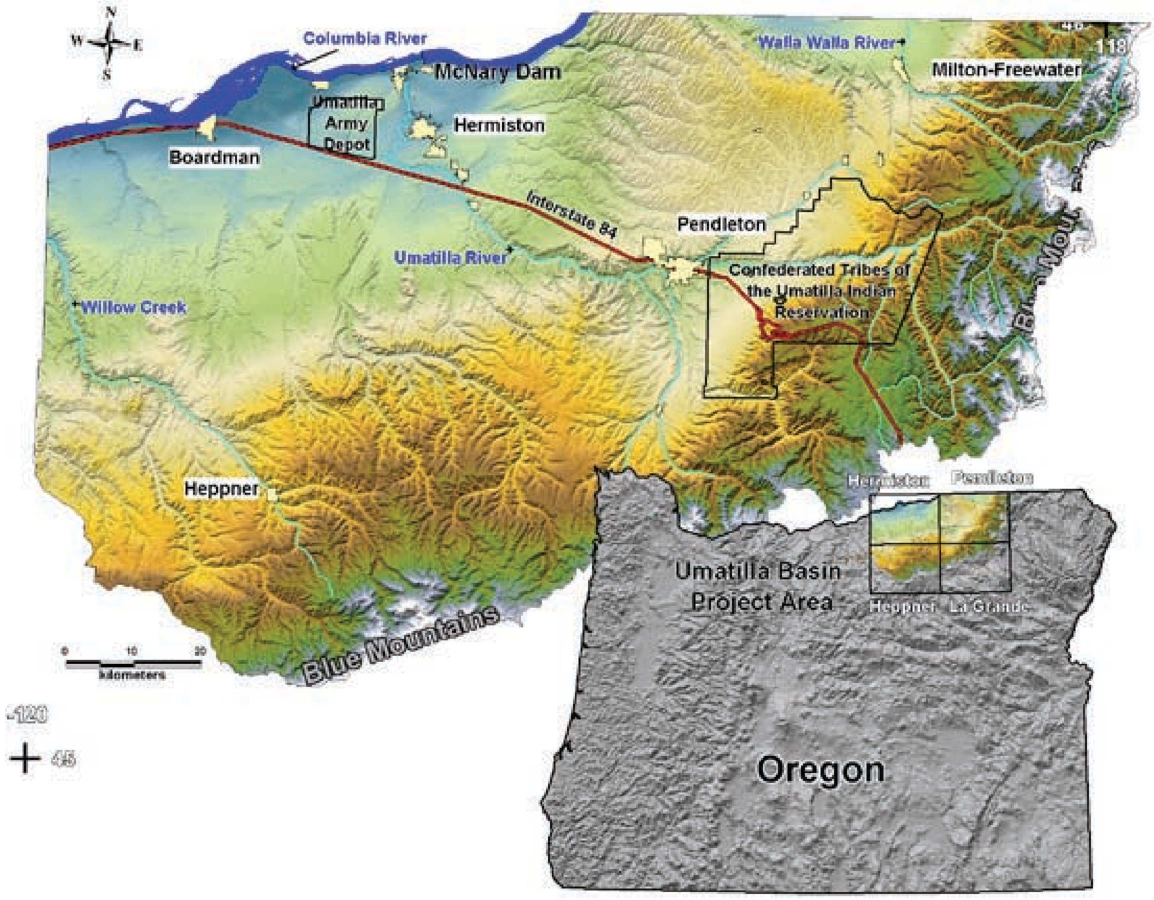



Figure 1. Study area location map. Color-shaded relief map outlines study area.

Elevation in the study area ranges from 80 m to 1850 m (260 ft to 6065 ft). Relief is generally quite low in the northern lowlands and moderate in the highlands, except along the major streams, which generally cut very steep sided canyons in to a gently rolling upland surface. The major streams draining the area are the Umatilla and Walla Walla rivers and Butter and Willow creeks.

The resultant map was designed to be used at a scale of 1:100,000 and covers all or part of five 30′ × 60′ map sheets. Because of the size of the map it is impractical to print it in its entirety; instead, we provide an Adobe® Acrobat® .pdf image of the full map (Plates 1, 2, and 3) and associated GIS files, map images, and databases in CD-ROM format.

## METHODOLOGY

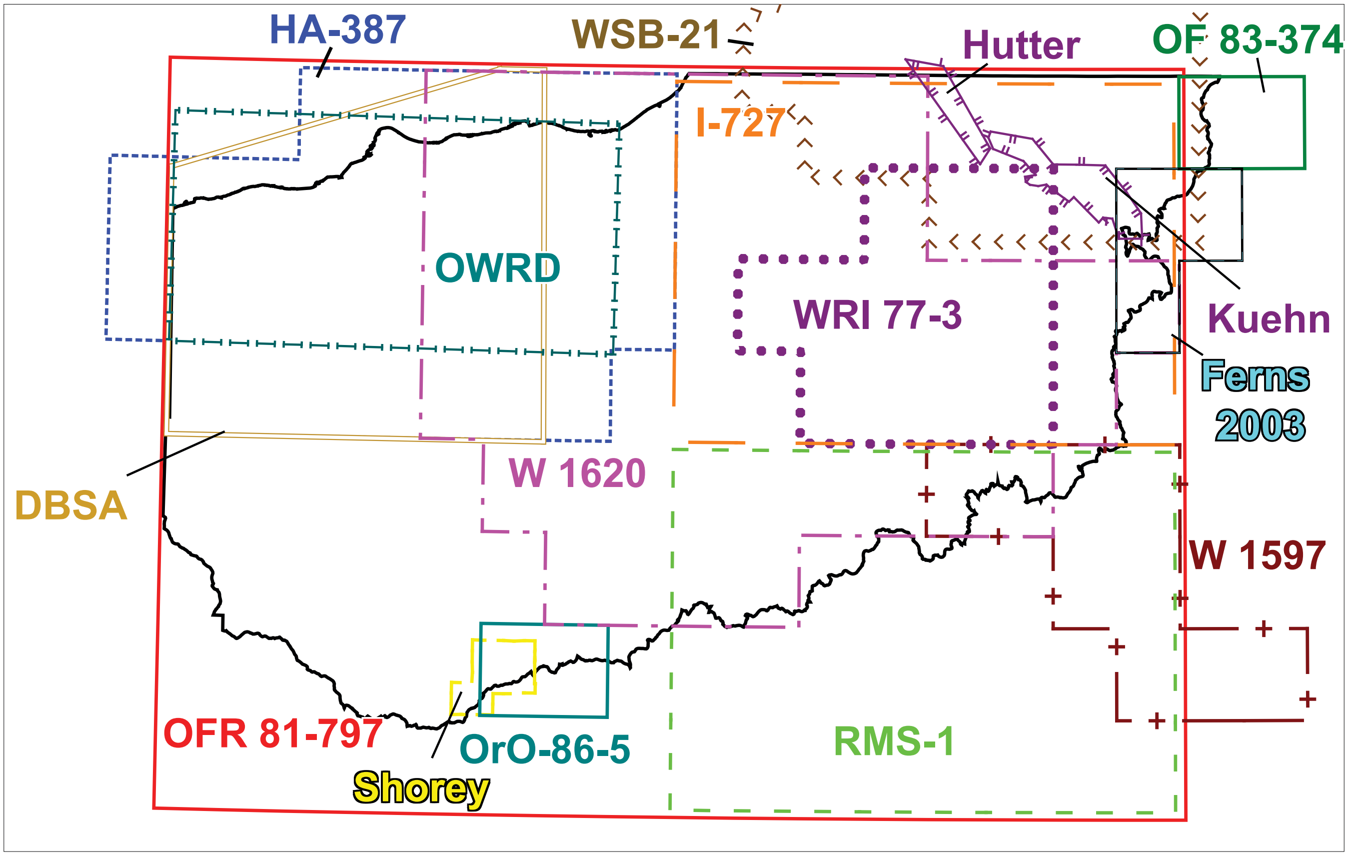
The compilation map was produced using a variety of data sources, including existing geologic maps, air photos, water well logs, and geochemical data. Data sources were collected in digital format in a MapInfo®-based geographical information system (GIS) and then plotted on 1:24,000 scale digital raster graphic (DRG) mosaics in blocks of eight at a scale of 1:44,000. The data were interpreted, and contacts and structures were inked onto Mylar overlays on the data plots. The inked data were scanned, georeferenced, and converted to vector lines. The resultant lines were then digitally stitched together, converted to polygons or lines as appropriate, and attributed.

The primary sources of map data are shown in Figure 2. The most widely used source map was the Swanson and others (1981) 1:250,000 scale geologic map. We obtained the original ink on greenline Mylar version of this map from USGS, scanned it, and converted the scanned image to vector geologic polygons. We also used a scanned and georeferenced raster image of Hogenson (1964) and vector polygon data from Grondin and others (1995). Data were transferred from other maps by inspection.

We used color infrared air photo coverage at a scale of 1:58,000 for the entire study area to look for obvious contacts and faults and to map bedding traces. In much of the area underlain by flows of the Columbia River basalt, the tops of individual flows can be easily traced on air photos as obvious cliffs or outcrop bands, as strong color changes, or as vegetation lineaments. Over 3,500 such traces were seen on the air photos and were digitized using georeferenced digital orthophoto quadrangle (DOQ) photo images, as were faults and other structures. Bedding traces were overlaid on a 10-m USGS digital elevation model (DEM) in our GIS system (MapInfo) and used to select over 5,500 apparent dip vectors. Azimuths and apparent dip values were calculated for each vector, and pairs of vectors were then chosen and used to calculate over 1,800 strikes and dips using GeoCalculator (R. J. Holcombe, personal comm., 2001).

Geochemical data were collected from several published and unpublished sources including Ferns and others (2001), Ingrid Hutter (personal communication, 2001), Kuehn (1995), and Wright and others (1979, 1980). In addition, 88 samples were collected for this project and analyzed. The geochemical data points are shown on Plate 2 and are included as Microsoft Excel® spreadsheets on the accompanying CD-ROM. We also analyzed well cuttings from water wells drilled in the area and provided by Oregon Water Resources Department (OWRD), drillers and local engineering firms. Cuttings and samples were analyzed by X-ray diffraction (XRD) by Dr. Stan Mertzman at Franklin and Marshall College, Lancaster, Pennsylvania. The whole-rock analyses for major and trace elements were performed using a Phillips 2404 X-ray fluorescence vacuum spectrometer equipped with a 102-position sample changer. Loss on ignition (LOI) was determined by heating accurately pre-weighed amounts of sample rock powder to 950° C for one hour, then reweighing the sample to determine the relative percentage of weight gain and loss. The amount of ferrous iron was titrated using a modified Reichen and Fahey (1962) method.

We used water well logs from located and unlocated wells to help interpret the surface and subsurface geology. We obtained digital files of located wells from OWRD, which had linked well logs to surveyed water right point of diversion data. Raster images of the logs for these wells are available on CD-ROM and on online from OWRD. We did not include the well logs in the data CD-ROM as the logs are available online.




| Map | Scale | Reference |
|---|---|---|
| OF 83-374 | 1:24,000 | Swanson and others (1983) |
| OrO-86-5 | 1:24,000 | Ferns and Brooks (1985) |
| W 1597 | 1:62,000 | Hampton and Brown (1964) |
| W 1620 | 1:25,000 | Hogenson (1964) |
| WRI 77-3 | 1:62,000 | Gonthier and Harris (1977) |
| RMS-1 | 1:100,000 | Ferns and others (2001) |
| OFR 81-797 | 1:250,000 | Swanson and others (1981) |
| HA-387 | 1:125,000 | Robison (1971) |
| I-727 | 1:250,000 | Walker (1973) |
| Shorey | 1:24,000 | Shorey (1976) |
| Kuehn | 1:45,000 | Kuehn (1995) |
| Hutter | 1:48,000 | Hutter (1997) |
| OWRD | 1:24,000 | Grondin and others (1995) |
| DBSA | 1:100,000 | Tolan and Lindsey (2000) |
| Ferns | 1:24,000 | Ferns and others (2003) |
| WSB-21 | 1:100,000 | Newcomb (1965) |

Figure 2. Geologic maps used in the Umatilla Basin compilation.

# DESCRIPTION OF MAP UNITS

Many of the geologic units on this map are similar or identical to units from the adjacent La Grande 30′ × 60′ sheet (Ferns and others, 2001). In those instances, the unit descriptions here are largely taken from that publication and are modified where appropriate for the current map area.

## Quaternary Sedimentary Deposits

**Qe** **Eolian sand and ash (Holocene)** — Eolian deposits, primarily unconsolidated wind-blown sand and silt reworked from older Missoula Flood deposits, and airfall volcanic ash deposits. In the lowlands this unit is entirely composed of reworked sand and minor silt and was mapped on the basis of USDA Natural Resources Conservation Service (NRCS) digital soil survey data and from dune fields depicted on the 1:24,000-scale DRG topographic maps. In the highlands a few patches of 0.5- to 1-m-thick accumulations of the circa 6,700 yr BP Mazama ash are mapped. A thin veneer of loess and ash covers much of the area outside of the Missoula flood deposits. The veneer generally does not completely obscure the underlying bedrock and is not mapped.

**Qal** **Alluvium (Holocene)** — Sand, silt, and gravel deposited on the channels and on the floodplains of modern streams and rivers. Generally unconsolidated and ranging in thickness up to a few meters or tens of meters at most. This unit was mapped almost exclusively by using digital soils data from NRCS.

**Qmf** **Missoula Flood deposits (Pleistocene)** — Boulder to pebble gravel, sandy gravel, sand, and silt deposited during catastrophic floods caused by the repeated failure of the glacial ice dam that impounded glacial Lake Missoula (Bretz and others, 1956; Baker and Nummedal, 1978; Waitt, 1985; Allen and others, 1986). Date of most recent catastrophic flood is estimated to be 15,500 to 13,000 yr BP (Mullineaux and others, 1978; Waitt, 1987). Floodwaters inundated much of the study area up to an elevation of approximately 300 m (1,000 ft), as indicated in part by the presence of ice-rafted bocks of exotic intrusive and metamorphic rocks up to several meters. The floods scoured some areas, leaving bare bedrock scabland in some instances (east of Hermiston), enlarging drainages (Butter Creek southeast of Echo) and building huge bars (Coyote Coulee, on the Umatilla Army Depot). This map does not differentiate coarse- and fine-grained deposits. The upper limit of flood deposits was taken largely from digital soil mapping by NRCS. Maximum thickness is approximately 45 m (150 ft), but thickness is more commonly 5 to 15 m.

**Qf** **alluvial fan gravel (Holocene and Pleistocene)** — Poorly sorted and partly consolidated boulder to pebble gravel, sand, silt, and clay deposited by intermittent streams draining the Cabbage Hill escarpment southeast of Pendleton and at the mouth of the canyon of Sand Hollow Creek northeast of Heppner. At Cabbage Hill, water well data indicate that about 5 to 15 m (15 to 50 ft) of fan deposits overlie older Columbia River Basalt Group lavas and McKay Formation sedimentary rocks. At Sand Hollow Creek the fan deposits overlie Columbia River Basalt lavas and sandstone and conglomerate of the Alkali Canyon Formation. Thickness is difficult to estimate, as the contact with the underlying Alkali Canyon is not obvious in water well logs, but is probably 5 to 25 m (15 to 85 ft). In both locations the deposits produce obvious fan morphology, and at Cabbage Hill the fans coalesce into a bajada.

**Qls** **landslides (Holocene and Pleistocene)** — Unconsolidated, chaotically mixed masses of rock and soil. Landforms typified by sloping hummocky surfaces marked by closed depressions, springs and wet seeps, scarps, and cracks and crevices. Landslides typically occur near the contact between Columbia River Basalt lavas and underlying older rocks (headwaters of Birch and Rhea creeks) or on a thin (unmapped) sediment layer separating Columbia River Basalt lavas from overlying Powder River Volcanic Field lavas (northeast of Meacham).

**Qt** **alluvial terrace gravel (Pleistocene)** — Partly consolidated deposit of sand to cobble gravel that forms a terrace surface along the south side of the Umatilla River just east of Pendleton. The terrace stands about 10 m (30 ft) above the modern floodplain of the Umatilla River.

**QTm** **alluvium and alluvial fan gravel of Milton-Freewater (Miocene? to Pleistocene)** — Interbedded gravel, sand, and clay deposited by the ancestral Walla Walla River and adjacent minor drainages in the basin around Milton-Freewater. Known largely from water well logs and poorly mapped, this unit underlies the younger Quaternary alluvium and Missoula Flood deposits that cover the flat valley floor north of Milton-Freewater and that are exposed in a few areas of the adjacent highlands. Thickness is as great as 150 m (500 ft).

**QTs** **older loess (Miocene? to Holocene)** — Extensive deposits of wind-laid silt that cover much of the broad plateau north of the Umatilla River. Thickness from water well logs is up to 30 m (100 ft) but is more commonly 10 to 15 m (30 to 45 ft). Age range is uncertain, but the unit generally sits directly on Miocene Columbia River Basalt lavas and probably overlies Mio-Pliocene McKay Formation north of Pendleton. The area underlain by this unit has a pronounced northeast topographic grain (Plate 2), expressed by the common orientation of minor drainages. These drainages appear to have been influenced by northeast trending dunes formed in the loess, but as the drainages commonly have eroded down into the underlying basalt, it is likely that substantial time has passed since the deposit and associated dunes were laid down.

## Miocene and Pliocene Dalles Group Sedimentary Rocks

**Tmm** **McKay Formation (middle? to upper Miocene)** — Basaltic fluvial sedimentary rocks exposed around McKay Reservoir south of Pendleton. Mainly weakly indurated basalt cobble conglomerate, pebbly sandstone, and tuffaceous siltstone. Mostly coarse-grained horizontally bedded basalt cobble gravels with lenticular interbeds of weakly carbonate-cemented quartzose sandstone and tuffaceous sandy siltstone (Farooqui and others, 1981). From water well logs the unit is as much as 100 m (330 ft) thick. Overlies Frenchman Springs Basalt at Pilot Rock and is overlain by loess (QTs) north of Pendleton. Age is based on Hemphillian mammal fossils (Shotwell, 1956; Farooqui and others, 1981).

**Tac** **Alkali Canyon Formation (upper Miocene to Pliocene)** — Interbedded fluvial and lacustrine sedimentary rocks deposited on top of Columbia River Basalt lavas in the northwest quarter of the study area. Lindsey and Tolan (1996) reported that the lower portion of the formation consists of interbedded, laminated to bedded clay and silt, diatomaceous silt, and conglomerate bearing exotic clasts interpreted to originate in the ancestral Snake River drainage. The top of the formation includes similar fine-grained deposits overlying exotic clast conglomerate of Hemphillian age. Maximum thickness from water well logs is 115 m (360 ft).

## Miocene Powder River Volcanic Field

### Sugarloaf Mountain Volcanics

**Tpsb** **trachyandesite (upper Miocene)** — Mainly thick (30 m) trachyandesite and basaltic trachyandesite lava flows that mark small, intensely eroded, shield volcanoes at Wilbur Mountain, Spring Mountain, Black Mountain, and Green Mountain. Each shield appears compositionally distinct. Lava at Spring Mountain is a pilotaxtic basaltic trachyandesite with clinopyroxene and olivine phenocrysts 3 mm in length. The Late Miocene age of the unit is based on three radiometric K/Ar dates of 6.54 ± 0.14 Ma, 7.26 ± 0.11 Ma, and 7.32 ± 0.15 Ma (Kienle and others, 1979).

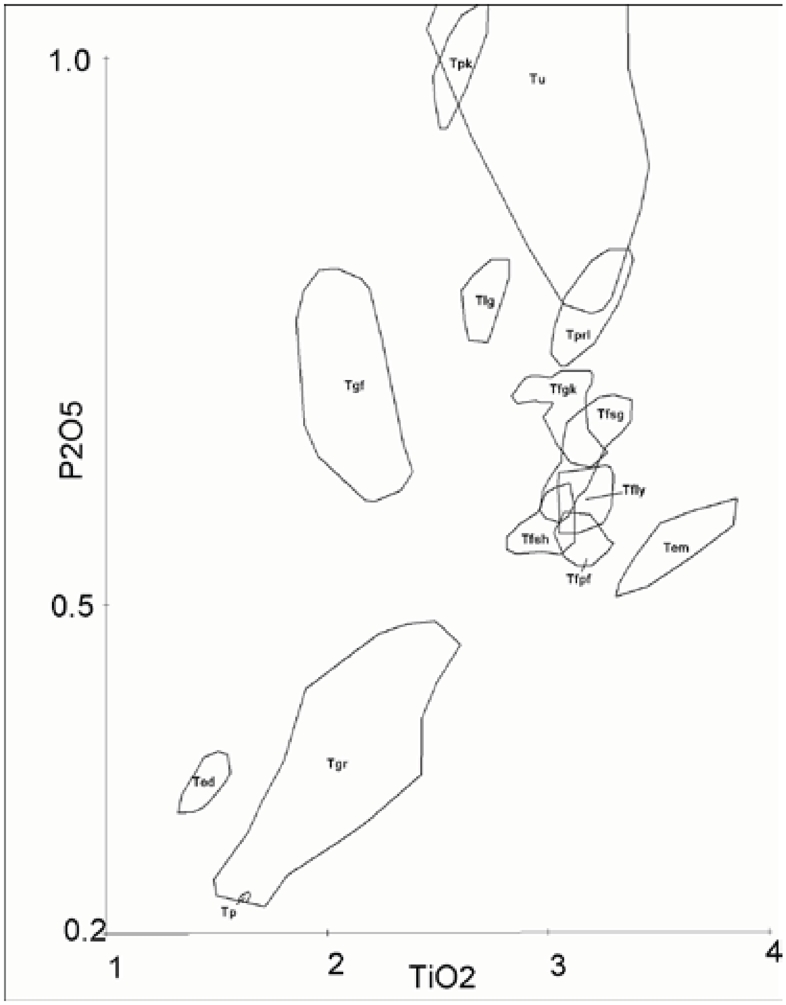



Figure 3. $TiO_2$–$P_2O_5$ plot of Columbia River Basalt units. Data from Hooper and others (1995), Ferns and others (2001), Kuehn (1995), Hooper and Swanson (1990), and Hutter (1997). Saddle Mountains Basalt: Tem, Elephant Mountain Member; Tp, Pomona Member; Tu, Umatilla Member. Wanapum Basalt: Tpk, Powatka Member; Tfly, Frenchman Springs Lyons Ferry; Tfsg, Frenchman Springs Sentinel Gap; Tfsh, Frenchman Springs Sand Hollow; Tfgk, Frenchman Springs Ginkgo; Tfpf, Frenchman Springs Palouse Falls. Grande Ronde Basalt: Tgf, Fiddlers Hell; Tgr, Grande Ronde N2, R2, N1, and R1.

## Glass Hill Volcanics

**Tpgb** **Olivine Basalt (middle Miocene)** — Flow-on-flow sequence of vesicular holocrystalline olivine basalts. Generally gray or light gray in color and weathering to compact rounded boulders in a granular soil. Characterized by a diktytaxitic texture where olivine phenocrysts as much as 3 mm in diameter are set in an open-textured groundmass of coarse feldspar laths. Individual basalt flows are typically 5 to 10 m (15 to 20 ft) thick. Locally separated from underlying Columbia River Basalt by thin layer of tuffaceous sediments, ash-flow tuff, or cobble gravels. The middle Miocene age of the unit is based on whole rock $^{40}Ar/^{39}Ar$ ages of 13.3 ± 0.8, 13.7 ± 0.1, and 14.4 ± 0.2 Ma for a similar olivine basalt flow to the southeast (Bailey, 1990).

## Miocene Ellensburg Formation

**Teb** **claystone and mudstone (middle Miocene)** — Mudstone and claystone interbed deposited between the top of the Frenchman Springs Member of the Wanapum basalt and the overlying Umatilla Member of the Saddle Mountains basalt. Possibly correlates to the Mabton interbed of the Ellensburg Formation. Thickness is about 7 to 10 m (20 to 30 ft).

**Teu** **claystone and mudstone (middle Miocene** — Mudstone and claystone interbed deposited between the Frenchman Springs and Lookingglass Members of the Wanapum basalt. Thickness is about 10 to 20 m (30 to 60 ft).

## Miocene Columbia River Basalt Group

Almost all of the study area is underlain by early to middle Miocene tholeiitic flood lavas of the Columbia River Basalt Group (CRBG). CRBG units in the quadrangle comprise but a small part of the approximately 164,000 $km^2$ of the Pacific Northwest underlain by CRBG flows (Tolan and others, 1989). Individual Columbia River Basalt Group map units are defined on the basis of stratigraphic position, geochemistry (Figure 3), magnetic polarity, and petrography following the work of Swanson and others (1981) and Reidel and others (1989). CRBG formations exposed in the map area include the Saddle Mountains Basalt, represented by three members; Wanapum Basalt, represented by four members; and the Grande Ronde Basalt, represented by three members.

### Saddle Mountains Basalt

The Saddle Mountains Basalt is represented by three members, which are largely confined to the lower reaches of the study area along the Columbia River. There are also scattered exposures in the highlands in the eastern portion of the area. Along the Columbia, the Saddle Mountains Basalt units are largely buried and are known mostly from water well logs and limited geochemical data derived from well cuttings. In this area it is generally possible to identify units in well logs on the basis of their stratigraphic position and the presence of interbeds. However, proceeding south from the Columbia River the units are eventually lost, and increasingly sparse well data make it difficult to accurately track various members. Hence, the southern extent of these units in the lower basin is very poorly constrained. Between Hermiston and Boardman the Saddle Mountains Basalt members are separated by sedimentary interbeds of the Ellensburg Formation. These interbeds are too thin to depict on the cross section and are not mapped at the surface. They include the Rattlesnake Ridge interbed (between the Elephant Mountain and Pomona Members), the Selah interbed (between the Pomona and Umatilla Members), and the Mabton interbed, which underlies the Umatilla Member.

Saddle Mountains Basalt Members are generally easily distinguished by their stratigraphic position, lithology, and geochemistry. Lithologic and petrographic descriptions of these units are from Swanson and others (1979). Geochemistry of surface and subsurface samples is presented in the chemical databases on the data CD-ROM.

#### *Elephant Mountain Member*

**Tem** **Elephant Mountain basalt (upper Miocene)** — Aphyric, fine-grained basalt flows. Distinguished geochemically by relatively high $TiO_2$ (3.59 percent) and moderate $P_2O_5$ (0.55 percent) (Figure 3). Unit is largely buried under Quaternary deposits through much of the study area and is exposed only along the Columbia River west of Boardman and in the lower reaches of Eightmile Creek. There are also small exposures around Boardman and south of Boardman. In the subsurface the unit can be traced east to within a kilometer or two of the Service Anticline; it appears to be absent east of the anticline. South of the Columbia River the limit of the unit is well defined only along Eightmile Creek. Near the Service Anticline the unit is very poorly constrained. Thickness from well logs ranges from 7 to 28 m (20 to 95 ft). Age is considered by Tolan and others (1989) to be 10.5 Ma. Magnetic polarity is transitional and normal (Swanson and others, 1979).

### *Pomona Member*

**Tp** **Pomona Basalt (middle Miocene)** — Sparsely phyric basalt, characterized by wedge-shaped plagioclase phenocrysts up to 5 mm long and scattered clinopyroxene and olivine phenocrysts. Locally contains clots of plagioclase, pyroxene, and olivine up to 10 cm across (Swanson and others, 1979). The unit is distinguished by very low $TiO_2$ (1.6 percent) and $P_2O_5$ (0.23 percent) (Figure 3). The unit is exposed in Eightmile Canyon, in patches around Hermiston and along the Service Anticline, and in broad flood-scoured regions east of Hermiston along the Columbia River. In the subsurface, the unit can be traced from near Cold Springs reservoir west to the edge of the study area. The southern edge of the unit is poorly constrained by scattered outcrops in the western part of the region, and is very poorly constrained between Hermiston and Echo. Thickness derived from well logs ranges from 25 to 55 m (80 to 180 ft). The overlying Rattlesnake Ridge interbed is typically reported by drillers as clay and is typically reported as 10 to 20 m (30 to 60 ft) thick. Age is considered by Tolan and others (1989) to be 12 Ma. Magnetic polarity is reversed (Swanson and others, 1979).

### *Umatilla Member*

**Tu** **undivided Umatilla flows (middle Miocene)** — Very fine grained basalt with rare small plagioclase and olivine phenocrysts. Locally displays ramp joints and flow banding. The unit is distinguished by high $TiO_2$ (2.9 percent), high $P_2O_5$ (0.92 percent), and very high barium (3200 ppm). Umatilla Member flows are commonly exposed in the highlands along the eastern edge of the area, in scattered exposures near Hermiston, and around Helix, Athena, and Milton-Freewater. In the subsurface the unit can be traced from Hermiston west to the edge of the study area and from the Columbia River south at least as far as Interstate Highway 84. Farther south the limit is poorly constrained. From water well logs and analyzed cuttings the unit is 15 to 45 m (50 to 150 ft) thick. Age considered by Tolan and others (1989) to be between 13 Ma and 14.5 Ma. The underlying Mabton interbed is typically 5 to 15 m (15 to 50 ft) thick. Magnetic polarity is normal (Swanson and others, 1979).

## Wanapum Basalt

The Wanapum Basalt is represented in the study area by four members: Priest Rapids (only in the subsurface), Powatka (informal), Frenchman Springs, and Lookingglass. Wanapum basalts are generally more compositionally similar than the Saddle Mountains basalts but can be distinguished, sometimes with difficulty, on the basis of lithology and geochemistry. In general, the unit is thickest along the Columbia River, where the unit is hundreds of meters thick, thins to nothing to the south, and thins to a few tens of meters to the east. Unlike the Saddle Mountains Basalt, where substantial sedimentary interbeds separate the members, the Wanapum Basalt flows are generally flow on flow with little or no intervening sediments.

### *Priest Rapids Member*

**Basalt of Lolo (middle Miocene)** — Fine-grained plagioclase and olivine-phyric basalt. Distinguished by relatively high $TiO_2$ (3 percent) and high $P_2O_5$ (0.78 percent). In the study area, the unit is known only from chemically analyzed cuttings from one well (MORR-1526) in Boardman. Absent from the appropriate stratigraphic interval in analyzed wells near Hermiston, the subsurface distribution is difficult to estimate but is probably restricted to the Boardman area, where all the overlying Saddle Mountains units are also fairly thick. Thickness at Boardman is 30 m (100 ft). Age is considered by Tolan and others (1989) to be 14.5 ma. Magnetic polarity is reversed (Swanson and others, 1979).

***Frenchman Springs Member***

The Frenchman Springs Member is a thick and widely distributed unit that comprises the chemically distinct and areally restricted Powatka flows and a series of six voluminous flow groups that are notoriously similar in appearance and chemistry and difficult to distinguish (Figure 3). All the flows are black to dark gray, aphyric to sparsely plagioclase-phyric, holocrystalline, tholeiitic basalt. Flows are typically 1 to 30 m thick, with rubbly flow tops and solid, jointed interiors. Here we have relied on distinctions made in previous studies, or we used new surface and subsurface geochemistry in areas in which previous studies did not differentiate flow groups. There are still large areas for which there are no data to distinguish flow groups; those areas are mapped as Frenchman Springs undifferentiated. The age of the Frenchman Springs Member as reported by Tolan and others (1989) is between 15.6 Ma (age of the top of the Grande Ronde Basalt) and 14.5 Ma (age of the Priest Rapids Member) with the age of the basalt of Sand Hollow, a Frenchman Springs flow group, determined as 15.3 Ma. The total thickness of Frenchman Springs Member rocks penetrated in analyzed wells ranges from 110 to 190 m (360 to 620 ft).

**Tpk** **basalt of Powatka (middle Miocene)** — Fine-grained-aphyric basalt restricted to the far eastern edge of the study area, where it occurs between the main body of the Frenchman Springs Member and the overlying Umatilla Member of the Saddle Mountains Basalt. Distinguished by moderate $TiO_2$ (2.7 percent) and very high $P_2O_5$ (1.2 percent). Unit is 15to 30 m (50 to 100 ft) thick. Magnetic polarity is normal (Hooper and Swanson, 1991).

**Tf** **undifferentiated Frenchman Springs basalt flows (middle Miocene)** — Unit is present largely south and west of the Umatilla River, where there is not sufficient data to divide out flow groups.

**Tfi** **intrusion, undifferentiated Frenchman Springs (middle Miocene)** — Dikes and moderately dipping sills, which cut Grande Ronde Basalt units. Vertical dikes are found along the eastern edge of the study area and south of Milton-Freewater. Sills are found near Blalock Mountain. The intrusions are distinguishable from the Grande Ronde flows by generally fresher appearance and inclined columns in the case of low-angle dikes, visible discordant margins, glassy chilled margins, and sometimes by the presence of large plagioclase phenocrysts (Kuehn, 1995). Kuehn reported an average strike and dip for the sills of N15°W, 12°W. South of Milton-Freewater, Swanson and others (1981) mapped sills that dip about 20°.

**Tfly** **basalt of Lyons Ferry (middle Miocene)** — Flows correlated with the basalt of Lyons Ferry are penetrated in several chemically analyzed wells and crop out in a few areas around Adams and Athena. These flows are distinguished from other Frenchman Springs flows by their high $TiO_2$ (3.2 to 3.3 percent) and stratigraphic position at the top of the section. Beeson and others (1985) reported that the unit is rarely to sparsely phyric with plagioclase phenocrysts that range from 0.5 to 1 cm and that the unit has a medium-grained groundmass and is microphyric with equant and acicular plagioclase microphenocrysts. The unit appears to be about 10 to 20 m (30 to 60 ft) thick in analyzed water wells.

**Tfsg** **basalt of Sentinel Gap (middle Miocene)** — Numerous flows of basalt, with widespread distribution through out the northern half of the study area. The unit is described by Beeson and others (1985) as rarely to sparsely phyric with plagioclase phenocrysts and glomerophenocrysts from 0.3 to 2 cm and a fine- to medium-grained groundmass that is sparsely to abundantly microphyric with equant and acicular plagioclase. The unit is distinguished from the underlying basalt of Sand Hollow by lower chromium (about 20 ppm) and from the overlying basalt of Lyons Ferry by lower $TiO_2$. Thickness in analyzed water wells ranges from 45 to 70 m (150 to 230 ft).

**Tfsh** **basalt of Sand Hollow (middle Miocene)** — Numerous flows of basalt, with widespread distribution throughout the northern half of the study area. The unit is described by Beeson and others (1985) as rarely to abundantly phyric with plagioclase phenocrysts and glomerophenocrysts from 0.3 to 3 cm and a fine to coarse-grained groundmass that is sparsely microphyric with acicular plagioclase. The unit is distinguished from the underlying basalt of Ginkgo by higher chromium (40 ppm), lower $TiO_2$ (2.9 to 3.0 percent) and $P_2O_5$ (0.56 percent), and higher MgO (4.3 to 4.4 percent). Thickness in analyzed water wells ranges from 60 to 105 m (200 to 345 ft).

**Tfgk** **basalt of Ginkgo (middle Miocene)** — Numerous flows of basalt, mapped in the Wallula fault escarpment west of Milton-Freewater by Hutter (1997) and at Blalock Mountain by Kuehn (1995). Also present in the subsurface near Hermiston. Hutter (1997) described a single flow fine-grained, with moderately abundant to highly abundant plagioclase phenocrysts/glomerocryst. Kuehn described a single Ginkgo flow that he believes was fed by nearby Ginkgo dikes and sills. Beeson and others (1985) described the unit as phyric to abundantly phyric with plagioclase phenocrysts and glomerocryst 0.3 to 2 cm and a fine- to medium-grained groundmass that is sparsely to abundantly microphyric with tabular plagioclase. The unit is distinguished from the underlying basalt of Palouse Falls by lower chromium (about 24 ppm) and higher $P_2O_5$ (0.67 to 0.71 percent). Thickness is about 30 m (100 ft) in the Wallula Fault escarpment, about 45 m (150 ft) at Blalock Mountain, and 25 m (80 ft) in the analyzed well (UMAT-5375) at Hermiston.

**Tfgi** **intrusions, basalt of Ginkgo (middle Miocene)** — Moderately dipping sills of Ginkgo chemical type mapped by Kuehn (1995) near Blalock Mountain.

**Tfpf** **basalt of Palouse Falls (middle Miocene)** — Three flows of basalt mapped in the Wallula fault escarpment west of Milton-Freewater by Hutter (1997). Lithology ranges from coarse grained with abundant plagioclase phenocrysts (upper flow) to aphyric with a glassy groundmass (lowest flow). All three flows have consistent chemistry except the lowest flow, which has anomalously high barium (about 1,000 ppm) (Hutter, 1997). Distinguished from other Frenchman Springs flows by its combination of high $TiO_2$ (3.18 percent) and chromium (40 ppm) and low $P_2O_5$ (0.54 percent). Thickness as mapped by Hutter (1997) is greater than 60 m (200 ft).

### *Lookingglass Member*

**Tlg** **basalt of Lookingglass (middle Miocene)** — Single flow of aphyric, fine-grained basalt found in a swath starting near the confluence of the North and South Forks of the Walla Walla River and extending southeast through Blalock Mountain, eastern Weston Mountain, and Buck Mountain. Distinguished from other CRBG units by its unique combination of moderate $TiO_2$ (2.7 percent) and high $P_2O_5$ (0.78 percent). The age is reported by Tolan and others (1989) to fall between 15.3 Ma (overlying Sand Hollow flows) and 15.6 Ma (underlying basalt of Sentinel Bluff). Magnetic polarity is normal (Hutter, 1997).

### Eckler Mountain Basalt

**Td** **basalt of Dodge (middle Miocene)** — Coarse-grained basalt with moderately abundant plagioclase phenocrysts and glomerocrysts to 2 cm. Flow or flows of basalt found capping ridges at Pikes Peak east of Milton-Freewater, further east along the extreme north edge of the area along Mill Creek, in the far east of the area at Yellowjacket Point and layered between the top of the Grande Ronde Basalt and the bottom of the

Lookingglass Member along the divide between Skookum Spring and Bone Spring. Magnetic polarity is normal (Swanson and others, 1979). The unit is distinguished by its unique combination of low $TiO_2$ (1.44 percent) and moderate $P_2O_5$ (0.33 percent). Thickness in the study area ranges from 10 to 15 m (30 to 45 ft) at Skookum Spring to over 60 m (200 ft) at Pikes Peak.

### Grande Ronde Basalt

Most of the Columbia River Basalt Group lavas exposed in the study area are part of the Grande Ronde Basalt. Regionally, Grande Ronde Basalt lava flows make up more than 85 percent by volume of the Columbia River Basal Group. The Grande Ronde Basalt consists of a monotonous flow-on-flow sequence of bluish-black aphyric to sparsely plagioclase phyric lava flows. Includes both holocrystalline and glassy lavas that weather to form steep slopes. Generally weathers to orange-brown, angular blocks. Differential weathering results in distinctive bench topography, where flow tops and basal breccias are marked by bands of trees. Grass-covered benches mark more resistant flow interiors. Separated into three magnetostratigraphic units on the basis of magnetic polarity as measured in the field by a fluxgate magnetometer. For the most part, flows do not differ markedly in chemistry. Chemically distinct high-silica ferroandesites that locally mark the top of the N2 unit have been separately mapped where possible. Magnetostratigraphic unit contacts on this map are taken entirely from the mapping of Swanson and others (1979), Hutter (1997), Kuehn (1995), and M. L. Ferns (personal comm., 2002). Due to the difficulty of separating chemical types within flow units, only the Fiddlers Hell unit has been differentiated beyond the magnetostratigraphic level.

**Tgf** **Ferroandesite of Fiddlers Hell (middle Miocene)** — Dark gray to gray and bluish-gray, aphyric to sparsely plagioclase-phyric lavas, usually glassy. Found along the southeast edge of the study area. Chemically distinctive, high-silica tholeiitic lava flows at the top of the N2 magnetostratigraphic have been designated a separate geochemical unit of the Grande Ronde Basalt, named as the Ferroandesite of Fiddlers Hell (Ferns and others, 2001). Commonly contains as much as 5 percent plagioclase and clinopyroxene phenocrysts. Separated from other CRBG units on the basis of conspicuously higher abundances of $SiO_2$ (56 to 62 percent), $K_2O$, $TiO_2$ (1.7 to 3 percent), and $P_2O_5$ (0.7 to 0.8 percent). The majority of Fiddlers Hell flows display normal magnetic polarity. Middle Miocene age based on 15.54 + 0.01 Ma $^{40}Ar/^{39}Ar$ age determination (Madin, 1998).

**Tgn2** **N2 magnetostratigraphic unit (middle Miocene)** — Flow-on-flow sequence of fine-grained, generally holocrystalline lava flows. Overlies the R2 magnetostratigraphic unit. The age of the N2 unit is between 15.5 and 15.7 ± 0.3 Ma (Baksi, 1989).

**Tgr2** **R2 magnetostratigraphic unit (middle Miocene)** — Flow-on-flow sequence of aphyric to sparsely plagioclase-phyric lava flows. Overlies the N1 magnetostratigraphic unit and is overlain by the N2 magnetostratigraphic unit. The age of the R2 unit is between 15.7 + 0.3 and 15.9 + 0.2 Ma (Baksi, 1989).

**Tgn1** **N1 magnetostratigraphic unit (middle Miocene)** — Flow-on-flow sequence of aphyric to sparsely plagioclase phyric lava flows. Overlies the R1 magnetostratigraphic unit and is overlain by the R2 magnetostratigraphic unit. The age of the N1 unit is between 15.9 + 0.2 Ma and approximately 16.1 Ma (Baksi, 1989).

**Tgr1** **R1 magnetostratigraphic unit (lower and middle Miocene)** — Flow-on-flow sequence of mainly plagioclase-phyric holocrystalline lava flows. Present only in the subsurface. Although the age of the R1 unit is generally accepted as being between 16.1 Ma and 17.0 ± 0.3 Ma (Baksi, 1989), Madin (1998) reported an $Ar^{40}/Ar^{39}$ date of 15.5 + 0.1 Ma from a Buckhorn Springs flow in the Tucker Flat quadrangle.

## Paleocene to Oligocene Volcanic and Sedimentary Rocks

**Tc** **Clarno Formation undivided (upper Eocene to lower Oligocene)**—Interbedded andesite, andesite porphyry, and basalt flows, tuff, and volcanic debris flows, exposed along the crest of the Blue Mountain anticline at the head of Willow and Rhea Creeks. Shorey (1976) described over 175 m (575 ft) of Clarno Formation divided equally between flow rocks and volcaniclastics. Although contact relations with the underlying Herren Formation are not clear, Shorey (1976) also reported Clarno Formation andesite dikes in the adjacent Herren Formation, suggesting that part of the Clarno is as old as Eocene. The unit includes coarsely porphyritic dacite dikes and sills that crop out along Birch Creek. The dikes typically contain quartz phenocrysts and chalky white, blocky feldspar phenocrysts up to 1 cm in diameter. Commonly biotite and hornblende-phyric and characteristically heavily altered, with biotite commonly converted to a mixture of white mica, chlorite, and carbonate. Includes a heavily altered rhyodacite dike marked by small, rounded quartz phenocrysts set in a dense groundmass composed of cryptocrystalline silica and potassium feldspar. Eocene age and correlation with the Clarno Formation is based on the presumption that the unit includes flows interbedded with Eocene sandstone (Trauba, 1975; Pigg, 1961; Hogenson, 1964).

**Tca** **Clarno Formation andesite porphyry (Eocene to Oligocene)**—Tabular masses of andesite porphyry that occur within the Eocene Herren Formation along the axis of the Blue Mountain Anticline near the head of Willow Creek and Butter Creek. Ferns and Brooks (1986) interpreted the bodies as either andesite flows from a nearby vent or as sills and dikes. Although the masses occur in older Herren Formation rocks, they are included here with the overlying Clarno because of their lithologic affinity and because it is likely that the ages of the two units overlap.

**Th** **Herren Formation (lower Eocene and upper Paleocene)**—Mainly interbedded, medium-grained, arkosic sandstone, gray silt- and mudstone, and carbonaceous shale. Medium- and coarse-grained sandstones are moderately to poorly sorted lithic arkose characterized by feldspar, quartz, and muscovite grains. Accessory minerals include biotite, garnet, zircon, and staurolite. Lithic fragments are metamorphic or granitic and are composed of quartz, feldspar, and muscovite. Unit includes friable, fine-grained micaceous sandstone and black to greenish-gray siltstone and shale. Sandstones commonly display planar crossbeds. Interbedded, fine-grained sedimentary rocks range from finely laminated black, organic rich shales to yellowish white siltstone. Leaf fossils are locally abundant. Unit is over 400 m (1,300 ft) thick at East Birch Creek and is interpreted as a deltaic sequence that coarsens upward (Fisk, 1986; Elmendorf and Fisk, 1978). Ferns and Brooks divided the unit into three members at Arbuckle Mountain; a 90-m- (300 ft) thick basal unit of medium to coarse arkose and coarse conglomerate including boulders of the underlying quartz diorite basement, a middle section about 45 m (150 ft) thick of micaceous sandstone and siltstone with lignite and shale beds, and a highly weathered upper section of orange-yellow medium to coarse feldspathic arenites. Shorey (1976) described the unit as 600 m (2,000 ft) thick at Bald Mountain and composed of arkose with interbedded mudstone, carbonaceous shale, and minor coal seams that occur in normally graded sets of strata that grade up from coarse arkose to shale and mudstone. Sedimentary structures indicative of fluvial deposition are common (Shorey, 1976) and include festoon cross-bedding, planar cross beds, asymmetric ripples, load casts, and channel fills; sparse paleocurrent indicators suggest flow from the southeast. Shorey (1976) collected leaf fossils indicative of early to middle Eocene age from the Bald Mountain section. Late Paleocene to early Eocene plant fossils have also been recovered from Birch Creek and Pearson Creek (Fisk, 1986; Gordon, 1985; Elmendorf and Fisk, 1978).

## Mesozoic Intrusive Rocks

**Carney Butte stock (upper Jurassic or lower Cretaceous?)**

The Carney Butte stock is a composite intrusion exposed along the southern edge of the study area astride U.S. Highway 395. The stock and satellite intrusions are generally deeply weathered and poorly exposed. The intrusive suite includes gabbro, tonalite, trondhjemite, and two-mica granite. None of the intrusions have been radiometrically dated; Late Jurassic or Early Cretaceous ages are assigned on the basis of similarities to other granitoid intrusions in northeast Oregon. Individual units include:

**KJcg** **Granodiorite of Table Mountain (upper Jurassic or lower Cretaceous?)** — Light gray to white, medium-grained granodiorite. Generally poorly exposed and slightly foliated. Typically contains about equal amounts of plagioclase and quartz, about 5 modal percent orthoclase, and about 2 percent modal percent biotite and muscovite (Trauba, 1975). Accessory minerals include zircon, apatite, iron oxide, and rare garnet. Slightly cataclastic textures evidenced by mortar-textured quartz and plagioclase rims. Alteration minerals include white mica, epidote, and red iron oxide (Trauba, 1975).

**KJct** **Trondhjemite of Johnson Creek (upper Jurassic or lower Cretaceous?)** — Light-gray, medium-grained hornblende trondhjemite. Typically hypidiomorphic-granular with about equal amounts of plagioclase and quartz and about 5 modal percent hornblende and with only a minor amount of biotite (Trauba, 1975); accessory minerals include apatite, zircon, and iron oxide. Alteration products include chlorite and epidote. Quartz crystals display mortar textures and undulatory extinction; evidence of late-stage cataclasis (Trauba, 1975). Chemical composition ranges from 67.0 to 76.0 weight percent $SiO_2$, 13.02 to 16.7 weight percent $Al_2O_3$, and 0.21 to 0.37 weight percent $K_2O$.

**Jcda** **Diorite of Alexander Creek (upper Jurassic?)** — Light-gray to gray, medium- to coarse-grained hornblende diorite. Deeply weathered and generally poorly exposed; usually mantled by deep gruss. Typically hypidomorphic-granular in texture, with plagioclase and hornblende and about 12 modal percent quartz and 6 modal percent biotite (Trauba, 1975). Accessory minerals include apatite, zircon, iron ore, and a yellow sulfide mineral. Alteration minerals include colorless amphibole, epidote, white mica, chlorite, and red iron oxides. Unit is locally foliated along contacts with metasedimentary country rock and contains numerous metasedimentary and hornblendite xenoliths (Trauba, 1975). Chemical composition ranges from 56.8 to 57.8 $SiO_2$, 16.4 to 16.9 weight percent $Al_2O_3$, and 0.65 to 0.69 weight percent $K_2O$ (Trauba, 1975). Unit apparently intrudes the gabbronorite of Carney Butte.

**Jcnc** **Gabbronorite of Carney Butte (upper Jurassic?)** — Gray to dark gray, medium-grained quartz-gabbronorite. Typically hypidiomorphic granular in texture with subanhedral plagioclase and poikilitic hornblende crystals and about 10 modal percent hypersthene, 3 modal percent pale green augite, about 3 modal percent quartz, and rare biotite (Trauba, 1975). Accessory minerals include apatite, iron ore, and a yellow sulfide mineral. Alteration minerals include clear amphibole, chlorite, white mica, and red iron oxides. Unit is locally cut by garnet- and tourmaline-bearing pegmatites. Chemical composition ranges from 53.2 to 54.5 weight percent $SiO_2$, 17.3 to 18.82 weight percent $Al_2O_3$; and 0.24 to 0.48 weight percent $K_2O$ (Trauba, 1975).

**Jcbr** **Gabbronorite of Ridenor Canyon (upper Jurassic?)** — Fine- to medium-grained, gray, pyroxene-hornblende gabbronorite. Typically deeply weathered, massive, and devoid of xenoliths. Compositionally heterogeneous, ranging from coarse-grained pyroxene hornblendite made up of large hypersthene and hornblende crystals to medium-grained, allotromorphic, granular-textured gabbronorite made up of plagioclase and hornblende crystals and about 15 modal percent augite and 10 modal percent hypersthene (Trauba, 1975); accessory minerals include zircon, apatite, and iron ore. Alteration minerals include actinolite, tremolite, chlorite, carbonate, epidote, white mica, and red iron oxides. Chemical composition ranges from 44.0 to 50.8 weight percent $SiO_2$, 3.4 to 19.0 weight percent $Al_2O_3$, and 0.4 to 0.40 weight percent $K_2O$ (Trauba, 1975).

### Upper Rhea Creek Intrusives

KJtj **trondhjemite of Coalmine Hill (Jurassic to Cretaceous)** — Small plugs of trondhjemite to granodiorite that intrude older metamorphic rocks at Coalmine Hill. Shorey (1976) described the plugs as fine-grained, leucocratic and pervasively altered, stained orange, and silicified. Shorey (1976) correlated them with the Jurassic-Cretaceous Bald Mountain and Wallowa batholiths on the basis of a lack of blue quartz and high $K_2O$ content. However, these rocks may be related to other Paleozoic-age trondhjemites in the area.

## Mesozoic and Paleozoic Metamorphic Rocks

MzPzm **metamorphic rocks, undivided (Jurassic to Permian)**

### Mountain Home Metamorphic Complex

Variably metamorphosed Mesozoic and Paleozoic igneous and sedimentary rocks are exposed in widely separated areas along the crest of the Blue Mountains Anticline. Although the foliated, regionally metamorphosed rocks and intercalated, deformed intrusive rocks exposed adjacent to the Carney Butte stock have been assigned by various authors to either the Baker terrane (Vallier, 1995) or the Wallowa terrane (Avé Lallemant, 1995), similar regionally metamorphosed rocks have not been described elsewhere in northeast Oregon. Ferns and others (2001) considered the rocks separate from any known terrane and assigned them to the Mountain Home Metamorphic Complex.

JTRmy **Biotite schists of Yellow Jacket Road (Triassic-Jurassic)** — Black to dark brown, fine-grained mica schist. A deeply weathered, prominently foliated, complexly folded, biotite-rich mica schist that is best exposed along road cuts. Typically finely laminated; breaking apart along micaceous partings. Contact with adjoining intrusive is a broad migmatite zone marked by lensoid and irregularly shaped masses of hornblende- and biotite-rich diorite. Metamorphic mineral assemblages in pelitic rocks include quartz + biotite + garnet + muscovite + plagioclase, quartz + biotite + muscovite + staurolite, quartz + biotite + hornblende, and quartz + sillimanite + staurolite + biotite. Metamorphic protolith assumed to have been fine-grained metavolcanic sediments; chemical composition of one mica schist is 67.12 weight percent $SiO_2$, 14.33 weight percent $Al_2O_3$, and 2.49 weight percent $K_2O$. Includes rock unit mapped as hornblende gneiss by Trauba (1975) that includes hornblende + plagioclase gneiss and plagioclase + quartz + garnet gneiss. Amphibolite gneiss includes low-potassium basalts, on the basis of an analysis of 52.97 weight percent $SiO_2$, 16.16 weight percent $Al_2O_3$, and 0.27 weight percent $K_2O$. Age uncertain, appears tectonically intercalated with metagabbro and intruded by diorite of Alexander Creek. On basis of metamorphic structures was considered by Avé Lallemant (1995) to be part of the Wallowa terrane. If the structural correlation is correct, the metamorphic fabric was imposed in the Late Jurassic — in which case, these rocks may be highly metamorphosed equivalents to Late Triassic Lower Sedimentary Series or Late Triassic–Jurassic Hurwal Formation.

TRPms **Chlorite-mica schists of Pearson Creek (Permian, Triassic–Jurassic?)** — Gray-green to pale yellow-green, fine-grained, chlorite-mica schist. Typically massive with a distinct foliation marked by shear planes.

Ranges from fine-grained schist and phyllite to coarse chlorite schist. Metamorphic mineral assemblages include white mica + quartz + quartz, chlorite + quartz; and quartz + white mica + plagioclase + chlorite + epidote. Trauba (1975) reported relict sheared plagioclase and quartz phenocrysts as evidence for metavolcanic protolith. Geochemical analyses suggest a silicic metavolcanic protolith for exposures on Pearson Creek with 73.78 to 79.42 weight percent $SiO_2$, 10.77 to 14.39 weight percent $Al_2O_3$, and 0.22 to 1.52 weight percent $K_2O$. Age is uncertain; Avé Lallemant (1995) presented metamorphic structural evidence linking exposures to the Wallowa terrane. Relationship to schists of Yellow Jacket Road is unclear; mineralogical differences may reflect a lower metamorphic grade rather than lithologic contrast as suggested by Trauba (1975). Unit is apparently intruded by geochemically similar metatrondhjemite of Pearson Creek prior to metamorphism (Trauba, 1975).

**TrPj** **Metatrondhjemite (Permian or Triassic)** — Light gray, medium-grained metatrondhjemite. Typically consists of deformed, mortar-textured plagioclase and quartz crystals with about 4 modal percent hornblende and scarce biotite. Igneous feldspars nearly completely replaced by albite, clinozoisite, and white mica; hornblende is partially replaced by biotite, epidote, and chlorite. Geochemically similar to metavolcanic rocks in adjoining chloritic greenschists, with 76.04 weight percent $SiO_2$, 13.0 weight percent $Al_2O_3$, and 0.21 weight percent $K_2O$ (Trauba, 1975). Permian or Triassic age is inferred from lithologic similarities to other metamorphosed, low-potassium intrusive complexes in northeast Oregon.

**TrPt** **Metatonalite (Permian or Triassic)** — Gray to dark gray, coarse- to medium-grained metatonalite. Typically foliated, with gneissic appearance due to elongated clots of biotite and hornblende. Characterized by a pronounced lepidoblastic texture characterized by annealed quartz and plagioclase crystals. Relict igneous minerals include plagioclase, hornblende, quartz, and biotite. Biotite is often partially replaced by chlorite and white mica, while hornblende is partially replaced by epidote and biotite (Trauba, 1975). Geochemical analyses are typical of low-$K_2O$ metamorphic trondhjemite–tonalite complexes, with 60.0 to 67.0 weight percent $SiO_2$, 16.3 to 16.4 weight percent $Al_2O_3$, and 0.21 to 0.37 weight percent $K_2O$ (Trauba, 1975). Age is unknown but presumed to be Permian or Triassic in age from lithologic similarities to other metamorphosed low-potassium intrusive complexes in northeast Oregon.

**TrPg** **Metagabbro (Permian or Triassic)** — Dark greenish-gray, medium-grained metagabbro. Typically a distinctly foliated hornblende metagabbro composed of plagioclase, hornblende, and minor relict clinopyroxene. Unit includes hornblende schist and porphyroblastic hornblende gneiss. Commonly retains relict igneous textures (Trauba, 1975). Metamorphic mineral assemblages include actinolite + tremolite + chlorite and plagioclase, hornblende, biotite, and quartz. Along one contact with schistose metasediments, lenses of metagabbro are intercalated along foliation planes (Trauba, 1975). Geochemical analyses show notably low $K_2O$ abundances, with 51.8 to 52.0 weight percent $SiO_2$, 16.6 to 18.9 weight percent $Al_2O_3$, and 0.18 to 0.24 weight percent $K_2O$ (Trauba, 1975). Age is unknown but presumed to be Permian or Triassic from lithologic similarities to other metamorphosed, low-potassium intrusive complexes in northeast Oregon.

**TrPh** **Hornblendite and hornblende gabbro (Permian or Triassic?)** — Green to greenish-black, coarse-grained hornblendite. Generally poorly exposed, weathering to reddish brown, iron oxide stained outcrops. Hornblendite typically consists of more than 90 modal percent green hornblende. Intersertal minerals include quartz, plagioclase feldspar, apatite, and zircon; alteration minerals include light green amphibole, chlorite, sphene, and titaniferous iron oxide (Trauba, 1975). Includes samples with more than 90 modal percent colorless to light brown amphibole that displays high birefringence. Analyzed sample contained 49.43 weight percent $SiO_2$, 9.11 weight percent $Al_2O_3$, and 0.15 weight percent $K_2O$. Intruded by the Alexander Creek diorite. Interpreted as metamorphosed pyroxenite.

TrPu **serpentine (Permian or Triassic?)** — A serpentinite mass crops out adjacent to hornblende gneiss in the Mountain Home Metamorphic complex. Trauba (1975) noted that the rock is extensively serpentinized, relict olivine crystals are nearly totally converted to mesh-textured serpentine minerals, and hypersthene is nearly totally uralitized

### Baker Terrane

Baker Terrane units form an eastward-trending belt of extensively disrupted late Paleozoic and early Mesozoic ocean-floor and island arc rocks. Baker terrane units in the study area occur at the head of Rhea and Willow Creeks and were assigned to the terrane by Shorey (1976) on the basis of lithologic similarities.

Trtw **trondhjemite of Willow Creek (Triassic)** — Small pluton of medium- to coarse-grained trondhjemite at the head of Willow Creek that intrudes metagabbro and is overlain by the Herren Formation. Shorey (1976) mapped the pluton and assigned it to the Baker terrane on the basis of lithology and the presence of blue quartz. Age is based on correlation with Triassic age trondhjemites elsewhere in the Baker terrane.

Trmg **metagabbro (Triassic)** — Fine-grained, dark-green gabbro and medium-grained, green-gray gabbro that occur at the head of Willow Creek. Assigned by Shorey (1976) to the Baker terrane on the basis of similar lithology and assigned a Triassic age on the basis of that correlation. Gabbro is made of plagioclase, pyroxene, fibrous green amphibole, and trace sulfides. The rock is weakly foliated.

Trmt **metatroctolite (Triassic)** — Elongate pods of metatroctolite up to 100 m (330 ft) long occur within the metagabbro described above (Shorey, 1976). The metatroctolite consists of olivine and plagioclase with minor pyroxene, and exhibit cumulate textures with layers rich in euhedral olivine and others of plagioclase ad poikilitic pyroxene. Age Triassic by association with the metagabbro.

Tru **serpentinite (Triassic)** — Small pod of serpentinite located at the head of Rhea creek. Shorey (1976) described it as dark green, very fine grained, foliated rock and assigned it a Triassic age. The rock is serpentine with minor olivine, brucite, bronzite, magnesite, and chromite and has relict textures suggesting it was originally peridotite.

TrPa **amphibolite (Permian-Triassic)** — Small bodies of amphibolite interbedded with metasedimentary rocks of Elkhoen Ridge argillite (TrPe) at the head of Rhea creek. Shorey (1976) described the rocks as fine-grained foliated rock composed of plagioclase, amphibole, and minor sulfide and assigned it a Permian-Triassic age and likely metavolcanic origin.

TRPe **Elkhorn Ridge Argillite (Triassic, Permian, Pennsylvanian, and Devonian?)** — Interbedded phyllite, chert, biotite schist, and biotite-garnet gneiss, with minor marble and amphibolite, mapped by Shorey (1976) at the head of Rhea Creek. Shorey assigned these greenschist facies metamorphic rocks to the Elkhorn Ridge Argillite of the Baker terrane on the basis of lithology and metamorphic grade. Permian and Triassic age range is based on invertebrate fossils from limestone pods and ribbon chert at exposures outside the study area. Pennsylvanian (Coward, 1983; Ferns and others, 1987: Blome and others, 1986), and questionable Devonian fossils have also been reported (Morris and Wardlaw, 1986; Evans, 1989; 1995) from the Elkhorn Ridge Argillite outside the study area.

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