STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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GEOLOGIC MAP OF THE MAHOGANY MOUNTAIN 30 X 60 MINUTE QUADRANGLE, MALHEUR COUNTY, OREGON, AND OWYHEE COUNTY, IDAHO

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Geologic Map of the Mahogany Mountain 30 x 60 Minute Quadrangle, Malheur County, Oregon, and Owyhee County, Idaho

By M.L. Ferns and others

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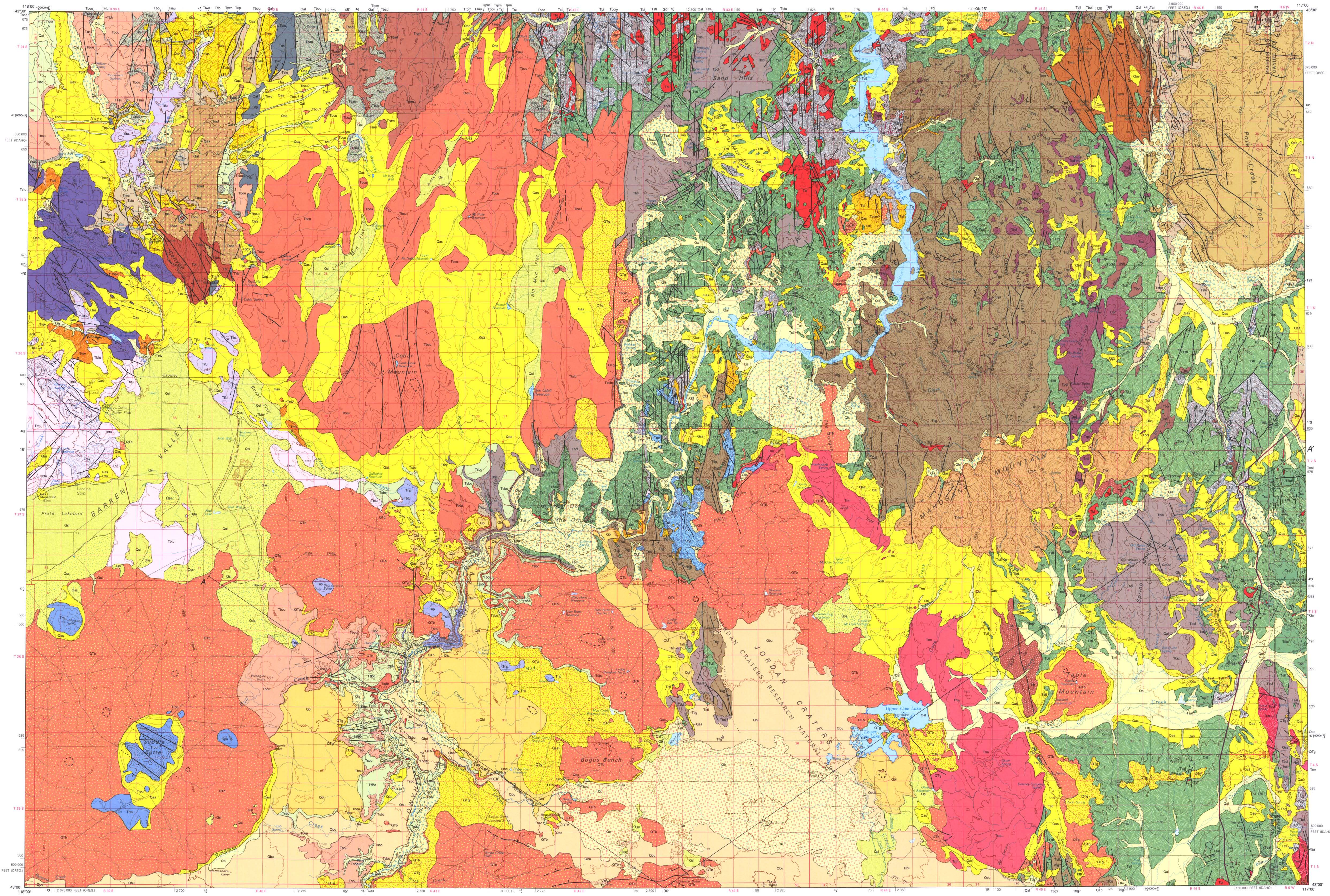
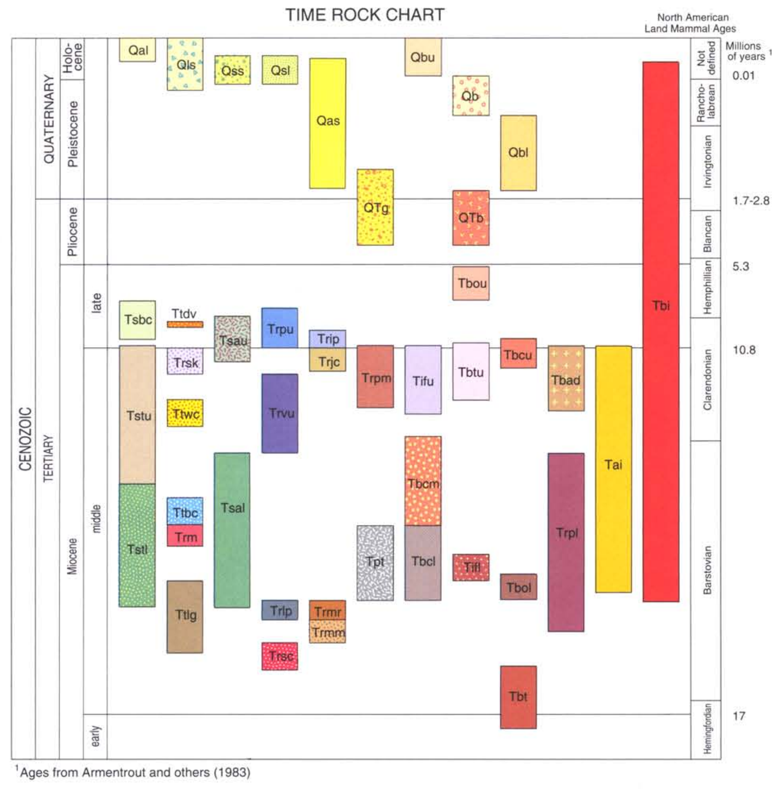


TIME ROCK CHART



[1]Ages from Armentrout and others (1983)

EXPLANATION

(Description of units and of geologic history, resources, and hazards in accompanying text)

- Qal — **Alluvium (Holocene)**
- Qls — **Landslides (Holocene and Pleistocene)**
- Qss — **Lake sediments (Holocene and Pleistocene)**
- Qsl — **Lake and eolian deposits (Holocene and Pleistocene)**
- Qas — **Terrace gravels and alluvial-fan deposits (Holocene? and Pleistocene)**

UNITS RELATED TO ANTELOPE VALLEY GRABEN AND OTHER EAST-WEST-TRENDING BASINS

- Qbu — **Olivine basalt (Holocene and upper Pleistocene)**
- Qb — **Lava flows of Clarks Butte (upper Pleistocene)**
- Qbl — **Older intracanyon basalt flows (Pleistocene)**
- QTb — **Plateau basalts (lower Pleistocene? and Pliocene)**
- QTg — **Terrace and interflow sand and gravel deposits (Pleistocene and Pliocene)**
- Tbou — **Upper olivine basalt flows (upper Miocene)**
- Tsbc — **Lacustrine sedimentary deposits (upper Miocene)**
- Ttdv — **Devine Canyon Ash-flow Tuff (upper Miocene)**

LATE BIMODAL VOLCANIC SUITE

- Tbtu — **Upper tholeiitic lava flows (upper and middle Miocene)**
- Tifu — **Upper ferrolatite lava flows (upper and middle Miocene)**
- Trip — **Rhyolite of Iron Point (upper or middle Miocene)**
- Trsk — **Rhyolite at Stockade Mountain (upper or middle Miocene)**
- Trpu — **Rhyolite and quartz latite domes (upper or middle Miocene)**
- Trvu — **Rhyolite and rhyolite vitrophyre at Star Mountain (middle Miocene)**

OREGON-IDAHO GRABEN DEPOSITS

- Tai — **Basaltic andesite, andesite, dacite, and latite plugs, dikes, and sills (upper and middle Miocene)**
- Tbcu — **Upper calc-alkaline lava flows (upper and middle Miocene)**
- Tsau — **Upper arkosic sandstone, conglomerate, and tuffaceous siltstone (upper and middle Miocene)**
- Tstu — **Tuffaceous siltstones, tuffs, and nonwelded ash-flow tuff (upper and middle Miocene)**
- Trjc — **Jump Creek Rhyolite (upper or middle Miocene)**
- Ttwc — **Wildcat Creek Welded Ash-flow Tuff (middle Miocene)**
- Tsal — **Lower arkosic sandstone and conglomerate (middle Miocene)**
- Tbad — **Basalt, basaltic andesite, and andesite lava flows (upper and middle Miocene)**
- Trpm — **Rhyolite and rhyodacite of Dry Creek (upper and middle Miocene)**
- Tbcm — **Middle calc-alkaline lava flows (middle Miocene)**
- Tbcl — **Lower calc-alkaline lava flows (middle Miocene)**
- Tpt — **Palagonite tephra deposits (middle Miocene)**
- Tbol — **Lower olivine basalt flows (middle Miocene)**
- Tstl — **Lower tuffaceous sedimentary rocks (middle Miocene)**

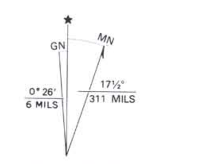
EARLY BIMODAL VOLCANIC SUITE

- Trpl — **High-silica rhyolite domes and shallow intrusions (middle Miocene)**
- Ttbc — **Tuff of Birch Creek (middle Miocene)**
- Trlp — **Littlefield Rhyolite (middle Miocene)**
- Trm — **Rhyolite of McCain Creek (middle Miocene)**
- Tifl — **Lower ferrodacite lavas (middle Miocene)**
- Ttlg — **Leslie Gulch Ash-flow Tuff (middle Miocene)**
- Trmr — **Rhyolite of McIntyre Ridge (middle Miocene)**
- Trmm — **Rhyolite of Mahogany Mountain (middle Miocene)**
- Trsc — **Rhyolite of the Silver City Range (middle Miocene)**
- Tbt — **Lower tholeiitic lava flows (middle and lower? Miocene)**

INTRUSIVE ROCKS

- Tbi — **Basalt intrusions (Holocene to Miocene)**

Base map compiled from USGS 1:24 000-scale topographic maps dated 1967-1972
Map edited 1981
Projection and 10 000-meter grid, zone 11, Universal Transverse Mercator
25 000-foot grid ticks based on Oregon coordinate system, south zone, and Idaho coordinate system west zone
1927 North American Datum

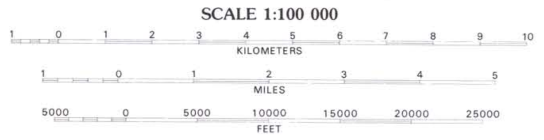


UTM GRID AND 1981 MAGNETIC NORTH DECLINATION AT CENTER OF MAP

MAP SYMBOLS

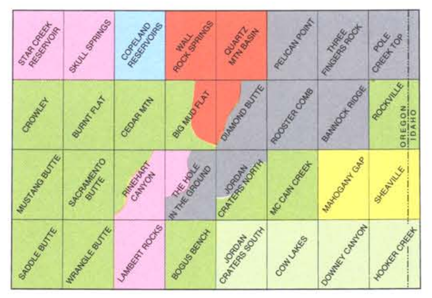
- **Contact**—Approximately located
- **Fault**—Dashed where approximately located; dotted where concealed; ball and bar on downthrown side
- **Anticlinal fold axis**
- **Synclinal fold axis**
- **Strike and dip of beds**
- **Dike**
- **Volcanic fissure**
- **Volcanic vent**

SCALE 1:100 000



CONTOUR INTERVAL 40 METERS
SUPPLEMENTARY CONTOURS AT 20 METERS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

INDEX MAP SHOWING 7½′ QUADRANGLES AND SOURCES OF GEOLOGIC DATA USED FOR THIS MAP



- M.L. Ferns, Oregon Department of Geology and Mineral Industries, 1991-1992
- N.S. MacLeod, Oregon Department of Geology and Mineral Industries, 1989
- H.C. Brooks, Oregon Department of Geology and Mineral Industries, 1992
- N.S. MacLeod and M.L. Ferns, Oregon Department of Geology and Mineral Industries, 1990-1991
- J.G. Evans, U.S. Geological Survey, 1987 and 1992
- D.B. Vander Meulen and others, U.S. Geological Survey, 1985-1989
- M.L. Cummings, Portland State University, 1990, 1991, 1992

Geology by Mark L. Ferns, Oregon Department of Geology and Mineral Industries; James G. Evans, U.S. Geological Survey; and Michael L. Cummings, Portland State University

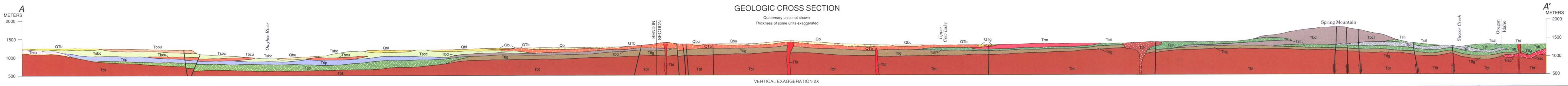
Reviewed by Bill Bonnichsen, Idaho Geological Survey, and Norman S. MacLeod

Cartography by Mark E. Neuhaus

QUADRANGLE LOCATION

GEOLOGIC CROSS SECTION

Quaternary units not shown
Thickness of some units exaggerated



VERTICAL EXAGGERATION 2X

Geologic Map of the Mahogany Mountain 30 x 60 Minute Quadrangle, Malheur County, Oregon, and Owyhee County, Idaho

By Mark L. Ferns, Oregon Department of Geology and Mineral Industries; James G. Evans, U.S. Geological Survey; and Michael L. Cummings, Portland State University

INTRODUCTION

Contacts on the map have been taken from original mapping done by the workers cited in the text. The senior author assumes all responsibility for inaccuracies that may have occurred in the adaptation.

Analyses presented in the unit descriptions are from XRF analyses and have not been normalized on a volatile-free basis. Complete analyses are available in cited references. For a brief description of analytical procedures, see discussion in Ferns and O'Brien (1992).

The discussion of geologic resources and hazards is an interpretative summary of the geologic processes that formed both resources and hazards in the quadrangle. A more extensive treatment of the geologic resources and hazards encountered during the mapping project will be given in a subsequent publication.

ACKNOWLEDGMENTS

Gary Baxter, senior analyst for the Oregon Department of Geology and Mineral Industries, provided invaluable help in obtaining analyses for the project. The authors benefited from discussions with Jim Rytuba and Dean Vander Meulen, U.S. Geological Survey; Peter Hooper, Washington State University, Pullman, Washington; Bill Hart, Miami University, Oxford, Ohio; and Spencer Wood, Boise State University, Boise, Idaho. Additional thanks go to Bill Bonnichsen, Martha Godcheaux, and Margaret Jenks of the Idaho Geological Survey. Many thanks are also extended to the participants of the Portland State University geologic field camps.

EXPLANATION OF GEOLOGIC UNITS

Qal **Alluvium (Holocene)**—Mainly gravel, sand, and silt deposited along active streams. Includes overbank flood deposits ranging from silt to gravel. Locally includes playa-lake, alluvial-fan, and colluvium deposits

Qls **Landslides (Holocene and Pleistocene)**—Mainly unconsolidated, poorly-sorted deposits formed as the result of bedrock failure. Includes debris-flow, scree, and talus deposits. Major landslides along the Owyhee River are characterized by hummocky topography and generally occur where basalt flows overlie sedimentary units. Older landslides along the flanks of Pole Creek Top have been cut by modern streams

Qss **Lake sediments (Holocene and Pleistocene)**—Mainly playa-lake deposits of unconsolidated silt and sand. May include saline evaporite deposits in Barren Valley

Qsl **Lake and eolian deposits (Holocene and Pleistocene)**—Mainly lacustrine and eolian sand deposits fringing playa shorelines. Includes pebbly gravels along windward edge of the ancient lake bed in Barren Valley

Qas **Terrace gravels and alluvial-fan deposits (Holocene? and Pleistocene)**—Mainly poorly consolidated deposits of coarse gravel, locally with thin bentonitic clay and tuffaceous limy siltstone interbeds. Unit includes dissected fan, pediment, and terrace gravel locally mantled by wind-blown silts and colluvium as well as slope-mantling scree and talus deposits. Terrace gravel clasts are mainly locally derived from nearby basalt and rhyolite units

UNITS RELATED TO ANTELOPE VALLEY GRABEN AND OTHER EAST-WEST-TRENDING BASINS

Qbu **Olivine basalt (Holocene and upper Pleistocene)**—Morphologically young, dark-gray olivine basalt flows that fill modern topographic lows. Includes flows that have flowed down the Owyhee River canyon. Individual flows retain pristine flow features such as spatter cones, pahoehoe surfaces, tumuli, collapse features, and open lava tubes. Also includes small cinder cones at Jordan Craters and West Crater. Surface of youngest flow at Jordan Craters is bare of soil and loess. Older Saddle Butte and Rocky Butte flows are locally mantled by discontinuous soil cover, and lacustrine and eolian deposits between tumuli. Unit is generally diktytaxitic, with olivine and plagioclase phenocrysts set in a subophitic groundmass of clinopyroxene, opaques, and glass. Includes a hyalophitic, augite-phyric flow at West Crater. Includes both alkali olivine basalt (Jordan Crater, West Crater, and Rocky Butte flows) and high-alumina olivine basalt (Saddle Butte flow). Flows range in age from about 4,000 years at Jordan Craters to about 100,000 years (Hart and Merzman, 1983)

Qb **Lava flows of Clarks Butte (upper Pleistocene)**—Grayish-black olivine basalt flows forming lava field about Clarks Butte. Well-preserved tumuli, pahoehoe surfaces, and collapse structures are mantled by eolian and lacustrine silts. Consists of phenocrysts of olivine and plagioclase with glomerocrysts of plagioclase and olivine set in an intergranular groundmass of plagioclase, opaques, and clinopyroxene. Chemically, unit is an alkali olivine basalt. Dated radiometrically at 0.25 Ma (Hart and Mertzman, 1983)

Qbl **Older intracanyon basalt flows (Pleistocene)**—Mainly dark-bluish-gray to dark-grayish-black, plagioclase-phyric olivine basalt flows forming ledges above the present Owyhee River level. Flows are remnants of intracanyon flows emplaced early during downcutting of the Owyhee River canyon. Unit includes hyalopilitic flows with microphenocrysts (1–2 mm) of plagioclase as well as holocrystalline, aphyric flows. Unit composition includes both alkali olivine and high-alumina olivine (Hart and Mertzman, 1983). Equivalent to part of unit Qb of Walker and Repenning (1966). Ages range from about 0.4 to 1.5 Ma (Hart and Mertzman, 1983)

QTb **Plateau basalts (lower Pleistocene? and Pliocene)**—Gray and grayish-black diktytaxitic olivine basalt flows with well-preserved flow tops. Flows are locally heavily mantled by wind-blown silt deposits. Mainly olivine basalt, ranging in composition from alkali-olivine basalt to high-alumina basalt. Includes alkali-olivine and transitional basalt flows forming the east and west rims of the Owyhee River canyon. High-alumina basalts typically contain less than 2 percent olivine phenocrysts 1–3 mm in diameter. Groundmass minerals include lath-shaped plagioclase and subophitic titanaugite. Equivalent to unit Qtb of Vercoutere and others (1987) and part of unit Qb of Walker and MacLeod (1991) and Walker and Repenning (1966). Age is from about 1.9 to about 4 Ma (Hart and Mertzman, 1983)

QTg **Terrace and interflow sand and gravel deposits (Pleistocene and Pliocene)**—Mainly unconsolidated fluviatile sand and gravel deposits. Includes semiconsolidated lacustrine tuffaceous sedimentary rocks and unconsolidated clay, sand, and gravel deposits interbedded with intracanyon basalt flows of unit **Qbl** in the central part of the quadrangle. Also includes semiconsolidated terrace gravel that caps ridges north and south of Cow Creek and bench-capping gravel along the flanks of the Owyhee River. Gravel commonly contains cobbles of chert, quartzite, and plutonic igneous rocks. High-bench gravel along the Owyhee River is laterally continuous with unit Qs of Walker and Repenning (1966) in the Jordan Valley quadrangle to the south and is in part correlative to the Bruneau Formation of Malde and Powers (1962)

Tbou **Upper olivine basalt flows (upper Miocene)**—Mainly black to greenish- and grayish-black olivine basalt flows, palagonitic breccia, and interbedded, tan to white, tuffaceous siltstone and claystone. Includes lava flows exposed along the Owyhee River near Wrangle Butte. Typically holocrystalline or hyalocrystalline with 2-mm-diameter olivine and plagioclase phenocrysts with ophitic and subophitic clinopyroxene. Includes quartz tholeiite with $TiO_2 > 2$ percent and $K_2O > 0.39$ percent (Ferns, 1992e). Unit is about 130 m thick north of Chalk Basin

Tsbc **Lacustrine sedimentary deposits (upper Miocene)**—Mainly pale-yellow to white, tuffaceous siltstone and sandstone. Includes zeolitic tuff, conglomerate, bentonitic clay, diatomite, and minor limestone. Along the western edge of the quadrangle, unit includes poorly consolidated fanglomerate. Locally includes interbedded welded ash-flow tuffs, including a 1-m-thick exposure of welded Devine Canyon Ash-flow Tuff (unit **Ttdv**) near the top of the section northwest of Chalk Basin (Ferns, 1992e). The sedimentary section beneath the Devine Canyon Ash-flow Tuff thickens eastward from less than 30 m of coarse fanglomerate west of Crowley to 150 m of lacustrine sediments at Chalk Basin. Age is late Miocene, based on late Clarendonian and early Hemphillian vertebrate fossils (Evans and others, 1990b) and interbedded Devine Canyon Ash-flow Tuff. Correlative with the "Rome beds" of Baldwin (1959)

Ttdv **Devine Canyon Ash-flow Tuff (upper Miocene)**—Mainly pale yellowish-white to light-gray, vitric welded ash-flow tuff exposed along the western edge of the quadrangle. Typified by a silky sheen on freshly broken surfaces due to alignment of pumice clasts. Typically contains less than 1 percent lithic fragments and about 3 percent sanidine and quartz phenocrysts measuring approximately 3 mm in diameter. Accessory minerals include clinopyroxene. The ash-flow tuff is peralkaline with distinctively high abundances of Zr (1,000–1,500 ppm) (Greene, 1973; Brooks and O'Brien, 1992). Unit comprises the distal edges of a large-volume ash-flow tuff that was erupted from an inferred buried caldera complex to the west at Burns at about 9.2 Ma (Walker, 1990). Tuff thins eastward from about 10 m along west border of area to 1 m where the ash flow interfingers with upper part of unit **Tsbc** in Bull Creek along the Owyhee River. Laterally continuous with exposures of the Devine Canyon Ash-flow Tuff of Walker (1979)

LATE BIMODAL VOLCANIC SUITE

Tbtu **Upper tholeiitic lava flows (upper and middle Miocene)**—Bluish-black to bluish-gray, platy mafic lava flows ranging in composition from alkali olivine basalt to ferroandesite. At least three flows with an aggregate thickness of 70 m are exposed north of Mooreville. Lower flows are glomeroporphyritic ferroandesite (59 percent SiO_2, 9.2 percent Fe_2O_3) with clear plagioclase phenocrysts as large as 2 cm in diameter, plagioclase and orthopyroxene glomerocrysts, and rare quartz xenocrysts. Unit grades upward into alkali olivine basalt (48–54 percent SiO_2, 1.1–2.2 percent K_2O) (Ferns, 1992c; Ferns and Williams, 1993b). Age based on K-Ar date of 11.3 Ma from uppermost of three flows east of Crowley (Hart and Carlson, 1985). May be in part equivalent to unit Tba of Sherrod and others (1989), mapped in the Sheepshead Mountains to the south and dated at 11.2–11.7 Ma (Hart and Mertzman, 1982)

Tifu **Upper ferrolatite lava flows (upper and middle Miocene)**—Bluish-black, coarsely phyric, porphyritic vitrophyre flows of ferrolatite and ferrodacite. Three separate flows exposed on the west edge of the map area. Upper flow forms crest of Rooster Comb Ridge north of Crowley. Flows at Rooster Comb Ridge and south of Star Mountain both flowed southward from north-striking feeder dikes. Individual flows contain about 20 percent embayed and partially resorbed phenocrysts of plagioclase, potassium feldspar, augite, orthopyroxene, and olivine. Feldspar and quartz crystals are as long as 2 cm. Unit **Tifu** typically contains about 5 percent xenoliths of olivine basalt and coarse diorite. According to Ferns and Williams (1993a,b), flows at Barren Valley and west of Crowley Ranch are ferrolatites (62–65 percent SiO_2, 12.8–13.7 percent Al_2O_3, 5.72–7.37 percent Fe_2O_3, 2.87–3.75 percent Na_2O, 3.40–4.10 percent K_2O) and are petrographically and chemically similar to the Square Mountain ferrolatite of Bonnichsen and others (1988). Age is middle and late Miocene based on stratigraphic position above the Wildcat Creek Welded Ash-flow Tuff (unit **Ttwc**) and below the Devine Canyon Ash-flow Tuff (unit **Ttdv**)

Trip **Rhyolite of Iron Point (upper or middle Miocene)**—Mainly light-gray to purple quartz-sanidine-phryic rhyolite. Includes two thick rhyolite flows with ash-flow interbeds at Iron Point. Lower flow is a reddish-gray porphyritic rhyolite with a perlitic vitrophyre carapace. Both flows are dark gray to reddish gray and contain sanidine, quartz, and plagioclase phenocrysts. Lower flow contains dark-brown pleochroic phenocrysts of aenigmatite. Basal vitrophyre of uppermost flow is peralkaline in chemistry, while the lower flow is metaluminous (Ferns and Evans, 1993). Aggregate thickness of flows and tuffs is over 300 m at Iron Point, where Evans (1991) identified a 240-m-thick basal ash flow overlain by a 120-m-thick upper unit. Rhyolites at Iron Point are interpreted by Evans (1991) as multiple cooling units of densely welded ash-flow tuff and by Plumley (1986) as multiple rhyolite flows. Unit grades laterally into the lower part of unit **Tsbc** at Chalk Basin (Evans, 1991)

Trsk **Rhyolite at Stockade Mountain (upper or middle Miocene)**—Pinkish-gray to gray, spherulitic porphyritic rhyolite typified by steeply dipping, northwest-striking bands of 5-cm-diameter lithophysae. Characteristically, unit contains 5 percent phenocrysts (sanidine and plagioclase) as much as 6 mm in diameter in a cryptofelsitic groundmass containing radiating clots of chalcedony and opaques. Also contains sparse orthopyroxene and altered olivine phenocrysts. Chemically a metaluminous, high-silica rhyolite with 76–77 percent SiO_2 (Ferns and Williams, 1993b). Along the crest of Stockade Mountain, the unit includes spherulitic, densely welded ash-flow tuff with rotated phenocrysts. Bands of lithophysae dip steeply to the south and strike consistently to the northwest for 5 km along the north flank of Stockade Mountain. Rotation of originally subhorizontal emplacement boundaries to a near-vertical attitude is considered by Bonnichsen and others (1988) as evidence for plastic deformation and rheomorphic flowage. Part of unit Tvs of Walker and MacLeod (1991). Unconformably overlain by flows of unit **Tbtu**. Age based on presumed correlation with rhyolites to the west that have a K-Ar age of 11.3 Ma (Greene and others, 1972; Fiebelkorn and others, 1982)

Trpu **Rhyolite and quartz latite domes (upper or middle Miocene)**—Light-gray to reddish-brown, sanidine-phyric and quartz-sanidine-phyric domes. Includes a sparsely sanidine-phyric, high-silica, metaluminous rhyolite dome at Mustang Butte and an evolved, sanidine-plagioclase-phyric dome at Saddle Butte that ranges in composition from quartz latite to metaluminous high-silica rhyolite (Ferns, 1992d). Largest exposed dome at Saddle Butte is about 7.5 km^2 in size

Trvu **Rhyolite and rhyolite vitrophyre at Star Mountain (middle Miocene)**—Purplish-gray to gray porphyritic rhyolite flows exposed at Star Mountain. Sanidine-phyric, metaluminous rhyolite flows with well-developed carapace vitrophyre breccias. Individual lava flows are marked by basal vitrophyre zones. Includes low-silica rhyolites (70–71 percent SiO_2; 13.1–13.4 percent Al_2O_3) with 5–10 percent plagioclase, sanidine, hypersthene, and augite phenocrysts and high-silica rhyolites (76 percent SiO_2, 12.1 percent Al_2O_3) with sanidine, plagioclase, and quartz phenocrysts (Ferns and Williams, 1993b). Intrudes and overlies the Wildcat Creek Welded Ash-flow Tuff (unit **Ttwc**) west of Road Canyon. Middle Miocene age based on stratigraphic position beneath flows of unit **Tbtu**

OREGON-IDAHO GRABEN DEPOSITS

Tai **Basaltic andesite, andesite, dacite, and latite plugs, dikes, and sills (upper and middle Miocene)**—Includes small, in most cases areally restricted, lava flows. Includes latite porphyries with potassium feldspar, plagioclase, pyroxene, and quartz phenocrysts and holocrystalline, olivine-phyric basaltic andesites (Plumley, 1986). According to Vander Meulen and others (1987a,d), some intrusions contain biotite and hornblende

Tbcu **Upper calc-alkaline lava flows (upper and middle Miocene)**—Mainly black to gray, vesicular, holocrystalline, and generally hypersthene-phyric calc-alkaline basalt and basaltic andesite. Basaltic andesite typically contains plagioclase, hypersthene, and olivine phenocrysts. Individual flows are commonly glomeroporphyritic, with clots of plagioclase, hypersthene, and lesser olivine. Groundmass textures range from pilotaxitic to ophitic. Includes as much as 100 m of flow-on-flow basaltic andesites ranging in composition from 52 to 56 percent SiO_2 and 15.5 to 16 percent Al_2O_3 (Ferns, 1992a; Ferns and Williams, 1993a). Main source area is the large shield volcano at Cedar Mountain. Unit thins westward across Antelope Flat. Middle to late Miocene age is based on stratigraphic position between the overlying Devine Canyon Ash-flow Tuff (unit **Ttdv**) and underlying middle Miocene sediments of unit **Tstl**. Correlative to the Antelope Flat Basalt of Kittleman and others (1965, 1967)

Tsau **Upper arkosic sandstone, conglomerate, and tuffaceous siltstone (upper and middle Miocene)**—Mainly white to pale-yellow and pale-orange, medium-grained, well-sorted fluviatile arkosic sandstone and conglomerate. Lower part of unit includes tuffaceous siltstone and claystone. Upper part of unit includes interbedded mafic lithic ash-flow tuff with yellow, inflated pumice and mafic scoria clasts. Unit locally fines upward to white to pale-yellow diatomaceous siltstone and claystone. Pebbly arkosic sandstone and conglomerate are micaceous and rich in quartz and feldspar grains. Clasts include black obsidian, rhyolite, granite, and black chert. Unit includes all clastic sediments in the northwest and north-central part of the map area lying below unit **Tbou** and above unit **Tbcm** as well as arkosic sediments interbedded with flows of unit **Tbcu**. Presence of abundant obsidian clasts in conglomerate distinguishes the unit from the stratigraphically lower arkose of unit **Tsal**. Arkosic sandstone in the western part of the map area may interfinger with the lower part of unit **Tsbc** along the Owyhee River. Age based on late Barstovian to early Hemphillian vertebrate fossils collected to the north in the Vale quadrangle (Kittleman and others, 1965; Ferns and others, 1993). Includes sediments situated in the lower part of the Grassy Mountain Formation of Kittleman and others (1965, 1967)

Tstu **Tuffaceous siltstones, tuffs, and nonwelded ash-flow tuff (upper and middle Miocene)**—Mainly white to pale-yellow vitric tuff, grayish-green bentonitic claystone, and pale-yellow to grayish-green tuffaceous siltstone. Locally includes poorly consolidated, granite-clast arkosic conglomerate and white, nonwelded lithic ash-flow tuff. Occurs in three areas of exposure that likely represent separate Miocene basins. Exposures north and west of Crowley include tuffaceous sediment exposed beneath the Wildcat Creek Welded Ash-flow Tuff (unit **Ttwc**) and above the calc-alkaline flows of unit **Tbcm** and are correlative in part with the Butte Creek Volcanic Sandstone of Kittleman and others (1965, 1967). Exposures near Dry Creek Buttes in the north-central part of the quadrangle immediately underlie unit **Tsal** sandstone and include tuffaceous siltstone in Cummings' (1991a) sequence of Oxbow Basin. Exposures along the east edge of the quadrangle are interbedded with unit **Tsal** sandstone and are equivalent to the upper part of the Sucker Creek Formation of Kittleman and others (1965, 1967) and unit Tuss of Ferns (1988c). Age based on Barstovian vertebrate fossils

Trjc **Jump Creek Rhyolite (upper or middle Miocene)**—Light purplish-gray to bluish-gray, plagioclase-phyric, low-silica rhyolite flow. Distal edges of the rhyolite typically contain 10–15 percent plagioclase phenocrysts as long as 1 cm with trace amounts of clinopyroxene (Ferns, 1988a). According to Vander Meulen and others (1989b), parts of the flow contain abundant sanidine phenocrysts. Composition ranges from quartz latite to low-silica rhyolite (68–71 percent SiO_2) (Ferns and Gilbert, 1992). Unit consists of a single large rhyolite flow. Thickest part of the flow is exposed east of Succor Creek, where vertically jointed outcrops over 300 m in thickness are exposed. Distal edges are marked by flow breccia. Age is 10.6–11.1 Ma based on K-Ar age determinations (Armstrong and others, 1980; Ekren and others, 1981; Rytuba and others, 1990). Unit is equivalent to the easternmost exposures of the Jump Creek Rhyolite of Kittleman and others (1965, 1967)

Ttwc **Wildcat Creek Welded Ash-flow Tuff (middle Miocene)**—Pale-red to grayish-red and light-gray welded lithic ash-flow tuff. Includes at least two separate ash flows exposed east of Rooster Comb Ridge. Tuffs are generally crystal poor with sparse phenocrysts of sanidine, plagioclase, and clinopyroxene. Typically contains abundant flattened pumice clasts. Chemically, unit is a low-silica peralkaline rhyolite with 400 ppm Zr (Evans, unpublished analyses, 1992; Ferns and Williams, 1993b). Underlies the Devine Canyon Ash-flow Tuff (unit **Ttdv**) and overlies unit **Tbcm** flows. Includes the Wildcat Creek Welded Ash-flow Tuff as defined by Kittleman and others (1965, 1967). Also includes parts of the unnamed tuffs near Crowley as mapped by Kittleman and others (1965, 1967)

Tsal **Lower arkosic sandstone and conglomerate (middle Miocene)**—Mainly orange-weathering, massive, white arkosic sandstones exposed in the north-central part of the quadrangle. Sandstone is generally well indurated and moderately to well sorted. Fine- to coarse-grained sandstone contains quartz, plagioclase, and potassium feldspar grains. Sandstone beds commonly contain detrital biotite and/or muscovite. Unit also includes medium to coarse conglomerate with clasts of granitic, metamorphic, and silicic volcanic rocks. Exposures at Dry Creek Buttes in the north-central and eastern part of the map area near Succor Creek are interbedded with tuffaceous siltstone of unit **Tstu** and make up part of the sequence of Dry Creek Buttes (Cummings, 1991a,b) in the Deer Butte Formation of Corcoran and others (1962) and Kittleman and others (1965, 1967). Unit **Tsal** exposures east of the Owyhee River make up part of the Sucker Creek Formation (Corcoran and others, 1962; Kittleman and others, 1965)

Tbad **Basalt, basaltic andesite, and andesite lava flows (upper and middle Miocene)**—Mainly red-weathering, gray to bluish-gray, sparsely phyric, holocrystalline lava flows. Includes trachytic andesite flows with plagioclase and rare olivine and clinopyroxene phenocrysts and pilotaxitic andesite with orthopyroxene microphenocrysts. Unit is made up of calc-alkaline lava flows ranging from high-silica basalt ($SiO_2 > 52$ percent) to high-silica andesite (62 percent SiO_2) (Brooks, 1992; Ferns and Williams, 1993a). Basaltic andesite flows near Dry Creek are interbedded with rhyodacite and rhyolite flows of unit **Trpm** and with sediments of unit **Tstl**. Unit **Tbad** includes all aphyric mafic lava flows on the west side of the quadrangle that overlie coarsely plagioclase-phyric basalts of unit **Tbt** and underlie diktytaxitic andesite flows of unit **Tbcm** or the Wildcat Creek Ash-flow Tuff (unit **Ttwc**). Includes separate flow sequences erupted from vents on Dry Creek and on the northeast flank of Star Mountain. Age is based on stratigraphic position beneath Barstovian vertebrate fossil locality near Skull Springs (Kittleman and others, 1965). Unit is correlative in part with the "unnamed igneous complex" of Kittleman and others (1965, 1967) and includes mafic flows in the sequence of Hurley Flat (Cummings, 1991a)

Trpm **Rhyolite and rhyodacite of Dry Creek (upper and middle Miocene)**—Mainly purplish-gray to dark-gray plagioclase-phyric and aphyric rhyodacite and rhyolite domes and flows that constitute a dome field in the northwest corner of the quadrangle. Includes relatively small-volume, silicic domes and flows separated by pumiceous tuff and tuff breccia. Individual lava flows are commonly bordered by masses of obsidian. Locally interbedded with mafic flows of unit **Tbad**. Compositions range from 66 to 76 percent SiO_2 and 12.4 to 15.7 percent Al_2O_3, (Ferns and O'Brien, 1991; Brooks, 1992, 1993). Age is based on stratigraphic position underlying Barstovian vertebrate fossil localities at Skull Springs and Red Rock quarry (Kittleman and others, 1965). Constitutes part of the Littlefield Rhyolite of Kittleman and others (1965, 1967) and includes the rhyolites of Dry Creek (Brooks, 1992)

Tbcm **Middle calc-alkaline lava flows (middle Miocene)**—Mainly black to gray, vesicular, holocrystalline calc-alkaline basalt and basaltic andesite flows. Typical basaltic andesite has plagioclase, hypersthene, and olivine phenocrysts and groundmass textures that range from pilotaxitic to ophitic. Mainly basaltic andesites forming flow-on-flow sections as much as 100 m thick. Flows range in composition from high-alumina basalt to andesite (50–57 percent SiO_2, 15.9–17.1 percent Al_2O_3) (Ferns, 1988b,c; Ferns and Cummings, 1992). Flows are commonly underlain by thick sections of palagonite breccias and pillow-palagonite complexes (Ferns and Cummings, 1992). Includes Blackjack Basalt of Bryan (1929), Tims Peak Basalt of Kittleman and others (1965), and flows in the sedimentary sequence of Freezeout Creek (Cummings, 1991a,b). Flows overlie mafic tephra deposits of unit **Tpt** and are locally interbedded with arkosic conglomerates of unit **Tsal**. K-Ar ages for the Blackjack Butte flows in the Vale quadrangle to the north range from about 11 to 13.6 Ma (Ferns and others, 1993)

Tbcl **Lower calc-alkaline lava flows (middle Miocene)**—Mainly dark-gray to black, fine-grained, platy plagioclase-phyric lava flows and autoclastic breccia that characteristically weather to shades of red and brown. Also includes sparsely plagioclase- and olivine-phyric calc-alkaline and tholeiitic basalt, basaltic andesite, and andesite flows with interbedded subaqueous hyaloclastite deposits. Hyaloclastites include pillow breccia and subaerial mafic tephra deposits. Tephra interbeds include massive to thinly bedded hyaloclastic tuff, lapilli tuff, tuff breccia, and agglutinate. Flows range from pilotaxitic olivine basalt with sparse olivine and plagioclase phenocrysts to hyalocrystalline basaltic andesite and andesite flows with abundant plagioclase and rare clinopyroxene and orthopyroxene phenocrysts. Characterized by silica contents of 51–56 percent SiO_2 (MacLeod, 1990a,b). Includes basalt of Hammond Hill of Cummings (1991a) and flows at Spring Mountain of MacLeod (1990a). Underlies unit **Trm** along the eastern edge of the map area and is considered correlative to the approximately 14.2-Ma Owyhee Basalt (Bottomley and York, 1976) exposed in the Vale quadrangle to the north. Interbedded with units **Tstl** and **Tpt**

Tpt **Palagonite tephra deposits (middle Miocene)**—Mainly yellowish-brown, pale-brown, and orange-brown hyaloclastite deposits formed by explosive eruption of mafic magmas in a water-saturated environment. Hyaloclastites include palagonitic lapilli tuff, laharic breccia, and pyroclastic surge deposits. Locally, unit includes interbedded epiclastic sandstone, siltstone, and waterlain silicic tuff. Includes proximal, intermediate, and distal facies of basaltic tephra deposits, zonally arranged about hydrovolcanic eruptive centers, including tuff cones, tuff rings, and maars. Main vent areas are marked by basalt dikes and sills. As mapped, unit **Tpt** includes vents of several different ages. Includes parts of the Drip Springs and Sucker Creek Formations of Kittleman and others (1965, 1967) and, within the Deer Butte Formation, hydrovolcanic deposits in the sequences of Hurley Flat, Dry Creek, Freezeout Creek, and

Oxbow Basin (Cummings, 1991b). Includes tephra deposits coeval with flows of unit **Tbcl**. Lower strata equivalent to unit Tptl of Ferns and others (1993). Thickest accumulations of mafic tephra mark the location of middle Miocene hydrovolcanic vents

Tbol **Lower olivine basalt flows (middle Miocene)**—Mainly black to dark-gray, vesicular, aphyric olivine basalt flows exposed in the northeast corner of the map. Locally includes interbedded palagonitic sandstone and breccia near the base of the section. Mostly aphyric and sparsely phyric with plagioclase and olivine phenocrysts. Includes glomeroporphyritic basalt with plagioclase, clinopyroxene, and olivine glomerocrysts. Groundmass textures range from pilotaxitic to ophitic, with ophitic clinopyroxene and intersertal olivine. Includes both high-alumina olivine tholeiite (Al_2O_3 > 17 percent, K_2O < 0.3 percent) and alkalic basalt (Al_2O_3 < 15 percent, K_2O > 1.5 percent) (Ferns, 1988a,c). Unit thickens to about 100 m west of Succor Creek. Middle Miocene age is based on stratigraphic position immediately above tuffaceous sediments of unit **Ttlg**

Tstl **Lower tuffaceous sedimentary rocks (middle Miocene)**—Mainly light-colored tuffaceous siltstone and fine-grained sandstone, air-fall tuff, and pale-yellow epiclastic sandstones. Includes isolated exposures of nonwelded ash-flow tuff and lignitic claystone. Also includes arkosic sandstone and nonwelded pumiceous lithic ash-flow tuff that, according to Vander Meulen and others (1987a), underlie the outflow facies of the Leslie Gulch Ash-flow Tuff (unit **Ttlg**). Unit is made up of the lower strata of the Deer Butte and Sucker Creek Formations of Corcoran and others (1962) and Kittleman and others (1965, 1967) and includes the sequences of Hurley Flat, Dry Creek, and Freezeout Creek of Cummings (1991a,b). Middle Miocene age is based on Barstovian leaf and vertebrate fossils (Kittleman and others, 1965, 1967)

EARLY BIMODAL VOLCANIC SUITE

Trpl **High-silica rhyolite domes and shallow intrusions (middle Miocene)**—Mainly dark-grayish-red to reddish-brown, sanidine- and quartz-sanidine-phyric rhyolite flows, domes, tuff breccia, and ash-flow tuff. Variably porphyritic with 2–20 percent phenocrysts as much as 10 mm in diameter. Phenocrysts are mainly sanidine and quartz, with lesser plagioclase, augite, ilmenite, and sphene. Some domes near Three Fingers Rock also contain biotite or hornblende phenocrysts (Vander Meulen and others, 1989b). Generally characterized by high silica content (> 76 percent SiO_2) and low to moderate alumina abundances (< 12 percent Al_2O_3) (Ferns and Gilbert, 1992). Includes the 12.8-Ma rhyolite at Bannock Ridge (Rytuba and others, 1990) and older 14.5- to 15.2-Ma rhyolite porphyry dikes and plugs

Ttbc **Tuff of Birch Creek (middle Miocene)**—Mainly gray and bluish-gray to reddish-brown, partly to densely welded porphyritic ash-flow tuff with 12–20 percent phenocrysts of plagioclase, hornblende, and biotite. Locally strongly flow-foliated with highly stretched pumice fragments and gas cavities and local recumbent folds. Unit is 80 to 150 m thick and consists of at least two separate cooling units. Thicker parts of the tuff are welded to densely welded and contain irregularly shaped pods and stringers of dark vitrophyre (Vander Meulen and others, 1990). Includes massive hornblende- and biotite-phyric, vertically-jointed, reddish-brown rhyolite outcrops that are interpreted by Plumley (1986) as a series of endogenous domes that mark a major vent area. Chemically a calc-alkaline rhyolite with 73–75 percent SiO_2, 13.4–15.4 percent Al_2O_3, and 1.6–2.3 percent FeO* (Plumley, 1986). Age based on stratigraphic position above unit **Trm**. Equivalent to tuff of Birch Creek of Vander Meulen and others (1990)

Trlp **Littlefield Rhyolite (middle Miocene)**—Mainly massive, purplish- to light-gray, plagioclase-phyric rhyolite lava flows exposed in the northwest corner of the map. Individual flows generally weather to shades of red and brown. Locally includes interbedded yellowish air-fall tuff, tuffaceous siltstone, and ash-flow tuff. Individual rhyolite flows are marked by basal vitrophyre and capping autoclastic breccia made up of vesiculated vitrophyre. Flows are as much as 70 m thick, with flow interiors of platy-jointed, lithoidal rhyolite. Individual lava flows are sparsely phyric, with 5 percent plagioclase phenocrysts as long as 8 mm. Typically, phenocrysts are set in a devitrified groundmass composed of intimately intergrown potassium feldspar and quartz. Mainly low-silica rhyolites (71–73 percent SiO_2, 12–13 percent Al_2O_3) in which alumina abundances increase with increasing silica (Brooks and O'Brien, 1992; Ferns and O'Brien, 1992). Includes part of the Littlefield Rhyolite of Kittleman and others (1965, 1967)

Trm **Rhyolite of McCain Creek (middle Miocene)**—Purplish-gray to gray, crystal-rich, plagioclase-phyric rhyolite. Unit consists of a single, large-volume porphyritic rhyolite flow that extends across the south-central and extreme eastern parts of the map area. Generally a reddish gray, crystal-rich lithoidal rhyolite capped by a carapace breccia made up of randomly oriented blocks of black vitrophyre arrayed in vesicular red matrix. Commonly contains 10–15 percent broken and embayed plagioclase phenocrysts, lithic fragments, and < 1 percent pigeonite and sanidine phenocrysts. Chemically, unit is a slightly peraluminous, low-silica rhyolite with 71.4–72.4 percent SiO_2 and about 13.7 percent Al_2O_3 (Ferns, 1992b). Although westernmost exposures south of the Owyhee River are interpreted by Vander Meulen and others (1987b) as a pre-collapse flow dome emplaced along the rim of the Mahogany Mountain caldera, thickening of the unit southward toward Downey Canyon indicates that the rim exposures instead mark the distal end of a large rhyolite flow. Based on wide areal extent and broken phenocrysts, unit is herein interpreted as a rheomorphic ash-flow tuff, petrographically and chemically similar to the tuff of Swisher Mountain (cf. analyses in Ekren and others, 1982; Ferns, 1992b) mapped by Evans (1987) to the south. Exposures on the east edge of the quadrangle are part of the tuff of Swisher Mountain of Ekren and others (1981, 1982). Unit **Trm** is considered to be correlative with the tuff of Swisher Mountain of Ekren and others (1981, 1982), which, according to Bonnichsen (written communication, 1992), also contains rhyolite lava flows. Ekren and others (1982) and Minor and others (1987) indicate radiometric ages of 13.9 and 14.7 Ma, respectively, for the tuff of Swisher Mountain

Tifl **Lower ferrodacite lavas (middle Miocene)**—Aphyric, iron-stained dacite flows exposed south of Mahogany Mountain (MacLeod, 1990a). Includes at least two separate aphanitic flows emplaced following eruption of the Leslie Gulch Ash-flow Tuff (unit **Ttlg**). Includes ferrodacites with 66 percent SiO_2 and 5.3 percent Fe_2O_3 (MacLeod, 1990b). Flows may be related to the same period of magmatism that generated intermediate-composition intrusions (unit **Tai**) exposed along the Owyhee River

Ttlg **Leslie Gulch Ash-flow Tuff (middle Miocene)**—Nonwelded intracaldera- and outflow-facies ash-flow tuff. Unit herein includes three major units as mapped by Vander Meulen and others (1987a,b,c,d): the tuff of Spring Creek, the Leslie Gulch Ash-flow Tuff, and the tuffs of the Honeycombs volcanic center. Mainly high-silica, sanidine-phyric, weakly peralkaline to metaluminous ash-flow and air-fall tuffs. Includes thick sections of pale-yellow to light-green, weakly porphyritic, nonwelded to partly welded lithic ash-flow and air-fall tuffs. Unit is comprised of both massive, poorly welded, and conspicuously altered intracaldera facies and more densely welded outflow facies. Includes intracaldera surge deposits of massive and planar-parallel lapilli tuffs and vent breccias at Leslie Gulch. Outflow facies includes air-fall tuffs and a single cooling unit of a grayish-yellow to greenish-brown, crystal-rich, lithic welded ash-flow tuff with 5–20 percent phenocrysts of sanidine and minor amounts of quartz. In the less altered parts of the unit, individual ash flows as much as 20 m thick are characteristically marked by discontinuous black basal vitrophyres. Although the unit as a whole is sparsely phyric, basal vitrophyres contain as much as 20 percent phenocrysts of sanidine, plagioclase, quartz, and rare pyroxene. Thicker sections (360 m) of ash-flow and air-fall tuff are interpreted by Rytuba and others (1985, 1989) to mark caldera-fill sequences related to at least two cycles of caldera collapse in adjacent centers. Thick section of tuff and tuff breccia at the Honeycombs is interpreted by Rytuba and others (1990) to be a series of coalescing silicic tuff cones that are presumed to have cooled as a single unit (Vander Meulen and others, 1987b). According to Vander Meulen and others (1987b), some of the tuffs exposed at the Honeycombs are sparsely hornblende phyric. Age of the main sequence of ash flows is about 15.4 Ma (Rytuba and Vander Meulen, 1991). Two separate cooling units of an orange to tan, densely welded, sanidine- and quartz-phyric ash-flow tuff exposed in the extreme southern part of the quadrangle are herein considered to be correlative with the Leslie Gulch Ash-flow Tuff (unit **Ttlg**). Pale-orange, poorly welded, poorly sorted massive ash flows exposed at Jordan Craters and along the Owyhee River at The Hole in the Ground are also considered to be part of unit **Ttlg** (Plumley, 1986; Vander Meulen and others, 1990)

Trmr **Rhyolite of McIntyre Ridge (middle Miocene)**—A large, quartz- and sanidine-phyric, high-silica rhyolite flow-dome complex emplaced following eruption of the Leslie Gulch Ash-flow Tuff (unit **Ttlg**). Consists of a pale-reddish-brown to tan and purple-gray porphyritic rhyolite with 5–30 percent quartz and sanidine phenocrysts as large as 2.4 mm in length. Characterized by about 75 percent SiO_2 and 12.3 percent Al_2O_3. Rhyolite flow at McIntyre Ridge is as much as 200 m thick. Middle Miocene age is based on sanidine K-Ar age of about 15.8 Ma (Ekren and others, 1984). Considered by Vander Meulen and others (1989b) to be a rhyolite dome emplaced along the northeast margin of the Three Fingers caldera. Equivalent to the rhyolite of McIntyre Ridge of Vander Meulen and others (1989b)

Trmm **Rhyolite of Mahogany Mountain (middle Miocene)**—Massive, flow-banded, light-purple to purple-gray, feldspar-phyric, low-silica rhyolite flows and domes forming Mahogany Mountain. Includes at least two separate flows. Upper flow consists of a lithoidal, spherulitic rhyolite with sparse plagioclase and quartz phenocrysts. Lower flow is a massive to strongly flow-banded, slightly porphyritic rhyolite that shows ubiquitous vapor-phase alteration and contains sparse phenocrysts of plagioclase and sanidine along with rare orthopyroxene and clinopyroxene phenocrysts. Chemically, both flows are relatively unevolved low-silica rhyolites with 74–76 percent SiO_2, 13–13.2 percent Al_2O_3, and 1.5–2.1 percent FeO* (MacLeod, 1990b; Ferns, 1992b). Unit is interpreted by Rytuba and others (1985) as a precollapse flow-dome complex that now forms the south topographic wall of the Mahogany Mountain caldera. Defined by Kittleman and others (1965, 1967) as part of their Jump Creek Rhyolite based on presumed stratigraphic position above the Leslie Gulch Ash-flow Tuff (unit **Ttlg**). Equivalent to rhyolite of Mahogany Mountain of Rytuba and others (1990)

Trsc **Rhyolite of the Silver City Range (middle Miocene)**—Reddish- to purple-gray, aphyric, sparsely sanidine-phyric flow-foliated rhyolite and rhyolite-vitrophyre flows and breccias. Includes flow-foliated vitrophyre with thin pumiceous ash-flow and air-fall tuff interbeds. Chemically metaluminous, high-silica rhyolites with $K_2O > Na_2O$ (Ferns and MacLeod, 1992). Equivalent to the 16.1-Ma rhyolites of the Silver City Range of Ekren and others (1981, 1982)

Tbt **Lower tholeiitic lava flows (middle and lower? Miocene)**—Dark-gray, fine-grained, platy aphyric and plagioclase-phyric lava flows and autoclastic breccias that weather to various shades of red and brown and form ledges 3–12 m thick. Includes massive basalt, platy basalt, and vesicular glassy basalt breccias. Lower part of section on Road Canyon includes coarsely plagioclase-phyric basalt flows with as much as 50 percent plagioclase phenocrysts as long as 2.5 cm. Stratigraphically higher flows at Road Canyon are platy and aphyric. Includes holocrystalline and hyalocrystalline flows with sparse phenocrysts of plagioclase (labradorite), olivine, and ilmenite. Over 250 m of flows with interbedded palagonitic sediments are exposed on Road Canyon, where the unit includes thin, lenticular deposits of subaerial tuff and scoria. Coarsely plagioclase-phyric flows on Road Canyon contain about 47.8–49 percent SiO_2, 17.0–20.1 percent Al_2O_3, and 9.2–12.0 percent Fe_2O_3 (Ferns and Williams, 1993a,b,). Unit **Tbt** flows on the east edge of the quadrangle are composed of 52.1–53.2 percent SiO_2, 13.7–16.2 percent Al_2O_3, and 9.8–13.3 percent Fe_2O_3 (Ferns, unpublished data, 1992). Includes latite and ferrolatite flows in the northeast corner of the quadrangle that contain about 67 percent SiO_2, 14 percent Al_2O_3, and 5–9 percent Fe_2O_3 (Ferns, 1988c). Age based on K-Ar age determinations of about 15.5–17 Ma (Ekren and others, 1982; Fiebelkorn and others, 1982). Unit includes rocks mapped as the "basalt of Bishop's Ranch" by Kittleman and others (1965, 1967). Easternmost exposures are correlative with the basalt and latite unit of Ekren and others (1982) and unit Tbtv of Ferns and others (1993). Western exposures are correlative with the Steens Basalt of Fuller (1931) and the "unnamed igneous complex" of Kittleman and others (1965, 1967) and equivalent to the basalt of Malheur Gorge of Evans (1990) and unit Tbtl of Ferns and others (1993)

INTRUSIVE ROCKS

Tbi **Basalt intrusions (Holocene to Miocene)**—Mainly olivine-phyric basaltic dikes and sills. Holocene feeder dikes shown only in cross section

GEOLOGIC HISTORY

INTRODUCTION

The Mahogany Mountain quadrangle encompasses part of the Owyhee Upland geomorphic province of Idaho and Oregon. This sage-steppe highland includes that older part of the topographically subdued northern Basin and Range geologic province that lies north of the Brothers fault zone and south of the Vale fault zone. These structures, commonly considered to be major right-lateral shear zones (Lawrence, 1976), bound structural basins of middle to late Miocene age. The basins are part of a complex, north- to northeast-trending graben, herein referred to as the Oregon-Idaho graben, that is now largely filled with volcanic and volcaniclastic deposits. North of the map area, in the Vale quadrangle, the Oregon-Idaho graben is truncated by the northwest-trending western Snake River Plain. The Antelope Valley graben, a younger Pliocene-Pleistocene depression, truncates the Oregon-Idaho graben along the southern edge of the map area.

EARLY BIMODAL VOLCANISM

Northern Basin and Range rocks in the Mahogany Mountain area include a middle Miocene basement of tholeiitic flood basalts upon which middle Miocene rhyolitic caldera complexes of the Lake Owyhee volcanic field (Rytuba and others, 1990; Rytuba and Vander Meulen, 1991) were developed. The flood lavas (unit Tbt) are now exposed to the west near Crowley and along the Idaho-Oregon border. The stratigraphically lower exposures in the Crowley area include coarsely porphyritic lavas characterized by large plagioclase crystals as long as 3 cm. Tholeiites exposed along the Idaho-Oregon border are notable for relatively higher alumina concentrations and show chemical similarities to flows in the Weiser Basalt (cf. analyses in Fitzgerald, 1982; Ferns, 1988c).

Weakly peralkaline and metaluminous high-silica rhyolites were erupted from the Mahogany Mountain and Three Fingers calderas (Rytuba and others, 1990; Rytuba and Vander Meulen, 1991) during the waning stages of middle Miocene tholeiitic magmatism at 15.5 Ma (Rytuba and others, 1990). The distribution of the Leslie Gulch and Spring Creek outflow sheets along Succor Creek (Ferns, 1988a,c) indicates possible topographic development related to graben subsidence prior to ash-flow eruption and caldera collapse.

Large-volume, metaluminous rhyolite lava flows of the Littlefield Rhyolite (unit Trlp) were erupted from now buried vents northwest of the map area. Other post-caldera metaluminous rhyolite flows and domes (units Trmr and Trpl) were erupted along the eastern margin of the intracaldera facies of the Leslie Gulch Ash-flow Tuff (unit Ttlg).

Taken as a package, the mafic tholeiite lavas, large-volume rhyolite flows, and caldera-related rhyolites record an early period of bimodal volcanism coincident with east-west-directed middle Miocene extension (Norman and Leeman, 1989). Although the rate of extension may have been at a maximum during extrusion of the mafic lavas (Rytuba and Vander Meulen, 1991), there is no indication of contemporaneous Basin and Range-style block faulting. Confinement of the outflow facies of the Leslie Gulch and Spring Creek tuffs, herein combined in unit Ttlg, to the west of the Graveyard Point fault indicates that north-south-trending Basin and Range faults had begun to develop shortly after eruption of the tholeiite lavas. The striking preponderance of north-south-trending rhyolite dikes (unit Trpl) emplaced shortly after the eruption of the ash flows that comprise the Leslie Gulch Ash-flow Tuff (unit Ttlg) may indicate an east-west extensional regime during ash-flow eruption.

CALC-ALKALINE VOLCANISM AND THE OREGON-IDAHO GRABEN

Hornblende- and biotite-phyric calc-alkaline rhyolite flows and tuffs (unit Ttbc) were erupted from vents along the southwestern flanks of the older caldera complex (Vander Meulen and others, 1987b, 1990). These silicic magmas mark the start of a shift toward calc-alkaline magmatism, as basalt and basaltic-andesite lavas were erupted within grabens flanking the old caldera field. Mafic volcanic and volcaniclastic rocks of the Deer Butte and Sucker Creek Formations (unit Tstl) were deposited in basins controlled by concurrently developing regional fault systems. Basal tuffaceous and lignitic shales record early shallow-water and swampy conditions indicative of closed drainages and high water tables within the basins.

Thin sheets of muscovite-bearing arkosic channel-sands (unit Tsal) record small-scale input of extrabasinal sediments from the southeast. Lacustrine and fluvial deposition was interrupted by phreatomagmatic eruptions that formed maars and tuff cones and left thick deposits of palagonite tuffs and breccias (unit Tpt) on both flanks of the caldera field.

Early high-alumina olivine and quartz tholeiite basalts (unit Tbol) exposed peripherally to the hydrovolcanic centers grade stratigraphically upward into quartz tholeiite basalt, basaltic andesite, and andesite lava flows (unit Tbcl). Overlapping hydrovolcanic centers were located along active north- and northeast-trending faults (Cummings and Growney, 1988; Cummings, 1991a,b; Ferns and Cummings, 1992), producing local topographic highs. Unit Tbcl flows and unit Tpt hyaloclastite deposits form a composite section over 200 m thick on Spring Mountain.

The thickest section of unit Tbcl lavas includes the well-studied Owyhee Basalt (Bryan, 1929), an approximately 14.5-Ma sequence of calc-alkaline lavas (Brown and Petros, 1985; Goles, 1986). Flows were fed in part by north- to northeast-trending dike swarms emplaced along active faults (Ferns, 1988a,b; Ferns and Cummings, 1992), again indicating a general east-west extensional regime during volcanism.

Cessation of the main pulse of calc-alkaline volcanism was accompanied by subsidence of parts of the graben floor along the east and west flanks of Owyhee Ridge, resulting in successive development of flanking, fault-bounded subsidiary sedimentary-volcanic basins (Ferns, 1988c; Cummings, 1991a,b). Distal edges of the Swisher Mountain Tuff (unit Trm), an extremely large, low-silica rheomorphic ash-flow tuff, flowed northward into the basins from a source area somewhere to the south.

Subsidence in the central part of the map area and along the Idaho-Oregon border formed shallow lacustrine basins in which bentonitic clays (unit Tstu) were deposited. Subsidence along the Dry Creek fault zone (Cummings, 1991a,b) to the west left a low ridge of older rocks between the two basins. Fault zones along both flanks served to localize conduits for contemporaneous hydrothermal systems, resulting in the formation of hot-spring-type gold deposits.

Arkosic sand and gravel (unit Tsal) derived from an eroded Idaho Batholith source to the east were deposited in a braided stream system that entered into both the central and eastern basins from the north (Rytuba and others, 1990; Cummings, 1991a,b). The locus for a second phase of calc-alkaline volcanism moved west of the Dry Creek fault zone to Cedar Mountain.

LATE BIMODAL VOLCANISM

Moderately large volumes of peraluminous rhyolite lava flows and lithic ash-flow tuffs were erupted on fringing highlands to the east and west. The earliest ash flows, including the Wildcat Creek Welded Ash-flow Tuff (unit Ttwc) and the approximately 12-Ma rheomorphic rhyolite at Stockade Mountain (unit Trsk), were erupted from vents near Star Mountain, along the western edge of the map area. The vent area is marked by vitrophyre flows and domes at Star Mountain that intrude through the old tholeiite basement rocks. Distinctive xenolith-bearing ferrolatite (unit Tifu) and 10- to 11-Ma tholeiitic basalts (unit Tbtu) overlie the rhyolites. The similar-age low-silica rhyolite lava flow on Pole Creek Top (unit Trjc) was erupted on the east flank at about 10.6 Ma (Rytuba and others, 1990).

The central graben area had apparently been largely filled with sediments following the eruptions at Star Mountain and Pole Creek Top. A thick section of predominantly shallow-water sedimentary deposits (unit Tsbc) along the Owyhee River (Evans, 1991) may indicate, for that time, a subdued topography in which shallow, sediment-choked, northeast-trending basins were drained to the west. The 9.2-Ma Devine Canyon Ash-flow Tuff (unit Ttdv) was erupted from a caldera complex near Burns (Walker, 1990) and flowed eastward across the older basement rocks north of Crowley and onto the sediments of unit Tsbc.

DEVELOPMENT OF ANTELOPE VALLEY GRABEN

Thin stacks of unit Tbou flows that include both quartz and "Snake River-type" olivine tholeiites spread out into the unit Tsbc basin and across shallow, diatom-rich lakes. Over 150 m of unit Tbou flows are exposed along the Owyhee River. Individual thin flows can be traced for several kilometers and had apparently spread out over an area of very low relief. Characteristic basal palagonitic breccias indicate interaction with water as the flows advanced into the shallow lake. Apparent thickening of the basalt pile to the south may indicate that the basin deepened in that direction, perhaps marking initial development of the cross-cutting Antelope Valley graben.

Downwarping to the south resulted in the development of small structural basins now largely filled with Pliocene-Pleistocene and Holocene lava flows erupted from small vents along the northern margin of the Antelope Valley graben. Deformation continued through the Pliocene and into the Pleistocene as the central part of the east-west-trending Antelope Valley graben continued to develop.

Downcutting of the Owyhee River canyon was apparently initiated by a regional increase in stream gradients following rapid emptying of the large Pliocene Lake Idaho to the north (Jenks and Bonnichsen, 1989). The large areal distribution of fanglomerates (unit Qas) on benches above the Owyhee River canyon may record alluvial fans and plains peripheral to the high stand of the lake. Alluvial fan and terrace gravels prograded onto an eroded surface of lake sediments following emptying of the lake (Jenks and Bonnichsen, 1989). Small intracanyon basalt flows (units Qbl, Qb, Qbu) at different levels of the canyon wall mark the different river levels. The youngest of the flows was erupted from a well-preserved vent at Jordan Craters.

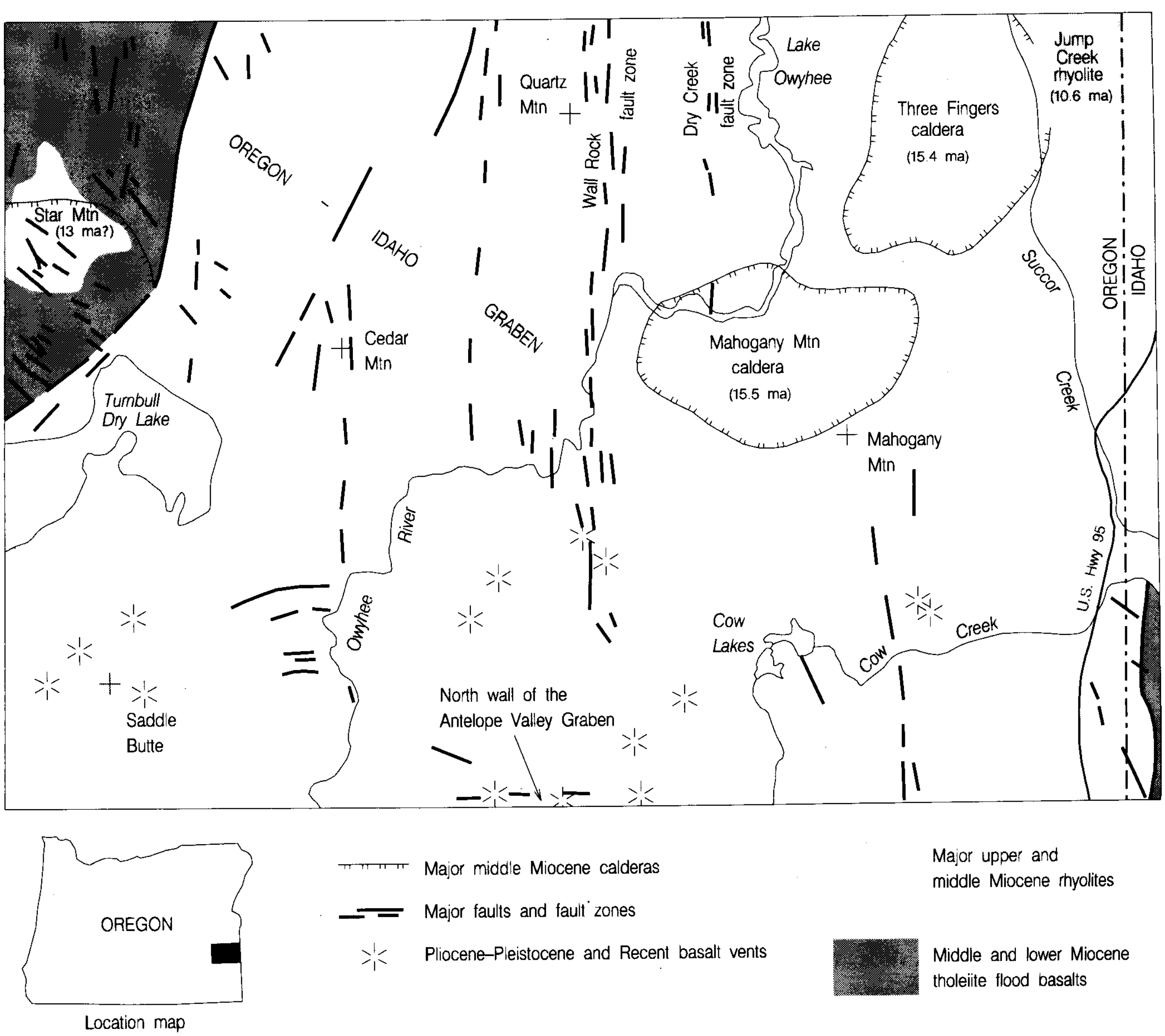


Figure 1. Sketch map showing major geologic and geographic features of the Mahogany Mountain quadrangle.

GEOLOGIC RESOURCES AND HAZARDS

INTRODUCTION

At the present time zeolite is the only mineral resource that is actively being mined on a commercial scale in the quadrangle.

NONMETALLIC MINERALS

Zeolite

The largest clinoptilolite zeolite producer in the United States is Teague Mineral Products of Adrian, Oregon. Commercial zeolite is mined from its "CH" deposit, located on the Idaho-Oregon border north of Sheaville. The CH deposit is hosted in a massive air-fall tuff that crops out in the upper part of unit Tstl. According to Leppert (1990), the deposit contains minable reserves of at least 20 million tons. The zeolite bed reportedly averages about 80–85 percent clinoptilolite. Large zeolite resources also occur in the upper part of unit Tstl near Sheaville. Several thousand tons of clinoptilolite-rich material from an 18-m-thick tuff has been mined here in the past by the Occidental Mineral Corporation and the Norton Company (MacLeod, 1990b). Holmes (1990) reports at least five thick, massive beds of zeolitic tuff at Sheaville and indicates that the Sheaville district has a large quantity of high-grade clinoptilolite.

Semiprecious gemstones

Semiprecious gemstones occur throughout much of the quadrangle. Varicolored, banded silicified tuffs known as "picture jaspers" are highly prized by lapidarists. The picture-rock deposits occur as replacement masses in bedded tuffs of units Ttlg, Tstl, and Ttbc adjacent to major north-trending fault zones. The largest identified picture-rock resources occur in the Morrison Ranch and Wild Horse deposits (Vander Meulen and others, 1987c, 1990).

Thundereggs (silicified lithophysae) occur adjacent to fault zones in rhyolite units. Main deposits occur along Succor Creek in both the rhyolite of McIntyre Ridge (unit Trmr) and the Jump Creek Rhyolite (unit Trjc). Thundereggs are also found in the rhyolite of the Silver City Range (unit Trsc) and near Star Mountain in unit Trvu.

Small amounts of gem-quality feldspar known as "Oregon sunstone" occur as phenocrysts in unit Tbtu on the west edge of the quadrangle. The plagioclase feldspars form clear, pale-yellow crystals as long as 2.5 cm. None of the crystals found to date display schiller, a characteristic structure found in some Oregon sunstones.

Other nonmetallic mineral resources

Potentially valuable nonmetallic resources include perlite, pumice, pumicite deposits (Wagner, 1969) associated with aphyric rhyolites of units Trpm and Trsc, and silica sand deposits in unit Tsal. Other possible nonmetallic resources include bentonite clay (Gray and others, 1989) and diatomite deposits in units Tstu and Tstl, rare-earth deposits in unit Ttlg, and fluorine deposits in unit Tsbc.

METALLIC MINERALS

Introduction

Several metallic-mineral resources are found in the map area. The main known metallic resource present is gold, followed by silver. Geologic indications of uranium and mercury have spurred detailed exploration for these commodities in the past but with little success.

Gold and silver

Aside from largely anecdotal "lost gold mine" legends (Hanley and Lucia, 1973), there are no published records of early mining operations. Even so, old workings on Red Butte are evidence of an early, unrecorded period of gold exploration and mining that presumably began in the 1860s.

Mineral-resource assessments, with the conspicuous exception of Gray and others (1982) and Robinson and others (1984), have generally downplayed the region's potential for economic deposits of gold and silver. Following a stream-sediment survey, Gray and others (1983) first identified the region about Lake Owyhee as an area with a high potential for gold resources.

However, the announcement by Atlas Precious Metals, Inc., in 1988 of a major discovery at the company's Grassy Mountain prospect in the Vale quadrangle to the north made clear that the geologic framework upon which the earlier evaluations were based needed reassessing.

The Grassy Mountain deposit, located some 30 km north of the quadrangle, typifies the type of gold mineralization that might be expected to occur in the Mahogany Mountain quadrangle. Grassy Mountain itself is a paleo-hot-spring deposit located along the flank of a northeast-trending graben. The deposit lies within the fluviatile section of the middle Miocene arkosic sediments of unit Tsau. The main ore zone is situated just to the east of a silicic volcanic center of unit Trcu of Ferns and others (1993). The main ore body is hosted by siliceous sedimentary rocks and lies beneath a capping layer of strongly silicified arkosic sandstones adjacent to a series of small, northeast-trending faults (Ferns and Ramp, 1989). Silicified sandstones occur to the northeast and southwest. Eroded hot-spring sinter blocks are found peripheral to the main ore zone, with sinter cropping out in places within the arkose section. Published reserves for the main and satellite deposits are 995,990 oz gold and 2,467,400 oz silver (The Mining Record, 1992).

Future exploration targets will likely be bonanza-style deposits formed beneath hot springs. This style of mineralization will require considerable attention to recognizing stratigraphic horizons in which dynamic hot springs were active. In general in the quadrangle, those hot-spring systems in which the thermal waters reached a subaerial surface are capped by siliceous sinter deposits containing silicified reeds. Actively boiling or geysering systems are recognizable by silica-cemented breccias with sinter blocks. Hot springs that discharged into lakes are characterized by cherty, sulfide-rich zones where impermeable muds have been silicified. Geothermal paleoaquifers are identified by laterally extensive zones of silicification or calcification within originally permeable sandstone or volcanic horizons.

Several paleo-hot springs have been identified in the Mahogany Mountain quadrangle, most notably the Red Butte (Evans, 1986) and Quartz Mountain (Page) prospects on the west side of Lake Owyhee and the Katey and Mahogany prospects (Gilbert, 1988; Rytuba and others, 1990; Zimmerman, 1991) on the east side of Lake Owyhee. All four prospects contain bedded sinter or sinter breccia that clearly record subaerial paleo-hot-spring activity. Bedded sinter deposits also crop out on the east side of Lake Owyhee near the head of Carlton Canyon and on the west side of Lake Owyhee near North Table Mountain.

Several other areas of silicified sediments occur in the quadrangle. Large masses of silicified arkoses that are exposed on Dry Creek Buttes may mark a significant paleoaquifer. Several large mounds of silicified tuff and chalcedonic and opaline cherts crop out in the extreme southeast corner of the quadrangle, immediately north of Jordan Valley.

Uranium

Past uranium exploration centered on areas with above-background radiation levels in arkosic sandstones in units Tsal and Tsau. Limited sampling and drilling programs failed to define a uranium resource. Finding their organic content low, Erikson (1977) considered these units to be poor depositional hosts for sandstone-type uranium mineralization. He indicated that silicic eruptive centers and adjacent areas are the best uranium exploration targets in the quadrangle, even though samples of rhyolitic flows and tuffs generally exhibited only background uranium concentrations. Anomalous concentrations of uranium and thorium are reported by Vander Meulen and others (1989a), who suggest that vein-type uranium deposits may occur near the central resurgent vent complex in the Mahogany Mountain caldera.

Rare earths

Unusually high levels of certain rare-earth elements have also been reported from the Mahogany Mountain and Three Fingers calderas (Vander Meulen, 1989; Zimmerman, written communication, 1989). Although well below ore grade, niobium abundances as high as 163 ppm and yttrium abundances as high as 736 ppm (Vander Meulen, 1989) may indicate a potential for rare-earth resources in the intracaldera facies of the Leslie Gulch Ash-flow Tuff (unit Ttlg). Zimmerman (unpublished analyses, 1989) has identified similarly high yttrium (600–1,400 ppm), with cerium and lanthanum in excess of 1,000 ppm, in mafic clasts within the tuff of Spring Creek. Vander Meulen (1989) suggests that the rare-earth enrichment in clasts within the Leslie Gulch Ash-flow Tuff is related to magmatic processes active prior to eruption of the ash flow.

Other metallic mineral resources

Although no other metallic mineral resources have been clearly identified in the map area, elevated levels of several elements may indicate the presence of other types of metallic mineral resources. Anomalous concentrations of zinc, fluorine, barium, and tin are reported by Vander Meulen and others (1987c, 1989) in and adjacent to the Mahogany Mountain caldera. They note that the rhyolites contain truly unusual concentrations of zinc and that, although not of ore grade, zinc abundances of 200–700 ppm may indicate a potential for a new type of zinc deposit (Vander Meulen and others, 1987c).

GEOLOGIC HAZARDS

Ground-water pollution

Ironically, the same geothermal and hydrothermal waters that have concentrated the precious metals have also concentrated potentially hazardous elements such as arsenic, mercury, molybdenum, uranium, thallium, and selenium. In the Mahogany Mountain quadrangle, geothermal waters have built up considerable concentrations of arsenic and, to a much lesser extent, mercury and uranium in permeable zones peripheral to the main identified paleo-hot springs. Although below presently economical concentrations, mercury-enriched zones occur at Quartz Mountain (Brooks, oral communication, 1992). Elevated concentrations of arsenic are common in lithified sandstones. Arsenic concentrations as high as 1,000 ppm have been reported from fault zones and silicified sandstones to the north (Ferns, 1988a; Ramp and Ferns, 1989; Evans and others, 1990a). These geologic zones may be responsible for elevated levels of mercury reported from fish in Lake Owyhee.

Seismic hazards

The lack of sufficient data so far prevents characterization of the seismic risk for the area. The map of Oregon seismicity (Jacobson, 1986) places the epicenters for two magnitude 3+ earthquakes in the southeast corner of the quadrangle (Jacobson, 1986). Although the northwest-trending Vale and Brothers fault zones, commonly interpreted as major right-lateral shear zones (Lawrence, 1976), are exposed just to the north and south of the map area, no clearly Quaternary faults along that trend were identified in the field. East-west trending rifts in some young volcanic flows (unit Qb) of the Jordan Craters field that parallel the north boundary faults along the Antelope Valley graben may indicate late Quaternary north-south extension in this region.

Volcanic hazards

The only other potential geologic hazard noted in the mapping project is that presented by renewed eruption of basalt flows from vents in the Jordan Craters area. Over the last 1.9 m.y., an area of about 750 km^2 has been buried by lava flows from this lava field (Hart and Mertzman, 1983). Although much smaller in size, the eruptions were apparently similar to observed eruptions in Hawaii, producing pahoehoe flows. The small population within the field suggest that, if the size and characteristics of earlier eruptions are any guide, future basalt eruptions will likely pose little risk to human habitation.

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