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Department of Geology and Mineral Industries
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PRELIMINARY GEOLOGIC MAP OF THE OCHOCO RESERVOIR 7.5′ QUADRANGLE, CROOK COUNTY, OREGON

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PRELIMINARY GEOLOGIC MAP OF THE OCHOCO RESERVOIR 7 ½' QUADRANGLE

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INTRODUCTION

The Ochoco Reservoir 7 ½' quadrangle is situated at the junction of Ochoco Creek and Mill Creek, near the intersection of the High Cascades, High Lava Plains, and Blue Mountains geomorphic provinces. Topographic relief in the quadrangle ranges from 3001 ft (915 m) along the juniper- and sage-covered high desert terrain of the valley floor of Ochoco Creek to 4485 ft (1367 m) in the pine and juniper forested Ochoco Highlands on the north. The quadrangle encompasses a historic ranching and logging community that is transforming to a rural residential and recreation population. This map depicts a preliminary stratigraphic assessment for the Ochoco Reservoir area and provides a framework for further geologic and geohydrologic analysis of the Lower Crooked River Basin.

The Ochoco Reservoir quadrangle consists of a succession of Tertiary volcanic and sedimentary strata and includes from oldest to youngest: 1) Eocene lava flows and intrusive rocks of the Clarno Formation; 2) Oligocene rhyolite, tuff, and sedimentary rocks of the John Day Formation; 3) Oligocene(?) to Miocene sedimentary rocks; 4) middle Miocene basalt flows of the Prineville Basalt; 5) late Miocene to Pliocene sediments and lava flows of the Deschutes Formation; and 6) Quaternary surficial and valley fill deposits. A basement of Eocene andesite and dacite lava flows form a volcanic uplands in the northeast corner of the quadrangle. These flow rocks are invaded, displaced, and capped by bulbous to linear dacite and rhyolite intrusions that outcrop along the north and eastern edges of the quadrangle. Basement volcanic rocks are unconfomably overlain by south dipping, tuff, sedimentary rocks, and rhyolite that extend west of Ochoco Reservoir to the southern extreme of the map area. On Combs Flat, John Day strata are unconformably overlain by Oligocene to Miocene sedimentary rocks and the Prineville Basalt. Plateau-forming basalt of the Deschutes Formation fills and caps the channels incised into middle Miocene strata. Quaternary alluvium and terrace deposits of the Crooked River and tributary streams fill modern drainages. Ochoco Reservoir is lined by quaternary landslide deposits.

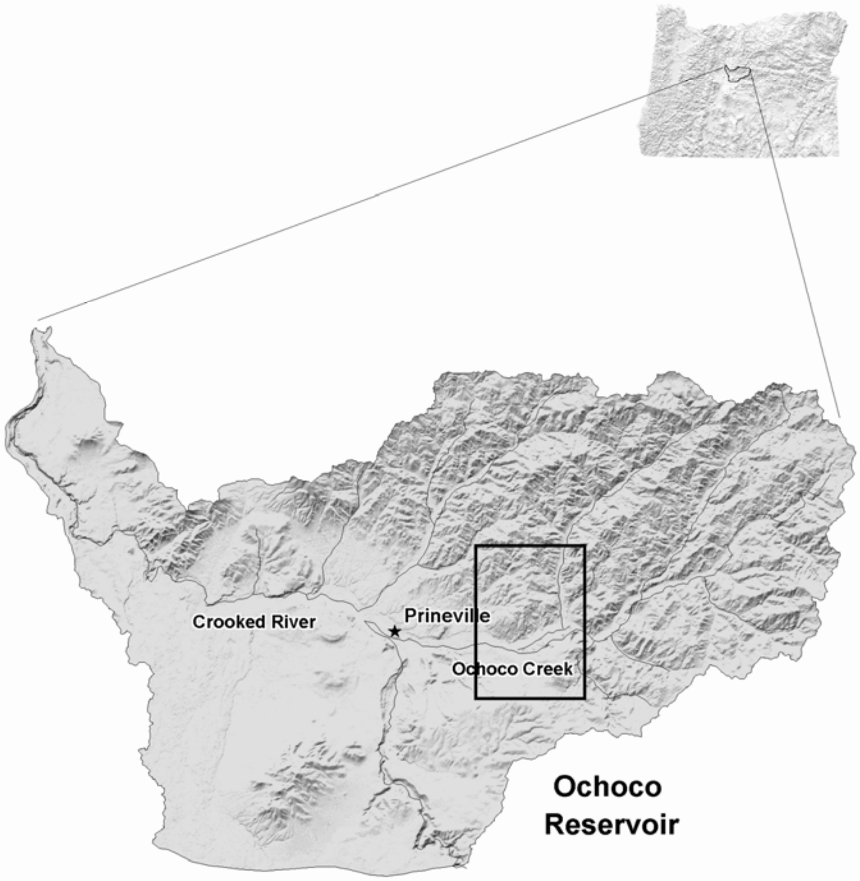

Figure 1. Digital Elevation Model (DEM) of the Lower Crooked River Basin, showing location of the Ochoco Reservoir quadrangle.

Methodology and Previous Work

The 1:24,000 scale geologic map of the Ochoco Reservoir quadrangle was funded by the USGS National Cooperative Geologic Mapping Program. 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 map is released as an interim open-file map product as part of a larger mapping project covering the Lower Crooked River basin (Figure 1) and has not yet been peer reviewed. The United States Government is authorized to reproduce and distribute reprints for governmental use. Geologic data were collected at the 1:24,000 scale combining new mapping with published and unpublished data from air photos, orthophotoquads, and digital shaded relief images derived from USGS 10 m DEM (Digital Elevation Model) grids. Mapping was supplemented with x-ray fluorescence (XRF) geochemical analyses from Franklin and Marshall College, Lancaster, PA. Age-date samples prepared and analyzed by the College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, Oregon. Subsurface geology in cross sections is based on analyses of water-well drill records.

Detailed geologic maps of the Prineville area are of comparatively recent vintage. The first large scale reconnaissance geologic maps for the area were made by Hodge (1942) and Williams (1957). Later mapping efforts focused on groundwater studies and mercury mineralization (Robinson and Price, 1963; Waters and Vaughn, 1968), enabling Swanson (1969) to produce a more detailed 1:250,000 scale map of the east half the Bend AMS sheet. Subsequent studies included an investigation of the geothermal potential at Powell Buttes (Brown and others, 1980). In the 1990's, the U.S. Geological Survey and Oregon Department of Water Resources began a detailed study of the upper Deschutes Basin; (Gannett and others, 2001, Lite and Gannett, 2002). The current mapping effort is designed in part to better define the geologic conditions along the east margin of the upper Deschutes Basin, building off of the stratigraphy established by Smith (1986a) and Sherrod and others (2004).

PRELIMINARY DESCRIPTION OF GEOLOGIC UNITS – OCHOCO RESERVOIR 7 ½' QUADRANGLE, CROOK COUNTY, OREGON

Surficial Deposits

Qa **Stream alluvium (Holocene and late Pleistocene)** – Gravel, sand, and silt deposited in active stream channels and on adjoining flood plains. Includes gravel and channel sand deposited in active or recently active channels and overbank fines deposited on the modern flood plains of Ochoco Creek and Mill Creek.

Qls **Landslide deposits. (Holocene and Pleistocene)** – Unconsolidated clast-supported breccia deposited by gravity-driven mass-wasting processes. Landslide deposits in the Ochoco Reservoir quadrangle are subdivided into those derived from the rhyolite of Ochoco Reservoir and those derived from Deschutes Formation plateau basalts. Rhyolite-derived landslide deposits consist of unconsolidated, clast-supported, interlocking cobble and boulder-dominated, chaotically mixed breccia with clasts of flow-banded rhyolite (Tjor) and white tuffaceous sedimentary rocks (Tjs). Gravel-sized clasts have maximum diameters of several meters across. The matrix component (15% of the volume) and consists of purple to white silt- to sand-sized grains of rhyolite and tuffaceous sedimentary rocks; the crushed equivalent of the gravel-sized clasts. Cliff-forming source scarps, segmented by distinct, cliff-parallel, tension cracks up to 100-m-long, are based in southerly dipping outcrops of the rhyolite of Ochoco Reservoir north of Ochoco Dam. Rhyolite-dominated landslide deposits onlap sedimentary rocks of unit (QTsg) at the western edge of the quadrangle. Thickness is highly varied; maximum thickness several tens of meters.

Basalt-derived landslide deposits form irregular slopes to the south of Ochoco Creek. These landslide deposits consist of unconsolidated, clast-supported, interlocking boulders of basalt deposited from toppling, en masse rotation, and rock avalanches. Clast-size averages 1-3-m-across, with the maximum intact landslide blocks up to 300-m-across. Crackle- and jigsaw-breccia fabrics are common in clasts (sensu stricto Yarnold and Lombard, 1989). Landslides originate from oversteepened, tension-cracked cliff-faces that calve and topple or rotate listrically along fractured columnar joint margins. Older slides have vegetated and soil-mantled upper surfaces; more recent deposits lack vegetation and soil and in places may be confused for tumuli capped intracanyon flows. Includes rhyolite landslide debris reworked and deposited by sediment gravity flows on the right abutment of Ochoco Dam and basalt landslide debris on the left abutment of Ochoco Dam. Thickness is highly varied; maximum thickness several tens of meters.

Qt **Terrace deposits (Pleistocene) –** Abandoned terraces of Ochoco Creek. Based on water well logs, the terrace deposits consist of brown to red clay, well-sorted gravel, and brown sand. The maximum thickness is approximately 20 m. Differentiated from Qal of Waters and Vaughan (1968) on the basis of stratigraphic position and topographic expression.

Tertiary Volcanic and Sedimentary Rocks

QTsg **Stratified sedimentary rocks (Pliocene to Pleistocene?) –** Moderately cemented to unconsolidated, brown, massive pebbly sandstone, gray to black plane-parallel to trough cross-stratified sandstone, and well-sorted pebble to cobble conglomerate. Age is unknown. The unit unconformably overlies John Day Formation unit Tjt and is overlain by Quaternary surficial deposits, including a rhyolite-dominated Qls deposit in the west portion of the map area, 1.6-km-west of Ochoco Dam. Differentiated from the fluviolacustrine deposits (Qpa) of Robinson and Price (1963) and unit Qs of Swanson (1969) based on lithologic character and stratigraphic position. Water-well drill logs indicate unit QTsg may be up to 55-m-thick.

Td – Deschutes Formation (Pliocene and late Miocene) Interbedded lava flows and sedimentary rocks. Equivalent to the Deschutes Formation of Smith (1986a) and subdivided into:

Tdsg **Plateau mantling sand and gravel (Pliocene and late Miocene?) –** Degraded, unconsolidated sand and gravel that caps late Miocene plateau-forming basalts. The sand component is fine-to medium-grained, well-sorted, and consists of angular to subround grains of clear feldspar (70 percent by volume), amphibole (15 percent), white pumice (10 percent), quartz (3 percent), and magnetite (2 percent). Some mineral grains maintain a euhedral crystal form. The gravel is moderately sorted, locally imbricated, and consists of subround to well-rounded, cobble-sized clasts of basalt, andesite, dacite, and rhyolite. The gravel is exposed as surface-armoring lag deposits, in-situ reworked upper surfaces of basalt lava flows, and incised channel deposits. The thickness of the unit is variable.

Tdp **Pyroclastic rocks (Pliocene) –** Cindercone capping the vent at the east end of Combs Flat. Unconsolidated, poorly sorted, pebble- to cobble-sized, angular to well-rounded, red scoria fragments that rest in a tan-yellow palagonite matrix. Scoria deposits contain interspersed cobble- to boulder-sized fluidal vesicular olivine-phyric basalt bombs up to 2.5-m-across. The pyroclastic cone is mantled by sand and gravel of unit Tdsg.

Tdv **Basalt vent (Pliocene) –** Low-profile shield on the east end of Combs Flat composed of open-textured, olivine-phyric basalt lava flows. The vent flow surface morphology consists of tumuli, flow lobes, and small (<1-m-across) lava tubes. The basalt vent at

Combs Flat is capped by a small cindercone (Tdp) and is mantled by degraded sediment of unit Tdsg.

Tdib **Basalt feeder dike (Pliocene) –** Erosionally resistant, vertically-oriented olivine- phyric basalt dike that invades and crosscuts vent rocks (Tdv) at the east end of Combs Flat. The Combs Flat feeder dike is not well-exposed, but is inferred from a N30°W trending structure visible on ortho-airphotos that cuts across the central to east margin of the Combs Flat vent. The apparent dike structure is ~2.8-km-long and ~40-m-wide.

Tdbc **Basalt of Combs Flat (Pliocene)** – Gray, coarse-grained, vesicular plagioclase- and olivine-phyric basalt flows that form the plateau south of Ochoco Creek. Displays multiple flow lobes whose flow tops are marked by tumuli. Bases to individual lobes are marked by basal flow breccias and collapsed lava tubes. In thin section, the basalt displays a diktytaxitic texture marked by euhedral plagioclase phenocrysts (up to 1 mm in diameter) and olivine phenocrysts (up to 2 mm in diameter) set in groundmass of plagioclase lathes separated by olivine and clinopyroxene grains and subophitic clinopyroxene crystals. Samples from the Ochoco Reservoir quadrangle display low titanium content; with ~ 50.25 weight percent SiO_2; 17 weight percent Al_2O_3; 1.29 weight percent TiO_2, and 0.45 weight percent K_2O (Samples 23 and 27, Table 1.1). The unit rests on irregular surface of Deschutes Formation gravel and sandstone and unconformably overlies unit Tmos sedimentary rocks, Prineville basalt (Tmcp), or John Day and Clarno volcanic rocks. Displays reversed magnetic polarity. Traceable to a vent complex to on the east end of Combs Flat. A Pliocene date is based on a K-Ar radiometric age of 3.36 $\pm$ 0.08 Ma (Smith, 1986a after Sutter, unpub.)(Sample A3, plate 1; Table 1.2). Equivalent in part of to unit Qob of Waters and Vaughan (1968) and unit QTb of Swanson (1969).

Tcp **Prineville Basalt (middle Miocene)** – Dark gray to black, fine-grained, plagioclase-phyric and aphyric basalt, basaltic andesite, trachybasalt, and basaltic trachyandesite lava flows exposed in flat-lying to southerly tilted blocks south of Combs Flat. Outcrop exposures are massive to columnar-jointed. West of Mill Creek, an isolated quarry exposure of a Hi-PT flow with 51.67 weight percent SiO_2, 1.89 weight percent P_2O_5, 3.08 weight percent TiO_2, Ba 2625 ppm (Sample 9, Table 1.1) rests unconformably upon the rhyolite of Ochoco Reservoir (Tjro). On Combs Flat, Prineville Basalt flows overly a thick section of sedimentary rocks of unit Tmos. The base of the basalt flows are composed of palagonite breccia and detached pillows encased in stratified tuffaceous sedimentary rocks of unit Tmos; the basalt invaded, displaced, and deformed the stratified sedimentary rocks. South of Combs Flat, upper flow surfaces have been reworked by fluvial processes into basalt lag gravels. In thin section the basalt is hypocrystalline (60 percent crystals, 40 percent glass), hyalopilitic with some intergranular olivine and clinopyroxene and abundant opaques. The basalt contains < 2 percent olivine microphenocrysts. Prineville flows in adjacent quadrangles include Bowman Dam, Hi-Si, and Hi-PT chemical types as defined by Hooper and others (1993) and are chemically characterized by a range of silica values (SiO_2 from 50.84 to 56.19 weight percent) and elevated concentrations of phosphorus (P_2O_5 from 1.24 to 2.02 weight percent) and barium (Ba from 1695 to 3202 ppm). Contact relationships with underlying units are obscured by talus and landslides. Includes normal and reversed magnetic polarity flows (Hooper and others, 1993). A middle Miocene age is based on a radiometric date of 15.7 ± 0.1 Ma (Smith, 1986a) on the basal flow at Pelton Dam in the Deschutes Basin and intertonguing relationships between reversed magnetic polarity Bowman Dam type flows and R2 Grande Ronde Basalt flows north of the Deschutes Basin (Hooper and others, 1993). Equivalent to the Prineville Basalt (Tolan and others, 1989; Hooper and others, 1993).

Tmos **Volcaniclastic sedimentary rocks (late Oligocene? and middle to early Miocene?)** – Moderately indurated deposits of brown to tan sandstone, stratified tuffaceous siltstone, claystone, and diatomite. Massive to stratified sedimentary rocks have been chaotically disassembled in quarries along the Post highway where invaded by overlying Prineville basalt flows. A middle Miocene age for the upper part of the unit is based on intertonguing and invasive relationships between Prineville Basalt flows, and/or conformable upper contacts with the Prineville Basalt. Although previously considered to be the upper part of the John Day Formation (Swanson, 1969) herein tentatively considered to be correlative to the Simtustus (Smith, 1986b) and Mascall (Merriam, 1901) Formations. The base of the unit is not exposed.

Tj – John Day Formation (early Miocene to early Oligocene) Succession of interbedded Rhyolite lava flows, tuff, and tuffaceous sedimentary rocks. Equivalent to the John Day Formation of Marsh (1875), Merrriam (1901), and Robinson and others (1990) and subdivided into:

Tjrh **Rhyolite of Hi-Tor Butte (late Oligocene? or Miocene) –** Distinct, cliff-forming plug of purple to black, aphyric to porphyritic, spherulitic, flow-banded rhyolite that intrudes and rests upon dacite porphyry (Tcp) at Hi-Tor Butte east of Ochoco Reservoir. The unit includes a plug of very fresh-appearing, vertically flow banded obsidian that outcrops beneath the stony rhyolite at the west base of Hi-Tor Butte. In thin section the rhyolite contains sanidine feldspar phenocrysts up to 1.25-mm-across that are rafted, rotated, and aligned in a micro flow banded glass-rich matrix. Flow bands of microlites are deformed around phenocrysts; rotated sanidine phenocrysts are often themselves sheared. Spherulitic textures in thin section appear to be secondary features. Chemically the unit is a rhyolite with 76.78 weight percent SiO_2; 12.24 weight percent Al_2O_3; and 4.66 weight percent K_2O (Sample 18, Table 1.1). The rhyolite is marked by relatively high levels of yttrium (91.4 ppm Y) and niobium (66.9 ppm Nb). The rhyolite at Hi-Tor Butte is thought to be of late Oligocene to Miocene? age, based on the fresh glassy appearance of obsidian. Equivalent to unit Tsi of Swanson (1969).

Tjlo **Pumice-lapilli tuff (Oligocene? to early Miocene?) –** White, poorly exposed moderately indurated, massive to bedded, pumice-lapilli tuff that overlies the Barnes Butte tuff (Tjtb) southwest of Ochoco Dam. Moderately altered pink feldspars and vesicle-filling botryoidal opaline quartz. The altered tuff overlies similarly altered outcrops of the Barnes Butte tuff (Tjtb) and rhyolite of Ochoco Reservoir (Tjro) at a gravel quarry in section 6, T. 14 S., R. 14 E.

Tjtb **Welded ash tuff of Barnes Butte (late Oligocene) –** Oxidized pink to red, indurated to friable, columnar jointed pumice-lithic-tuff exposed in cliff-forming ledges on the south side of Ochoco Reservoir. Flattened pumice occurs as blocks and lenses as large as 7 cm across. Lithics include angular to subrounded rhyolite clasts as much as 1-cm-across. The matrix is largely made up of ash and glass shards. At the gravel quarry in section 6, T. 14 S , R. 14 E., the tuff contains distinct glass shard fiamme up to several centimeters across; red opaline quartz and jasper are associated with the tuff at this locality. In thin section, the tuff displays a well developed structure marked by flattened and contorted glass shards. Sparse phenocrysts include potassium feldspar and quartz. The groundmass is cut by bands of spherulitic quartz. The tuff is strikingly similar in composition and is considered to be genetically related to the rhyolite dome at Barnes Butte. (Prineville 7 ½' quadrangle). Chemically, the tuff has high amounts of silica (77.83 – 83.90 weight percent SiO_2) and low amounts alumina (8.23 – 11.93 weight percent Al_2O_3) and sodium (1.78 – 3.15 weight percent Na_2O) (Samples 24 and , 26, Table 1.1). Contains comparatively low levels of zirconium (251 - 375 ppm) and higher levels of yttrium (47.6 -75.0 ppm) and niobium (36.5 – 46 ppm Nb). The maximum unit thickness in the quadrangle is 30 m. Equivalent in part to unit Tjw of Swanson (1969) and Tjrt of Waters and Vaughan (1968).

Tjto **Welded ash-tuff (late Oligocene) –** Orange to red, massive to spherulitic, welded aphyric ash-tuff overlying unit Tjvo at Gravy Gulch. The unit contains flattened glass shards and pumice, and opaline quartz-filled lithophysae. Chemically, the unit is a rhyolite tuff, with 78.64 weight percent SiO_2, 11.24 weight percent Al_2O_3, and 3.63 weight percent Na_2O (Sample 28, Table 1). The tuff contains relatively elevated levels of barium (583 ppm Ba) and zirconium (341 ppm Zr) (Sample 28, Table 1.1). Maximum unit thickness is 75 m.

Tjpo **Pumice-ash tuff (late Oligocene) –** Tan to green, massive, pumice-lithic-lapilli tuff poorly exposed above unit Tjro and below the Barnes Butte tuff (Tjtb) on the south shore of Ochoco Reservoir. The unit includes white, glass shard-rich ash tuff and volcaniclastic sandstone. Maximum unit thickness is 45 m. Equivalent, in part, to unit Tjrt of Waters and Vaughan (1968) and unit Tjt of Swanson (1969).

Tjvo **Vitric tuff and pumice-lapilli tuff (late Oligocene) –** Pink to red, hoodoo forming, pumice-crystal-lapilli tuff exposed along the western edge of Gravy Gulch. The unit contains relict, flattened pumice up to 3-4-cm-across. Chemically, the unit is a rhyolite tuff, with 76.28 weight percent SiO_2, 11.81 weight percent Al_2O_3, and 4.11 weight percent Na_2O (Sample, Table 1). The tuff contains relatively high levels of barium (988 ppm Ba), zirconium (495 ppm Zr), yttrium (39.3 ppm Y) and niobium (45.7 ppm Nb) (Sample 28, Table 1.1). Maximum unit thickness is 60 m. Equivalent, in part, to unit Tjw of Swanson (1969) and unit Tjwu of Waters and Vaughan (1968).

Tjro **Rhyolite of Ochoco Reservoir (late Oligocene) –** Rhyolite exposed to the north and south of Ochoco Reservoir and in cliff-forming outcrops in the vicinity of Lawson Creek and Gravy Gulch. At Ochoco Reservoir, the relatively planar unit strikes ~ N 85^{o} E, dips ~ 17^{o} south, and is made up of purple to gray, massive, platy to columnar jointed, porphyritic rhyolite. The unit is essentially flat-lying at Lawson Creek and Gravy Gulch and consists of a composite section of breccia and rhyolite; a base of interbedded, tightly packed, perlite cobble breccia, massive pumiceous tuff, and ash-rich breccia grades upward into massive to perlitic,flattened lythophysae rhyolite. The upper surface is vertically flow-banded and marked by convex flow-ridges (push up ridges). The Flow top north of Ochoco Reservoir has been eroded to form a planar table top surface. The unit is variable in thickness, forming cliffs as high as 45 m. Although considered by Waters and Vaughan (1968) to be a rheomorphic ash-flow tuff, considered herein to be a rhyolite lava flow. In thin section, potassium feldspar phenocrysts as much as 5 mm in cross section, are set in a groundmass composed of cryptocrystalline alkali feldspar and quartz with scattered opaque minerals. Chemically the unit is a rhyolite with ~ 75.00 weight percent SiO_2; ~ 12.50 weight percent Al_2O_3; ~ 4.30 weight percent Na_2O, and ~ 4.12 weight percent K_2O (Samples 22, 25, and 27, Table 1.1). The unit is marked by elevated levels of zirconium (~ 770 ppm Zr), yttrium (~ 100 ppm Y) and niobium (~ 60 ppm Nb). The age of the Ochoco rhyolite is 27.54 ± 0.36 (Sample A1, plate 1; Table 1.2). Equivalent to unit Tjwl of Waters and Vaughan (1968) and Tjr of Swanson (1969).

Tjs **Tuffaceous sedimentary rocks and tuff (Oligocene) –** Massive, slope forming, white and light green, zeolitized, tuffaceous siltstone, diatomite, and tuff that contains relict pumice, lapilli, feldspar, and mafic minerals. The white zeolitized tuffaceous siltstone weathers to angular chips and forms fractured exposures lacking bedding features. An Oligocene age is based on interbedded relations with the pumice tuff of unit Tjt and the rhyolite of Ochoco Reservoir. Forms a mass more than 90-m-thick north of Ochoco Reservoir. Part of unit Tjt of Swanson (1969) and unit Tjdt of Waters and Vaughan (1968).

Tjt **Pumice-lithic tuff (Oligocene) –** Gray to green, matrix-supported, pumice-lithic tuff. The unit is indurated to friable, weathering to form angular chips and rounded, low elevation hills around Barnes Butte in the Prineville 7 ½' quadrangle and northwest of Ochoco Reservoir. Clasts include tan to green, well-rounded pumice up to 6-cm-across and brown to black, angular to subround mafic and silicic rock fragments as much as 10-cm-across. The ash matrix contains feldspar crystals. Based on a sample from the Prineville quadrangle, the unit is chemically a rhyolite tuff, with 75.47 weight percent SiO_2, 12.65 weight percent Al_2O_3, and 1.64 weight percent Na_2O. The tuff contains relatively high levels of zirconium (512 ppm Zr) and yttrium (96 ppm Y) (Sample 2, Table 1.1). Unit Tjt is intruded by rhyolite of unit Tjrb (rhyolite of Barnes Butte) and overlain by unit Tjtb (tuff of Barnes Butte) in the vicinity of Barnes Butte in the Prineville quadrangle. Based on water wells, the unit is more than 335-m-thick north of Barnes Butte. The thickness of the tuff decreases abruptly to several tens of meters in the Ochoco Reservoir quadrangle where it unconformably onlaps lava flows of unit Tca.

Equivalent in part to unit Tjdt of Waters and Vaughan (1968) and unit Tjt of Swanson (1969).

Clarno Formation (Eocene) Dacite to rhyolite lava flows, intrusions, and volcaniclastic rocks. Equivalent to the Clarno Formation of Merriam (1901) and Walker and Robinson (1990), and subdivided into:

Tct **White crystal-ash tuff (Eocene? Or early Oligocene) –** White, massive to platy, fine-grained, crystal ash tuff that conformably overlies gravel of unit Tcg in section 13, T. 14 S., R. 17 E. The crystal fraction consists of mostly clear feldspar up to 1-mm-across and <2% phenocrysts of amphibole and/or pyroxene. Unit is between 3- to 4-m-thick. High silica rhyolite with 79.70 weight percent SiO_2; 11.65 weight percent Al_2O_3; and 4.06 weight percent K_2O. Marked by relatively low amounts of yttrium (37 ppm) and niobium (18 ppm). Although the age is presently unknown, considered, on the basis of contact relationships and lack of alteration, to be early Oligocene or older in age. Equivalent in part to unit Tt of Swanson (1969).

Tcg **Conglomerate (Eocene? Or early Oligocene) –** Slope-forming, loosely consolidated surface of rounded to well-rounded pebble- to cobble-sized conglomerate exposed in section 13, T. 14 S., R. 17 E. Clasts are composed mostly of rhyolite, rhyolite porphyry, and dacite with lesser amounts of basalt. The unit is a channel-filling deposit up to 24-m-thick that rests directly on the basalt of Mahogany Butte. Equivalent in part to unit Tt of Swanson (1969).

Tcb **Basalt of Mahogany Butte (Eocene? Or early Oligocene) –** Black, massive, medium-grained plagioclase- and olivine-phyric basalt exposed in section 13, T. 14 S., R. 17 E. In thin section, the basalt contains microphenocrysts of olivine, clinopyroxene, and zoned plagioclase set in a matrix of aligned, euhedral plagioclase laths and subophitic clinopyroxene. The subophitic clinopyroxene is altered to brown-colored serpentine. Opaque minerals are abundant. Chemically, the basalt of Mahogany Butte displays low titanium and potassium with moderate alumina content, with 50.14 weight percent SiO_2; 16.52 weight percent Al_2O_3; 1.42 weight percent TiO_2, and 0.26 weight percent K_2O (Sample 8, Table 1). The slope forming unit appears to be an intracanyon flow that unconformably overlies a red-weathering soil zone on top of dacite flows of the Clarno Formation (Tca). Capped by loosely consolidated conglomerate of unit Tcg. Maximum unit thickness is 15 m.

Tcv **Volcaniclastic rocks (Eocene) –** Bedded volcaniclastic rocks exposed along the west end of Ochoco Reservoir and along Mill Creek. Near Ochoco Dam, the unit consists of brown to yellow, distinctly bedded volcanogenic sandstone and massive, matrix-supported conglomerate that strike N 31^{o} W and dip 22^{o} N. Deposits south of the dam are unconformably overlain by the rhyolite of Ochoco Reservoir; along U.S. Highway 26 stratified rocks are overlain by rhyolite-dominated landslide deposits (Qls). Rocks exposed in the north part of the quadrangle along Mill Creek Road consist of brown to yellow, clast-supported, crudely stratified, pebble-dominated breccia with angular, mafic volcanic clasts. Angular to sub-round, vesicular, outsized mafic volcanic blocks and bombs up to 20-cm-across are common. Exposures along Mill Creek include bedded red scoria, purple-tan-brown lapilli tuff, and white pumice tuff. The Mill Creek section is intruded by dacite and rhyolite dikes of unit Tcid and unit Tcir.

Tcd **Aphyric dacite (Eocene) –** Black to bluish-gray, platy, sugar textured aphyric dacite dome that forms the north canyon wall of Polly Creek. In thin section, the dacite is sparsely porphyritic with euhedral plagioclase up to 0.5-mm-across and microphenocrysts of orthopyroxene set in a microlite plagioclase and glass matrix. Based on geochemical analyses the composition of the unit is a dacite with, 65.18 weight percent SiO_2; 16.39 weight percent Al_2O_3; 0.73 weight percent TiO_2; and 1.51 weight percent K_2O (Sample 11, Table 1.1). South of Polly Creek, the unit is in high angle contact with porphyritic dacite of unit Tcp.

Tch **Hornblende-phyric dacite (Eocene) –** Gray to black, cliff-forming, massive to platy, hornblende-phyric dacite dome exposed north of Hi-Tor Butte. In thin section, the dacite contains euhedral to corroded phenocrysts of hornblende (1.5 mm)and zoned plagioclase (0.7 mm) and microphenocrysts of clinopyroxene set in a seriate groundmass of similar composition. Groundmass plagioclase are strongly aligned. Based on geochemical analyses the composition of the unit is a dacite with, 65.75 weight percent SiO_2; 16.45 weight percent Al_2O_3; 0.72 weight percent TiO_2; and 1.68 weight percent K_2O (Sample 12, Table 1.1). The irregular intrusive contact between the hornblende-phyric dacite and the dacite porphyry of unit Tcp in section 25, T. 14 S., R. 17 E . is the source of a Qls deposit that pinches out to the north along Polly Creek

Tcdp **Dacite porphyry (Eocene) –** Domal masses of black to gray, massive, bulbous to spine-like, vertically flow banded outcrops of hornblende-plagioclase-hypersthene dacite porphyry exposed in the eastern portion of the map area. Centimeter-scale float of massive to banded, clear to white agate is commonly associated with this unit. A small alteration zone in the porphyry along U.S. Highway 26 consists of a 0.5-m-wide zone of white to purple chalcedonic quartz cored by gilsonite (?). Veinlets radiating into the country rock are encrusted with cinnabar. In thin section, the dacite contains blocky, equant phenocrysts of hornblende (0.5 mm), strongly zoned plagioclase (1.5 mm), and hypersthene (0.5 mm) set in a fresh appearing glassy groundmass. Glomerocrysts of hornblende, plagioclase, and subophitic pyroxene are also present. Based on geochemical analyses the composition of the porphyry mass includes dacite and rhyolite with a range of chemical abundances of 62.91 to 73.96 weight percent SiO_2; 12.45 to 16.33 weight percent Al_2O_3; 0.68 to 0.91 weight percent TiO_2; and 1.91 to 2.24 weight percent K_2O (Samples 14, 19, and 21, Table 1.1). Includes small-scale plugs of hornblende-phyric dacite in Gravy Gulch. Based on outcrop distribution, interpreted as an eroded dome complex or shallow, subvolcanic intrusive mass.

Tcr **Rhyolite (Eocene) –** Tan to orange, massive, flow-banded aphyric rhyolite exposed as distinct hoodoo erosional forms along Mill Creek and above unit Tca in sections 14 and 15, T. 14 S., R. 17 E. Flow textures range from planar flow banded to tightly folded horizontal to subvertical flow bands. Flow margins are marked by zones of black perlitic rhyolite. The base of the flow in places is distinguished by folded flow bands of purple-white aphyric rhyolite. In thin section, the rhyolite is aphyric with a finely banded, cryptocrystalline groundmass. The unit overlies andesite with angular unconformity at Mahogany Butte and is unconformably overlain by andesite flows of unit Tca south of Mahogany Butte. Chemically, the unit is a rhyolite marked by comparatively low yttrium and niobium contents, with 75.89 weight percent SiO_2; 12.55 weight percent Al_2O_3; 3.82 weight percent K_2O; 31.9 ppm Y and 15.9 ppm Nb (Sample 6, Table 1.1).

Tca **Dacite and andesite lava flows (Eocene) –** Stacked succession of gray to black, purple-weathering, fine- to medium-grained, aphyric, plagioclase phyric, and plagioclase-hornblende phyric dacite and andesite lava flows and domes. The flows are platy to locally columnar-jointed; outcrops weather to steep-sided, rounded hills littered with angular rock chips. Individual flow packages locally contain purple to brown, basal and marginal autobreccia deposits. Topographic breaks between flow units are locally marked by brick red, red-orange, and maroon clay soils. Petrified wood occurs in some intraflow zones. In thin section these rocks are aphyric to porphyritic, with pilotaxitic texture defined by aligned feldspar lathes. Phenocrysts include blocky, zoned plagioclase crystals as much as 4-mm-across and orthophyroxene crystals. Embayed quartz crystals rimmed by clinopyroxene grains and broken, twinned plagioclase crystals may be present as xenocrysts. Some rocks also contain crystalline xenoliths made up of intergrown clinopyroxene and plagioclase crystals. Based on geochemical analyses (Samples 2, 3, 7, and 15, Table 1.1) includes dacite and andesite, with silica contents ranging from 58.40 to 63.56 weight percent SiO_2; alumina contents ranging from 16.05 to 16.88 weight percent Al_2O_3; titanium contents ranging from 0.84 to 1.28 weight percent TiO_2; and potassium contents ranging from 0.88 to 1.60 weight percent K_2O. Equivalent to the Clarno Formation of Merriam (1901). Based on intraflow contacts and intervening weathering zones, the succession is likely composed of several lithologically similar appearing lava flows of variable age.

Tcir **Rhyolite intrusive rocks (Eocene) –** White, vertically flow banded, spine-forming, silicified rhyolite dikes oriented N50^{o}W that parallel the Mill Creek dacite dike (Tcid) and intrude unit Tcv volcaniclastic rocks along Mill Creek. The edges of the dikes are defined by 0.5-m-wide margins of black to green, friable perlite. Red and yellow jasper is common as float near rhyolite dike outcrops. The age of the intrusion is unknown.

Tcid **Hornblende-phyric dacite intrusive rocks (Eocene) –** Hornblende- and plagioclase-phyric dikes and irregularly shaped stocks. The unit includes a distinct dike that intrudes unit Tcv volcaniclastic rocks along Mill Creek Road and a large intrusive mass at the northern end of Johnson Creek . The Mill Creek dike is ~ 8-m-wide with a massive gray core and distinct black, glassy chilled margins about 0.75- m-thick. The dike has a trend of N50^{o}W and runs parallel to the rhyolite dikes (Tcir) , The Mill Creek dike is veined by blue to white opaline quartz. The Johnson Creek intrusive body is a bluish gray mass that forms a crudely elliptical stock measuring about 1,500 m by 1,000 m. The intrusion is plagioclase-phyric and contains white, medium-grained, holocrystalline xenoliths up to 8-cm-across. In thin section, the Mill Creek dike contains euhedral phenocrysts of hornblende and plagioclase up to 2-mm-across and microphenocrysts of plagioclase and clinopyroxene. Phenocrysts are set in a micro-plagioclase groundmass. In thin section, the Johnson Creek intrusion contains aligned, euhedral to subhedral, strongly zoned plagioclase (1-mm-across) and relict hornblende (0.5-mm-across) phenocrysts in a seriate groundmass of similar composition. Xenoliths in the Johnson Creek intrusion are diorite composed mostly of interlocking euhedral plagioclase and relict hornblende crystals with minor amounts of quartz crystals. The hornblende is largely replaced by opaque minerals while the quartz crystals have been recrystallized to a mortar texture.

The matrix is replaced by a mixture of feldspar, quartz, and very fine-grained sericite and calcite. Based on geochemical analyses the Mill Creek dike is a dacite, with 66.09 weight percent SiO_2; 15.68 weight percent Al_2O_3; 0.68 weight percent TiO_2; and 2.20 weight percent K_2O (Sample 4, Table 1.1). Chemically the Johnson Creek intrusion is a dacite with 65.05 weight percent SiO_2; 16.86 weight percent Al_2O_3; 0.80 weight percent TiO_2; and 1.48 weight percent K_2O (Sample 1, Table 1.1). The age of the Mill Creek dike is 42.79 ± 0.44 (Sample A2, plate 1; Table 1.2); age of the Johnson Creek dike is unknown. Equivalent to unit Tca of Waters and Vaughan (1968) and unit Tcmi of Swanson (1969).

STRUCTURE

Major structures in the Ochoco Reservoir quadrangle include northwest and east-northeast trending normal faults. Fault traces are generally obscured and their locations are inferred on the basis of apparent stratigraphic offset of marker beds, structurally disrupted zones of mineralization, and slickenside lineated surfaces. The most distinctive structures are a series of northwest and east-west trending normal faults observed crosscutting the Clarno age Mill Creek rhyolite (Tcr) and undifferentiated lava flows (Tca) in the northern part of the map area. Faults crosscutting the main mass of the Mill Creek rhyolite (Tcr) have orientations (~N50^{o}W) coincident with both dacite and rhyolite dikes exposed just to the northwest. A series of structures, perpendicular to those along Mill Creek are noted in the northwest part of the quadrangle along Johnson Creek.

North of Ochoco Reservoir, a N55^{o}W trending structure that parallels a northerly step in Ochoco Creek offsets the rhyolite of unit Tjro. Top to the south displacement along this structure has tilted the Ochoco rhyolite; the unit strikes ~N85^{o}E and dips ~17^{o}S. South of Ochoco Reservoir the relatively planar rhyolite (Tjro) body is interbedded with John Day age tuffs and plunges beneath the Deschutes Formation basalt-capped plateau.

The extreme southeast part of the quadrangle exposes the axis of a south-plunging syncline structure that includes deformed Oligocene age tuffs and rhyolite (Swanson, 1969). A N60^{o}E trending, top to the northwest, normal fault parallels the fold axis trace denoted by Swanson (1969). It is unclear, based on stratigraphic relations, if unit Tmos sedimentary rocks or the Prineville basalt were incorporated in this episode of structural deformation. Deformation in the Ochoco Reservoir quadrangle does not apparently affect younger rocks of the relatively stable Deschutes Formation volcanic plateau.

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Table 1.1. Analyses of major oxide and selected trace elements from samples collected in the Ochoco Reservoir quadrangle, Crook County, Oregon. Major oxides in percent and selected trace elements in parts per million (ppm). XRF analyses normalized to 100 percent on a volatile-free basis with total iron expressed as FeO. Samples analyzed by the Franklin and Marshall College, GeoAnalytical Laboratory, Lancaster, PA. Sample location numbers are keyed to the accompanying preliminary geologic map.

Map #	1	2	3	4	5	6	7
UTM_N	4914622	4916025	4915859	4915308	4914715	4913484	4915466
UTM_E	0681982	0684690	0684253	0685994	0685780	0685666	0687450
Group							
Formation	Clarno	Clarno	Clarno	Clarno	Clarno	Clarno	Clarno
Map_unit	Tcid	Tca	Tca	Tcid	Tca	Tcr	Tca
Lithology	Dacite	Andesite	Andesite	Dacite	Dacite	Rhyolite	Dacite
SiO2	65.05	58.4	61.82	66.09	63.18	75.89	63.56
Al2O3	16.86	16.88	16.2	15.68	16.11	12.95	16.05
TiO2	0.8	1.28	0.89	0.68	0.89	0.17	0.84
FeO_	5.07	7.64	6.43	4.47	5.34	2.19	5.19
MnO	0.13	0.15	0.11	0.07	0.12	0.02	0.13
CaO	4.91	7.25	6.56	4.9	5.89	0.81	6.05
MgO	1.76	3.72	3.12	2.19	3.18	0.15	3.42
K2O	1.48	1.11	1.35	2.2	1.63	3.82	0.88
Na2O	3.71	3.33	3.28	3.54	3.44	3.95	3.67
P2O5	0.23	0.24	0.24	0.18	0.21	0.05	0.21
Ni	20	38	42	20	20	3	21
Cr	45	42	90	39	75	<2	71
Sc	14	18	18	13	18	6	17
V	97	183	113	89	121	9	124
Ba	498	299	752	528	471	806	479
Rb	35	22	19	87	50	109	25
Sr	398	497	419	357	354	59	363
Zr	170	156	213	153	175	261	170
Y	22.1	20.7	23.8	14.4	21.8	31.9	19.7
Nb	13.5	10.5	13.3	9.6	12.5	15.9	11.1
Ga	17	22	20	18	19	17	19
Cu	43	51	50	28	28	14	32
Zn	61	75	82	55	71	57	67
Pb	6	3	4	4	6	11	8
La	25	19	28	21	22	39	23
Ce	40	42	60	47	48	84	48
Th	2.5	2.8	4.3	5.8	5.1	15	4.5
U	2	1.2	1.7	1.9	3.1	3.7	2.6
Co	13	27	22	12	17	<1	17

Map #	8	9	10	11	12	13	14
UTM_N	4913900	4913903	4913589	4912248	4910860	4911325	4910787
UTM_E	0688790	0688797	0688934	0689091	0688994	0687950	0687091
Group							
Formation	Clarno	Clarno	Clarno	Clarno	Clarno	Clarno	Clarno
Map_unit	Tcb	Tct	Tca	Tcd	Tch	Tca	Tcdp
Lithology	Basalt	Rhyolite tuff	Dacite	Dacite	Dacite	Andesite	Rhyolite
SiO2	50.14	79.7	63.07	65.18	65.75	60.04	73.96

Al2O3	16.52	11.65	15.88	16.39	16.45	15.85	12.45
TiO2	1.42	0.21	0.85	0.73	0.72	0.94	0.68
FeO_	9.97	0.44	5.34	4.52	4.98	6.31	4.32
MnO	0.19	0.02	0.16	0.09	0.15	0.17	0.02
CaO	11.08	0.43	5.95	5.31	4.71	7.24	3.16
MgO	7.99	0.15	3.38	2.32	1.69	5.06	0.48
K2O	0.26	4.06	1.81	1.51	1.68	0.99	2.02
Na2O	2.23	3.28	3.35	3.79	3.69	3.17	2.73
P2O5	0.2	0.05	0.2	0.17	0.18	0.22	0.17
Ni	47	<1	18	26	19	46	24
Cr	141	<2	95	41	48	144	46
Sc	30	9	18	13	14	18	11
V	233	7	121	100	92	152	88
Ba	147	831	435	484	886	415	545
Rb	9	90	61	43	45	36	61
Sr	290	42	362	382	377	361	241
Zr	107	322	172	156	159	169	149
Y	22.6	37	19	16.1	17	21	14.5
Nb	10	18	12.1	10	10.4	11.7	12
Ga	18	17	19	19	18	18	15
Cu	34	<2	12.1	28	24	27	29
Zn	83	42	69	60	61	72	36
Pb	2	1	4	7	5	3	9
La	13	51	18	23	23	20	23
Ce	28	1	43	48	4	43	51
Th	1	8.5	4.8	5	5.2	4	7.8
U	2.2	3.2	1.5	2.7	2	1.9	3.6
Co	46	<1	17	13	12	23	10

Map #	**15**	**16**	**17**	**18**	**19**	**20**	**21**
UTM_N	4911161	4910992	4910460	4909457	4909275	4908288	4908650
UTM_E	0685981	0685182	0684672	0688727	0688820	0688592	0686450
Group		CRBG					
Formation	Clarno	Prineville	John Day	John Day	Clarno	Clarno	Clarno
Map_unit	Tca	Tcp	Tjro	Tjrh	Tcdp	Tcdp	Tcdp
Lithology	Andesite	Basalt	Rhyolite	Rhyolite	Andesite	Dacite	Dacite
SiO2	61.54	51.67	75.38	76.78	62.91	68.1	64.5
Al2O3	15.42	13.5	12.45	12.24	15.66	15.41	16.33
TiO2	0.93	3.08	0.29	0.19	0.91	0.68	0.87
FeO_	6.34	11.97	2.47	2	5.75	4.57	5.46
MnO	0.14	0.25	0.05	0.04	0.11	0.08	0.16
CaO	6.06	8.45	0.33	0.4	5.8	3.43	5.17
MgO	4.51	4.34	0.17	0.12	3.48	1.2	1.56
K2O	1.6	1.93	4.32	4.66	1.91	2.4	2.29
Na2O	3.23	2.94	4.48	3.51	3.26	3.95	3.45
P2O5	0.23	1.89	0.05	0.05	0.2	0.18	0.22
Ni	87	15	5	<1	40	3	26
Cr	165	22	<2	1	83	7	25
Sc	18	39	2	2	15	14	15
V	131	300	15	7	129	76	120
Ba	398	2625	904	1001	491	671	517
Rb	53	38	124	128	61	69	79
Sr	289	410	46	35	294	232	324
Zr	152	146	788	485	218	245	196
Y	22.5	53	85.8	91.4	26.4	29.4	27.9

Nb	12.5	8.1	64.7	66.9	13.4	13.5	13.2
Ga	18	19	27	25	19	19	18
Cu	46	46	6	2	36	24	31
Zn	70	129	108	146	62	64	63
Pb	5	2	8	12	6	7	6
La	18	23	72	81	24	31	24
Ce	39	50	150	172	53	68	52
Th	5.7	4.1	15.4	15.9	6.9	8	6.9
U	2.7	2.3	3.4	5.2	2.8	2.9	2.6
Co	24	35	1	<1	18	11	16

Map #	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
UTM_N	4908454	4906960	4906819	4907131	4906651	4903316	4902500	4902562
UTM_E	0682626	0679930	0680842	0681221	0683720	0684816	0689042	0689380
Group								
Formation	John Day	Deschutes	John Day	John Day	John Day	Deschutes	John Day	John Day
Map_unit	Tjro	Tdbc	Tjtb	Tjro	Tjtb	Tdbc	Tjto	Tjvo
Lithology	Rhyolite	Basalt	Rhyolite tuff	Rhyolite	Rhyolite tuff	Basalt	Rhyolite tuff	Rhyolite tuff
SiO2	75.98	50.12	83.9	73.45	77.83	50.38	78.64	76.28
Al2O3	11.95	16.33	8.23	13.32	11.93	17.79	11.24	11.81
TiO2	0.28	1.29	0.18	0.31	0.17	1.29	0.13	0.18
FeO_	2.86	9.2	1.62	3.27	1.09	8.72	1.66	2.52
MnO	0.05	0.17	0.02	0.09	0.01	0.16	0.02	0.03
CaO	0.19	11.18	0.25	0.45	0.28	11.52	0.19	0.9
MgO	0.09	8.57	0.21	0.23	0.14	6.71	0.17	0.19
K2O	4.56	0.48	3.75	4.14	5.34	0.41	4.26	3.91
Na2O	3.98	2.39	1.78	4.66	3.15	2.71	3.63	4.11
P2O5	0.05	0.27	0.08	0.08	0.05	0.31	0.05	0.05
Ni	4	121	4	3	1	53	1	4
Cr	<2	304	b.d.	<2	0	151	1	3
Sc	3	35	2	2	1	32	2	2
V	9	221	14	20	8	251	17	17
Ba	765	258	410	841	615	348	583	988
Rb	118	8	67	109	134	6	114	122
Sr	29	557	44	47	18	709	14	16
Zr	771	97	251	769	375	102	341	495
Y	110.8	25.2	47.6	112	75	23.9	39.3	17
Nb	64.6	8.5	36.5	61.5	46.3	8.2	45.7	67.3
Ga	25	17	15	26	23	18	21	24
Cu	3	74	b.d.	4	<2	65	0	5
Zn	128	68	77	113	78	69	97	0
Pb	11	4	3	11	4	3	8	3
La	87	14	39	87	58	17	44	67
Ce	186	33	85	189	1	36	110	163
Th	14.4	1.7	6.8	15.2	14.3	2.3	13.6	0
U	4.5	1.8	4.2	4.9	4	<0.5	4.7	5.1
Co	1	42	b.d.	4	0	38	<1	1

Table 1.2. Whole-rock $^{40}Ar/^{39}Ar$ age determination for samples in the Ochoco Reservoir quadrangle, Crook County, Oregon. A1 and A2 samples prepared and analyzed by the College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, Oregon. Sample location numbers are keyed to the accompanying preliminary geologic map.

Map #	Map label	Lithology	Age (Ma)	Method	Material dated	Formation	UTM_N	UTM_E
A1	Tjro	Rhyolite	27.54 ± 0.36	$^{40}Ar/^{39}Ar$	Whole rock	John Day	4908454	0682626
A2	Tcid	Dacite	42.79 ± 0.44	$^{40}Ar/^{39}Ar$	Hornblende	Clarno	4915308	685994
A3[a]	Tdbc	Basalt	3.36 ± 0.08[c]	K/Ar	Whole rock	Deschutes	nd.	nd.

[a] Smith (1986) after Sutter unpublished data