Geologic Map of the Arco 30 x 60 Minute Quadrangle, South-Central Idaho

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Betty Skipp and and Mel A. Kuntz

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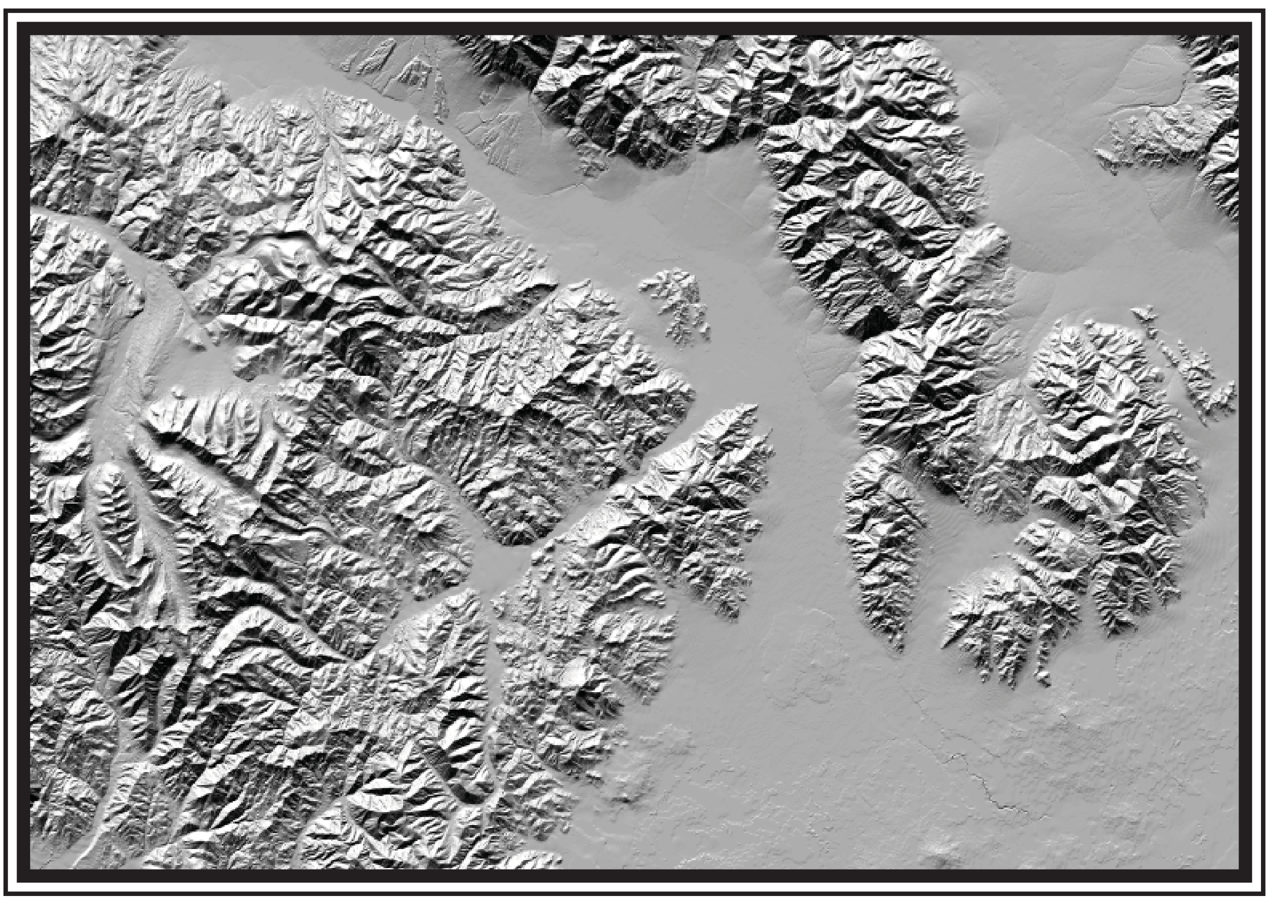

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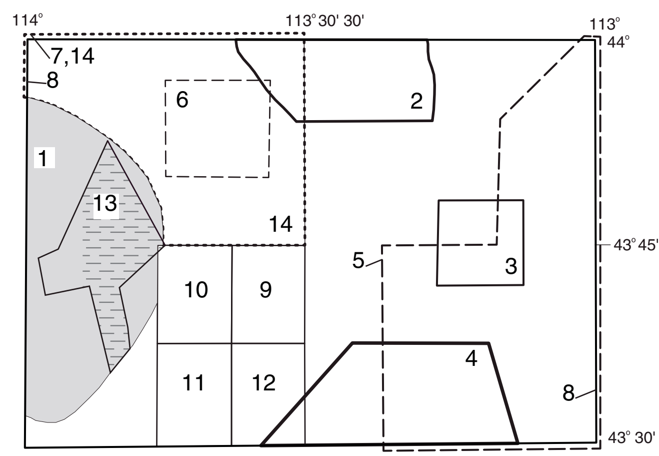
INTRODUCTION

The geology shown on the 1:100,000-scale Arco 30'x 60' quadrangle is based on published and unpublished mapping by the U.S. Geological Survey and Idaho Geological Survey, data from unpublished theses, and unpublished mapping by the authors and others that spans more than three decades (1968-2003). Primary sources (Figure 1) include published maps by Dover (1981), Janecke (1992a, 1992b), Kuntz and others (1988, 1994, 2007), Nelson and Ross (1968, 1970), Scott (1982), Skipp (1988a, 1989), Skipp and Bollman (1992), and Skipp and others (1990). Primary unpublished sources are Snider (1995) and Evenson (1978-1979). Secondary sources (Figure 2) include Master's theses from the University of Wisconsin-Milwaukee, completed under the direction of Richard A. Paull, from Idaho State University, under the direction of Paul K. Link, and one thesis from the University of Southern Mississippi. Also incorporated are unpublished map data from the U.S.



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2. Janecke, S.U., 1992a.
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4. Kuntz, M.A., D.E. Champion, R.H. Lefebvre, and H.R. Covington, 1988.
5. Kuntz, M.A., B. Skipp, W.E. Scott, K.L. Pierce, G.B. Dalrymple, L.A. Morgan, D.E. Champion, G.F. Embree, W.R. Page, R.P. Smith, W.R. Hackett, and D.W. Rogers, 1994.
6. Nelson, W.H., and C.P. Ross, 1968.
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9. Skipp, B., 1988.
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UNPUBLISHED MAPS

13. Evenson, E.B., 1978-1979.
14. Snider, L.G., 1995.

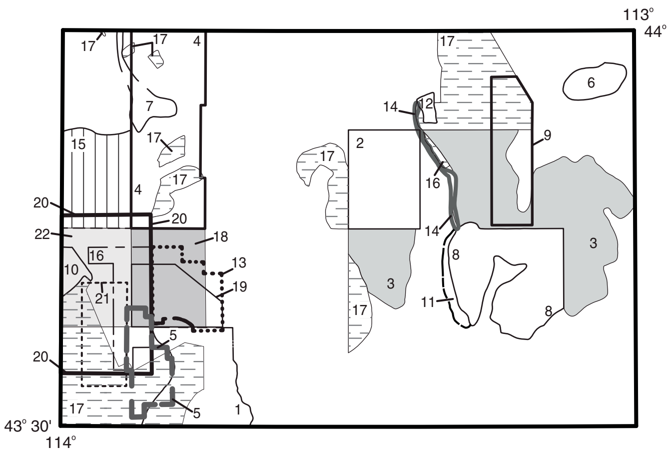
Figure 1. *Index of previous geologic mapping used as primary sources of data.*

[1] U.S. Geological Survey, MS 973, Federal Center, Box 25046, Denver, CO 80225

[2] Yukon-Nevada Gold Corporation, Jerritt Canyon Mine, HC 31, Box 78, Elko, NV 89801

[3] Geology Department, Utah Sate University, Logan, UT 84322

[4] U.S. Geological Survey, MS 980, Federal Center, Box 25046, Denver, CO 80225



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2. Davis, J.E., Jr., 1983.
3. Embree, G.F., R.D. Hoggan, E.J. Williams, M.H. Hait, Jr., S.U. Janecke, and B. Skipp, 1973-2002.
4. Erwin, C.R., 1972.
5. Gagnon, W.P., 1980.
6. Hait, M.H., Jr., 1970-1977.
7. Janecke, S.U., 2000-2004.
8. Janecke, S.U., and B. Skipp, 1980-2002.
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10. Link, P.K., and B. Skipp, 1996.
11. Mapel, W.J., 1960-1970.
12. Melnychenko, P.B., 1978.
13. Olig, S.S., A.E. Gorton, J.D. Bott, J.G.Wong, P.L.K. Kneupfer, S.L. Forman, R.P. Smith, D. Simpson, 1995; and Crone, A.J., 1983-1985.
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18. Warren, I., 1996
19. Wilson, E., 1994.
20. Winkler, G.R., W.K. Kunkel, R.F. Sanford, R.G.Worl, and F.J. Moye, 1995.
21. Wolbrink, M.S., 1970.
22. Malde, H.E., 1987; Crosthwaite, E.G., and others, 1970.

Figure 2. *Secondary map and cross- section sources.*

Geological Survey (Figure 2). A generalized version of the area at 1:250,000 is published in a map of the eastern part of the Challis National Forest (Wilson and Skipp, 1994).

Rocks exposed in the Arco quadrangle range in age from Precambrian (Mesoproterozoic) to Holocene; Mesozoic rocks, however, are absent. Mesoproterozoic sedimentary rocks of the Belt Supergroup are exposed only in the uplifted western margin of the Lemhi Range along the northeastern margin of the map. Paleozoic (Ordovician through Permian) marine rocks of several facies are present throughout the quadrangle except where buried beneath Tertiary volcanic rocks or where obscured by younger overlying Quaternary sedimentary deposits or, in the southeastern corner, by basalts of the Snake River Plain.

Paleozoic rocks consist of three dissimilar stratigraphic sequences that have been juxtaposed by two Late Cretaceous(?) Sevier-age thrust faults, the Pioneer and the Copper Basin, in the western third of the quadrangle (Link and others, 1995). These southwest-dipping thrust faults are largely buried beneath Tertiary volcanic rocks. Limited exposures on the northeastern margin of the Pioneer core complex (Figure 3) indicate that the Pioneer thrust plate on the west carries Devonian deep-water shales (Milligen Formation) and other western facies rocks. The western facies rocks are overlain unconformably by thick Late Pennsylvanian- to Permian-age sandy basinal carbonate rocks (Wood River Formation of the Sun Valley Group). The Copper Basin thrust plate beneath the Pioneer thrust carries thick, fine- to coarse-grained clastic and carbonate Mississippian flysch deposits (Copper Basin Group). The footwall of the Copper Basin thrust consists of faulted fold trains of miogeosynclinal sedimentary rocks of Cambrian through Permian age underlain by Mesoproterozoic or Neoproterozoic basinal rocks that probably underlie all of the Arco quadrangle (Skipp and Link, 1992; Link and others, 2007). Although no Mesozoic sedimentary rocks are preserved in the area, Triassic rocks probably were deposited at one time and then were removed during the uplift and erosion of the thrust belt in Cretaceous time.

Tertiary rocks include localized basal Challis (Smiley Creek Formation) conglomerates, extensive intermediate volcanic and intrusive rocks of the Eocene Challis Volcanic Group, Eocene to Oligocene(?) conglomerate and sandstone in the Arco Pass and Pass Creek basins in the Lost River Range (Figure 3), and a few ignimbrites of the Miocene Idavada Volcanics and the Neogene Heise Group. Volcanic centers for the Challis field lie north and south of the White Knob horst (Figure 3) and in the central Lost River Range. The volcanic centers shown on Figure 3, Lehman Basin cauldron complex (LBCC), Navarre Creek dome complex (NCDC), and Alder Creek eruptive center (ACEC), are all part of the southeastern Challis field (Moye and others, 1995; Snider, 1995). Sources for the Idavada Volcanics and Heise Group ignimbrites probably were calderas presently buried beneath basalts within the Snake River Plain (Pierce and Morgan, 1992; Morgan and McIntosh, 2005).

Quaternary basalts of the Snake River Plain and Craters of the Moon National Monument cover the southeastern corner of the Arco quadrangle. Letter symbols for the basalt units are the same in the complete “Description of Map Units” and in the detailed “Basaltic

Rocks" section. An extension of the Great Rift Zone of the Craters of the Moon National Monument (Kuntz and others, 2007) is marked by a string of small basalt vents that trend northwestward from the margin of the Snake River Plain and have intruded both Paleozoic and Tertiary rocks (Figure 3).

The "Basaltic Rocks" section by Mel A. Kuntz provides further details on the extent, physical characteristics, chemistry, petrography, and radiometric ages of these units. Descriptions and ages of the Quaternary surficial sedimentary deposits are based chiefly on the work of W.E. Scott (1982).

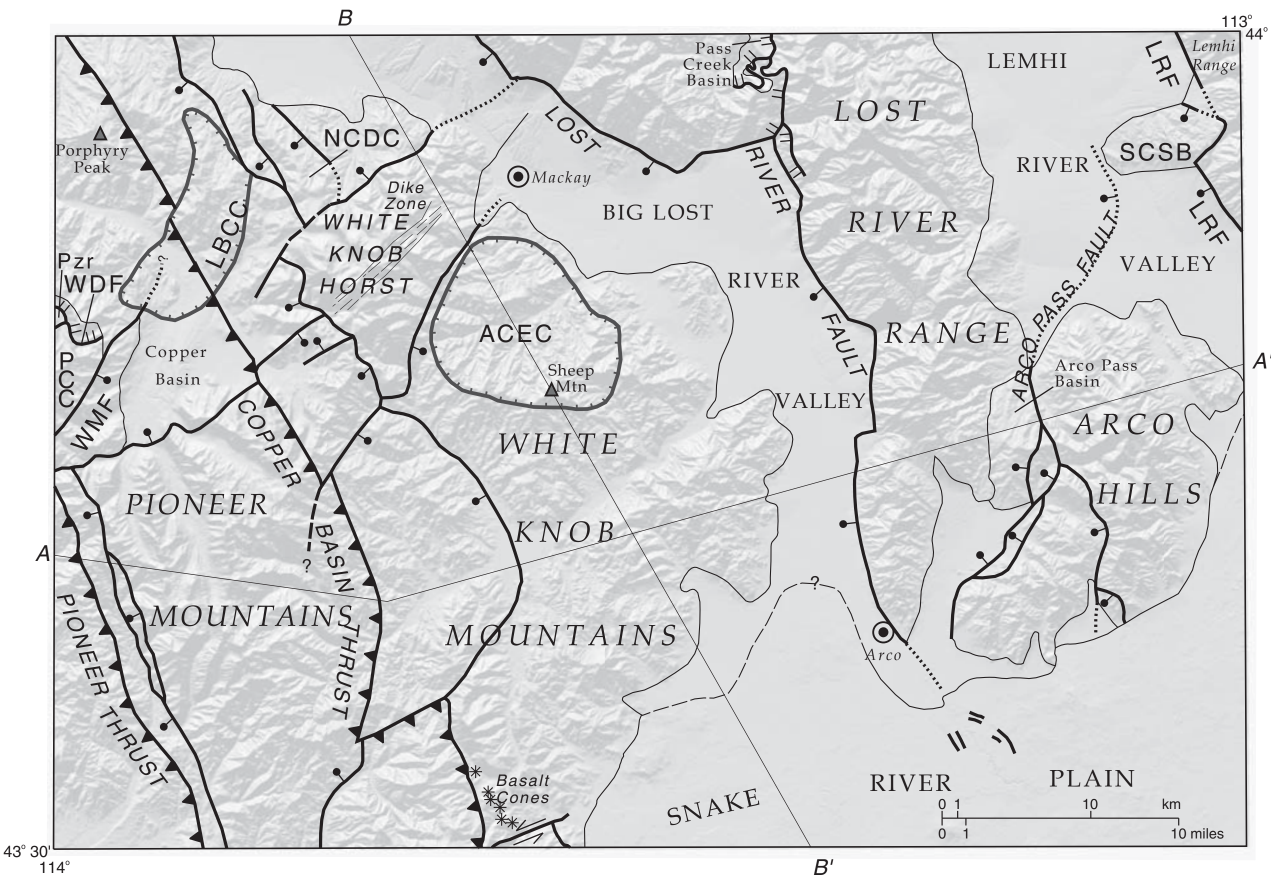

Figure 3. *Sketch map of Arco 30' x 60' quadrangle, Blaine, Butte, and Custer counties, Idaho, showing mountain ranges, river valleys, major structural features referred to in text, and the two largest towns, Arco and Mackay. Structural features include the largely buried Cretaceous thrust faults, the Pioneer fault on the west, and the Copper Basin fault a few miles (kilometers) to the east in the Pioneer Mountains; the easternmost part of the Tertiary Pioneer core complex (PCC) and the Paleozoic western facies rocks (Pzr), the White Mountains normal fault (WMF), and a segment of the Wildhorse detachment fault (WDF) associated with the complex; unnamed northwest-trending normal faults east of the Cretaceous thrust faults; the White Knob horst in the White Knob Mountains; three volcanic centers in the Eocene Challis Volcanic Group, the Lehman Basin cauldron complex (LBCC), the Navarre Creek dome complex (NCDC), and the Alder Creek eruptive center (ACEC); the Eocene and Oligocene(?) Pass Creek and Arco Pass extensional basins; the Elbow Canyon detachment fault (ECD); the Arco Pass fault; the Quaternary Snake River Plain with a questioned northern boundary; the Quaternary active range front normal faults on the western sides of the Lost River and Lemhi (LRF) ranges; the South Creek fault block (SCSB) of Beutner (1972); and basalt cones that extend northwestward into the White Knob Mountains from Great Rift Zone volcanism of the Craters of the Moon National Monument. Also shown are cross sections A-A′ and B-B′.*

DESCRIPTION OF MAP UNITS

QUATERNARY DEPOSITS

ALLUVIAL AND COLLUVIAL DEPOSITS

Qamf—Deposits of modern flood plain (Holocene)—Silt, sand, clay, and minor gravel; poor to moderate sorting; parallel bedding, very thin to thick beds obscure in places. In Little Wood, Big Lost, and Little Lost River valleys, unit includes spring areas close to modern flood plain. Thickness ranges from 1 to 3 m; locally thicker in abandoned channels (Scott, 1982).

Qaf1—Fan alluvium 1 (Holocene)—Pebble to cobble gravel, some pebbly sand; locally fine grained and humic; poor to moderate sorting; clasts subangular to round; parallel bedding and large-scale crossbedding. Forms fans and surfaces of active deposition within older fan deposits (Scott, 1982).

Qta—Alluvium of tributary streams (Holocene to late Pleistocene)—Silty sand to clayey silt, minor angular to round gravel, locally humic; nonbedded to parallel bedded. Overlies pebble and cobble gravel to gravelly sand, and lenses of sandy silt; crossbedded. Maximum exposed thickness of fine-grained deposits and underlying gravel about 8 m. Locally incl10udes colluvium. Maximum total thickness including older deposits several tens of meters (Scott, 1982).

Qp—Playa deposits (Holocene and late Pleistocene)—Silty sand to clayey silt, minor gravel, and scattered basalt boulders near margins. Mapped only along southeastern border of quadrangle (Scott, 1982; Kuntz and others, 1994).

Qfy—Fan alluvium 1 and 2 undivided (Holocene to late Pleistocene)—Pebble to cobble gravel; locally bouldery near fan heads; generally clast supported; contains sand and silty sand as matrix and small lenses. Unit locally faulted (Kuntz and others, 1994; Scott, 1982).

Qaf$_2$—Fan alluvium 2 (late Pleistocene)—Pebble to cobble gravel, locally bouldery near fan heads, generally clast supported; contains varied amounts of sand to silty sand as matrix and small lenses; clasts subangular to subround; parallel bedding and large-scale crossbedding; locally includes alluvium of Holocene age. Forms fans and coalescing fans at range fronts; unit disrupted by fault scarps along west-facing range front faults in Lost River and Lemhi ranges (Scott, 1982; Kuntz and others, 1994).

Qaf$_3$—Fan alluvium 3 (middle to early? Pleistocene)—Pebble to cobble gravel, locally bouldery near fan heads; contains varied amounts of sand to silty sand matrix and some lenses of sand and silty sand; poor to moderate sorting; clasts subangular to round; parallel bedding and large-scale crossbedding; locally crudely bedded; medium to thick beds. Forms terraces, small fan remnants, and some fan surfaces. Topographically higher position, better developed soil, and thicker caliche coats on clasts than fan alluvium 2; possibly Bull Lake age. Extensively faulted along western fronts of Lost River and Lemhi ranges (Scott, 1982).

Qafc—Fan deposits of alluvium and colluvium undivided (Holocene to middle Pleistocene)—Pebble to boulder gravel having a matrix of silty sand to clayey silt; very poorly sorted; crudely bedded. Includes material deposited by streams and debris flows at mouths of small drainage basins and thin gravel of small pediments in mountains (Kuntz and others, 1994; Scott, 1982).

Qc—Colluvium (Holocene and Pleistocene)—Angular blocks of locally derived material in a fine-grained matrix. Includes slopewash deposits, talus, and rock glaciers in Lost River Range.

Ql—Landslide deposits (Holocene and Pleistocene)—Blocks of bedrock, pebble to boulder size, chiefly angular to subangular, in a fine-grained matrix of silty sand to silty clay. Formed by slumps and earthflows derived principally from local sedimentary and volcanic rocks of Tertiary age (Kuntz and others 1994).

QTc—Colluvium undivided (Holocene to Pliocene)—Locally derived material; unit present only in Lost River Range (Janecke, 1992a).

QTf—Alluvial fan deposits undivided (Holocene to Pliocene)—Includes old fan deposits of possible Tertiary age overlain by younger deposits.

QTfo—Older alluvial fan deposits (middle Pleistocene to Pliocene?)—Fan deposits older than *Qfy*.

Equivalent to units *Qaf_3* and *$QTaf_4$* undivided. Used only in Lost River Range (Janecke, 1992a).

$QTaf_4$—Fan alluvium 4 (Pleistocene to Pliocene?)—Pebble to cobble gravel, scattered boulders, varied amounts of sand to silty sand matrix, local lenses of sand and silty sand; poor to moderate sorting; clasts subangular to round; parallel bedding and large-scale crossbedding. Locally to pervasively cemented with calcium carbonate derived from ground water (Scott, 1982).

QTg—Gravel deposits (Pleistocene to Pliocene?)—Pebble to cobble gravel, minor sand and silt; deposits postdate extrusion of Heise volcanics.

QTu—Sedimentary and volcanic deposits undivided (Pleistocene to Eocene)—Volcanics and interbedded sedimentary deposits on east side of Lost River Range and in isolated localities in the Arco Hills.

Glacial Deposits

Qd—Glacial drift undivided (late and middle Pleistocene)—Glacial till and outwash of both Pinedale and pre-Pinedale glaciations.

Qmt—Alluvial deposits of cut terraces of Pinedale age (late Pleistocene)—Pebble and cobble gravel to pebbly sand, and minor sand. Upper 0.5-2 m generally includes admixed sand and silt of eolian or alluvial origin. Forms terraces along Big Lost River near Arco (Kuntz and others, 1994).

Qpt—Till of Pinedale glaciation (late Pleistocene)—Pebble to boulder gravel in matrix of silty sand to clayey sandy silt; nonsorted to poorly sorted; clasts subangular to subround; nonbedded to crudely bedded. Forms moraines and sheetlike deposits with rolling to hummocky relief. Thickness from 1 m to more than 30 m (Scott, 1982).

Qpo—Outwash of Pinedale glaciation (late Pleistocene)—Pebble and cobble gravel, locally bouldery, varied amounts of sand matrix; poor to moderate sorting; clasts subangular to round; parallel bedding and large-scale crossbedding; thin to thick beds. Forms outwash fans and terraces along streams fed by glacial meltwaters (Scott, 1982).

Qgl—Glacial lacustrine deposits (late Pleistocene)—Thick clay deposits on flats of Copper Basin (Evenson and others, 1984).

Qamp—Deposits of major fill of Pinedale age along main streams (late Pleistocene)—Pebble and cobble gravel to pebbly sand; poor to moderate sorting; clasts subround to round; parallel bedding and large-scale crossbedding. Upper 0.5-2 m generally includes sand and silt of eolian origin. In Big and Little Lost River valleys, clasts chiefly quartzite. Forms terraces that lie 3-20 m above modern flood plains. Thickness ranges from a few meters to 1,000 m in Big and Little Lost River basins (Scott, 1982; Kuntz and others, 1994).

Qot—Till of pre-Pinedale glaciations (middle Pleistocene)—Pebble to boulder gravel in a loose to compact matrix of silty sand to clayey sandy silt; nonsorted to poorly sorted; clasts angular to subround; nonbedded to crudely bedded. Forms subdued moraines with broadly rounded crests and sheetlike deposits with low to rolling relief. Thickness from 1 m to more than 30 m (Scott, 1982).

Qoot—Outwash of pre-Pinedale glaciations (middle Pleistocene)—Pebble and cobble gravel, locally bouldery; contains varied amounts of sand matrix; poor to moderate sorting; clasts subangular to round; parallel bedding and large-scale crossbedding; thin to thick beds. Forms outwash fans and terraces in drainages that were glacier covered (Scott, 1982).

Qmo—Older alluvial deposits along main streams (middle Pleistocene)—Pebble and cobble gravel to pebbly sand and minor sand. Loess cover >1 m thick and contains at least one buried soil. Differentiated from unit *Qamp* on the basis of higher geomorphic position. Near Arco, unit predates basalt flows of unit *$Qsbb_1$* (Kuntz and others, 1994; 2007).

FLOWS AND CONES OF THE CRATERS OF THE MOON LAVA FIELD

$Qcfa_2$—Blue Dragon flows (Holocene)—Tube- and surface-fed pahoehoe basalt-hawaiite flows characterized by fresh, iridescent, dark to light blue glassy vesicular crusts (Craters of the Moon lava field). See "Basaltic Rocks" section.

$Qcfa_8$—Serrate flows (Holocene)—Surface-fed, olive-gray to medium dark gray, jagged block and a'a flows (Craters of the Moon lava field). See "Basaltic Rocks" section.

$Qcfg_1$—Sunset flows (latest Pleistocene)—Chiefly surface- and tube(?)-fed, hummocky, medium dark gray pahoehoe basalt-hawaiite flows. Slab pahoehoe pressure ridges, pressure plateaus, and collapse depressions common (Craters of the Moon lava field). Includes iridescent air-fall ash deposited near mouth of Lava Creek. See "Basaltic Rocks" section.

$Qcfg_3$—Lava Creek flows (latest Pleistocene)—Chiefly surface- and channel-fed, dark gray, blocky a'a basalt flows. Also includes thin, spattery pahoehoe basalt flows near vents (Craters of the Moon lava field). See "Basaltic Rocks" section. Small basalt outcrop in Dry Fork about 2 km north northwest of Black Cap (Skipp and Bollman, 1992) is tentatively assigned to this unit.

$Qccg_2$—Lava Creek basaltic cinder cones (latest Pleistocene)—Chiefly black cinders, agglutinated spatter, bombs, lapilli, coarse ash, and interlayered thin lava flows. Southernmost and largest cone (Black Cap) was source for main flow that extends eastward onto Snake River Plain (Craters of the Moon lava field). See "Basaltic Rocks" section.

LAVA FIELDS, CONES, AND ERUPTIVE-FISSURE DEPOSITS OF THE SNAKE RIVER GROUP

$Qsbb_1$—Lost River lava field (late Pleistocene)—Basaltic surface-, channel-, and tube-fed, medium gray pahoehoe flows and pyroclastic deposits erupted from a vent about 5 km west of Arco. Flows mantled by thin deposits of loess and eolian sand. See "Basaltic Rocks" section.

$Qsbb_{19}$—Quaking Aspen Butte lava field (late Pleistocene)—Tube-fed, dark gray and medium gray pahoehoe and shelly-pahoehoe basalt flows. Flows mantled by thin deposits of loess and eolian sand. Vent about 12 km south of southern border of quadrangle (Snake River Group). See "Basaltic Rocks" section and Kuntz and others (2007).

$Qsbb_{23}$—Vent 5206 lava field (late Pleistocene)—Surface-, channel-, and tube(?)-fed, medium gray pahoehoe basalt flows and reddish oxidized and black, fresh, near-vent pyroclastic deposits (Snake River Group). See "Basaltic Rocks" section.

$Qsbc_1$—Lavatoo lava field (late middle Pleistocene)—Surface-, channel-, and tube(?)-fed, dark to medium gray pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits (Snake River Group). Flows lie on flows of Crater Butte lava field (*$Qsbc_3$*). See "Basaltic Rocks" section.

$Qsbc_2$—Vent 5371 lava field (late middle Pleistocene)—Surface-, channel-, and tube(?)-fed, dark to medium gray pahoehoe basalt flows. Flows mantled by thin deposits of loess and eolian sand. See "Basaltic Rocks" section.

$Qsbc_3$—Vent 5334 lava field (late middle Pleistocene)—Surface-, channel-, and tube(?)-fed, dark to medium gray pahoehoe and shelly-pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits. Flows mantled by thin deposits of loess and eolian sand. See "Basaltic Rocks" section.

$Qsbc_4$—Crater Butte lava field (late middle Pleistocene)—Surface-, channel-, and tube(?)-fed, dark to medium gray pahoehoe and shelly pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits. Flows mantled by thin deposits of loess and eolian sand (Snake River Group). See "Basaltic Rocks" section.

$Qsbc_{33}$—Saddle Butte lava field (late middle Pleistocene)—Medium gray pahoehoe basalt flows not studied petrographically. See "Basaltic Rocks" section.

$Qsbc_{37}$—Vent 5571 lava field (late middle Pleistocene)—Surface-, channel-, and tube(?)-fed, medium gray pahoehoe and shelly pahoehoe basalt flows, and reddish oxidized and black, near-vent pyroclastic deposits. Vent about 1 km south of southern boundary of quadrangle (Kuntz and others, 2007). Flows mantled by thin deposits of loess and eolian sand. See "Basaltic Rocks" section.

$Qsbc_{45}$—Tin Cup Butte lava field (late middle Pleistocene)—Surface-fed, dark gray and medium gray pahoehoe basalt flows. Vents lie south of southern boundary of map. Only distal flows are present on this map. See "Basaltic Rocks" section.

$Qsbc_{46}$—Sixmile Butte lava field (late middle Pleistocene)—Tube-fed, medium black and medium gray pahoehoe basalt flows that lie atop a steep-sided shield volcano that rises 100 m above surrounding flows. Flows are mantled by thin deposits of loess and eolian sand. See "Basaltic Rocks" section.

$Qsbc_{47}$—Teakettle Butte lava field (late middle Pleistocene)—Surface- and channel-fed, dark gray and medium gray pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits. Vent depression is atop a 100-m-high eruptive fissure-cinder cone complex having steep slopes. Much of vent area mantled by reddish oxidized and black pyroclastic deposits and shelly pahoehoe flows. Flows mantled by thin deposits of loess and eolian sand. See "Basaltic Rocks" section.

$Qsbc_{48}$—Vent 5217 lava field (late middle Pleistocene)—Surface- and channel-fed, dark gray and medium gray pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits. Vent area is eruptive-fissure system having vent 5217 at south end. Proximal flows are mantled by thin loess and eolian sand. Medial and distal flows are covered by younger flows of vent 5371 (*$Qsbc_2$*) and Quaking Aspen Butte (*$Qsbb_{19}$*) lava fields. See "Basaltic Rocks" section.

$Qsbc_{49}$—Vent 5218 lava field (late middle Pleistocene)—Surface-, channel-, and tube-fed(?), dark gray and medium gray pahoehoe basalt flows. Vent consists of four low cinder cones mantled by reddish oxidized and black cinders, ash, and lapilli. Distal parts of flows covered by flows of units *$Qsbb_{19}$* and *$Qsbc_{48}$*. See "Basaltic Rocks" section.

$Qsbc_{50}$—Vent 5968 lava field (late middle Pleistocene)—Basalt flows as in *$Qsbc_{49}$*. Vent area is a northwest-trending shallow crater atop a broad shield volcano summit that lies 1 km north of kipuka of Ordovician quartzite. See "Basaltic Rocks" section.

$Qsbc_{51}$—Nichols Reservoir lava field (late middle Pleistocene)—Surface-, channel-, and tube-fed(?), dark gray and medium gray pahoehoe basalt flows. Vent area is crater atop broad shield volcano. Near-vent flows mostly shelly pahoehoe. Flows mantled by thin loess and eolian sand. See "Basaltic Rocks" section.

$Qsbd_1$—Vent 5968 lava field (early middle Pleistocene)—Surface- and channel-fed, dark gray and medium gray pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits. Vent area is 25-m-deep crater. Vent crater and proximal flows surrounded by flows of the Crater Butte lava field (*$Qsbc_4$*). See "Basaltic Rocks" section.

Qb—Basalt flow in Friedman Creek (middle Pleistocene)—Medium gray, vesicular, columnar-jointed basalt; weathers olive-gray; age estimated; estimated thickness as much as 35 m (Lukowicz, 1972; Gagnon, 1980).

$Qsbe_1$—Pahoehoe flows (early Pleistocene)—Surface- and channel-fed, dark gray and medium gray pahoehoe flows mantled by loess and eolian sand. May be flows of Knob Vent lava field, the vent for which lies 0.5 km east of eastern boundary of map (Kuntz and others, 1994; 2007). See "Basaltic Rocks" section.

HEISE GROUP AND IDAVADA VOLCANICS AND RELATED DEPOSITS

Th—Heise Group (Pliocene and Miocene)—Grayish purple, pale red, light brown, light gray, and black, densely welded rhyolitic ignimbrites containing vitric and devitrified vapor phase and lithophysal zones; locally, spherulites are present in vitrophyres. Includes the Walcott Tuff (6.27 Ma) and tuff of Blacktail Creek (6.62 Ma) (Morgan and McIntosh, 2005). Pliocene units are not present in area. Total phenocryst or crystal content of Walcott Tuff is 0.5% and of Blacktail Tuff about 10% to 15% of plagioclase, quartz, sanidine, augite, orthopyroxene, magnetite, and zircon, in addition to common pumice and lithic fragments. Walcott Tuff has trace amounts of biotite. Thickness of unit from 0 to about 30 m (Skipp and others, 1990; Morgan, 1992). Found only near mouths of Hammond, Spring, and Champagne creeks on north margin of Snake River Plain.

Tiv—Idavada Volcanics undivided (Miocene)—Grayish red, moderate reddish brown, moderate brown, dark yellowish brown and black, densely welded to nonwelded rhyolitic ignimbrites and minor fall deposits and polymict gravels. Total phenocryst or crystal content ranges from 2% to 15% and includes sanidine, plagioclase, pyroxene, opaque iron oxide, and rare hornblende, biotite, and quartz. Black vitrophyre zones locally are perlitic. Lithophysal zones have cavities as long as 30 cm. Thin polymict alluvial gravels cemented by an ash matrix are rare. Vents thought to be on Snake River Plain (Moye and others, 1988b; Pierce and Morgan, 1992). Includes tuff of Little Chokecherry Canyon of Snider (1995) and Arbon Valley Tuff Member of the Starlight Formation (Carr and Trimble, 1963; Kellogg and others, 1994; Morgan and McIntosh, 2005). Radiometric ages range from 8.77 Ma to 11.72 Ma. Thickness 0-185 m (Skipp, 1989; Snider, 1995; Kuntz and others, 2007).

Tgu—Upper gravel deposits (Miocene to Oligocene)—Includes pebble- to boulder-sized polymict alluvial gravel at base of and between ignimbrites of Idavada Volcanics along southwestern margin of quadrangle, and nearly flat but highly dissected deposits of gravel and conglomerate in Arco Pass area (Ta_2 of Janecke, 1992b) where clasts are composed chiefly of upper Paleozoic carbonates (Janecke, 1992a, 1995; Kuntz and others, 2007). Post middle Eocene and older than Heise Group. Thickness 100-200 m.

CHALLIS VOLCANIC GROUP AND RELATED DEPOSITS IN CENTRAL LOST RIVER RANGE (MIOCENE TO EOCENE)

Nomenclature and descriptions for the following units are taken from Janecke (1992a).

Tgl—Lower gravel deposits (Oligocene to middle Eocene)—Pebble- to boulder-sized clasts of dacite and andesite lava near base, and carbonate, chert, and sandstone clasts near the top of moderately dipping beds of gravel and conglomerate of Arco Pass. White tuff locally interstratified near base. Largely coeval with gravels and conglomerates present in the Lost River Range in unit Tb_2 (Janecke, 1992a, 1995). Includes unconsolidated gravels that unconformably overlie Challis Volcanic Group northwest of the White Knob horst in the northwest part of the quadrangle (*Tgr* of Snider, 1995). Isolated exposures of subhorizontal Miocene ignimbrites and basalt unconformably buttress these deposits south of Arco Pass, suggesting an angular unconformity separates the lower gravel deposits from the Miocene volcanic rocks (Janecke, 1995); deposits as much as 1.5 km thick.

Tu—Volcanic and sedimentary deposits undivided (Miocene to Eocene)—Volcanics and interbedded sedimentary deposits on east side of Lost River Range that do not include deposits as young as some of those in unit *QTu*.

Tb_2—Conglomerates of Pass Creek-Wet Creek reentrant, unit 2 (Oligocene? and Eocene)—Primarily pebble- to cobble-sized clasts of Carboniferous limestone and chert with minor Pennsylvanian Quadrant quartzite; characteristic bright red soils developed on unit; intercalated white tuffs produced disturbed Eocene ages (Janecke and Snee, 1993). The tuff is chemically correlated to the 39-Ma Norwood tuff (Nelson and others, 1984; M. Perkins and Janecke, unpublished data, 1996), confirming an Eocene age for the lower part of this unit; formerly gravels of Wet Creek of Mapel and Shropshire (1973).

Tb_1—Conglomerates of Pass Creek-Wet Creek reentrant, unit 1 (late to middle Eocene)—Pebble- to boulder-sized clasts of dacite and andesite lavas, and Carboniferous limestones; formerly gravels of Wet Creek of Mapel and Shropshire (1973); unwelded vitric tuffs (*Tct*) interbedded near base dated at 45.4 Ma (Janecke and Snee, 1993); characteristic tan to brown soils developed on unit; some interbedded tuffaceous sandstones and siltstones; top is older than the 39 Ma ash of unit Tb_2.

Tcu—Lava flows, tuffs, and sedimentary rocks undivided (middle Eocene)—Includes units *Tctt*, *Tctu*, and Tb_1.

Tcr—Tuff of Challis Creek (middle Eocene)—White, unwelded quartz-sanidine bearing tuff with a probable source northwest of Challis; 45.5-46.0 Ma (Janecke and Snee, 1993).

Tdu—Upper dacite lava of Crows Nest Canyon (middle Eocene)—Massive, cliff-forming dacitic lava flows as thick as 650 m (Janecke and Snee, 1993).

Tctu—Nonwelded tuffs and reworked volcaniclastic rocks (middle Eocene)—Buff, off-white or tan; grain size typically <1 cm; gradational contact between this unit and Tb_2.

Tdi—Dikes and small intrusive bodies (middle Eocene)—Includes small plugs, sills, and dikes in northern Lost River Range.

Tmaf—Tuff of Mud Lake (middle Eocene)—Welded crystal lithic ignimbrite about 10-15 m thick; partly welded; contains plagioclase, 2-3 mm kinked biotite, pyroxene and sanidine crystals. Biotite from the tuff produced a slightly discordant spectrum (sample 88-134; Figure 6, Table 1; Janecke and Snee, 1993); apparent ages from the flattest part of the age spectrum have a high of 48.5 ± 0.2 Ma and a low of 47.6 ± 0.2 Ma, suggesting a "true" age close to 48 Ma. The total gas age of 47.7 ± 0.2 Ma probably reflects minor argon loss. The similar age for the tuff of Mud Lake and the base of the white biotite tuffs suggests very little time is represented by the tuffaceous rocks.

Tctt—White biotite tuffs (middle Eocene)—White, biotite-bearing, vitric, nonwelded, massive to laminated, mostly fine-grained, well-sorted; accretionary lapilli in basal tuff; base age 48.0 ± 0.2 Ma (sample 88-132; Janecke and Snee, 1993).

Tca—Andesite, high-K andesite, and latite lavas (middle Eocene)—Aphanitic to porphyritic; thin intercalated lapilli tuff and conglomerate; includes local mafic flows.

Tct—Tuff and tuffaceous volcaniclastic rocks (middle Eocene)—Lapilli tuffs.

Tcnbx—Tuff breccias of Crows Nest Canyon (middle Eocene)—Dacitic, laterally discontinuous.

Tcn—Dacite lava of Crows Nest Canyon (middle Eocene)—Oxyhornblende separated from a lava flow near the top of the dacite of Crows Nest Canyon yielded a two-step "near-plateau" age of 48.6 ± 0.1 Ma based on 65% of the gas (Janecke and Snee, 1993). Feeders for this dacitic dome probably are buried beneath it.

Twbx—Dacitic tuff breccia of Warren Mountain (middle Eocene).

Tw_2—Upper unit of dacite lavas (middle Eocene)—Intercalated welded tuffs of Warren Mountain separate the upper and lower units of dacite lava.

Tw_1—Lower unit of dacite lavas of Warren Mountain (middle Eocene)—Conspicuous plagioclase and varying amounts of hornblende, pyroxene, and biotite; flow banded; 48.8 Ma (Janecke and Snee, 1993). Two $^{40}Ar/^{39}Ar$ ages (48.4 Ma and 48.8 Ma) from the unit imply a fairly rapid extrusion rate. Hornblende separated from a vitrophyre collected in the lower one-third of the lower dacitic lava flow section yielded an plateau age of 48.8 ± 0.2 Ma (sample 88-139; Figures 4 and 6; Table 1). A sample collected near the top of the unit showed some argon loss but yielded a plateau age on hornblende of 48 .4 ± 0.3 Ma (Janecke and Snee, 1993). Feeders for these dacitic domes probably are buried beneath them.

Twt—Dacitic ignimbrite of Warren Mountain (middle Eocene)—Possibly correlates with Tuff of Ellis Creek of McIntyre and others (1982).

Tcc—Basal Challis conglomerate (Eocene)—Pebble- to boulder-conglomerate and minor interbeds of coarse- to granule-sized quartz sandstone of alluvial origin; locally derived; clasts rounded to subrounded; chiefly silica-cemented quartz sand; thick-bedded to poorly bedded. Unconformably overlies Paleozoic rocks and is disconformably to conformably overlain by volcanic rocks of Challis Volcanic Group. Fills paleovalleys in the Lost River Range. Some pebbles to small cobbles of Copper Basin Formation indicate west to east fluvial transport. Equivalent to Smiley Creek Conglomerate of Paull (1974) in White Knob Mountains.

CHALLIS VOLCANIC GROUP AND RELATED INTRUSIVE AND SEDIMENTARY ROCKS IN PIONEER AND WHITE KNOB MOUNTAINS (EOCENE)

Nomenclature and descriptions for the following units are adapted from Snider (1995) and Blakley (2001).

Tj—Jasperoid (Miocene? to Eocene?)—Light gray to black and medium brownish gray, aphanitic to fine-grained, commonly brecciated, silicified rocks that chiefly are replacements of limestone, carbonaceous limestone, and mudstone, and, less commonly, of sandstone and volcanic rock; weathers light to moderate brown, brownish gray, and black; forms ledges and ridges; gradational contact with unsilicified host rock. Contains minor associated precious metal deposits (Soulliere and others, 1995b).

Ttv—Travertine (Miocene? to Eocene?)—Float of light gray fresh-water limestone from a spring deposit in isolated outcrop near mouth of Alder Creek in White Knob Mountains.

Ts—Skarn (Eocene)—Chiefly metasomatized limestone consisting primarily of garnet mixed with varied amounts of pyroxene (diopside) and subordinate magnetite, hematite, actinolite, scapolite, wollastonite, epidote, and fluorite; most common along contact zones of limestone with leucogranite porphyry (*Tlp*); has yielded economic concentrations of copper, lead, and zinc (Umpleby, 1917; Nelson and Ross, 1968).

Tcv—Challis Volcanic Group undivided (Eocene)—Andesitic, dacitic, basaltic, and rhyolitic ignimbrites, flows, domes, dikes, plutons, and minor interbedded sedimentary rocks.

Td—Dikes undivided (Eocene)—Porphyritic and nonporphyritic rhyolite, dacite, trachydacite, latite, andesite, and basalt dikes, sills, and other small intrusive bodies. Includes rhyolite and porphyritic rhyolite dikes of dike swarm in central and northern parts of Mackay horst that are characterized by dipyramidal phenocrysts of high temperature quartz (Nelson and Ross, 1968).

Tcdu—Upper dacite flow and dome complexes (Eocene)—Porphyritic dacite to trachydacite and lesser latite flows, intrusive and extrusive domes, and intercalated tuff breccias, and volcaniclastic sediments; total phenocryst or crystal content about 35% phenocrysts of dominantly plagioclase, lesser clinopyroxene, biotite, hornblende, and opaque oxides, and local quartz and plagioclase-rimmed orthoclase. Individual flows as much as 100 m thick, locally interbedded with accumulations (as much as 250 m) of tuff breccia and volcaniclastic sediments in Lehman Basin. Radiometric date on biotite is 47.31 Ma (Snider, 1995).

Tcru—Upper rhyolite flow and dome complex (Eocene)—Grayish purple to light gray banded and locally brecciated porphyritic rhyolite to dacite flow and dome complex at The Needles in the southwestern part of quadrangle; contains phenocrysts of plagioclase, quartz, sanidine, and rare biotite in a fine-grained devitrified groundmass; black glassy porphyritic chill zones common (Skipp and Bollman, 1992). Thickness about 100 m. Radiometric dates are 47.78 Ma on biotite and 47.44 Ma on sanidine (Snider, 1995).

Tcs—Tuff of Stoddard Gulch (Eocene)—Grayish red-purple, pale red-purple, light olive-gray, brownish gray to brownish black nonwelded to densely welded, devitrified and vitrophyric, varied pumice- and lithic-rich, porphyritic, trachydacite ash-flow tuff locally interbedded with volcaniclastic sediments and tuff breccias. Total phenocryst or crystal content ranges from 20% to 25% and includes plagioclase and lesser biotite and opaque oxides with minor clinopyroxene. Xenoliths include volcanic rocks, sandstone, and metamorphic rocks (Skipp, 1989). Thickness 280 m at type section near Grouse in Antelope Valley. Radiometric date on biotite is 47.37 Ma (Snider, 1995).

Tg—Granitoid intrusions (Eocene)—Plutons of holocrystalline rock, ranging from granite to quartz diorite in composition; locally subdivided into quartz monzonite (*Tqm*), Mackay Granite (*Tm*), and leucogranite porphyry (*Tlp*) by Nelson and Ross (1968). Radiometric dates on biotite from the Garfield Stock and Mackay Granite are 48.51 Ma and ~48 Ma, respectively, and 49.0 Ma on magmatic zircons from the Pioneer Mountains pluton partly exposed on the western margin of the quadrangle (Link and others, 2007).

Tlp—Leucogranite porphyry (Eocene)—Very light gray, porphyritic; as much as two-thirds phenocrysts of nearly equal abundances of quartz and orthoclase, lesser oligoclase, and minor diopside; very fine-grained groundmass of quartz and feldspar; grades into rhyolite dikes (*Td*) that cut Mackay Granite (*Tm*); hosts thick skarn deposits (*Ts*) shown diagrammatically on cross-section B-B′ that are sources for copper, lead, and zinc ores (Nelson and Ross, 1968).

Trpi—Porphyritic rhyolite intrusions (Eocene)—Medium light gray to dark gray porphyritic dacite to rhyolite intrusive domes, dikes, and other small intrusive bodies having minor associated lava flows and intercalated volcaniclastic sediments; total phenocryst or crystal content ranges from 20% to 30% and includes plagioclase, lesser quartz and biotite and minor hornblende- and plagioclase-rimmed orthoclase.

Radiometric date on biotite from Navarre Creek dome complex is 47.47 Ma (Snider, 1995).

Tcsu—Volcaniclastic sediments (Eocene)—Sandstone and tuffaceous sediments, well-bedded, fine-grained to conglomeratic; included are interbedded heterolithologic tuff breccias eroded from the Navarre Creek dome complex. Porphyritic rhyolite dikes crosscut the sediments.

Tm—Mackay Granite (Eocene)—Greenish gray granite porphyry that weathers a characteristic pinkish gray; total phenocryst or crystal content ranges from 25% to 35% and includes orthoclase, and 5-15% quartz, in a fine-grained groundmass of orthoclase and quartz, lesser plagioclase, and minor biotite and hornblende; composes core of the Mackay horst and is largest of the intrusive bodies in the area (Nelson and Ross, 1968).

Tri—Rhyolite intrusions (Eocene)—Very light gray to medium gray rhyolite to trachydacite composing the Boone Creek stock and related hypabyssal intrusions; characterized by 4% phenocryst or crystal content including plagioclase and biotite and local traces of clinopyroxene and sanidine; extends from Copper Basin north to Lehman Basin caldron complex. Radiometric date on biotite is 48.36 Ma. Unit *Tcri* of Blakley (2001).

Tqm—Quartz monzonite (Eocene)—Light gray to medium gray; small oligoclase phenocrysts make as much as 25% of rock; darker and finer grained than Mackay Granite (*Tm*); groundmass fine-grained, chiefly orthoclase, quartz, and minor oligoclase, and 10% to 20% mafic minerals, diopside, hornblende, and biotite. May be older than Mackay Granite (Nelson and Ross, 1968).

Tclu—Upper latite lavas and intrusions (Eocene)—Dark gray and dark brown, porphyritic, locally aphyric, dominantly latite, locally andesite and dacite lava flows; total phenocryst or crystal content 25% and includes plagioclase, clinopyroxene, hornblende, and minor biotite; intercalated tuff breccia, interbedded volcanic sediments, and shallow intrusions. Unit is present on north side of Mackay horst; overlies unit *Tcch*.

Tclc—Tuff of Little Lake Creek (Eocene)—Gray-orange-pink and grayish orange, weakly to moderately welded, devitrified, vapor-phase, poorly sorted, pumice- and lithic-rich, porphyritic dacitic ignimbrite; single compound cooling unit; total phenocryst or crystal content ranges from 23% to 25% and includes plagioclase and traces of clinopyroxene and opaque oxides; rests on tuff of Cherry Creek (*Tcch*); 100 m thick just south of Lehman Basin.

Tcch—Tuff of Cherry Creek (Eocene)—Pale reddish brown, pale yellowish brown, light brownish gray to pinkish gray, and various shades of pink, green, and black; nonwelded to densely welded, devitrified and vitrophyric, locally pumice- and lithic-rich, porphyritic trachydacitic to rhyolitic ignimbrites; common eutaxitic structure; seven major compound cooling units locally interbedded with volcaniclastic sediments; total phenocryst or crystal content ranges from 5% to 10% and includes plagioclase and biotite, and local traces of clinopyroxene, sanidine, and opaque oxides. At source area in Lehman Basin, caldera thickness about 600 m (Blakley, 2001); thickness at composite type section more than 230 m (Snider, 1995, p. 37). Apparent radiometric age on sanidine is 48.87 (Blakley, 2001).

Tcrl—Lower rhyolite lavas (Eocene)—Light gray to medium light gray and moderate reddish orange, porphyritic, massive trachyandesite to rhyolite lava flows, intercalated tuff breccias and volcaniclastic sediments; total phenocryst or crystal content ranges from 7% to 9% and includes plagioclase and altered biotite, and a local trace of opaque oxides and altered pyroxene; about 200 m thick near Porphyry Peak. Radiometric date on biotite is 48.10 Ma (Snider, 1995).

Tcau—Upper andesite lavas (Eocene)—Dark gray, porphyritic, thin lava flows; total phenocryst or crystal content ranges from 10% to 25% and includes plagioclase, pyroxene, and lesser hornblende; as much as 100 m thick.

Tccl—Tuff of Cliff Creek (Eocene)—Grayish to moderate brown, moderate reddish brown, light brown, pale brown, moderate orange-pink, and black; weakly to densely welded, devitrified and vitrophyric, locally pumice- and lithic-rich, porphyritic trachyandesite ignimbrites; four to six cooling units locally interbedded with volcaniclastic sediments; total phenocryst or crystal content ranges from 6% to 37% and includes plagioclase, clinopyroxene, hornblende, opaque oxides, and local traces of biotite. Four to six cooling units about 250 m thick south of Mackay.

Tcdl—Lower dacite flow and dome complex (Eocene)—Medium light gray to light brownish gray, medium gray to grayish orange, grayish red, and reddish brown, porphyritic, massive trachydacite to latite to andesite lava flows, intrusive and extrusive domes, intercalated tuff breccias, interbedded ignimbrites, bedded tuffs, and volcaniclastic sediments; total phenocryst or crystal content ranges from 32% to 48% and includes plagioclase, lesser clinopyroxene, biotite, hornblende, and opaque oxides. Contains xenoliths of argillite, quartzite, and granitic gneiss (Skipp, 1989; Skipp and others, 1990). Individual lava flows as much as 100 m thick; about 470 m thick at Sheep Mountain. Radiometric date on biotite is 48.86 Ma (Snider, 1995).

Tct—White tuffs (Eocene)—Grayish yellow bedded tuffs; pumice- and lithic-rich; total phenocryst or crystal content is 5% clinopyroxene and lesser opaque oxides; thin; interbedded at top of *Tcal* and base of *Tcdl*; mapped in southwestern part of quadrangle. Less than 20 m thick.

Tcll—Lower latite lavas (Eocene)—Dark gray, mostly porphyritic, locally aphyric, thin, dominanatly latite, lesser andesite, shoshonite, and basalt lava flows; intercalated tuff breccias, interbedded volcaniclastic sediments and shallow intrusions; total phenocryst or crystal content as much as 25% includes clinopyroxene, plagioclase, local olivine, orthopyroxene, hornblende, biotite, and minor quartz. As much as 700 m thick in Porphyry Peak area. Radiometric date on biotite is 48.8 Ma (Snider, 1995).

Tcac—Tuff of Antelope Creek (Eocene)—Pale yellowish brown, grayish orange, dusky yellow-brown, dusky yellow-green, olive-gray to black, nonwelded to densely welded, devitrified and vitrophyric, locally pumice- and lithic-rich, porphyritic andesitic to latitic ignimbrites; seven simple and compound cooling units locally interbedded with volcaniclastic sediments and mafic lava flows; total phenocryst or crystal content ranges from 26% to 34% and includes plagioclase, lesser clinopyroxene, opaque oxides, and local hornblende. Sandstone xenoliths are rare (Skipp,1988a). Seven cooling units and interbeds of mafic lavas and volcanic sediments are as much as 550 m thick.

Tcal—Lower andesite lavas and tuff breccias (Eocene)—Dark gray, medium dark gray, medium gray, and brownish gray, mostly porphyritic, locally aphyric; thin; dominantly andesite, lesser latite and shoshonite lava flows; intercalated tuff breccias; interbedded volcaniclastic sediments; and shallow intrusions. Total phenocryst or crystal content ranges from 24% to 50% and includes dominant plagioclase, lesser pyroxene, hornblende, opaque oxides, and a trace of biotite. Sandstone and quartzite xenoliths present (Skipp, 1988a). Accumulations as much as 350 m in upper Antelope Creek drainage and as much as 700 m in the Porphyry Peak area. A radiometric age on hornblende from Antelope Creek area is 49.3 Ma (Marvin and others, 1989), and a radiometric age on biotite from northwestern part of area is 48.80 Ma (Snee in Blakley, 2001).

Tcc—Basal Challis conglomerate, breccia, and sandstone (Eocene)—Light-colored, granule- to boulder-conglomerate and breccia composed of locally derived clasts of quartzite, limestone, sandstone, siltstone, argillite, and chert, and of interbedded sandstone lenses; weathers moderate brown to black. Contains no volcanic detritus in southern part of quadrangle (Smiley Creek Conglomerate of Paull (1974)). In Porphyry Peak area, however, tuffaceous pebbly sandstone and conglomerate are present in upper part, indicating the onset of Challis volcanism during deposition (Burton and Blakley, 1988; Moye and others, 1988). Fills paleovalleys in Paleozoic rocks. Thickness 0-115 m.

SEDIMENTARY ROCKS ON HANGING WALL OF PIONEER THRUST

Wood River Formation of Sun Valley Group (Permian to Pennsylvanian)

Nomenclature and descriptions for the following units are adapted from Mahoney and others (1991) and Hall and others (1974).

Pww—Wilson Creek Member of Wood River Formation (Lower Permian)—Light brown to reddish brown, fine-grained siliceous sandstone and siltstone and silty micrite, and dark gray micritic siltstone; thin-bedded, laminated, having graded and convoluted bedding; weathers to reddish brown slopes; present in southwest corner of quadrangle. Thickness at type section in Pioneer Mountains to west more than 800 m; correlates with units 7-8 of Hall and others (1974; 1978).

PIPwe—Eagle Creek Member of Wood River Formation (Lower Permian to Middle Pennsylvanian)—Upper part is light brown, very light gray to medium gray micritic sandstone, siliceous sandstone, sandy micritic limestone, and minor siltstone, laminated and brecciated, medium- to thick-bedded; weathers brown and reddish brown; correlates with units 5 and 6 of Wood River Formation of Hall and others (1974). Upper beds of lower part are medium gray to medium dark gray sandy micrite, micritic sandstone, and minor granule- to pebble-conglomerate, and lower beds of lower part are pale red and pale reddish purple, thin- to medium-bedded siltstone and mudstone; forms slope; fossiliferous-fusulinids, pelmatazoan, bivalve, and molluscan debris common. Member correlates with units 3 through 6 of the Wood River Formation of Hall and others (1974); estimated thickness 350 m.

IPwh—Hailey Member of Wood River Formation (Middle Pennsylvanian)—Medium gray to medium dark gray micritic limestone, sandy limestone, and calcareous sandstone, interbedded conglomerate and minor thin beds of dark gray mudstone that weather pale reddish purple; sandy limestone and calcareous sandstone similar to lithologies of Eagle Creek Member; conglomerate clasts as much as 10 cm in diameter; thin- to thick-bedded; forms cliffs and low ledges; slightly fossiliferous. Member correlates with units 1 and 2 of Wood River Formation of Hall and others (1974); in-cludes Hailey Conglomerate Member of Thomasson (1959); estimated thickness 200 m.

Dm—Milligen Formation (Devonian)—Black and gray, massive, weakly cleaved argillite, and lesser carbonaceous shale, chert, limestone, tremolitic calc-silicate beds, and diamictite lenses of the Triumph argillite of Turner and Otto (1995); beds have tight to isoclinal folds. Unconformably overlain by Hailey Member of Wood River Formation along southwestern edge of quadrangle; thickness unknown.

SEDIMENTARY ROCKS ON HANGING WALL OF COPPER BASIN THRUST

Mcb—Copper Basin Group undivided (Mississippian)—Conglomerate, sandstone, mudstone or argillite, and limestone as described below. Unit nomenclature and descriptions adapted from Link and others (1996), Paull and others (1972), Paull and Gruber (1977), Wilson and others (1994), Warren (1996), and Nilsen (1977). Deposited in a faulted foreland basin where thicknesses exceeded 5,900 m (Link and others, 1996). Comprises the Argosy Creek Formation, Drummond Mine Limestone, and Little Copper Formation in descending stratigraphic order.

Mca—Argosy Creek Formation of Copper Basin Group (Lower and Upper Mississippian)—Light to dark gray pebble- to boulder-conglomerate, quartzose sandstone, mudstone or argillite, and minor limestone of the Iron Bog Creek, Brockie Lake Conglomerate, Muldoon Canyon, and Scorpion Mountain members in descending stratigraphic order (Warren, 1996).

Iron Bog Creek Member—Dark gray to grayish black silty mudstone or argillite that weathers light gray to dark gray, and olive-gray; fine- to very coarse-grained lithic sandstone that weathers brownish gray to moderate brown, and lesser dark gray granule- to pebble-conglomerate and minor limestone; lithologies represent channelized conglomerate and sandstone, hummocky sandstone and conglomerate, and graded mudstone lithofacies; included macrofaunal and microfaunal collections indicate a late Mississippian age; thickness exceeds 1,100 m; unconformable contact with overlying Eocene conglomerate of Smiley Creek (Burton and Blakley, 1988); gradational contact with Brockie Lake Conglomerate Member below.

Brockie Lake Conglomerate Member—Medium light gray granule- to boulder-conglomerate having a dark gray to medium light gray quartzitic and quartzose sandstone matrix, and minor interbedded dark gray mudstone or argillite representing a proximal fan delta; contains both Early and Late Mississippian faunas; thickness about 660 m; unconformable contact with Muldoon Canyon Member below.

Muldoon Canyon Member—Chiefly dark gray to medium light gray silty mudstone or argillite and minor medium dark gray quartzite, dark gray chert-argillite granule- to pebble-conglomerate, grayish black sandy micritic limestone that weathers grayish orange to light gray (Green Lake

Limestone of Paull and others, 1972); contains primarily fine-grained turbidite lithofacies; faunal collections indicate an Early Mississippian age; maximum thickness 1,260 m; gradational contact with Scorpion Mountain Member below.

Scorpion Mountain Member—Interbedded medium gray to medium dark gray chert-quartzite-argillite granule- to cobble-conglomerate and medium- to coarse-grained sandstone, and minor dark gray mudstone or argillite making up a channelized turbidite and graded conglomerate lithofacies; no fossils have been collected; measured thickness 1,100 m; gradational contact with Drummond Mine Limestone below (Link and others, 1996; Paull and others, 1972).

Mcl—Limestone lenses in Copper Basin Group (Mississippian)—Includes dark gray, light gray weathering micrite of Green Lake Limestone in the Muldoon Canyon Member of the Argosy Creek Formation (Paull and others, 1972), bioclastic limestone in the Iron Bog Creek Member of the Argosy Creek Formation, and scattered isolated lenses north and south of Muldoon Creek on Muldoon Ridge and near Buck Canyon that are bioclastic limestone locally containing oncolites. These lenses are in the Drummond Mine Limestone or in the Little Copper Formation below.

Mcd—Drummond Mine Limestone of Copper Basin Group (Lower Mississippian)—Dark gray to medium dark gray chiefly micritic limestone that weathers light olive-gray, argillaceous, silty and sandy; medium to thick bedded; a few interbeds of dark gray mudstone or argillite, chert, and minor granule conglomerate; limestone represents locally derived channelized calciclastic turbidite lithofacies; in places, hosts silver and base metal deposits and replacement barite deposits (Winkler and others, 1995). Micro- and mega-faunal collections indicate Early Mississippian age; thickness ranges from 0 to 910 m; gradational contacts above and below (Link and others, 1996; Paull and others, 1972).

Mclc—Little Copper Formation of Copper Basin Group (Lower Mississippian)—Dark gray mudstone or argillite, thin- to medium-bedded; some interbeds of medium gray quartzite, granule conglomerate, and minor limestone; fine-grained turbidite lithofacies in lower part and a channelized turbidite lithofacies in upper part indicate submarine basin-plain succeeded by distal- to middle-fan depositional environments; ammonoids and conodonts indicate an Early Mississippian age; thickness about 1,120 m; rests unconformably on tilted lower Paleozoic sedimentary rocks (Paull and Gruber, 1977; Wilson and others, 1994; Link and others, 1996).

Dc—Carey Dolomite (Middle and Lower Devonian)—Light gray, medium- to thick-bedded recrystallized dolomite; weathers olive-gray; locally mineralized (Winkler and others, 1995); base not exposed; unconformable upper contact with Little Copper Formation. Present only in Garfield Canyon and Deep Gulch east of Copper Creek in southwestern part of quadrangle and at Fish Creek Reservoir 5 km south of quadrangle. Represents carbonate platform environment (Skipp and Sandberg, 1975; Kuntz and others, 2007).

Oe—Ella Marble (Middle Ordovician)—Light gray to buff, thin- to medium-bedded calc-silicate marble that weathers buff; intruded by Tertiary stock within core of Pioneer metamorphic core complex; crops out along westernmost margin of quadrangle; in fault contact with overlying Copper Basin Group (Dover, 1983; Rothwell, 1973).

SEDIMENTARY ROCKS ON FOOTWALL OF COPPER BASIN THRUST

Mw—White Knob Limestone (Upper to Lower Mississippian)—Medium gray to grayish black, medium- to coarse-grained pure bioclastic limestone in upper part and spiculitic micrite in lower part; interbedded medium gray to moderate yellowish brown lenses of quartzose pebble conglomerate, medium- to coarse-grained sandstone, and siltstone in upper part; a few interbedded thin mudstone and chert beds near base; large-scale graded bedding and lateral gradations common; thin- to thick-bedded; intruded by Mackay Granite; mineralized west of Mackay. Formation represents west-prograding carbonate platform interfingering with an east-prograding fan delta in upper part; conodonts, calcareous foraminifers, and brachiopods indicate an Early to Late Mississippian age; minimum measured thickness 1,700 m in White Knob Mountains; faulted gradational contact with McGowan Creek Formation below; probably abruptly gradational with Mississippian Middle Canyon through Surrett Canyon formations to south. Overlain unconformably by Challis Volcanic Group (Skipp and Mamet, 1970; Link and others, 1996).

Mmg—McGowan Creek Formation (Lower Mississippian)—In Mackay area is medium gray to grayish black, siliceous, carbonaceous, mudstone or argillite, medium- to thin-bedded, that locally weathers grayish red-purple; contains a few intercalated light gray limestone, fine-grained quartzose sandstone, and blue-gray chert beds that weather very light gray in upper part of section; locally intruded by Mackay Granite. In other areas, two informal members are recognized. In the Grouse area 20 km west of Arco, the upper member consists of grayish black to medium gray, yellowish brown and purplish weathering, laminated mudstone at top, and mudstone interbedded with varicolored thin-bedded calcareous siltstone, very fine-grained sandstone, and medium to dark gray, medium-bedded limestone in lower part; 493-386 m thick in measured sections; the lower member is medium to dark gray interbedded siltstone, fine-grained sandstone, conglomeratic sandstone, and granule- to pebble-conglomerate; 108-175 m thick in measured sections (Skipp, 1988a). In Lost River Range, upper member consists of medium gray, pinkish gray-weathering calcareous siltstone and silty micritic limestone as much as 150 m thick; lower member contains medium to dark gray mudstone or argillite and minor sandstone as much as 1,000 m thick (Link and others, 1996). Upper member is absent east of Lost River Range. Formation represents deposits of distal flysch trough (Sandberg, 1975); trace fossils of *Nereites* ichnofacies suggest an oxygen deficient depositional environment (Poole, 1974; Burton and Link, 1991; Link and others, 1996); conodonts indicate Early Mississippian age; total measured thicknesses range from 561 m to 1,150 m from west to east; unconformably overlies Devonian carbonate rocks; conformably underlies White Knob Limestone and Middle Canyon Formation (Link and others, 1996; Skipp and others, 1990; Sandberg, 1975).

Pl—Unnamed limestone (Lower Permian)—Dark gray to very dark gray, thin-bedded, argillaceous and silty, locally phosphatic, fossiliferous, fine- to coarse-grained limestone that weathers brownish gray and grayish orange; contains crossbeds and cut-and-fill structures; abundant brachiopod and molluscan faunas indicate age equivalence to the Phosphoria Formation (Nelson and Ross, 1969, 1970; Skipp, 1988a); minimum thickness 48.8 m; neither top nor base exposed; found only in fault block on north side of Antelope Creek in White Knob Mountains.

PMs—Snaky Canyon Formation (Lower Permian to uppermost Mississippian)—Very dark to very light gray and grayish orange, medium- to thick-bedded sandy and silty limestone and dolomite, locally cherty, and thin interbeds of medium gray and light brownish gray, very fine-grained, thin-bedded, calcareous quartzose sandstone, and local chert and quartzite pebble breccia and conglomerate, and bedded chert. Minimum thickness 1,033 m in Arco Hills (Shannon, 1961). Estimated total thickness 1,240 m north of Antelope Creek in southern White Knob Mountains. Composed of three members: Juniper Gulch, Gallagher Peak Sandstone, and Bloom, in descending order (Skipp and others).

Juniper Gulch Member (White Knob Mountains) (Lower Permian? to Upper Pennsylvanian)—Light gray and yellowish gray, very fine- to fine-grained, cherty and sandy dolomite and dolomitic sandstone containing very fine-grained dolomitic sandstone, locally cherty; contains chert and quartzite pebble breccia and conglomerate, and bedded chert; lenses and nodules of banded chert and incipient chert form as much as 20% of carbonate beds; contains molds and casts of megafauna; breccia and conglomerate form ledges as thick as 12.8 m; carbonates and sandstones form slopes; base and top covered; measured minimum thickness 194 m in White Knob Mountains (Skipp, 1988a).

Juniper Gulch Member (Lost River and Lemhi Ranges) (Lower Permian to Upper Pennsylvanian)—Light gray to medium dark gray, light gray weathering, sandy and cherty dolomite and limestone; typically weathers light gray and light olive-gray; light gray to grayish black chert in nodules, beds, and complex networks form as much as 40%; includes medium dark gray, oolitic, ledge-forming dolomite marker bed in upper half; some sandy beds near base; fusulinid faunas indicate a Late Pennsylvanian and Early Permian age; carbonate buildups of *Paleoaeplysina* and phylloid algae common in Arco Hills. Characterized as a shallowing-upward carbonate platform to eolian dunes sequence (Cantor and Isaacson, 1991). Unit gradationally overlies Gallagher Peak Sandstone Member and upper contact with Phosphoria Formation is abrupt and conformable in eastern Lemhi Range east of Arco quadrangle (Skipp and Hait, 1977); about 600 m thick.

Gallagher Peak Sandstone Member (Upper Pennsylvanian)—Light gray to grayish orange, very fine-grained, chiefly well-sorted, calcareous quartzose sandstone, and medium gray sandy limestone and pale brown calcareous siltstone; in White Knob Mountains, contains minor ledges of medium gray pebble breccia and conglomerate as thick as 1 m; brachiopods and pelecypods indicate Late Pennsylvanian age; gradational upper and lower contacts; may be series of lenses; measured thickness ranges from 30 m to 59 m (Skipp and others, 1979; Skipp, 1988a).

Bloom Member (Upper Pennsylvanian to Upper Mississippian)—Chiefly medium gray to medium dark gray, sandy and silty, locally cherty, and fossiliferous limestone; altered to jasperoid in places; interbedded with thin beds of quartzose sandstone or siltstone and dark gray to brownish gray, light gray weathering calcareous mudstone in upper part; minor conglomerate present in White Knob Mountains; contained sand is very fine- to coarse-grained quartz and chert; chert and incipient chert compose 10% to 30% of beds in lower part; abundant fossils indicate age; gradational upper and lower contacts. Partial measured sections of Lower to Middle Pennsylvanian parts of this member in the Lost River and Lemhi ranges may have been deposited on a shallow-water carbonate ramp during a single second order relative rise and fall of sea level about 10-14 m.y. in duration (Archuleta and others, 2006); measured thickness 613 m in White Knob Mountains and 647 m in Lemhi Range (Skipp, 1988a; Skipp and others, 1979).

Mba—Bluebird Mountain and Arco Hills Formations undivided (uppermost Mississippian)—Medium gray to medium light gray, very fine-grained, quartzose, generally quartzitic, thin-bedded, cliff-forming sandstone that weathers light brown; thin interbeds of sandy or silty limestone, and minor chert in upper part (Bluebird Mountain Formation); lower part (Arco Hills Formation) medium gray, olive-gray, yellowish brown, and grayish red laminated argillaceous silty and sandy limestone, calcareous mudstone, siltstone, and minor sandstone, and medium-bedded pure limestone; locally cherty and phosphatic; weathers brownish gray and pale red. Calcareous foraminifers indicate a latest Mississippian age. Gradationally overlies Surrett Canyon Formation and gradationally underlies the Snaky Canyon Formation; interval thickness about 21 m in White Knob Mountains and 92-126 m in Lost River and Lemhi ranges (Skipp and others, 1979; Skipp, 1988a).

PMu—Snaky Canyon, Bluebird Mountain, Arco Hills, Surrett Canyon, South Creek, Scott Peak, and Middle Canyon Formations undivided (Permian through Mississippian)—Limestones, sandstones, and minor mudstones.

Msu—Surrett Canyon Formation (Upper Mississippian)—Medium light gray to dark gray, chiefly pure, locally cherty, fossiliferous, medium- to thick-bedded, cliff-forming, locally cavernous limestone; altered to jasperoid in places in White Knob Mountains; weathers medium gray. Abundant varied faunas including corals, conodonts, and smaller calcareous foraminifers indicate a Late Mississippian age. Gradational contacts with Arco Hills Formation above and South Creek Formation below; thins to east; maximum measured thickness in White Knob Mountains 396 m (Skipp, 1988a); about 200 m or less in Lost River Range and Arco Hills (Kuntz and others, 1994).

Msc—South Creek Formation (Upper Mississippian)—Medium to dark gray, chiefly thin-bedded, silty and clayey, fine-grained limestone; contains concentrically banded nodules of yellowish brown-weathering, partly silicified incipient chert; forms valleys between cliff-forming units above and below; sparse fauna indicates a Late Mississippian age; gradational contacts with limestones above and below; thickness 90-139 m in White Knob Mountains (Skipp, 1988a) and about 105 m in Lost River Range and Arco Hills (Kuntz and others, 1994).

Msp—Scott Peak Formation (Upper Mississippian)—Medium gray to medium dark gray, chiefly pure, partly silty and sandy, locally cherty, thin- to thick-bedded, cliff-forming, and cavernous limestone extensively altered to jasperoid in White Knob Mountains; weathers light to medium gray; abundant fossils include corals, brachiopods, conodonts, and calcareous foraminifers indicating a Late Mississippian age; gradationally overlain by South Creek Formation; gradationally underlain by Middle Canyon Formation; thins to east; more than 579 m measured in White Knob Mountains (Skipp, 1988a) and about 200 m thick in Lost River Range and Arco Hills (Kuntz and others, 1994).

Mss—Surrett Canyon, South Creek, and Scott Peak Formations undivided (Upper Mississippian)—Dominantly limestone. See descriptions above.

Mmc—Middle Canyon Formation (Mississippian)—Medium gray to grayish black, thin- to medium-bedded, chiefly fine- to medium-grained, spiculitic, silty limestone; weathers with thin light gray to light olive-gray rind; locally altered to jasperoid in White Knob Mountains; in Lost River Range and Arco Hills, is interbedded limestone and calcareous siltstone; limestone dark gray to medium gray, thin-bedded, cherty (10% to 50% black chert stringers and nodules); calcareous siltstone pale yellowish brown and dark yellowish brown, thin-bedded; weathers pale yellowish brown to moderate yellowish brown; gradational contacts with Scott Peak Formation above and McGowan Creek Formation (*Mmg*) below; measured thickness 186 m in White Knob Mountains (Skipp, 1988a); estimated thickness 300 m in Lost River Range (Kuntz and others, 1994).

Mu—Surrett Canyon, South Creek, Scott Peak, and Middle Canyon Formations undivided (Mississippian)—Dominantly limestone, minor siltstone. See individual unit descriptions. These units are shown to be gradational with the White Knob Limestone to the northwest in cross section B-B′.

Mmcg—Middle Canyon and McGowan Creek Formations undivided (Mississippian)—Interbedded limestone, mudstone, siltstone, and minor conglomerate. See individual unit descriptions.

Dp—Picabo Formation (Upper Devonian)—Medium light to dark gray, chiefly fine-grained, medium- to thick-bedded, locally silty or sandy, laminated dolomite and minor dolomitic sandstone; weathers medium dark gray to light gray; conodonts indicate a latest Devonian age (Skipp and others, 1990); incomplete measured thickness 100 m; base not exposed; disconformably overlain by McGowan Creek Formation on footwall of Copper Basin thrust at Timbered Dome (Skipp and others, 1990); present on hanging wall of Copper Basin thrust at Fish Creek Reservoir about 5 km south of quadrangle (Skipp and Sandberg, 1975; Kuntz and others, 2007).

Dt—Three Forks Formation (Upper Devonian)—Medium to dark gray limestone, silty limestone, and grayish black silicified siltstone; locally fossiliferous; commonly poorly exposed; forms slopes or swales; unconformable contacts with McGowan Creek Formation above and Jefferson Formation below; thickness about 25-43 m (Kuntz and others, 1994).

Dj—Jefferson Formation (Upper Devonian)—Light gray, grayish black, and yellowish brown dolostone, dolostone-limestone breccia, limestone, and minor sandstone, siltstone, and mudstone: dolostone and breccia finely to coarsely crystalline, sandy, silty, laminated in part, and locally petroliferous; limestone medium gray, fine-grained, and locally cherty; basal sandstone, siltstone, and mudstone, red to yellow-brown, laminated, and locally conglomeratic; some middle Devonian strata may be present at base in Arco Hills. Unit may include some Laketown Dolostone in southern Lost River Range. Unconformable lower contact with Laketown Dolostone or Fish Haven Dolostone; thickness 60-300 m (Kuntz and others, 1994).

Dtj—Three Forks and Jefferson Formations undivided (Upper Devonian)—Dolostone, limestone, and siltstone. See individual unit descriptions.

MDmt—McGowan Creek and Three Forks Formations undivided (Lower Mississippian and Upper Devonian)—Mudstone or argillite, siltstone, limestone, and minor sandstone. See individual unit descriptions.

MDmct—Middle Canyon, McGowan Creek, and Three Forks Formations undivided (Mississippian and Upper Devonian)—Limestone, mudstone or argillite, siltstone, and minor sandstone. See individual unit descriptions.

DOu—Three Forks, Jefferson, Laketown, and Fish Haven Formations undivided (Upper Devonian, Silurian, and Upper Ordovician)—Chiefly medium to dark gray dolostone, minor limestone, sandstone, siltstone, and mudstone. Includes some reddish carbonate beds in fault contact with Jefferson Formation along western margin of Lost River Range southeast of Mackay; may include older formations.

Sl—Laketown Dolostone (Silurian)—Medium to dark gray, fine to medium crystalline, medium-bedded dolostone; weathers medium to light gray; local thin beds of light yellowish gray fine-grained quartzite and sandy dolomite; forms ledges and cliffs; thickness 100-200 m (Mapel and others, 1965); unit may be mapped with Jefferson Formation (*Dj*) in southern Lost River Range.

Of—Fish Haven Dolostone (Upper Ordovician)—Chiefly medium to dark gray, massive, thick-bedded, crystalline dolostone; lesser mottled light to dark gray dolostone, minor black chert; light gray dolostone at top; lowest part is olive-gray to medium gray, argillaceous dolostone containing fine white dolostone stringers and silicified brachiopods and corals; disconformable lower contact with Kinnikinic Quartzite (*Ok*); thickness 18-300 m (Kuntz and others, 1994).

Ok—Kinnikinic Quartzite (Middle Ordovician)—White to light gray, massive, medium- to thick-bedded, well-sorted, medium- to fine-grained, vitreous orthoquartzite; locally laminated and crossbedded; rust-colored stains common; contains small lenses and ovoid patches of dolomitic sandstone in upper part; gradational lower contact with Summerhouse Formation (*Os*); thickness 100-230 m (Kuntz and others, 1994).

Os—Summerhouse Formation (Lower Ordovician)—White quartzite and locally interbedded calcareous sandstone and sandy dolostone; dolostone at top grayish red to reddish brown and coarse-grained; contains siliceous laminae; calcareous sandstone beds in middle yellowish brown to reddish brown and coarse-grained, and have bioturbation structures and cross-laminations; quartzite at base light gray to pale yellowish brown, very fine- to medium-grained, commonly bimodal and thick-bedded; unconformable contact with Tyler Peak Formation below in Lemhi Range; lower contact not exposed in Arco Hills; thickness 0-60 m (Kuntz and others, 1994).

Oks—Kinnikinic Quartzite (Middle Ordovician) and Summerhouse Formation (Lower Odovician) undivided—White to gray orthoquartzite and minor interbedded calcareous sandstone and sandy dolostone. Unit mapped in Lemhi Range. See individual unit descriptions.

–Ctp—Tyler Peak Formation (Lower Cambrian and Neoproterozoic?)—Yellowish brown to dusky purple sandstone, calcareous, locally limonitic, very fine- to fine-grained, medium-bedded, locally flaggy, commonly bioturbated, and cross laminated, interbedded light gray to grayish pink pure vitreous quartzite, fine- to coarse-grained, medium- to thick-bedded, cross laminated; at base, greenish gray to light gray fissile shale having an iridescent sheen, locally interbedded with sandy quartzite and siltstone; gradational lower contact with Wilbert Formation; thickness 267 m in Lemhi Range (McCandless, 1982; Kuntz and others, 1994).

€Zw—Wilbert Formation (Lower Cambrian and Neoproterozoic)—White, light to dark gray, reddish purple, and yellow-brown, relatively pure quartzite beds that generally coarsen upward; fine-grained to conglomeratic; contains abundant *Skolithes* burrows and other fossils in upper part; angular unconformity with underlying Mesoproterozoic beds; thickness 120-200 m in Lemhi Range (McCandless, 1982).

Ysl—Swauger Formation and Lemhi Group undivided (Mesoproterozoic)—Swauger Formation: grayish red, purple sandstone or quartzite, hematitic, medium-grained, thick-bedded; gradational lower con-tact with Lemhi Group; maximum exposed thickness a few hundred meters in map area. Lemhi Group: pale red and reddish gray, very fine- to fine-grained, thin-bedded, arkosic, locally micaceous sandstone, containing laminations of heavy minerals, local cross laminations, ripple marks, and rip-up clasts; interbedded grayish green slate and siltstone; locally folded; minimum exposed thickness 200 m in part of Lemhi Range in map area (Skipp and Link, 1992; Kuntz and others, 1994).

OYu—Kinnikinic Quartzite (Middle Ordovician) through Lemhi Group (Mesoproterozoic) undivided—Chiefly quartzites and sandstones and minor dolostones. Appears only on cross section.

BASALTIC ROCKS

ROCK NAMES AND ROCK COLORS FOR BASALTIC LAVA FLOWS

Rock names (e.g., basalt, hawaiite, latite) for lava flows of the Craters of the Moon (COM) lava field are based on chemical compositions of flows given by Kuntz and others (1985) and follow the nomenclature of Cox and others (1979) based on the weight percentages of Na_2O, K_2O, and SiO_2. Because of the uniformity in chemical composition of pre-Holocene lava flows of the map area and elsewhere in the eastern Snake River Plain (Kuntz and others, 1992), the pre-Holocene flows of this map are all deemed to be olivine basalts. In the “Description of Map Units,” these flows are simply referred to as “basaltic” lava flows.

In the COM lava field, some flows have unique colors. Most of the basalt and hawaiite pahoehoe flows have glassy crusts that are blue or olive green. Black, glassy crusts are typical of latite flows. Colors and numerical designation of hues, used to describe flows in the "Description of Map Units," are taken from the rock color chart of the Geological Society of America (1975). Because the glassy crusts have been removed from flow surfaces of the pre-Holocene lava fields, the color of these flows is typically dark or medium gray; no attempt was made to further qualify these flows by color charts; thus, these flows are simply referred to as "dark gray" or "medium gray." Rocks in cinder cones and eruptive fissure deposits are typically oxidized and highly weathered. Colors for these deposits vary greatly; thus, only general terms are used to describe these colors.

NOTES ON PETROGRAPHIC DESCRIPTIONS IN THE DESCRIPTION OF MAP UNITS

Standard petrographic examination of thin sections was used to prepare the petrographic descriptions of lava flows in "Description of Map Units." For Craters of the Moon flows, the composition of olivine was determined by the curvature of the isogyre, and thus they are only approximate. The composition of plagioclase was determined by measuring the extinction angles in crystals in which both (010) and (001) crystallographic planes were oriented vertically. Microprobe determinations of the composition of minerals in some flows of the COM lava field are given by Leeman and others (1976), Stout and Nicholls (1977), and Stout and others (1994).

Pre-Holocene olivine basalts of the eastern Snake River Plain (ESRP) are remarkably similar in their petrographic characteristics. Almost all rocks consist of olivine and plagioclase microphenocrysts that are 1-3 mm in longest dimension. Typically, the microphenocrysts are set in a matrix of olivine, plagioclase, intersertal clinopyroxene, opaque minerals, and, in some samples, intersertal glass. The largest crystals in the matrix are mostly ≤ 1 mm. Compositions of minerals in olivine basalts of the Snake River Plain are reviewed by Kuntz and others (1992). Briefly, olivine basalts typically contain olivine phenocrysts that are Fo_{70-90}; olivine crystals in the matrix that are Fo_{55-70}; plagioclase phenocrysts that are An_{70-90}; plagioclase crystals in the matrix that are An_{30-50}; a single clinopyroxene that is augite to ferroaugite; equant titanomagnetite; elongated to needle-like ilmenite; and various amounts of brown glass. Compositions of minerals in the lava flows of the Craters of the Moon lava field have been determined by Putirka and others (2009).

The kinds of minerals are mostly the same in all samples, but their sizes and proportions vary, and the textures of the rocks are commonly unique. Thus, these characteristics are described in some detail in the petrographic descriptions. Most flows are hypocrystalline, but some are holocrystalline. Glass that is free of inclusions of opaque minerals is extremely rare in Snake River Plain olivine basalt flows. Typically, the glass contains small areas of pinkish tan clinopyroxene and discrete microlites of opaque minerals that are mostly <0.2 mm in longest dimension. The glass is mainly intersertal in most samples and rarely occurs as a lining on vesicle walls.

Common textures of basaltic lava flows are microporphyritic-porphyritic, glomerophyric, and diktytaxitic. Microporphyritic rocks contain larger crystals 1 to 2 mm in a groundmass (matrix) consisting of crystals typically <0.5 mm. Porphyritic rocks have larger crystals that are typically 1-4 mm in a groundmass containing crystals typically <0.5 mm. Many basalt flows have a glomerophyric (also termed cumulophyric) texture in which phenocrysts in the rock are clustered together in irregular groups or clots of two to as many as thirty crystals. The clots typically consist either entirely of plagioclase crystals or olivine crystals, or of a mix of both. In diktytaxitic rocks, open spaces occur between the main minerals in the rock; the open spaces are mostly <1 mm. Syntaxial bundles of plagioclase are clusters in which several plagioclase crystals adhere to one another along similar crystallographic surfaces, typically 010 surfaces.

General terms, such as "elongated," "intermediate," and "stout," describe the shape of plagioclase crystals; these terms refer to the length-width ratios of the crystals. The typical ratio is 10:1 for elongated crystals, 5:1 for intermediate crystals, and 3:1 for stout crystals.

The petrographic character of a lava flow or lava field is also a function of where the sample for the thin section was collected. Surface samples are typically fine grained and contain varying amounts of glass. Samples collected from several centimeters to several meters beneath the flow surface are typically coarser grained and contain lesser amounts of glass or none. The reader is cautioned that the petrographic descriptions for various flows or lava fields are for the sample taken, and these descriptions may not reflect crystal sizes, proportions, or textures that may be obtained for a sample of the same lava flow or lava field taken elsewhere.

UNIT LABELS GIVEN TO LAVA FIELDS AND LAVA FLOWS

CRATERS OF THE MOON LAVA FIELD

The descriptive names for lava flows in the COM lava field (e.g., "Blue Dragon flow") in the "Description of Map Units" mostly follow the terminology of Stearns (1928) and Murtaugh (1961). New names, however, have been assigned to many flows; these are referenced in Kuntz and others (1986a) and Kuntz and others (1988). The unit symbols for COM flows, as they appear in the "Description of Map Units" and on the map, consist of letters and numbers arranged in the following system: The first letter, "Q," refers to the unit's age (Quaternary); the second letter, "c," identifies the flows as part of the Craters of the Moon lava field; the third letter refers to the type of deposit (f = flow, c = cinder deposits); the fourth letter refers to the eruptive period ("a" for the youngest through "h" for the oldest) to which the deposit belongs; and the final number, in subscript, refers to the stratigraphic order of deposits within an eruptive period (1 designates the youngest deposit; 2 designates the next oldest deposit, and so on).

PRE-HOLOCENE LAVA FIELDS EAST OF THE CRATERS OF THE MOON LAVA FIELD

Some lava fields are named for prominent vents and buttes near vents on U.S. Geological Survey 1:24,000-scale topographic maps that cover parts of this quadrangle. In the absence of named landmarks, spot elevations, mostly at high points at vents and buttes, are used to identify various basaltic lava fields: e.g., $Qsbb_1$ is the Lost River lava field, and $Qsbc_2$ is the vent 5371 lava field. The unit symbols for pre-Holocene lava fields, as they appear in the "Description of Map Units" and on the map, consist of letters and numbers arranged in the following system: "Q" refers to the age (Quaternary) of the unit; the second letter, "s," identifies the flows as part of the Snake River Group; the third letter, "b," refers to basalt; the fourth letter (e.g., "b," "c," "d," and so on) refers to arbitrary subdivisions of Pleistocene and Pliocene time, as described below; and the final numbers, in subscript, identify lava fields within the lava-field age units from stratigraphic data where available. However, because radiometric ages are available for only a few pre-Holocene lava fields, the numbers are not meant to imply absolute relative age relations of lava fields. Lava fields that have been given labels where identified on contiguous, previously published 30' x 60' quadrangles, have been given the same label on this map. For this reason, the numbers identifying lava fields within the lava-field age units may not be in consecutive order and thus are not meant to imply absolute relative age relations of lava fields.

SUBDIVISIONS OF HOLOCENE, PLEISTOCENE, AND PLIOCENE TIME FOR BASALTIC LAVA FLOWS AND LAVA FIELDS

For this map, Holocene time is defined as the period from the present to 11,680 sidereal years. Lava flows of the COM lava field having radiocarbon ages in the range from 15,100 years B.P. to 12, 010 years B.P. (Table 1) are late Pleistocene in age. These flows are included in the term "dominantly Holocene" used elsewhere on this map. Lava fields having radiometric or stratigraphically assumed ages between 11,680 years and 128,000 years are designated as late Pleistocene; the first four letters of unit labels are "Qsbb." Lava fields having radiometric ages or stratigraphically assumed ages of 128,000 to 400,000 years are designated as upper middle Pleistocene; the first four letters of unit labels are "Qsbc." Lava fields having radiometric ages or stratigraphically assumed ages of 400,000 years to

780,000 years are designated as lower Pleistocene; the first four letters of unit labels are "Qsbd." Lava fields having or assumed to have reversed magnetic polarity are believed to be part of the Matuyama reverse polarity chron, are thus older than 780,000 years, and are designated as early Pleistocene; the first four letters of unit labels are "Qsbe".

BASALTIC LAVA FLOWS OF THE SNAKE RIVER GROUP

LAVA FLOWS OF THE CRATERS OF THE MOON LAVA FIELD

Lava Flows and Related Cinder-Cone and Eruptive-Fissure Deposits of Eruptive-Period A

$Qcfa_2$—Blue Dragon pahoehoe and a'a basalt-hawaiite flows (Holocene)—Tube- and surface-fed pahoehoe and slab-pahoehoe basalt-hawaiite flows that are characterized by fresh, iridescent, dark to light blue (5PB3/2-5B7/6), glassy, vesicular crusts. Interiors of flows are more massive and medium dark gray (N4). Pressure ridges, pressure plateaus, and collapse depressions—common morphologic features on the surface of these flows—indicate a high-volume, short-duration eruption. Rock is fine grained (<0.3 mm), dense, mostly holocrystalline, and partly diktytaxitic. Olivine (about Fa_{50-60}) crystals are euhedral to subhedral, and many form aggregates of several crystals; plagioclase (about An_{35-50}) occurs as slender and stout laths <0.2 mm; and clinopyroxene occurs as poorly formed slender needles or granules. Opaque minerals occur as equant, partly skeletal crystals of magnetite as large as 0.25 mm, as granules of magnetite (<0.02 mm) in the matrix, and in aggregates of feathery ilmenite (?) crystals. Mean age of four radiocarbon samples of charcoal from tree molds and carbon-bearing material from sediment buried by unit is 2,076 ± 45 years.

$Qcfa_8$—Serrate block and a'a latite flow (Holocene)—Surface-fed, olive-gray (5Y4/1) to medium dark gray (N4), jagged, block and a'a. Flow fronts are steep and as high as 8 m. Unit contains prominent flow ridges that are perpendicular to and convex toward the direction of flow movement. Flow also contains longitudinal furrows and cracks that are roughly parallel to the direction of flow movement. Flow contains rafted blocks (monoliths) of bedded cinders and ash derived from a shattered cinder that were rafted on the surface of the moving flow. Rafted blocks have lengths and widths of as much as 150 m and exposed heights of ≤30 m. Bulbous lobes of lava, squeezed out at the edges of the flow ("squeeze-outs"), have black (N2), filamented, glassy crusts and are common along flow margins. Flow is overlapped on south by Blue Dragon flow (*$Qcfa_2$*). Rock is fine grained (mostly <0.10 mm) and hypocrystalline and has rounded xenocrysts of anorthoclase, plagioclase, and green clinopyroxene that are each as large as 2 mm. Xenocrysts of anorthoclase have wormy, corroded rims and, commonly, corroded cores. Rock also contains xenolithic clots as large as 3 mm that consist of anorthoclase, plagioclase (An_{35-55}), green clinopyroxene, equant magnetite, rare olivine (about Fa_{75-90}), and rare zircon. The matrix of the rock consists of plagioclase (An_{10-40}) laths; spindles and subophitic blades and needles and green clinopyroxene; granules of olivine; and opaque-charged brown glass.

Lava Flows and Related Cinder-Cone Deposits of Eruptive-Period G

$Qcfg_1$—Sunset pahoehoe and slab-pahoehoe basalt-hawaiite flows (latest Pleistocene)—Chiefly surface- and tube(?)-fed, hummocky, medium dark gray (N4) pahoehoe basalt-hawaiite flows. Slab pahoehoe occurs where pahoehoe flows collapsed or moved over steep slopes. Pressure ridges, pressure plateaus, and collapse depressions are common morphologic features on the surface of these flows and indicate high-volume, short-duration eruptions. Rock is hypocrystalline and porphyritic and contains microphenocrysts of euhedral olivine (about Fa_{40-50}), plagioclase (An_{40-50}) laths, and equant, skeletal magnetite, all 0.2-0.8 mm in longest dimension. The microphenocrysts are set in an intergranular matrix of the same minerals plus blades and patches of spindly clinopyroxene and opaque-charged brown glass. Age of unit, based on a single radiocarbon analysis of charcoal excavated from beneath the flow, is 12,010 ± 150 years.

$Qcfg_3$—Lava Creek a'a and pahoehoe basalt flows (latest Pleistocene)—Chiefly surface- and channel-fed, dark gray (N3), blocky a'a basalt flows. Unit also includes lesser amounts of thin, spattery, pahoehoe basalt flows near vents. The narrow section of the main flow, at the base of steep slopes east of Black Cap, has long, deep leveed channels. Squeeze-outs having filamented, glassy crusts are common along flow margins. Large exposure to east consists of two distinct lobes; the southern lobe overlaps the northern lobe. Both flows contain flow ridges that are perpendicular to and convex toward the direction of flow movement. Flow ridges have wave lengths as large as 100 m and amplitudes as much as 5 m. Lobes contain longitudinal furrows and cracks that are roughly parallel to the direction of flow movement. Vents are small cones and craters ($Qccg_2$) aligned along an extension of the Great Rift volcanic rift zone in the Pioneer Mountains. Rock is hypocrystalline, partly diktytaxitic, and microporphyritic to porphyritic. In porphyritic rocks, crystals observed are single euhedral crystals of, and clots of, several crystals of olivine (about Fa_{40-45}); euhedral laths of plagioclase (An_{45-55}); equant, partly skeletal magnetite, feathery to bladed ilmenite; and rare blades of clinopyroxene; all less than 0.1 mm; plagioclase laths that are 0.1-0.2 mm; and opaque-charged brown glass. Inclusions of dacitic volcanic rocks are common in hand specimens and thin sections. The older of two radiocarbon analyses of samples of carbon-bearing material from sediment buried by the flow is 12,760 ± 150 years.

$Qccg_2$—Lava Creek basaltic cinder cones (latest Pleistocene)—Chiefly black cinders, agglutinated spatter, bombs, lapilli, coarse ash, and interlayered thin lava flows. The surfaces of cinder cones are locally mantled by red and brown cinders and ash, lapilli, blocks of pahoehoe, and thin flows. Some bombs have cores of felsic volcanic rocks. Southernmost largest cone (Black Cap) was source vent for main flow that extends east onto Snake River Plain. The two northernmost cones fed a flow that extends north into the valley of Dry Fork Creek. A small crater that lacks an associated flow is 1 km northwest of Black Cap cinder cone.

Pre-Holocene Basaltic Lava Flows and Associated Vent and Eruptive-Fissure Deposits of the Snake River Group

$Qsbb_1$—Basaltic pahoehoe flows and pyroclastic deposits of the Lost River lava field (late Pleistocene)—Surface-, channel, and tube(?)-fed, medium gray pahoehoe basalt flows erupted from a vent about 5 km west of Arco. Vent area consists of north-trending, 730-m-long, eruptive fissure and a cinder cone at north end of fissure. Eruptive-fissure system is 300 m long and 20 m high and aligned N. 20° W. Cone consists of reddish oxidized and black cinders and fine ash. A prominent, long (1,200 m), narrow (50-300 m wide) lava pond is bordered by levees as high as 8 m. Lava pond extends northwest from cone-eruptive fissure system, suggesting that its location may have been controlled by the system. Lava field covers an area of about 30 km^2 and contains about 0.5 km^3 of lava. Proximal flows have smooth surfaces; local relief is ≤2 m. Medial and distal flows have relief of ≤5 m. Southern margin of lava field has flow fronts as high as 10 m. Flows are mantled by ≤1m loess and eolian sand. Rock has pronounced porphyritic texture, containing phenocrysts of plagioclase and olivine in a dense matrix. Clots as large as 5.5 mm of as many as fifteen olivine and plagioclase crystals are common. Slender, moderately zoned plagioclase phenocrysts are as long as 4 mm; cross-shaped clusters of plagioclase crystals are common. Olivine phenocrysts are euhedral to subhedral and many crystals are skeletal. Olivine phenocrysts typically contain equant magnetite inclusions as large as 0.1 mm. The phenocrysts are set in a matrix of plagioclase, olivine, clinopyroxene, and opaque minerals that are all <1.5 mm. Clinopyroxene is more concentrated near vesicle walls. Clinopyroxene crystals typically have blade and needle shapes. Magnetite greatly exceeds ilmenite in volume. Age of unit is about 40 Ka; flows lie on alluvial deposits of Pinedale age along the Big Lost River that Scott (1982) estimated to be 30-50 Ka.

$Qsbb_{19}$—Basaltic pahoehoe flows of Quaking Aspen Butte lava field (late Pleistocene)—Tube-fed, dark gray and medium gray pahoehoe basalt flows and shelly-pahoehoe basalt flows. Vent area is about 12 km south of the southern boundary of this map. Medial and distal flows are characterized by numerous tumuli, pressure ridges, and pressure plateaus. Flows are mantled by ≤1 m of loess and eolian sand. Rock examined is coarse and even grained. The rock contains euhedral crystals of plagioclase and olivine as large as 2.5 mm and anhedral, subophitic to ophitic crystals of clinopyroxene, also as large as 2.5 mm. The largest crystals in the rock grade downward in size to 0.3 mm. Equant and skeletal magnetite crystals and elongated ilmenite crystals are ≤0.4 mm. Magnetite and ilmenite are about equal in abundance. Age of unit bracketed by ages of younger flows that cover Quaking Aspen Butte flows (Fingers Butte, 57 ± 20 Ka), and flows that are covered by Quaking Aspen Butte flows (Coyote Butte, 64 ± 16 Ka); thus, age of unit is about 60 Ka (Kuntz and others, 2007).

Qsbb$_{23}$—Basaltic pahoehoe flows and near-vent pyroclastic deposits of vent 5206 lava field (upper middle Pleistocene)—Surface-, channel-, and tube(?)-fed, medium gray pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits. Medial and distal flows have rough surfaces; local relief is ≤5 m. Flows are mantled by ≤2 m loess and eolian sand. Flows are characterized by tumuli, pressure ridges, and pressure plateaus of moderate relief. Rock examined is coarse. Phenocrysts of plagioclase as long as 4.8 mm and equant, subhedral crystals of olivine ≤1.5 mm are set in a matrix of olivine, plagioclase, and intergranular to subophyitic, brown clinopyroxene that are all ≤0.6 mm. Cumulophyric clots of as many as ten olivine crystals and syntaxial bundles of pla-gioclase phenocrysts are common. Rare phenocrysts of green clinopyroxene about 1 mm long are present. Clinopyroxene in the matrix is charged with ≤0.5-mm-long needles of ilmenite. Ilmenite exceeds magnetite in volume. Age of unit was determined to be <200 Ka on the basis of geologic and paleomagnetic correlation with K-Ar dated flows in cores at the Idaho National Laboratory (Kuntz and others, 1992). Flows from vent 5206 Butte have been identified in drill cores BG-77-1 (flow 2), C-1A (flow 2), and USGS 118 (flow 1) where ages were derived from accumulation-rate assumptions. The ages thus determined are ~132 Ka, ~120 Ka, and <180 Ka for these three wells, respectively (Champion and others, 2002). Unit is correlated with Serviceberry Butte and the Blow Out lava fields in the Craters of the Moon 30' x 60' quadrangle on the basis of similar paleomagnetic directions; thus, age of unit is ~120 Ka (Kuntz and others, 2007).

Qsbc$_1$—Basaltic lava flows and near-vent pyroclastic deposits of the Lavatoo lava field (upper middle Pleistocene)—Surface-, channel-, and tube(?)-fed, dark to medium gray pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits. Vent area consists of a shallow (<20 m deep), 700-m-long, 300-m-wide depression atop a broad lava dome that rises about 50 m above surrounding flows. Flows near vent are largely shelly pahoehoe; near-vent area also mantled by cinders and tephra. Proximal, medial and distal flows are relatively smooth, local relief ≤2 m. Unit includes flows from two small cinder cones located 1.3 km south of main vent based on similarity in paleomagnetic directions (see Table 1). Unit not studied petrographically. Flows of unit lie on flows of Crater Butte lava field (*Qsbc$_4$*); thus, age is younger than about 292 Ka. Flows from Lavatoo Butte have been identified in drill cores BG-77-1 (flow 3), C-1A (flow 3), and USGS 118 (flow 2) at the Idaho National Laboratory; thus, age of unit is 211 ± 16 Ka (see Champion and others, 2002).

Qsbc$_2$—Basaltic lava flows of vent 5371 lava field (upper middle Pleistocene)—Surface-, channel-, and tube(?)-fed, dark to medium gray pahoehoe basalt flows. Vent area consists of a shallow (<15 m deep), 900-m-long, 100- to 300-m-wide lava-lake depression atop a broad lava cone. Lava lake appears to have been built atop the vent(s), which is now inundated. Flows near vent are smooth pahoehoe formed largely from overflow of lava lake. Proximal, medial, and distal flows are relatively smooth; local relief ≤2 m. Flows mantled by ≤2 m loess and eolian sand. Rock examined is microporphyritic, containing small phenocrysts of plagioclase ≤1.5 mm and olivine ≤0.6 mm in a fine matrix in which crystals are <0.3 mm long. Clots of as many as ten olivine and plagioclase crystals are as long as 2 mm and cross, and syntaxial clots of plagioclase crystals are common. Clinopyroxene in matrix occurs as granules ≤0.1 mm. Ilmenite needles and blades <0.2 mm exceed and equant magnetite crystals ≤0.1 mm in volume.

Qsbc$_3$—Basaltic lava flows and near vent deposits of vent 5334 lava field (upper middle Pleistocene)—Surface-, channel-, and tube(?)-fed, dark to medium gray pahoehoe and shelly-pahoehoe basalt flows, and reddish oxidized and black, near-vent pyroclastic deposits. Vent area consists of a N. 55° E.-trending, 1.2-km-long set of eruptive features. At southeast end is a 300-m-long, 150-m-wide, 20-m-deep vent depression. A 1-km-long eruptive fissure flanked by low spatter ramparts extends northwestward from the vent depression. At northwest end of eruptive fissure is a low (<20 m high) cinder cone. Flows near the vent depression are largely shelly pahoehoe; eruptive fissure area is mantled by cinders and tephra. Proximal, medial, and distal flows are relatively smooth, local relief ≤2 m. Flows are mantled by ≤2 m loess and eolian sand. Rock examined is porphyritic, containing phenocrysts of olivine and, rarely, bladelike clinopyroxene in a dense matrix in which all crystals are ≤0.3 mm. Clots of as many as fifteen olivine crystals are as large as 3 mm. Most large olivine crystals are skeletal and contain inclusions of glass and fine-grained matrix minerals. Single olivine phenocrysts are as large as 4 mm; all plagioclase crystals are ≤1 mm. Clinopyroxene crystals are as large as 2.1 mm; most crystals are subophitic and ≤1.2 mm. Opaque minerals are concentrated near vesicle walls; magnetite exceeds ilmenite in volume.

Qsbc$_4$—Basaltic lava flows and near-vent deposits of Crater Butte lava field (upper middle Pleistocene)—Surface-, channel-, and tube(?)-fed, dark to medium gray pahoehoe and shelly-pahoehoe basalt flows. Vent area consists of a N. 40° W.-trending, 750-m-long, 200-m-wide, 40-m-deep, steep-walled vent crater atop a broad shield volcano. Crater walls have numerous thin (<1.5 m thick) shelly-pahoehoe flows. Several rootless vents on lava-tube systems occur on southeast and south flanks of shield. The Crater Butte lava field forms a large shield volcano that covers about 220 km^2 and contains about 5 km^3 of lava flows. Flows have local relief of ≤4 m; flow fronts near flow margins are as high as 3 m. In distal parts, flows contain inflation and pressure plateaus having relief of ≤6 m. Flows are mantled by ≤3 m loess and eolian sand. Rock examined is weakly porphyritic, containing rare olivine and plagioclase phenocrysts ≤2 mm in a matrix of plagioclase laths, olivine granules, and blades of clinopyroxene that are ≤0.75 mm. Glomerophyric clots of three or four olivine crystals are common. Olivine crystals are typically equant, subhedral, and <0.5 mm. Plagioclase crystals are as large as 2 mm in longest dimension; some are moderately zoned, and syntaxial bundles of three to six crystals are common. Clinopyroxene is anhedral and subophitic, and crystals are <1.2 mm. Both magnetite and ilmenite crystals are <0.5 mm; magnetite exceeds ilmenite in volume. A K-Ar age of unit is 292 ± 58 Ka.

Qsbc$_{33}$—Pahoehoe basalt flows of Saddle Butte lava field (late middle Pleistocene)—Surface-fed, medium gray pahoehoe basalt flows. Vent area for flows believed to be Saddle Butte, about 5 km southwest of outcrops. Unit not studied petrographically.

Qsbc$_{37}$—Basaltic pahoehoe flows of vent 5571 lava field (upper middle Pleistocene)—Surface-, channel-, and tube(?)-fed, medium gray pahoehoe and shelly-pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits. Vent area is about 1 km south of the southern boundary of map. Proximal flows have smooth surfaces; local relief is ≤1 m. Medial and distal flows also have relatively smooth surfaces; local relief is <2 m. Flows are mantled by ≤2 m loess and eolian sand. Unit not studied petrographically. Unit correlated with flows of east Wildhorse Butte owing to the parallel alignment and closeness of vents of the two lava fields; thus, age is about 325 ± 10 Ka (Kuntz and others, 2007).

Qsbc$_{45}$—Basaltic pahoehoe flows and near-vent pyroclastic deposits of Tin Cup Butte lava field (late middle Pleistocene)—Surface-fed, dark gray and medium gray pahoehoe basalt flows, shelly pahoehoe, and red oxidized and black, near-vent pyroclastic deposits. Vent area is a shallow (≤10 m deep) lava lake that overlies a N. 40° W.-trending eruptive fissure. A small vent is present at the northwest corner of lava lake. Shelly pahoehoe covers much of vent area; pyroclastic deposits are present locally in vent area. Proximal flows are very smooth; local relief is ≤1 m. Medial and distal flows have rougher surfaces; local relief is ≤3 m. Rock examined is porphyritic, containing subhedral to euhedral phenocrysts of plagioclase ≤5 mm and euhedral to subhedral, mostly equant phenocrysts of olivine ≤1.5 mm. Rock is characterized by syntaxial bundles of plagioclase crystals, cumulophyric clots of plagioclase + plagioclase, plagioclase + olivine, olivine + olivine, starburst texture, and waist texture. Matrix of rock consists of crystals of olivine, laths of plagioclase, equant granules of clinopyroxene, and intersertal glass containing inclusions of clinopyroxene and opaque minerals. All minerals in matrix are ≤0.5 mm. Equant crystals of magnetite ≤0.25 mm are present in matrix; elongated crystals of ilmenite are ≤0.3 mm. Flows are mantled by ≤2 m of loess and eolian sand.

Qsbc$_{46}$—Basaltic pahoehoe flows of Sixmile Butte lava field (upper middle Pleistocene)—Tube-fed, medium black and medium gray pahoehoe basalt flows of the Sixmile Butte lava field. Vent area consists of a N. 45° W.-trending, shallow crater ≤3 m deep, 150 m long, and ≤50 m wide that lies atop a steep-sided shield volcano that rises 100 m above surrounding, younger lava flows. Flows in vent area are typically shelly pahoehoe. Medial flows are relatively smooth; local relief ≤2 m. Flows are mantled by ≤3 m loess and eolian sand. Outcrop located 2.5 km west of Butte City not studied petrographically; therefore, correlation with vent at Sixmile Butte is tenuous. Rock examined is porphyritic, containing phenocrysts of olivine and plagioclase in a dense matrix of olivine, plagioclase, clinopyroxene, and opaque minerals, all of which are <0.25 mm. Olivine phenocrysts are mostly equant, subhedral, and <1.2 mm. Cumulophyric clots of three to six olivine crystals are common. Plagioclase laths are stubby to intermediate in shape and as long as 4.5 mm; syntaxial clots of six to eight crystals are common. Clinopyroxene granules and small blades <0.25 mm are confined to the matrix. Magnetite exceeds ilmenite in volume. K-Ar age of unit is 609 ± 92 Ka.

$Qsbc_{47}$—Basaltic pahoehoe flows and near-vent pyroclastic deposits of Teakettle Butte lava field (upper middle Pleistocene)—Surface- and channel-fed, dark gray and medium gray pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits. Vent area consists of a 1-km-long, N. 50° W.-trending, slot-shaped, ≤5-m-deep vent depression. A small cinder-cone vent is at the northwest end of the elongated vent depression. Vent depression is atop a 100-m-high eruptive fissure-cinder cone complex having steep slopes. Much of vent area mantled by reddish oxidized and black, near-vent pyroclastic deposits and shelly-pahoehoe flows. Proximal and medial flows have relatively rough surfaces; local relief is ≤2 m. Flows mantled by ≤2 m loess and eolian sand. Rock examined is porphyritic, containing phenocrysts of plagioclase and olivine in a dense matrix. Stubby to intermediate, subhedral phenocrysts of plagioclase are ≤2.5 mm; subhedral, mostly equant phenocrysts of olivine are ≤2.4 mm. Cumulophyric clots of as many as ten plagioclase crystals and as many as forty plagioclase + olivine crystals are common. The fine-grained matrix of the rock, in which all crystals are ≤0.4 mm, consists of olivine, plagioclase, and intergranular clinopyroxene. Opaque minerals occur as tiny crystals in the matrix intergrown with clinopyroxene.

$Qsbc_{48}$—Basaltic pahoehoe flows and near-vent pyroclastic deposits of vent 5217 lava field (upper middle Pleistocene)—Surface- and channel-fed, dark gray and medium gray pahoehoe basalt flows and reddish oxidized and black, near-vent pyroclastic deposits. Vent area consists of a 1.2 km-long, N. 32° W.-trending eruptive-fissure system. A 25-m-high lava cone (vent 5217) occurs at south end of fissure system; two low cinder cones aligned along northern part of fissure system. Flows mantled by ≤2.5 m loess and eolian sand. Only proximal flows exposed; medial and distal flows covered by younger flows of vent 5371 ($Qsbc_2$) and Quaking Aspen Butte ($Qsbb_{19}$) lava fields. Rock examined is even-grained. Olivine crystals are euhedral to subhedral and as large as 2.0 mm. Plagioclase laths are as long as 1.5 mm, and clinopyroxene is anhedral, subophitic, and ≤1.0 mm. Magnetite and ilmenite crystals are <0.4 mm.

$Qsbc_{49}$—Basaltic pahoehoe flows and near-vent pyroclastic deposits of vent 5128 lava field (upper middle Pleistocene)—Surface-, channel-, and tube-fed(?), dark gray and medium gray pahoehoe basalt flows. Vent area consists of four low cinder cones aligned N. 20° W. Main cone at spot elevation 5,128 lies 0.5 km south of southern boundary of map. Cinder cones mantled by reddish oxidized and black cinders, ash, and lapilli. Flows are medium gray pahoehoe in medial parts. Distal parts of flows covered by flows of Quaking Aspen Butte ($Qsbb_{19}$) and vent 5217 ($Qsbc_{48}$). Unit not studied petrographically.

$Qsbc_{50}$—Basaltic pahoehoe flows and near-vent pyroclastic deposits of vent 5968 lava field (upper middle Pleistocene)—Surface-, channel-, and tube-fed(?), dark gray and medium gray pahoehoe basalt flows. Vent area consists of a N. 65° W.-trending, shallow (≤5 m), 500-m-long, 110-m-wide crater atop a broad shield volcano summit. Vent area lies 1 km north of a kipuka of Ordovician quartzite having the spot elevation of 5,968 feet. Near-vent flows are dominantly shelly pahoehoe; near-vent pyroclastic deposits are rare. Flows mantled by 2-3 m of loess and eolian sand. Unit not studied petrographically. Age based on depth of loess and eolian sand cover and local stratigraphic relationships.

$Qsbc_{51}$—Basaltic pahoehoe flows and near-vent pyroclastic deposits of Nichols Reservoir lava field (upper middle Pleistocene)—Surface-, channel-, and tube-fed(?), dark gray and medium gray pahoehoe basalt flows. Vent area consists of a N. 40° W.-trending, shallow (≤10 m), 600-m-long, 350-m-wide crater atop a broad shield volcano. A prominent lava channel having levees as high as 12 m extends northwest from vent area. Near-vent flows are mostly shelly pahoehoe. Flows are mantled by 2-3 m of loess and eolian sand. Distal flows largely covered by alluvial deposits. Rock examined is even-grained, containing equant, subhedral crystals of olivine ≤0.75 mm; weakly zoned plagioclase laths ≤1.3 mm; and subhedral, subophitic crystals of clinopyroxene ≤1.0 mm. Magnetite exceeds ilmenite in volume; both opaque minerals are ≤0.15 mm in longest dimension. Age based on depth of loess and eolian sand cover and local stratigraphic relationships.

Table 1. Radiocarbon and potassium-argon ages, and paleomagnetic data for the Arco 30' x 60' quadrangle, Idaho.

Part A. Radiocarbon ages of lava flows of the Craters of the Moon lava field (Arco 30' x 60' quadrangle; data from Kuntz and others, 1986b)

Eruptive Periods/ Lava Flows	Sample pretreatment	Lab. Number	^{14}C date (yr B.P.)
Eruptive Period A			
Blue Dragon flow	caaa	W-4578	2,030±80
Eruptive Period B			
Sunset flow	ca	W-4296	12,010±150
Lava Creek flow	saaa	W-4476	12,760±150

Note—For sample pretreatment: ca = charcoal leached with dilute HCl acid only; caaa = charcoal pretreated by acid-alkali-acid method; saaa = charred sediment pretreated by disaggregation-deflocculation-acid treatment and by acid-alkali-acid treatment. See Kuntz and others (1986b) for sample pretreatment methods.

Part B. Potassium-argon data for samples of basalt from surface flows.

Field No.	Lava field	K_2O (wt. %)	$^{40}Ar_{rad}$ (mol/g x 10^{-13})	$^{40}Ar_{rad}$ (%)	[2]Calculated age: Sample age	Flow age[1]
91ILe-2	Crater Butte	0.556±0.001	1.984	1.26	248±78	
		0.556±0.001	2.730	1.57	349±88	292±58
84ILe-30	Unnamed flow	0.439±0.002	3.854	2.64	609±92	609±92

[1]Weighted mean of the two sample ages, where weighting is by the inverse of the variance, and weighted standard deviation.
[2] $\lambda_\varepsilon = 0.581 \times 10^{-10}\ yr^{-1}$, $\lambda_\beta = 4.962 \times 10^{-10}\ yr^{-1}$ $^{40}K/K = 1.167 \times 10^{-4}$ mol/mol. Errors are estimates of the standard deviation of analytical precision.

Part C. Paleomagnetic data.

Unit Name	Site	Lat	Long	N/No	Exp	I	D	α95	k	R	Plat	Plong
Quaking Aspen Butte	4B655	43.551°	246.985°	12/12	20+	63.6°	344.8°	1.1°	1493	11.99263	79.0°	170.9°
Crater Butte (summit)	4B631	43.607°	246.838°	12/12	20+	63.1°	342.1°	1.6°	784	11.98597	77.1°	167.4°
Crater Butte	4B643	43.580°	246.910°	9/12	30	60.5°	345.8°	1.2°	1764	8.99546	79.3°	150.4°
Vent near Lavatoo Butte	A9595	43.518°	246.911°	11/12	10	56.1°	357.5°	1.5°	908	10.98899	82.9°	83.4°
Lavatoo Butte	A9607	43.520°	246.905°	12/12	10+	54.8°	354.7°	1.3°	1069	11.98971	80.8°	95.2°
Box Canyon	4B943	43.558°	246.783°	10/12	20	50.4°	348.2°	1.2°	1541	9.99416	74.5°	107.6°

N/No = Number of samples used to calculate mean site direction vs. total number of samples taken at site
Exp = Experiment strength of alternating magnetic field (mT)
I = Inclination
D = Declination (degrees east)
α95 = Radius of cone of 95% confidence about the mean direction (degrees)
k = Fisher's precision parameter
R = Length of resultant vector
Plat = Latitude (degrees north) of Virtual Geomagnetic Pole
Plong = Longitude (degrees east) of Virtual Geomagnetic Pole

$Qsbd_1$—Basaltic pahoehoe flows and near-vent pyroclastic deposits of vent 4959 lava field (lower middle Pleistocene)—Surface- and channel-fed, dark gray and medium gray pahoehoe basalt flows and reddish oxidized and black near-vent pyroclastic deposits. Vent area consists of a N. 80° W.-trending, 500-m-long, 250-m-wide, 25-m-deep crater. Proximal flows are smooth shelly pahoehoe formed by overflow of crater. Vent crater and proximal flows surrounded on all sides by flows of the Crater Butte ($Qsbc_4$) lava field. Unit not studied petrographically. Vent crater is aligned with vents of the AEC Butte lava field 2.4 km southeast. K-Ar age of AEC Butte flows is 641 ± 51 Ka (Kuntz and others, 1994).

$Qsbe_1$—Basaltic pahoehoe flows (early Pleistocene)—Surface- and channel-fed, dark gray and medium gray pahoehoe basalt flows. Flows mantled by ≤3 m loess and eolian sand. Flows are believed to be related to flows of Knob vent lava field, the vent of which lies 0.5 km east of eastern boundary of map. This correlation is not confirmed by paleomagnetic or petrographic studies. Flows at Knob vent have reversed magnetic polarity (Kuntz and others, 1994); thus, they are older than 780 Ka. Unit not studied petrographically.

STRUCTURE

CONTRACTIONAL FEATURES

Indirect evidence indicates that the area of the Arco quadrangle was affected by the west to east thrusting of the Late Devonian-Early Mississippian Antler orogeny. Clastic rocks of the Copper Basin Group were shed from a probable accreted arc or transpressional highland on the west into an adjacent faulted foreland basin on the east (Link and others, 1995; Link and Janecke, 1999). Remnants of both the highland and the basin are present in the western part of this quadrangle on the hanging walls of the Pioneer and Copper Basin thrust faults of the Late Jurassic to Tertiary Sevier orogenic belt.

The Pioneer thrust plate in the southwestern corner of the map carries deformed, relatively deep-water shales and siltstones of the Devonian Milligen Formation overlain unconformably by Pennsylvanian and Permian shallow water sandy carbonates and conglomerates of the Wood River Formation on its hanging wall. No Mississippian rocks are present. The unconformity represents a western highland that, during Mississippian time, contributed detritus to a faulted foreland basin to the east (Wilson and others, 1994). At the central western edge of this quadrangle, tightly folded western facies mudstone and siltstone of the Milligen Formation are thrust over folded clastics of the Mississippian Copper Basin Group, bringing older rocks over younger. The southward extension of this thrust into the Craters of the Moon 30' x 60' quadrangle places younger Pennsylvanian rocks over older Mississippian rocks (Skipp and Hall, 1975; Kuntz and others, 2007). This juxtaposition of younger over older rocks indicates the thrust had later normal movement on it, dropping the hanging wall down to the west (cross section A-A′). The Pioneer thrust fault has inferred top-to-the-east-northeast slip of several tens of kilometers (Rodgers and others, 1995).

The Copper Basin thrust carries a thick sequence of fine- to coarse-grained siliceous clastics and minor carbonates of the Lower to Upper Mississippian Copper Basin Group on its hanging wall. This thick sequence, in excess of 5,900 m, consists of proximal and distal turbidites deposited in a faulted foreland basin (Nilsen, 1977; Wilson and others, 1994; Link and others, 1996). The great thickness led Nilsen (1977) to propose a duplication of the sequence along a thrust fault, but later work (Wilson, 1994; Wilson and Rodgers, 1993) indicated the proposed thrust fault does not exist. In addition, fossil evidence, though sparse, favors a mostly continuous stratigraphic sequence (Link and others, 1996) proposed earlier by Paull and others (1972) and Paull and Gruber (1977). The Copper Basin thrust is buried through much of this quadrangle, but, where exposed, the rocks in the hanging wall have different, more western facies than the coeval deposits in the footwall. A continuation of the thrust that has minor stratigraphic separation is mapped by Skipp in the southeastern corner of the Challis quadrangle to the northwest (Fisher and others, 1992). At the latitude of cross section A-A′, lower to upper Mississippian rocks of the lower part of the Argosy Creek Formation override uppermost Mississippian to Pennsylvanian carbonate rocks of the Snaky Canyon Formation. Further south and east, an exposed offset part of the thrust along Dry Fork brings Little Copper Formation against the upper part of the McGowan Creek Formation. Both formations are considered Early Mississippian in age, and the fault has juxtaposed rock units of nearly the same age but of different facies, much like the segment mapped in the Challis quadrangle to the north. Thus, this fault is dying out to the north and south and was later inverted by normal movement, much like the Pioneer fault.

Siliceous Mississippian rocks carried on the hanging wall of the Copper Basin thrust override tightly folded Mississippian to Permian carbonate platform rocks exposed across the eastern two-thirds of the Arco quadrangle. Folds axes trend north-northwest, and folds are open and upright to overturned to the east. Shortening due to map-scale folding is estimated to be at least 25 percent; folds trend N. 20° W. on both sides of the Copper Basin thrust (Rodgers and others, 1995; Jeppson and Janecke, 1995) and plunge south toward the Snake River Plain (McQuarrie and Rodgers, 1998). Cross section A-A′ shows probable small thrust faults at depth to explain overturned fold limbs and other space problems. These faults and the shortening due to folding are typical of the Hawley Creek thrust in the Tendoy Mountains of western Montana (Skipp, 1988b) and indicate the presence of one or more major thrust faults at depth beneath the quadrangle.

EXTENSIONAL FEATURES

Following the shortening of the late Jurassic to Tertiary Sevier orogeny, the Arco area has been dominated by extension and volcanism to the present. Extension began before the extrusion of the middle Eocene Challis Volcanic Group in response to the relaxation of the compressional stresses and crustal thickening of the Sevier orogeny (Link and Janecke, 1999). Unnamed north- to northwest-trending normal faults east and subparallel to both the Pioneer and Copper Basin thrust traces (Figure 3) may have first formed shortly after thrusting ceased along the Cretaceous thrust faults, and then were offset and reactivated during one or more of the following three major extensional periods: (period 1) NW-SE extension during peak Challis volcanism 49-48 Ma; (period 2) ENE-WSW basin-forming extension during a younger middle Eocene to Oligocene period that also included the uplift of the Pioneer Mountains metamorphic core complex at the western edge of the quadrangle; and (period 3) NE-SW basin-range extension from the Miocene to the present (Janecke, 1992c; Rodgers and others, 1995; Link and Janecke, 1999). In addition, a

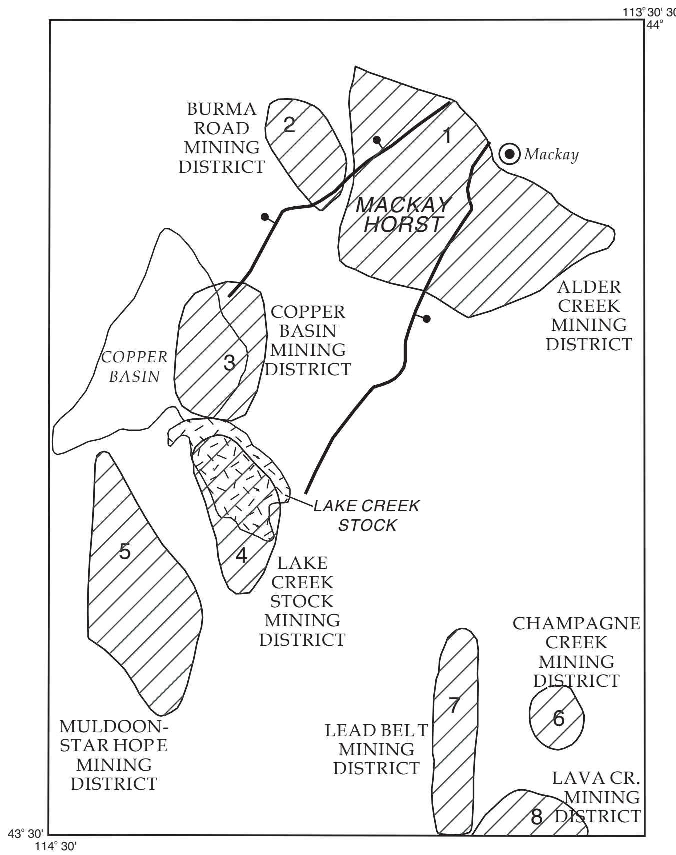

Figure 4. *West half of Arco quadrangle showing locations of major mining districts (lined) in relation to the town of Mackay, Copper Basin, the boundary faults of the Mackay horst, and the Lake Creek stock. Index of previous geologic mapping used as primary sources of data.*

few small east-striking normal faults that may reflect late Cenozoic north-south extension in the wake of the Yellowstone hot spot are concentrated near the Snake River Plain (Skipp and others, 1990; Janecke and others, 2001; Janecke, 2007).

The northwest to southeast extension of period 1, 49-48 Ma, includes the relative uplift of the White Knob horst along east-northeast-trending boundary faults, one of which marks the southern boundary of Copper Basin, and the initiation of the White Mountains fault along the southeast margin of the Pioneer metamorphic core complex (Rodgers and others, 1995). Numerous smaller east- or east-northeast-trending normal faults cut the volcanics and sedimentary rocks of the White Knob Mountains and a segment the Lost River Range to the east. Regional dike trends are parallel to these faults in the White Knob and Pioneer Mountains. Offsets on the normal faults are at most a few kilometers. The northeast-trending normal faults offset traces of the Sevier thrust faults and parts of both of the southwest-dipping normal faults formed just east of the older Pioneer and Copper Basin thrust faults. Post-Challis (Miocene?) reactivation of some northeast-striking normal faults seems likely and may be related to initiation of the Yellowstone hot spot (Sears and Ryan, 2003).

Extension of period 2 includes the formation of the Pass Creek and Arco Pass basins (Figure 3) in the Lost River Range and Arco Hills, respectively (Janecke, 1992c), and the reactivation of the White Mountains fault along with the uplift and unroofing of the Pioneer Mountains metamorphic core complex along the Wildhorse detachment (Silverberg, 1990a; Rodgers and others, 1995; Wust and Link, 1988). This period was the most important extensional event in the Arco area. It began during the waning phases of Challis volcanism. The sequence of deformational events in the basins of the Lost River Range tightly constrain the near-90° flip in extension directions from NW-SE (period 1) to ENE-WSW (period 2) to 46-48 Ma (Janecke, 1992c). Though details of the beginning of period 2 extension are known, details of the end of basin formation are less known. Tuffs from the lower and middle parts of the Pass Creek basin are dated at 45.7 Ma and 45.4 Ma, respectively, and extrapolated sedimentation rates suggest that the youngest preserved Tertiary sedimentary rocks may be Eocene in age (Janecke, 1992c; Janecke and Snee, 1993). Two tuffs in the lower basin fill of the Arco Pass half graben and the carbonate-clast conglomerate in the Pass Creek basin have been chemically correlated to a dated 39-Ma tuff (Janecke and Perkins, unpublished data). Movement along the west-dipping extension faults bounding the Pass Creek and Arco Pass basins, however, probably continued into Oligocene or possibly Miocene time. These basins may have been active before or at the same time as much better dated east-tilted half grabens farther east (Janecke, 1992c; M'Gonigle and Dalrymple, 1993, 1996; Janecke and others, 1999; Janecke and others, 2005).

Most of the unroofing of the Pioneer core complex is estimated to have taken place during the early Oligocene, 36-33 Ma, with a top-to-the-northwest sinistral oblique sense of shear (Silverberg, 1990a; 1990b; Huerta and Rodgers, 1996). Janecke (1992c) proposes that plate boundary forces controlled the extension directions of period 1, but that period 2 extension probably resulted from internal stresses within the thickened crust of the Sevier thrust wedge.

The older north-northwest-trending fold axes in the southern Lost River Range and Arco Hills were oblique to the southern end of the Arco Pass fault system and may have acquired much of their southeast plunge during tilting of the hanging wall and footwall of these fault zones. This is contrary to the interpretation of McQuarrie and Rodgers (1998), who concluded that all southward plunge was due to subsidence of the eastern Snake River Plain.

Extension of period 3 encompasses west-dipping, north-northwest-striking Basin and Range faults that are active within the area today as evidenced by the rupture of a segment of the Lost River fault during the 1983 Borah Peak earthquake just north of the northern boundary of the Arco quadrangle. Active faults control the present landscape of south-central Idaho and include both the Lost River and Lemhi faults (Figure 3) that cut Quaternary deposits. Several north-northwest-trending faults in the southern White Knob Mountains have Miocene Idavada ignimbrites as young as 9.4 Ma (Snider, 1995) on their hanging walls, do not cut Quaternary deposits, and are assigned to this period. They indicate that some Basin and Range deformation was limited to latest Miocene and pre-Quaternary time, or that these faults have very long recurrence intervals or both. East-striking small normal faults in the southern White Knob Mountains may be associated with subsidence of the eastern Snake River Plain, as well as Basin and Range faults of period 3, but neither set is well dated.

Subsidence of the Snake River Plain dominates the southeastern corner of the Arco quadrangle and has produced tilted rock units, plunging folds, and east-striking normal faults (McQuarrie and Rodgers, 1998; Janecke and others, 2001; cross-section B-B′). Miocene ignimbrites dip as much as 25 degrees southward or southeastward beneath basalts of the plain (Kuntz and others, 2007), and this map. Southeastward plunges of older folds were steepened by this second period of southeast tilting (McQuarrie and Rodgers, 1998).

The epicenter (hypocenter) of the 1983 Borah Peak earthquake has been projected into the northwestern corner of this quadrangle (Haller and Crone, 2004).

MINERAL DEPOSITS, ENERGY, AND MISCELLANEOUS RESOURCES

MINERAL DEPOSITS

Mineral deposits including copper, silver, gold, lead, zinc, and barite are common in the western half of the Arco quadrangle and have played a major role in the settlement of the area (Umpleby, 1917). Figure 4 gives generalized outlines of six of the seven mining districts as defined by Worl and Johnson (1995), and the Alder Creek or Mackay district as defined by Nelson and Ross (1968) and Wilson and others (1995). Only four of the districts have had significant production; these include the Alder Creek or Mackay, the Muldoon, Lava Creek, and Champagne Creek (Worl and Johnson, 1995). The richest deposits of copper, silver, gold, lead, and zinc were mined in the 1880s and 1890s, and again in the 1940s through 1960s (Nelson and Ross, 1968; Winkler and others, 1995; Wilson and others, 1995). The richest barite bodies were mined in the 1950s and 1960s (Winkler and others, 1995).

The Alder Creek or Mackay district is characterized by copper skarn deposits in contact aureoles of Tertiary granite and leucogranite porphyry with Mississippian sedimentary carbonates of the Mississippian White Knob and McGowan Creek formations (Nelson and Ross, 1968; Wilson and others, 1995; cross-section A-A′). Outer zones of the skarns contain polymetallic veins and local iron skarn (Worl and Johnson, 1995). Minor mineral concentrations are associated with secondary jasperoid replacement of carbonate (Soulliere and others, 1995b). Mineral deposits found in the Copper Basin district are similar to those found in the Alder Creek district.

Mississippian rocks of the Copper Basin Formation in the Muldoon district host vein, replacement, and distal skarn deposits of silver-lead-zinc and minor copper. Locally, these deposits are associated with stratabound veins and replacements of barite. The richest metal deposits are in skarns of the Drummond Mine Limestone Member of the Copper Basin Formation located near Tertiary quartz monzonite stocks or swarms of dikes. Where cut by high-angle faults, some skarns have associated veins unusually rich in precious metals. Significant resources of base- and precious-metals and barite remain in the Muldoon district (Winkler and others, 1995).

The Lava Creek and Champagne Creek districts have produced silver, lead, and zinc from mineralized epithermal fissures in hydrothermally altered Challis volcanic rocks that overlie Mississippian flysch facies of both the hanging wall and footwall of the Copper Basin thrust. North- to northwest-trending faults and veins characterize the area of the Champagne Creek mining district (Anderson, 1947; Skipp and others, 1989; Erdman and others, 1995), whereas east-west faults and fissures are dominant in the Lava Creek district (Skipp and others, 1989). Epithermally altered intrusive bodies are also present in the Lava Creek district that extends southward into the Craters of the Moon quadrangle (Kuntz and others, 2007).

Minor base- and precious-metal production in the Lead Belt district has been from both Tertiary polymetallic veins and epithermal precious-metal veins. Major northwest-trending low-angle fractures and north-trending high-angle fracture zones in Mississippian footwall rocks of the Copper Basin thrust and overlying Eocene volcanic rocks host the mineral deposits (Worl and Johnson, 1995; Soulliere and others, 1995a).

The Lake Creek Stock district is characterized by Tertiary polymetallic veins and replacement veins in northeast-trending fracture systems associated with the diorite complex of the Lake Creek stock and the enclosing rocks of the Mississippian Copper Basin Formation and the Eocene Challis Volcanic Group (Winkler and others, 1995; Worl and Johnson, 1995).

The Burma Road district is similar to the Champagne Creek district in that Tertiary antimony veins and epithermal precious-metal veins are in structurally controlled brecciated fault zones. In the Champagne Creek district, the zones of brecciation or fissures trend north, whereas in the Burma Road district ore deposits are localized along north- and northeast-trending structures related to subsidence of the Lehman Basin cauldron complex (Figure 3; Moye and others, 1989).

ENERGY AND MISCELLANEOUS RESOURCES

Hydrothermal alteration in several of these mining districts is related to convective movement of meteoric waters heated by shallow intrusions or high heat flow associated with one or more periods of extension (Snider and Moye, 1989). The presence of hot springs and deposits scattered through the south-central area indicates a high geothermal potential at relatively shallow depths for this part of the quadrangle (Skipp and others, 1990).

Hydrocarbon potential is low for oil and moderate for gas in the southern White Knob Mountains as indicated by conodont alteration indices (Skipp, 1988a, 1990; Skipp and others, 1990; Skipp and Bollman, 1992). The area has been subjected to temperatures well above those required for preservation of liquid hydrocarbons, though Devonian mudstones in the region originally may have been source rocks.

Relatively pure limestones are found in some of the upper Mississippian formations of the White Knob Mountains and the Lost River Range. The Ordovician Kinnikinic Quartzite is almost pure quartz in places in the Lost River Range. Some of the well-bedded Paleozoic sandstones and many of the well-indurated Mesoproterozoic quartzites are excellent dimension-stone resources.

Extensive deposits of sand and gravel exist in all of the valleys and locally in the large alluvial fans generated along the faulted range fronts. Basaltic ash and crushed lavas have been used for road metal in places.

GEOLOGIC HISTORY

The area of the Arco quadrangle has been a part of the North American continent since Proterozoic time and possibly since Archean time. Archean xenoliths have been found in basalts of the Great Rift Zone in the Craters of the Moon National Monument (Leeman and others, 1985; Wolf and others, 2005), and the core of the Pioneer core complex immediately west of the quadrangle exposes 2,600-2,700 Ma Archean orthogneiss (Link and others, 2007).

Recent reconstructions of the Precambrian basement of south-central Idaho and areas to the north present two interpretations of the Arco area, primarily because of the unpenetrated thick cover. In one, the basement of the Arco quadrangle is evenly divided between mixed Archean-Proterozoic in the northwest and Archean of the Wyoming Province in the southeast (Sims and others, 2005). In the other, the area is assigned to either the Proterozoic Farmington zone or the Selway terrane (Foster and others, 2007b; Foster and others, 2007a). A few gneissic granite xenoliths in Eocene volcanics adjacent to the Craters of the Moon National Monument (Skipp, 1988; Skipp and others, 1989) have not been studied.

Though the age of some xenoliths in basalts along the northern border of the Snake River Plain is established, the identity of the Archean terrane from which they were derived is not (Foster and others, 2007b). Recent work in the Pioneer core complex just west of the Arco quadrangle suggests that the Archean basement there is a northward extension of the Grouse Creek terrane (Link and others, 2007).

A Mesoproterozoic sedimentary basin with thick accumulations of sandstones and carbonates is documented in the Lemhi Range and probably covered much of the area of the quadrangle as far west as the Pioneer core complex (Link and others, 2007). The roots of a Mesoproterozoic meteor impact crater may exist just north of this area (Hargraves and others, 1990; McCafferty, 1995; Kellogg and others, 2003), and the northern part of the Arco quadrangle may have undetected detritus or other evidence of meteor impact buried beneath the thick cover. Neoproterozoic to Cambrian sandstone, quartzite, and conglomerate unconformably overlie Mesoproterozoic rocks in the Lemhi Range and appear to be northward extensions of the Paleoproterozoic rift basin south of the plain (McCandless, 1982; Skipp and Link, 1992).

During Early Paleozoic time, the Arco area experienced several incursions and withdrawals of the Paleozoic seas punctuated by periods of uplift and erosion. Cambrian, Ordovician, Silurian, and Devonian rocks of various marine facies are present in the Lemhi and Lost River ranges, and in a few windows through volcanic rocks in the White Knob Mountains. The rocks record parts of the Tippecanoe and Sauk sequences (Sloss, 1963) described for the cratonic interior of western North American (Laurentia). In latest Devonian time, the relative quiescence of Early Paleozoic time came to an end with the Antler orogeny (Poole, 1974; Poole and Sandberg, 1977; Poole and others, 1992). West- to east-directed thrusting was initiated at the continental margin (Poole and Sandberg, 1977; Wright and Wyld, 2006), and the structural welt that resulted shed detritus eastward into a faulted Mississippian flysch basin (Nilsen, 1977; Wilson and others, 1994). The resultant detritus is represented by the thick sedimentary rocks of the Copper Basin Group and most of the McGowan Creek Formation further east. Strike-slip deformation within the Idaho part of the foreland basin could explain the great thickness of the synorogenic flysch deposits (Wilson and others, 1994). It has also been suggested that the deformation may have been a local process within an overall transcurrent plate boundary (Wright and Wyld, 2006). East of the McGowan Creek Formation, coeval, areally extensive, shallow water marine carbonates were deposited in a miogeosynclinal basin on the craton margin.

When thrusting ceased, crustal rebound in the flysch basin area formed a Pennsylvanian Copper Basin highland (Skipp and others, 1979b) concurrent with the rise of the ancestral Rocky Mountains resulting from either the collision of South American-Africa with North America (Kluth, 1986) or the continued transcurrent deformation along the cordilleran margin (Wright and Wyld, 2006). The rise of the highlands in Pennsylvanian time accompanied the downfaulting of the adjacent western Pennsylvanian and Permian Wood River and Oquirrh basins (Mahoney and others. 1991; Rodgers and others, 1995). To the east of the Copper Basin highland, areally extensive Pennsylvanian and Permian shallow water marine carbonates, chert, and phosphates were deposited on the craton margin, bringing the Paleozoic to a close in south-central Idaho.

Little is known of the Triassic and possibly Jurassic sedimentary strata, which may have covered the area. Permian Phosphoria Formation crops out in the southern Lemhi Range. Just to the east, in the southern Beaverhead Mountains, the Phosphoria Formation is overlain by Triassic Dinwoody Formation (Skipp and others, 1979a), but no outcrops of Triassic rocks have been found in the Arco area. The deposition of Mesozoic sediments, however, probably took place until Jurassic or Cretaceous time when rapid subduction along the western margin of the continent produced the Sevier orogeny. At this time, Mesozoic and older sediments were stripped off, and the detritus was deposited in a foreland basin far to the east (DeCelles, 2004).

Thrusting and folding of the Sevier orogeny deformed all of the older sedimentary rocks in the area. The Pioneer and Copper Basin thrusts were responsible for shortening the crust in the western part of the quadrangle. Folding east of these thrusts accommodated much of the remainder of the shortening, which is estimated to exceed 25 percent (Rodgers and others, 1995). One or more major thrusts underlie the entire area and reach the present surface much further east in the Beaverhead Mountains and Tendoy Mountains (Skipp, 1987; 1988b; Rodgers and Janecke, 1992; Lonn and others, 2006 (2000)). Major Sevier thrusting and thickening of the crust proceeded from west to east through earliest Tertiary time (DeCelles, 2004). At that time, the overthickened thrust wedge began a gradual collapse that initiated the prolonged period of extension and volcanism that has dominated this area.

Intrusion and uplift of the Cretaceous Idaho batholith just to the west of the quadrangle provided fluids and metals for most of the mineral deposits of this and adjacent areas (Worl and Johnson, 1995; Rodgers and others, 1995). Uplift of the batholith and its satellites elevated the region and preceded early Eocene volcanism. Regional uplift is recorded in steep gradient stream deposits preserved in places as conglomerates and sandstones at the base of the Eocene Challis volcanic rocks (Smiley Creek Formation of Paull, 1974). The oldest directly dated Challis intermediate volcanic rocks (49 Ma) are found here (Snider, 1995). Detrital zircons in modern rivers, however, indicate that volcanism started earlier, about 52 Ma, and continued until about 42 Ma (Beranek and others, 2006). Eocene volcanism in the Arco quadrangle proceeded from south to north and produced the volcanic centers shown in Figure 3, the Alder Creek eruptive center (ACEC), the Lehman Basin caldera complex (LBCC), and the Navarre Creek dome complex (NCDC), all part of the southeastern Challis field (Moye and others, 1995; Snider, 1995). Challis volcanism was accompanied by the intrusion of the Mackay and Lake Creek stocks (Worl and Johnson, 1995) and numerous east-northeast-trending dikes, including the dike swarm in the Mackay horst (Nelson and Ross, 1968). Eocene intermediate volcanic rocks blanket large areas of Paleozoic rocks in the White Knob and Pioneer Mountains and once covered most of the Lost River Range to the east.

Extrusion of the thick Eocene intermediate volcanics was accompanied by and then followed by extension that resulted in deposition of the thick Eocene to Oligocene sediments that fill the Arco Pass and Pass Creek basins in the Lost River Range (Janecke, 1992c; Figure 3).

Subsidence and volcanism in the eastern Snake River Plain overprinted older structures and produced a new set of east-striking normal faults (Janecke and others, 2001; this map). Miocene rhyolitic ignimbrites and associated deposits, which originated in calderas and vents now buried beneath the Snake River Plain, are exposed along its margins and are present below the Quaternary basalts (Morgan and others, 1984). Volcanic fields, each consisting of several nested calderas, become younger to the northeast as the North American plate has moved southwestward ~2.9 cm/year over a fixed mantle plume or hot spot (Pierce and Morgan, 1992). The hot spot is currently under the Yellowstone Plateau volcanic field (Yuan and Deuker, 2005). The Idavada Volcanics were established as a formal stratigraphic unit south of the Snake River Plain (Malde and Powers, 1962) and later were described on the north side of the plain as consisting of "thick layers of devitrified welded tuff" that disconformably overlie the Challis Volcanic Group (Malde and others, 1963). As used here, Idavada Volcanics is an evolving stratigraphic term that refers to an undifferentiated suite of Miocene rhyolitic ignimbrites exposed along the northern margin of the central Snake River Plain (Kuntz and others, 2007). The Heise Group refers to the youngest suite of caldera-forming ignimbrites and associated deposits on the eastern Snake River Plain (Morgan and McIntosh, 2005) and includes the Miocene Walcott and Blacktail Creek Tuffs exposed in the Arco quadrangle. Faulting and earthquakes, associated with the Yellowstone hot spot in the adjacent basin-and-range mountains, and volcanism will continue to affect the area.

Quaternary basalts of the Snake River Plain and the Craters of the Moon National Monument cover the southeastern corner of the Arco quadrangle. An extension of the Great Rift Zone (Kuntz and others, 2007) into the footwall of the Copper Basin thrust fault is marked by a string of small basalt cones that trend northwestward from the margin of the plain (Figure 3).

Pleistocene and Holocene sedimentary deposits, including the extensive alluvial fans of several ages at the fronts of the Lost River and Lemhi ranges, are indications of a much wetter climate in Pleistocene time (Scott, 1982). Remnants of alpine glacial deposits, chiefly outwash, abound in the high valleys of the White Knob Mountains. Glaciers and basaltic volcanoes were active at about the same times. At present, the area is high desert with about 10 inches of annual rainfall.

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