Geologic Map of the Idaho Part of the Grangeville 30 x 60 Minute Quadrangle and Adjoining Areas of Oregon and Washington

Mapped and Compiled by
John D. Kauffman, Keegan L. Schmidt, Reed S. Lewis,
David E. Stewart, Kurt L. Othberg, and Dean L. Garwood

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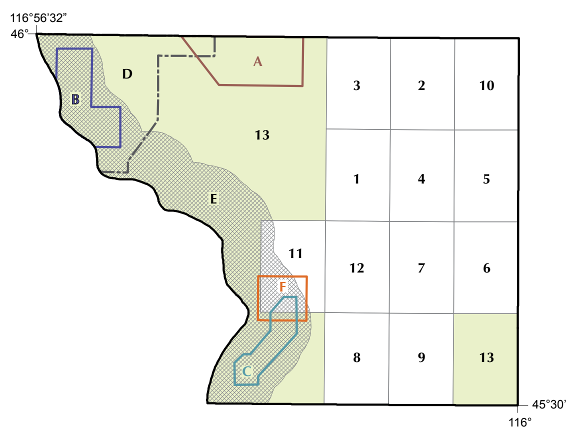
INTRODUCTION

The geology of the Grangeville 30 x 60 minute quadrangle is based on previous mapping by the Idaho Geological Survey from 2006 to 2010 and on other primary mapping sources (Figure 1), supplemented with geology from secondary sources (Figure 2) and additional field work in 2011. Whole-rock X-Ray fluorescence (XRF) analyses were conducted at the Washington State University GeoAnalytical Laboratory. Analytical results and locations for samples collected in the quadrangle are in the accompanying electronic files. Magnetic polarity of basalt units was measured by a fluxgate magnetometer in the field. U-Pb zircon ages reported in Table 1 (on map) were determined at Washington State University.

Basement rocks within the quadrangle include cratonic and accreted terrane assemblages juxtaposed along a north-south zone in the eastern part of the map. The cratonic assemblage consists of Proterozoic metamorphic and Cretaceous intrusive rocks. The accreted terrane assemblage includes Permian to Cretaceous volcanic, volcaniclastic, sedimentary, and intrusive rocks with varying degrees of metamorphism. Miocene Columbia River Basalt Group lava flows and minor interbedded sediments cover much of the quadrangle and lie unconformably on the prebasalt rocks. Remnants of Tertiary gravels locally cap the flows. All of these rocks are now deeply incised by the Snake and Salmon rivers and their tributaries.



IGS mapping

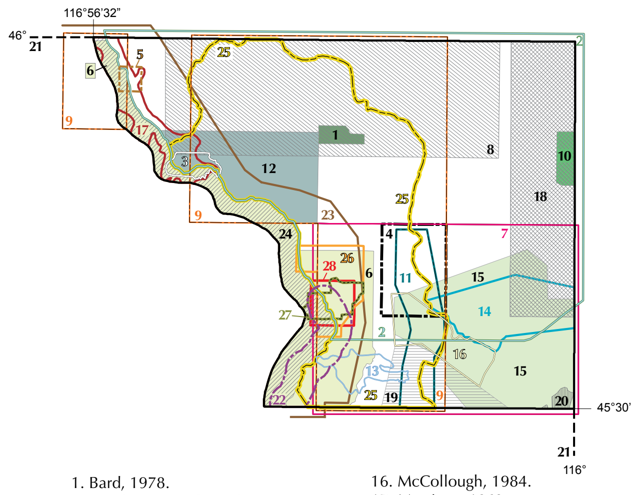
1. Garwood and others, 2007.
2. Kauffman and Othberg, 2007.
3. Kauffman and others, 2007.
4. Kauffman and others, 2008a.
5. Kauffman and others, 2008b.
6. Kauffman and others, 2011a.
7. Kauffman, and others, 2011b.
8. Lewis and others, 2011a.
9. Lewis and others, 2011b.
10. Schmidt and others, 2007.
11. Schmidt and others, 2009a.
12. Schmidt and others, 2009b.
13. IGS, unpublished mapping, 2011.

Other primary mapping sources

A. Borovicka, 1988.
B. Goldstrand, 1987.
C. Kurz, 2001 and Kurz, 2010.
D. Reidel, 1978.
E. Vallier, 1998.
F. White and Vallier, 1994.

Figure 1. *Primary sources of geologic mapping.*

Pleistocene glacial deposits are present in the higher-elevation areas in the southeast part of the quadrangle. Pleistocene to Holocene alluvial deposits form terraces and stream deposits along the major rivers and tributary streams. Landslide and mass-wasting deposits, also of Pleistocene to Holocene age, are common throughout the quadrangle, especially in areas of steep relief.



1. Bard, 1978.
2. Bond, 1962 and Bond, 1963.
3. Chen, 1985.
4. Coffin,1967.
5. Grant, 1980.
6. Gualtieri and Simmons, 1978 and Gualtieri and Simmons, 2007.
7. Hamilton, 1963, plate 2.
8. Holden, 1973.
9. Hooper, 1979, unpublished mapping.
10. Hoover, 1986.
11. Jones, 1991.
12. Kleck, 1976.
13. LeAnderson and Richey, 1985.
14. Lund, 1984.
15. Lund and others, 1993.
16. McCollough, 1984.
17. Morrison, 1963.
18. Myers, 1970s and 1980s, unpublished mapping.
19. Onasch, 1977.
20. Reed, 1939.
21. Swanson and others, 1979a and Swanson and others, 1981.
22. Vallier, 1968.
23. Vallier, 1974.
24. Walker, 1979.
25. Wagner, 1945.
26. White, 1972.
27. White, 1985.
28. White, 1994.

Figure 2. *Secondary sources of geologic mapping.*

DESCRIPTION OF MAP UNITS

Intrusive rocks are classified according to IUGS nomenclature using normalized values of modal quartz (Q), alkali feldspar (A), and plagioclase (P) on a ternary diagram (Streckeisen, 1976). In addition, we use a normative feldspar classification scheme (Barker, 1979) to distinguish tonalite and trondhjemite. Pre-Miocene volcanic rocks are classified by total alkalies versus silica chemical composition according to IUGS recommendations (Le Maitre, 1984). The Miocene Columbia River Basalt Group contains basalt, basaltic andesite, and andesite by that classification, but the term basalt is applied here, as it has been historically. Soil information is from Barker (1982). Soil parent materials include loess, but loess deposits are thin and are not included on this map.

ARTIFICIAL DEPOSITS

m—Man-made ground (Holocene)—Artificial fills composed of excavated, transported, and emplaced earth materials.

p—Placered ground (Holocene)—Areas in the Florence mining district that were placer mined for gold, primarily between 1861 and 1872 (Reed, 1939). Consists of Quaternary and Tertiary stream deposits and deeply weathered granitic bedrock.

SEDIMENTARY AND MASS MOVEMENT DEPOSITS

ALLUVIAL DEPOSITS

Stream Deposits

Qam—Alluvium of major rivers (Holocene)—Channel and flood-plain deposits that are part of the present major river systems, including the Snake, Salmon, and South Fork Clearwater rivers. Typically well-sorted and well-rounded pebble to boulder gravel in river bars and islands, and coarse sand in thin shoreline deposits.

Qamo—Older alluvium of major rivers (early Holocene)—Primarily stratified sand and well-rounded pebble to boulder gravel of bar remnants that are above modern levels of the Snake, Salmon, and South Fork Clearwater rivers. Height above the river is 6-12 m (20-40 ft). Thickness ranges from 1.5 to 6 m (5 to 20 ft). Remnants of gold placer mines common.

Qas—Channel and flood-plain deposits of tributaries and side streams (Holocene)—Primarily stratified and rounded pebble to boulder gravel in larger streams and gravel, sand, and silt in smaller streams.

Qaso—Older channel and flood-plain deposits of tributary streams (early Holocene to late Pleistocene)—Stratified and rounded pebble to boulder gravel in local terrace remnants.

Qaf—Alluvial-fan deposits (Holocene)—Crudely bedded, poorly sorted, brown muddy gravel derived from colluvium on steep canyon slopes. Gravel is composed of subangular and angular pebbles, cobbles, and boulders in a matrix of granules, sand, silt, and clay. May include beds of silt and sand reworked from loess and Mazama ash.

Qaff—Alluvial-fan deposits, fine-grained (Holocene)—Crudely bedded, poorly sorted, brown sand and pebble gravel deposited primarily by sheet wash and debris flows. Forms broad fans composed of thin deposits that cap bedrock and overlie Bonneville Flood gravels in the Pittsburg Landing area. Thickness highly variable, ranging 1.5 to 7.5 m (5 to 25 ft).

Qafo—Older alluvial-fan deposits (Pleistocene)—Coarse-grained, poorly sorted gravel deposits of incised remnants of alluvial fans and debris flow deposits in drainageways. Texture and lithology similar to *Qaf.* Thickness highly variable, ranging from 3 to 15 m (10 to 50 ft).

Qtg_2—Gravel of second terrace, averaging 18m (60 ft) above Salmon and Snake rivers (Pleistocene)—Forms terrace remnants locally capped by thin loess or *Qafo*. Thickness 6-12 m (20-40 ft) and may locally overlie a bedrock strath. Late Pleistocene age of about 40 ka (see Schmidt and others, 2009b). Remnants of gold placer mines common.

Qtg_3—Gravel of third terrace, averaging 43 m (140 ft) above Salmon and Snake rivers (Pleistocene)—Forms terrace remnants capped by thin loess or *Qafo* with well-developed soil. Thickness 12-24 m (40-80 ft).

Qtg_4—Gravel of fourth terrace, averaging 70 m (230 ft) above Salmon River (Pleistocene)—Forms terrace remnants consisting of prominent high benches. Capped by thin loess and *Qafo* with well-developed soils. Highly varied thickness ranging from 15 to 61 m (50 to 200 ft).

Qtg_5—Gravel of fifth terrace, averaging 116 m (380 ft) above Salmon River (Pleistocene)—Forms terrace remnants consisting of prominent high benches. Capped by loess and *Qafo* with well-developed soils. Overlies bedrock strath at Squaw Bar. Highly varied thickness ranging from 15 to 76 m (50 to 250 ft).

Qtg_6—Gravel of sixth terrace, above Salmon River (Pleistocene)—Coarse-grained, rounded, pebble-cobble gravel with clast lithologies similar to those in the present Salmon River. Identified at two locations where gravels are deposited on river-cut surfaces between 180 and 245 m (600 and 800 ft) above the present river. Deposits are 6-8 m (20-60 ft) thick. Terrace gravel is conformably overlain by bouldery colluvium (*Qc)*.

Older Alluvial Sediments

QTa—Alluvial gravel deposits of ancient streams draining Mt. Idaho uplift (Pleistocene or Pliocene)—Crudely bedded pebble to cobble gravel with a sandy, clayey matrix. Pebble clasts are subrounded to rounded. A few small remnants mapped in the Grangeville area. Moderately weathered. Thickness <1-3 m (2-10 ft).

Ts—Sediment, undivided (Pliocene? to Miocene)—Well-rounded pebble to cobble gravels locally mixed with finer grained sediments interpreted to overlie Columbia River Basalt flows. Clasts include quartz, quartzite, porphyritic igneous rocks, granitic rocks, and basalt. Some of the nonbasalt clasts may be reworked from older *Tli* sediments. Large areas of *Ts* in the Florence area were placered for gold (Reed, 1939).

Tli—Latah Formation sediments (Miocene)—Silt, sand, and gravel deposits within or beneath the Columbia River Basalt sequence and equivalent to the Latah Formation. Gravels are well rounded, with quartz, quartzite, porphyritic igneous rocks, and granitic rock clasts. Basalt clasts are absent or rare. Thickness difficult to determine, but some deposits may be 10-30 m (30-100 ft) thick.

Lake Missoula Floods Deposits

Qm—Lake Missoula Floods backwater deposits (Pleistocene)—Pale brown silty sand deposited when one or more Lake Missoula Floods backwatered the Snake and Salmon rivers. Forms terrace remnant at and below 365 m (1,200 ft) in elevation. Commonly capped by loess or alluvial-fan deposits. Thickness 3-6 m (10-20 ft).

Bonneville Flood Deposits

$Qabg_1$—Sand and gravel in giant flood bars, maximum flood stage (Pleistocene)—Stratified deposits of boulders, cobbles, and pebbles in a matrix of coarse sand deposited during highest-energy, maximum stage that flooded the Snake River valley. Thickness highly variable, ranging from 6 to 60 m (20 to 200 ft).

$Qabg_2$—Sand and gravel in large flood bars and terraces, lower flood stages (Pleistocene)—Stratified deposits of boulders, cobbles, and pebbles in a matrix of coarse sand deposited at lower elevations than $Qabg_1$

during later, lower stages of flood. Thickness variable, ranging from 6 to 25 m (20 to 80 ft).

Qabgl—Sand and gravel in eddy deposits and lower-energy bars (Pleistocene)—Stratified coarse sand and gravel. Deposited in eddies and side-channel positions associated with higher positions of maximum stage and also in eddies formed during later, lower stages of the flood. Thickness variable, ranging from 3 to 19 m (10 to 60 ft).

GLACIAL DEPOSITS

Qgt—Till deposits (late Pleistocene)—Unsorted, unstratified, loose to compact gray till. Composed of gravelly coarse sand with a silty fine-sand matrix. Forms moraine remnants in southeast part of map where Slate Creek valley glacier overtopped a divide and flowed northwest into Mill Creek. Thickness is highly variable and ranges from 3 to 30 m (10 to 100 ft).

Qgta—Alpine till deposits (Holocene and late Pleistocene)—Unsorted, unstratified, sandy cobble to boulder till deposited by late Pleistocene and neoglacial glaciers. Includes local protalus, periglacial deposits, outwash, landslide deposits, and small debris-flow fans. Thickness is highly variable and ranges from 3 to 30 m (10 to 100 ft).

Qgo—Outwash gravel (late Pleistocene)—Subrounded to rounded, moderately sorted sandy cobble to boulder gravel that forms floor of glaciated valleys. Unit is 3-12 m (10-40 ft) thick.

Qgto—Old till deposits (early Pleistocene)—Unsorted, unstratified, relatively compact yellowish brown till. Composed of gravelly coarse sand with a silty, clayey matrix. Forms eroded remnants of piedmont moraine deposited by early glaciations on a Tertiary erosion surface. Thickness is highly variable and ranges from 1 to 30 m (3 to 100 ft).

EOLIAN DEPOSITS

Qed—Dune sand (Holocene)—Stratified fine- to medium-grained sand of stabilized wind dunes. Shown as a pattern only.

MASS MOVEMENT DEPOSITS

Qt—Talus (Holocene and Pleistocene)—Angular pebble-, cobble-, and boulder-sized rock fragments fallen and rolled from bedrock outcrops and accumulated below. Commonly stabilized by vegetation.

Qlsa—Deposits of active landslides (Holocene)—Poorly sorted and poorly stratified angular cobble- and boulder-sized clasts mixed with silt and clay. Deposited by slumps and slides that have been active within the last several decades.

Qls—Landslide deposits (Holocene and Pleistocene)—Poorly sorted and poorly stratified angular cobble- and boulder-sized clasts mixed with silt and clay. Deposited by slumps, slides, and debris flows.

Qms—Mass-movement deposits (Pleistocene to Pliocene?)—Angular to subangular, poorly sorted sandy, silty, and clayey gravel derived from basalt above the North and South forks of Skookumchuck Creek and above McKinzie Creek. Shown as a pattern only. Thickness varies; water-well logs show thicknesses of 15-25 m (50-81 ft).

Qc—Colluvial deposits (Holocene to Pleistocene)—Poorly sorted and poorly stratified soil and angular to rounded rock fragments deposited by rainwash, sheetwash, and downslope creep. Thickness variable.

VOLCANIC ROCKS

COLUMBIA RIVER BASALT GROUP

Flows of the Columbia River Basalt Group cover much of the upland surface of the Grangeville quadrangle. The thickest exposed sequences occur in the Salmon River and Snake River canyons where thickness can exceed 1,000 m (3,000 ft). The stratigraphic nomenclature follows that of Swanson and others (1979b) and Camp (1981); stratigraphic position of some units revised according to Kauffman and Garwood (2009).

Tcrbd—Columbia River Basalt Group dikes of unknown affinity (Miocene)—Columbia River Basalt Group dikes of uncertain correlation that cut Grande Ronde Basalt units at several locations in the quadrangle.

Saddle Mountains Basalt

Tcg—Basalt of Craigmont flows and dikes (Miocene)—Dark gray, fine- to medium-grained plagioclase-phyric basalt with uncommon to common plagioclase phenocrysts 2-5 mm in length, rarely 7-10 mm; uncommon olivine about 1 mm in diameter. Normal magnetic polarity. Flow thickness 15-45 m (50-150 ft). Flows restricted to the northeast part of the map. Several dikes are exposed along Slate Creek Road cutting *Kto* and west of Little Slate Creek cutting *KPgs*.

Twe—Basalt of Weippe (Miocene)—Medium to dark gray, medium- to coarse-grained basalt with scattered to common plagioclase phenocrysts 2-5 mm long; abundant olivine crystals and clots generally visible to the naked eye. Reverse magnetic polarity. Occurs stratigraphically above *Tgv* at several locations north of Grangeville. Thickness is 15-45 m (50-150 ft).

Tgv—Basalt of Grangeville (Miocene)—Medium to dark gray, fine- to medium-grained basalt with common plagioclase phenocrysts 1-4 mm in length and scarce to common olivine grains generally <1 mm in diameter that tend to weather pinkish or orangish. Reverse magnetic polarity. Forms the surface unit west of Grangeville and forms remnant caps on the Joseph plateau between the Salmon and Snake rivers. A large, rotated block caps slumped sediments in the White Bird Battlefield National Historical Site north of White Bird, and scattered outcrops associated with sediments occur in the Deer Creek drainage south of White Bird. Thickness is 10-25 m (30-80 ft).

Twrb—Basalt of Windy Ridge (Miocene)—Medium to dark gray, fine-grained to grainy textured basalt flows that occur on Windy Ridge below the basalt of Grangeville. Common to abundant 1-3 mm plagioclase phenocrysts and common to very abundant olivine grains typically <1 mm. Named by P.R. Hooper for exposures on Windy Ridge (Wolf Creek 7.5-minute quadrangle). Composition resembles basalt of Lewiston Orchards, Weissenfels Ridge Member. Polarity not determined. Thickness is about 15 m (50 ft). One dike with Windy Ridge composition noted along lower reach of Getta Creek (Kleck, 1976).

Taw—Asotin Member and Wilbur Creek Member, undivided (Miocene)—Dark gray, fine-grained basalt with scattered plagioclase phenocrysts 1-4 mm in length and occasional to common olivine grains <1 mm in diameter. Normal magnetic polarity. Occurs only in the northeast corner of the map; thickness is about 60 m (200 ft).

Wanapum Basalt

Tpr—Priest Rapids Member (Miocene)—Medium to dark gray, fine- to medium-grained basalt flows and dikes with common plagioclase phenocrysts 2-8 mm in length and common olivine grains 1-2 mm in diameter. Reverse magnetic polarity. Poorly exposed in Threemile Creek in the northeast corner of the map and a small area east of Dairy Mountain and north of Slate Creek. Several dikes are exposed along Slate Creek Road cutting *Kto* and *KPgs*.

Grande Ronde Basalt

Tgr_2—Grande Ronde Basalt, R_2 magnetostratigraphic unit (Miocene)—Medium to dark gray, fine-grained basalt, commonly with a sugary texture. Uncommon to common 1-2 mm plagioclase phenocrysts. Reverse magnetic polarity, although field magnetometer readings commonly give weak normal or conflicting results. Maximum thickness is about 120 m (400 ft).

Tgn_1—Grande Ronde Basalt, N_1 magnetostratigraphic unit (Miocene)—Dark gray, fine-grained generally aphyric to plagioclase-microphyric basalt. Normal magnetic polarity, although flows near the R_1-N_1 boundary commonly have inconsistent and weak field magnetometer polarity readings. Maximum thickness is about 360 m (1,200 ft).

Tgr_1—Grande Ronde Basalt, R_1 magnetostratigraphic unit (Miocene)—Mostly dark gray, fine-grained aphyric to microphyric basalt. Plagioclase phenocrysts 2-4 mm in length in one or more flows near base of section. Reverse magnetic polarity, although flows near the R_1-N_1 boundary commonly have inconsistent and weak field magnetometer polarity readings. Maximum thickness is about 300 m (1,000 ft).

Tgbd—Grande Ronde breccia dikes (Miocene)—Several breccia dikes cut Grande Ronde Basalt in Grave Creek, Rock Creek, and Von Berge Gulch. Dikes consist of fused angular fragments and do not exhibit typical horizontal jointing common to most feeder dikes. Samples of the dikes have Grande Ronde chemistry and terminate within the Tgn_1 sequence.

Tgrd—Grande Ronde Basalt dikes, undivided (Miocene)—Grande Ronde Basalt dikes with undetermined magnetostratigraphic correlation.

Imnaha Basalt

Tim—Imnaha Basalt (Miocene)—Dark gray, medium- to coarse-grained, sparsely to abundantly plagioclase-phyric basalt; olivine common; plagioclase phenocrysts generally 0.5-2 cm long but some are as large as 3 cm. Normal magnetic polarity. Maximum thickness is about 320 m (1,200 ft). Commonly weathers to dark brown-gray granular detritus. Two Imnaha dikes were documented: one on the southwest flank of Haystack Mountain (Slate Creek 7.5-minute quadrangle) cutting lower Imnaha flows but terminating within the Imnaha section; and the other along Slate Creek Road cutting *Pf* unit.

OLDER VOLCANIC ROCKS

Tab—Trachyandesite dike (Eocene?)—Highly weathered trachyandesite dike about 0.5 m (1.5 ft) wide cuts *Kto* unit along the South Fork Clearwater River. Fresh samples are greenish gray; weathered samples are brown to rusty brown. Characterized by very high Sr (>1000 ppm), Ba (>1000 ppm), Nb (>70 ppm), and Zr (>400 ppm), and low V (<90 ppm) concentrations relative to Columbia River Basalt Group dikes (Schmidt and others, 2007). High Sr content suggests possible correlation with Eocene dikes.

INTRUSIVE ROCKS

Kgt—Granodiorite and tonalite (Cretaceous)—Biotite granodiorite, lesser biotite tonalite, and minor hornblende-biotite tonalite gneiss. Potassium feldspar typically inconspicuous and in concentrations low enough for some samples to be classified as tonalite. Only intrusive unit on map with initial $^{87}Sr/^{86}Sr$ (Sr_i) values consistently greater than 0.704 (Criss and Fleck, 1987; King and others, 2007). U-Pb zircon age determination of ~85 Ma from sample southwest of Rocky Bluff campground (Gaschnig and others, 2010).

Khto—Hornblende-biotite tonalite (Cretaceous)—Foliated hornblende-biotite tonalite and hornblende-biotite tonalite gneiss that occurs in a sheeted igneous complex intruding along the 0.704/0.706 Sr_i boundary. Includes minor amounts of biotite tonalite, plagioclase-hornblende gneiss, and biotite-feldspar-quartz gneiss. Characterized by considerable outcrop-scale variability and lit-par-lit injection. Contains epidote interpreted to be primary. No radiometric ages.

Kto—Tonalite and trondhjemite (Cretaceous)—Biotite tonalite cut by dikes and pods of fine-grained to pegmatitic, biotite-muscovite trondhjemite. Includes mylonitic trondhjemite dikes intrusive into the Lucile Slate (*JTRl*). Biotite plates in tonalite locally as large as 2 cm define a foliation that is locally strong. Local hornblende. Garnet common. Epidote interpreted to be primary on the basis of textural relations and indicative of high pressure (≥8 kb) crystallization (Zen and Hammerstrom, 1984). Trondhjemite contains as much as 10 percent muscovite and local garnet and epidote. U-Pb zircon ages range from ~111-116 Ma (Table 1, on map; McClelland and Oldow, 2007; Unruh and others, 2008).

KPd—Dikes and sills, undivided (Cretaceous? to Permian?)—Mafic and felsic dikes and sills. See *KPdf* and *KPdm* below.

KPdf—Felsic dikes, sills, and small stocks (Cretaceous? to Permian)—Light-colored rocks, probably tonalite or trondhjemite, consisting largely of quartz and plagioclase. Coarse grained to aphanitic, with porphyritic samples containing phenocrysts of quartz and plagioclase. Mostly metamorphosed to greenschist facies. Small stocks typically iron stained and locally intensely altered. Most probably Permian in age, but few radiometrically dated. Mylonitic trondhjemite dike collected 1.5 km (1 mi) south of Buckhorn Spring immediately south of map yielded Permian (~260 Ma) age (Table 1, on map). Foliated but less deformed dike 2.6 km (1.6 mi) northeast of Buckhorn Spring dated at ~145 Ma (Table 1, on map).

KPdm—Mafic dikes, sills, and small stocks (Cretaceous to Permian?)—Fine-grained dikes and sills, and less commonly medium-grained and porphyritic bodies with plagioclase and hornblende (or pyroxene) phenocrysts. Many have been metamorphosed to greenschist facies, with groundmass and phenocrysts largely recrystallized to chlorite and epidote. None radiometrically dated.

TRdg—Diorite and Gabbro (Triassic)—Primarily pyroxene diorite, but includes small bodies of pyroxene gabbro and quartz diorite. Mostly medium- to coarse-grained; less commonly very fine grained. Hornblende rimming clinopyroxene is typical; local orthopyroxene. Metamorphism generally not apparent, but mylonitic fabric locally present. Kurz and others (2012) report Triassic U-Pb zircon ages of 229 Ma for both the Klopton Creek pluton and gabbro at Suicide Point along the Snake River. Plutonic bodies probably represent crystallized magma chambers that fed Wild Sheep Creek Formation lava flows (Vallier, 1995).

Ꞧgq—Granodiorite and quartz diorite (Triassic)—Composite intrusive body of biotite-hornblende granodiorite and biotite-hornblende quartz diorite in southwest corner of map (Cold Spring pluton) and biotite-hornblende quartz diorite of the Snow Hole Rapids pluton at north edge of map. Metamorphism and fabric generally not apparent. Granodiorite phase dated at ~226 Ma and Snow Hole Rapids quartz diorite dated at ~233 Ma (Table 1, on map).

COUGAR CREEK COMPLEX AND RELATED ROCKS

ꞦPcc—Cougar Creek complex (Triassic and Permian)—Mixed unit, mostly intrusive, of trondhjemite, tonalite, diorite, and gabbro, in dikes, sills, and stocks. Also includes chlorite-epidote-actinolite schist with lenses of mylonitic tonalite grading to trondhjemite east of Grangeville and gneissic amphibolite southeast of Pittsburg Landing. Mylonitic and brittle shears overprint the original texture and mineralogy. Kurz and others (2012) and Walker (1986) report Permian and Triassic U-Pb zircon ages of 263-229 Ma for intrusive phases within the complex. Mylonitic tonalite grading to trondhjemite east of Grangeville dated at ~255 Ma (Table 1, on map).

ꞦPtt— Trondhjemite and tonalite (Triassic and Permian)—Tonalite or trondhjemite with varied composition and texture. Commonly with less than 3 percent biotite or hornblende. Quartz occurs as light gray to bluish phenocrysts as large as 1 cm and as a component of the groundmass. Generally medium grained and porphyritic; local coarse-grained and fine-grained varieties. High Na_2O content (Vallier, 1995) relative to younger intrusive rocks in region. Intimately intermixed with greenstone at many outcrops, and mutually crosscutting relationships are apparent. Typically greenschist metamorphosed and locally mylonitic. Kurz (2010) reports a Permian age (269 Ma) from metamorphosed tonalite (trondhjemite?) along the Salmon River about 2.6 km (1.6 mi) south of Slate Creek. Kurz and others (2012) report a Late Permian U-Pb zircon age of 254 Ma for the relatively unmetamorphosed hornblende-biotite tonalite that occurs on Triangle Mountain south of Pittsburg Landing. Triassic age determined for trondhjemite east of mouth of Imnaha River (~227 Ma, Table 1, on map) and for similar rocks northwest of Imnaha River mouth (225-228 Ma; Walker, 1986).

CHAIR POINT COMPLEX

KPdi—Diorite (Cretaceous to Permian)—Medium-grained hornblende diorite in a single body exposed along Brushy Ridge northeast of Lucile. Plagioclase and hornblende are the major constituents; minor quartz and potassium feldspar. Diorite enclosed in hornblende gneiss (*KPmsg*) and may be an unmetamorphosed core of an originally more extensive mafic plutonic body. Not radiometrically dated.

KPmsg—Mafic schist and gneiss (Cretaceous to Permian)—Garnet-plagioclase-hornblende-chlorite schist and gneiss intermixed with *Pf* and *ꞦPttc* units. Hornblende has grown along select layers in a radiating texture. Field relations indicate that at least some of mafic schist crosscuts the felsite and may represent metamorphosed mafic dikes or, alternatively, screens of mafic country rock (e.g. *KPgs*). Not radiometrically dated.

ꞦPttc—Trondhjemite and tonalite (Triassic and Permian)—Biotite trondhjemite and minor tonalite. Typically foliated and metamorphosed to amphibolite facies; characterized by recrystallized grains of quartz and feldspar. Recrystallized grains are small (1-3 mm across) and many are within mosaics of relict larger grains. Locally, thin large (1-3 cm across) irregular biotite masses give rock a spotted appearance on foliation surfaces. Minor muscovite and epidote; rare hornblende. High Na_2O content relative to younger intrusive rocks in region. Most is probably Permian, based on U-Pb dating of zircon from a sample in the upper part of Fiddle Creek drainage immediately south of the map (Karen Lund, oral commun., 2009), but includes Triassic intrusion(s) along Slate Creek that yielded ages of ~233 and ~243 Ma (Table 1, on map). Contact with Fiddle Creek Schist (*Pfc*) was originally either intrusive or a nonconformity; later metamorphism and deformation has obscured original relationships along this contact.

Pf—Felsite (Permian)—Massive to foliated felsite, typically iron stained. Characterized by fine grain size and lack of layering. Interpreted as shallow intrusive rocks of trondhjemitic composition metamorphosed to garnet grade. Largely plagioclase and quartz, with minor biotite, muscovite, and garnet. Permian age based on U-Pb dating of zircon from a sample in the upper part of Fiddle Creek drainage near the south edge of map (Karen Lund, oral commun., 2009). Relationship with Fiddle Creek Schist (*Pfc*) is undetermined, but was originally either intrusive or a nonconformity. Lens-shaped bodies of felsite in the schist may have been either sills or tectonic intercalations. Fabrics and textures that could be used to distinguish the two possibilities were not observed.

BLUE MOUNTAINS ACCRETED TERRANE ASSEMBLAGE

CRETACEOUS AND JURASSIC SEDIMENTARY AND VOLCANIC ROCKS

KJcms—Marine mudstone, sandstone, and conglomerate unit of the Coon Hollow Formation (Cretaceous? to Jurassic)—Mudstone and sandstone in the lower part of the section, and conglomerate and sandstone in the upper part. Sandstone typically poorly sorted, calcareous, and texturally and compositionally immature; feldspar grains and volcanic lithics are common clasts in the lower half of the section, whereas chert is more common in the upper half. Age based on presence of latest Jurassic detrital zircons in conformably underlying *KJcc* unit (LaMaskin and others, 2011). Top not exposed.

KJcc—Conglomerate, sandstone, and mudstone unit of the Coon Hollow Formation (Cretaceous? to Jurassic)—Conglomerate, sandstone, and mudstone. Unit fines upward. Conglomerate beds matrix and clast supported; clasts mostly volcanic and volcaniclastic, but include plutonic and clastic sedimentary rocks and chert. Tuffaceous material near the base yielded a 159.6 Ma age (Tumpane, 2010; Northrup and others, 2011). Higher in the section are ~150 Ma detrital zircon grains (latest Jurassic; LaMaskin and others, 2011). Unconformably overlies *JTRsv* unit at Pittsburg Landing.

KJf—Flysch facies of the Coon Hollow Formation (Cretaceous? to Jurassic)—Shale, sandstone, minor conglomerate, and mafic sills. Thickens and coarsens upward. Late Triassic radiolarian chert clasts abundant in upper part (Goldstrand, 1994). Lower part contains early late Jurassic ammonites (Imlay, 1981, 1986; Morrison, 1963). We interpret a Late Jurassic to Early Cretaceous age for youngest strata based on detrital zircon analysis (LaMaskin and others, 2011). Top not exposed. Lies conformably on *Jcs* unit.

Jcs—Sandstone and conglomerate facies of the Coon Hollow Formation (Jurassic)—Basal boulder and cobble conglomerate containing limestone and volcanic clasts that fines upward to sandstone and minor shale. Locally only sandstone at base. Deposited unconformably on surface with considerable relief developed in Wild Sheep Creek Formation (Goldstrand, 1994). Late Jurassic age based on detrital zircon analysis (LaMaskin and others, 2011) and position below ammonite-bearing strata (*KJf*).

Jct—Turbidite unit of the Coon Hollow Formation (Jurassic)—Sandstone and mudstone in structurally isolated outcrops west of Pittsburg Landing. Sandstone contains plagioclase, quartz, and volcanic rock fragments (White and Vallier, 1994). Unit contains a diverse ammonite fauna that provides a late Middle Jurassic age (Imlay, 1981, 1986; Morrison, 1963). Top and bottom structurally disrupted.

JTRsv—Sedimentary and volcanic rocks (Jurassic to Triassic)—Mixed unit of pink to red colored conglomerate, sandstone, tuff, limestone, mudstone, and volcanic flow rocks. Conglomerate typically matrix supported with clasts of mostly volcanic lithologies; sandstone and limestone clasts less common. Sandstones are immature, and contain grains of feldspar and quartz, as well as lithic clasts of mostly volcanic origin. Welded rhyolite tuff at Pittsburg Landing is 197 Ma (earliest Jurassic) based on U-Pb analysis of zircons (Northrup and others, 2011). Includes rocks mapped by White and Vallier (1994) as the "Red Tuff unit" of the Coon Hollow Formation. Lies unconformably on *TRdk*.

JTRvs—Volcanic and sedimentary rocks (Jurassic to Triassic)—Dominantly volcanic lithologies with some interlayered sedimentary units. Includes lithic tuff and lava flows of rhyolitic to basaltic andesite composition and less commonly volcanic breccia, conglomerate, limestone, graywacke, siltstone, and argillite. Conglomerates largely matrix supported, and contain a mix of mostly porphyritic rock of volcanic or shallow intrusive origin. Contact relationships with other stratigraphic units poorly exposed and uncertain. A U-Pb zircon date from lithic tuff near Hammer Creek yielded a latest Triassic (~202 Ma) age and a welded tuff southwest of St. Gertrude Monastery 2.6 km (1.6 mi) north of the map is ~199 Ma (Table 1, on map).We suspect entire unit is Late Triassic or younger because of the relatively low degree of metamorphism and because lithologies do not correlate well with older units. Top eroded. Bottom poorly established, but unit suspected to lie unconformably on *₮ws*.

SEVEN DEVILS GROUP

₮dk—Kurry unit of Doyle Creek Formation (Triassic)—Thinly bedded tuffaceous and calcareous sandstone and mudstone, and argillaceous limestone. Fossils (*Halobia* and ammonite molds) indicate Late Triassic age (N.J. Silberling, oral commun., 1985, in White and Vallier, 1994; LaMaskin and others, 2008). Unconformably overlain by *J₮sv* unit and the Coon Hollow Formation (*KJcc*). Lies conformably on, and interfingers with, *₮ws*.

₮dc—Doyle Creek Formation (Triassic)—Red and purple conglomerate, sandstone, shale, and tuff mapped by Goldstrand (1987, 1994) on west side of Snake River. Clasts largely volcanic but include some quartz diorite. Vitric tuff near base and crystal tuff higher in section. Overlies and interfingers with Wild Sheep Creek Formation but age otherwise poorly constrained. Alternate unit assignment is *J₮sv*, based on the presence of abundant quartz in the sandstone and quartz phenocrysts in the tuff.

₮ws—Wild Sheep Creek Formation, undivided (Triassic)—Mostly massive lavas and volcaniclastic rocks. Pillow lava and pillow breccia common north of Pittsburg Landing. Flows typically contain abundant plagioclase phenocrysts ranging from 0.5 to 1.0 cm in length. Basalt and basaltic andesite composition with rare andesite and dacite (White and Vallier, 1994). Volcaniclastic intervals are massive, mostly matrix supported, and characterized by basaltic clasts in a strongly recrystallized greenstone matrix. Uncommon sandstone, mudstone, and rare limestone and calcareous mudstone. Typically extensively metamorphosed to greenschist grade, with abundant albite, chlorite, and epidote growth. Fossils (*Daonella* and *Halobia*) indicate late Middle Triassic and Late Triassic age (Grant, 1980; White and Vallier, 1994).

₮wsv—Wild Sheep Creek Formation volcanic rocks (Triassic)—Massive flows, breccia, tuff, and some pillow lava. Combined lower and upper volcanic facies of Goldstrand (1994). Lower facies largely microcrystalline and porphyritic andesite and dacite; plagioclase is most common phenocryst and clinopyroxene the most common mafic mineral. Minor devitrified welded vitric tuff with minor quartz, andesine, and amphibole. Upper facies largely porphyritic basalt and basaltic andesite with plagioclase phenocrysts.

₮wss—Wild Sheep Creek Formation sedimentary rocks (Triassic)—Volcaniclastic sandstone, siliceous argillite, breccia, conglomerate, and minor fossiliferous limestone. Combined argillite-sandstone facies and sandstone-breccia facies of Goldstrand (1994).

₮wsl—Wild Sheep Creek Formation limestone (Triassic)—Limestone facies of Goldstrand (1994) consisting of micrite, pelmicrite, volcaniclastic limestone, and biomicrite. Volcanic material with the limestone consists largely of scoria, devitrified ash, lithics, and plagioclase.

Phc—Hunsaker Creek Formation (Permian)—Volcaniclastic, volcanic, and sedimentary rocks intruded by numerous dikes, sills, and small stocks. Conglomerate, mafic sandstone, and subordinate red argillite common; sandstones are generally quartz bearing. Rare chert(?) or reworked siliceous tuff present locally. Wide compositional range of igneous rocks from basalt to rhyolite (quartz keratophyre), including intermediate compositions. Greenschist-metamorphosed and strongly foliated to massive, but fabric is overall less developed than in the greenstone in the western Salmon River belt (*₮vg*). More highly deformed greenstone and minor muscovite-quartz schist near Snake River north of Dug Bar (Chen, 1985) tentatively included in this unit. Poor age control in this map; Permian age based on fossil localities to the south (Vallier, 1977) and ~260 Ma U-Pb age of dike cutting unit at south map border (sample M, Table 1, on map).

WESTERN SALMON RIVER BELT

J₮l—Lucile Slate (Jurassic? to Triassic?)—Dark gray, graphitic calcareous phyllite, sandstone, and thinly layered marble. Zoisite present in northernmost exposures. Sandstones locally contain granules. Commonly mylonitic. Metamorphosed to lower greenschist facies. Named for rocks near Lucile (Wagner, 1945; Hamilton, 1963) but no measured section established. Regional correlation uncertain, but most likely equivalent to the Triassic to Jurassic Hurwal Formation (Follo, 1994). May be equivalent to less deformed calcareous graphitic metasiltstone of the Squaw Creek Schist exposed at Riggins (Hamilton, 1963) and north of John Day Creek (this map).

TRmr—Marble of Race Creek (Triassic?)—Informal name applied by Lewis and others (2011a) to gray marble exposed southwest of Lucile. Best exposed along West Fork of Race Creek 2.3 km (1.4 mi) south of map. Probably correlative with the Triassic Martin Bridge Formation as suggested by Onasch (1977, 1987). May be the northern extension of marble mapped southwest of Riggins, 21 km (13 mi) southwest of this map, that contains Triassic conodonts (Sarewitz, 1983).

TRvg—Volcaniclastic greenstone (Triassic?)—Greenstone and minor argillite and phyllite. Greenstone varies from plagioclase-rich sandstone to conglomeratic rocks with stretched clasts of mostly felsite. Quartz is notably absent. Clasts locally may include pumice or sedimentary rip-ups. Argillite is red and phyllite is medium gray and similar to *JTRl*. Foliation and lineation well developed and much of the unit is mylonitic. Entirely volcaniclastic rocks, and thus different from *Phc*, which includes lava flows with vesicular zones. Association with marble (*TRmg*) probably indicates Triassic rather than Permian age. Unit may be metamorphosed Doyle Creek Formation (Vallier, 1977) or a clastic-rich facies of the Wild Sheep Creek Formation.

TRmg—Marble within volcaniclastic greenstone (Triassic?)—Gray marble exposed northeast and southwest of Lucile. Previously mapped by Onasch (1977, 1987) as a marble member within the Seven Devils Group. Appears to be more than one interval; may be equivalent to marble mapped within the Wild Sheep Creek Formation elsewhere. Age uncertain, as no fossils have been reported from this unit.

EASTERN SALMON RIVER BELT

JTRsc—Squaw Creek Schist (Jurassic to Triassic?)—Medium to dark gray calcareous biotite phyllite and schist. Layered to massive, fine-grained, carbonate-bearing clastic rocks with variably developed schistose fabric. Locally, the layering may represent original bedding. Calcite, plagioclase, quartz, biotite, muscovite, and opaque minerals (primarily graphite?) are the main constituents. Previously mapped as Martin Bridge Limestone and Lucile Slate by Hamilton (1963), as Lucile Formation by Lund (1984), and as redefined Martin Bridge Formation by Lund and others (1993). Rocks are most likely Squaw Creek Schist of the Riggins Group (Hamilton, 1963; 1969), which shares similar carbonaceous and carbonate-rich siltstone and sandstone protolith lithologies. Interpretation here is that the Squaw Creek schist of the Riggins Group and the Lucile Slate are correlative units, with the Lucile Slate being more deformed. Age of the Squaw Creek Schist is likely Jurassic (Lund and others, 2007), but it may include minor Triassic strata.

JTRscm—Marble associated with Squaw Creek Schist (Jurassic to Triassic?)—Coarsely crystalline light gray marble. Previously mapped by Hamilton (1963) as Martin Bridge Limestone and Lucile Slate and by Lund and others (1993) as Triassic Martin Bridge Formation. Interpreted here as a series of marbles younger than the Martin Bridge Limestone.

TRms—Marble of Sheep Gulch (Triassic?)—Informal name applied by Lewis and others (2011a) and Kauffman and others (2011b) to coarsely crystalline light gray marble exposed northeast of Lucile and along Slate Creek. Extent reduced here to only those exposures northeast of Lucile. Previously mapped by Lund and others (1993) as Triassic Martin Bridge Formation. Tentatively correlated with limestone of the Martin Bridge Formation and the marble of Race Creek.

TRlc—Lightning Creek Creek Schist (Triassic?)—Mafic schist and minor metaconglomerate in association with thin marble lenses (*TRlcm*). Unit interpreted to be largely clastic sedimentary in origin. Mafic schist contains plagioclase, chlorite, muscovite, biotite, quartz, epidote, Fe-carbonate, and opaque minerals. Mylonitic muscovite-quartz-plagioclase schist and interlayered(?) conglomerate 4 km (2.5 mi) southeast of town of Slate Creek tentatively assigned to this unit; alternative unit assignment is *Pfc*. Onasch (1977, 1987) assigned southern exposures of these rocks to the Fiddle Creek Schist of Hamilton (1963, 1969). Fiddle Creek (*Pfc*) also likely present, but rocks with associated marble are here assigned to Lightning Creek Schist, the type area of which is 4 km (2.5 mi) south of this map (Hamilton, 1963). Like previous workers, we tentatively correlate these rocks with the Seven Devils Group of Vallier (1977), more specifically the Triassic Wild Sheep Creek or Doyle Creek formations, based on the presence of interlayered marble.

Ŧlcm—Marble associated with Lightning Creek Schist (Triassic?)—Gray marble in multiple lenses within the Lightning Creek Schist. Interpreted here to be higher grade equivalents of our *Ŧmg* unit.

Pfc—Fiddle Creek Schist (Permian?)—Mafic and felsic schist and minor metaconglomerate. Garnet typically abundant, constituting as much as 20 percent of the rock locally. Radiating (late) hornblende present in John Day Mountain area. Unit interpreted to be mostly clastic sedimentary in origin, but may include some volcanic and (or) intrusive layers. In the southwestern part of map, Onasch (1977, 1987) mapped these rocks as the Fiddle Creek Schist, the type area of which is immediately south of this map (Hamilton, 1963, 1969). Like previous workers, we tentatively correlate these rocks with the Seven Devils Group of Vallier (1977), more specifically the Hunsaker Creek Formation, based on the abundance of volcaniclastic rock and the general lack of interlayered marble. Two marble lenses in upper John Day Creek (*Ŧms*) may be tectonic intercalations associated with the Slate Creek thrust.

KPum—Ultramafic rocks (Cretaceous to Permian)—Metamorphosed pyroxenite or peridotite with clusters of radiating amphiboles (anthophyllite), talc, and chlorite. Relict orthopyroxene and olivine(?) present locally.

KPgs—Gneiss and schist (Cretaceous to Permian)—Fine- to medium-grained plagioclase-hornblende gneiss to biotite-muscovite-plagioclase-quartz schist. Garnet common. Includes calc-silicate rocks containings zoisite, epidote, chlorite, plagioclase, quartz, pyroxene, and sphene. Includes small exposures of mylonitic amphibolite within the *Kto* pluton north of Slate Creek and two thin marble lenses along and east of the South Fork Clearwater River. Most or all of unit is probably metasedimentary. Age is poorly constrained, but detrital zircon ages from a sample along upper Slate Creek and one along Gold Springs Creek north of Asbestos Peak indicate that at least some of the original strata were Early Jurassic to Early Cretaceous deposits (Schmidt and others, 2013). We suggest that they may be metamorphosed equivalents of basinal units within the Blue Mountains accreted terrane assemblage. Lower grade rocks of similar bulk composition include the Squaw Creek Schist of likely Jurassic age (Lund and others, 2007). Exposures along southern boundary of map next to contact with Zqcs are rich in calc-silicate rocks and are only tentatively assigned to this unit. An alternative interpretation is that they are North American basement rocks (*Zqcs*), possibly Anchor Meadow Formation of Lund (2004).

NORTH AMERICAN BASEMENT ROCKS

Zsg—Schist and gneiss (Neoproterozoic?)—Sillimanite-biotite schist and medium-grained biotite-quartz-plagioclase gneiss. Similar sillimanite-bearing schist present in cratonal assemblages along the Salmon River south of map (Blake and others, 2009).

Zqcs—Quartzite and calc-silicate rocks (Neoproterozoic?)—Coarsely crystalline quartzite and calc-silicate rocks with coarsely crystalline garnet, hornblende, and diopside. More coarsely crystalline than calc-silicate rocks in *KPgs* but otherwise similar. Quartzite contains little or no feldspar and is difficult to distinguish from vein quartz. Feldspar-poor quartzite is typical of Neoproterozoic rocks elsewhere in region (Lund, 2004; Lewis and others, 2010). Unit lacks the abundant plagioclase-hornblende gneiss present in *KPgs*.

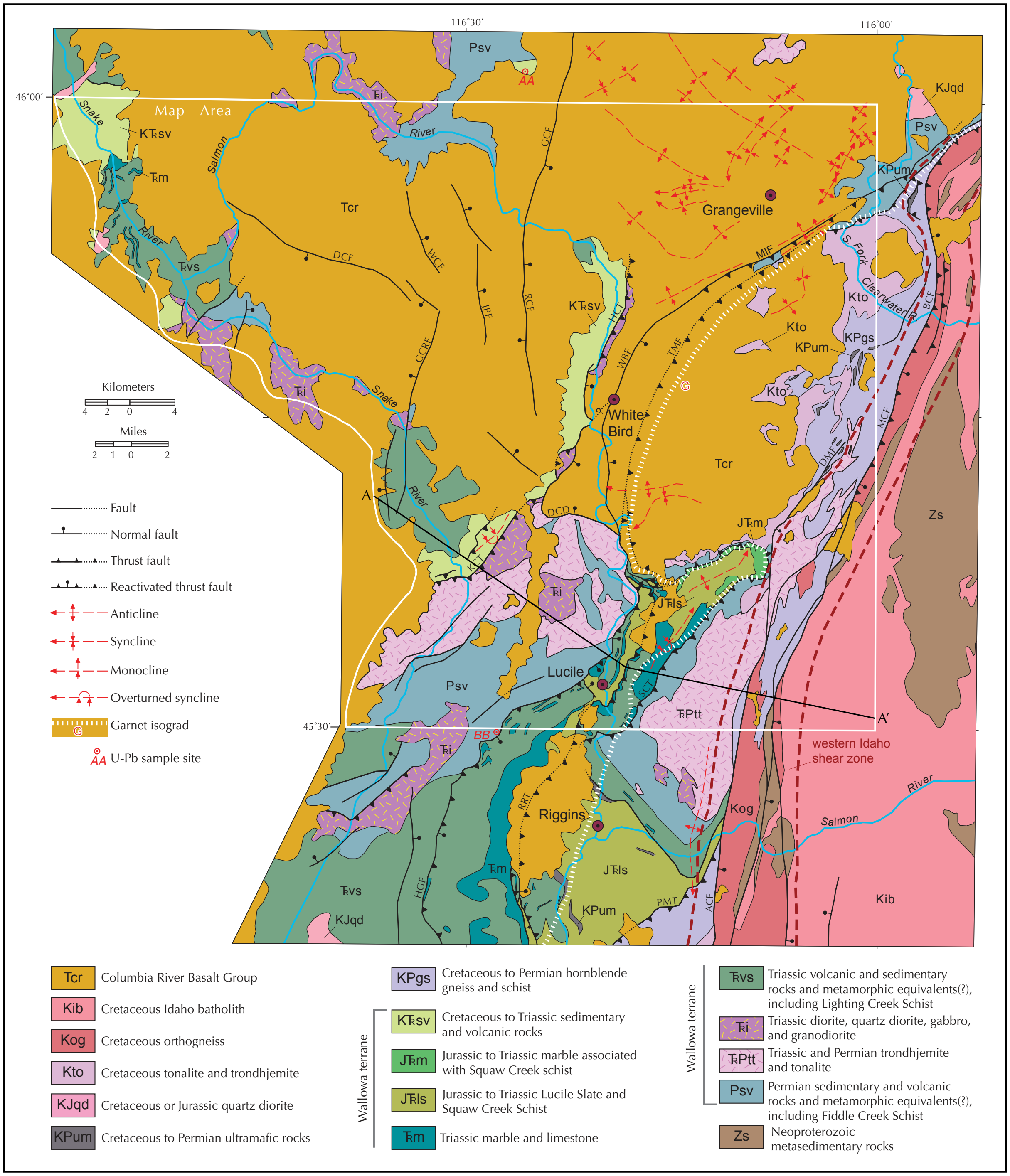


Figure 3. *Simplified geologic map of the Grangeville 30 x 60 minute quadrangle and surrounding area. Geology in areas outside the quadrangle adapted from Hamilton (1969), Myers (1982), Onasch (1987), Blake and others (2009), and Kauffman and others (2009). Abbreviations: ACF: Allison Creek fault; BCF: Browns Creek fault; DCD: Deer Creek detachment; DCF: Divide Creek fault; DMF: Dairy Mountain fault; GCF: Grave Creek fault; GCRF: Getta Creek fault; HGF: Heavens Gate fault; JPF: Joseph Plains fault; KCT: Klopton Creek thrust; MCF: Mill Creek fault; MIF: Mount Idaho fault; PMT: Pollock Mountain thrust; RCF: Rice Creek fault; RRT: Rapid River thrust; SCT: Slate Creek thrust; TMF: Threemile fault; WBF: White Bird fault; WCF: Wolf Creek fault.*

STRUCTURE

The Grangeville quadrangle is mostly underlain by island-arc rocks of the Paleozoic-Mesozoic Wallowa terrane, which forms part of the Blue Mountains accreted terrane assemblage (Figures 3 and 4). The Wallowa terrane was juxtaposed against North American Precambrian rock assemblages in Mesozoic time on structures that are present along the eastern side of this map. To the west of this lithospheric boundary, contractional structures include folds, thrust faults, and mylonitic shear zones that deform Wallowa terrane rocks and form a west-northwest vergent fold and thrust belt. Some of these structures show later brittle-ductile extensional deformation. Still later brittle extensional faulting reactivated older contractional shear zones along north-northeast-striking faults and also deformed Miocene cover rocks of the Columbia River Basalt Group. Latest deformation occurred on a series of folds that cross the regional structural grain.

EARLY STRUCTURES

Four major contractional fault zones and their intervening thrust plates comprise the northwest-vergent fold and thrust belt in the south-central part of the map (Figures 3 and 4 and section B-B′ on map). From northwest to southeast, these are the Klopton Creek and Hammer Creek, Heavens Gate, Rapid River, and Slate Creek, faults. The Klopton Creek and Hammer Creek thrusts affect rocks of the Wallowa terrane proper, which have been only mildly metamorphosed and within which bedding is still preserved. The Heavens Gate fault places more highly deformed rocks of the western Salmon River belt (terminology of Gray and Oldow, 2005) that we interpret of likely Wallowa terrane origin over less deformed Wallowa terrane rocks (Figure 4). East of the Heavens Gate fault, bedding is transposed and largely unrecognizable. The Rapid River thrust carries overall less deformed rocks of the eastern Salmon River belt over their more deformed counterparts in the Heavens Gate plate to the west. The Slate Creek thrust, within the eastern Salmon River belt, at least locally separates garnet-bearing rocks in the hanging wall from lower grade units in the footwall. The Threemile fault (Figure 3 and section A-A′ on map) is probably the northern continuation of the Heavens Gate and Rapid River faults. Each of these faults is described in more detail below starting with the least complex structures in the west, and working eastward concomitantly with increasing complexity towards the suture zone.

KLOPTON CREEK THRUST

The Klopton Creek thrust (White and Vallier, 1994) juxtaposes partially migmatized Permian and Triassic gneissic plutonic rocks of the Cougar Creek complex in the hanging wall with lower greenschist metamorphosed rocks of the Seven Devils Group and folded, little-metamorphosed overlying Triassic to Cretaceous(?) strata in the footwall. The structure does not deform the overlying Miocene Columbia River basalt sequence. Mylonite foliation strikes north to northeast, generally parallel to the strike of the fault, and dips moderately east to southeast; mylonite lineation pitches steeply in the foliation. Kinematic indicators, such as s-c fabrics and extensional crenulations, consistently indicate top-to-the-northwest shear sense in a direction parallel to mylonitic lineation and consistent with a thrusting mechanism for development of the fault. However, fracture pattern analysis yielded a mean fault-slip vector plunging 39°, S. 86° E. (Kurz and Northrup, 2008). This implies a significant component of dextral strike-slip displacement for the thrust fault at least during late stage brittle-ductile deformation and helps to explain the apparent difference in Jurassic-Cretaceous units across the fault (Figure 4). Ductile shear zones in the Cougar Creek complex that predate thrusting record both oblique sinestral and dextral sense of shear and contain a mylonitic foliation that strikes more northeasterly than the Klopton Creek thrust (Kurz and Northrup, 2008). The Klopton Creek thrust can be traced into the Salmon River valley to the northeast where it becomes the Hammer Creek thrust, which juxtaposes Triassic(?) diorite basement rocks with folded Triassic-Cretaceous volcanic and sedimentary cover sequences. The Hammer Creek thrust is covered by Columbia River basalt at its northern end and we are unsure of the trace beyond this point. Myers (1982) originally proposed that the Mount Idaho fault to the northeast linked with the Klopton Creek thrust to the southwest. We originally thought that the Hammer Creek fault was the connecting fault between the two, swinging east from its northernmost exposure in the Salmon River canyon to link with the Mount Idaho fault south of Grangeville (Schmidt and others, 2007). Our new interpretation is that the Hammer Creek fault may continue northward

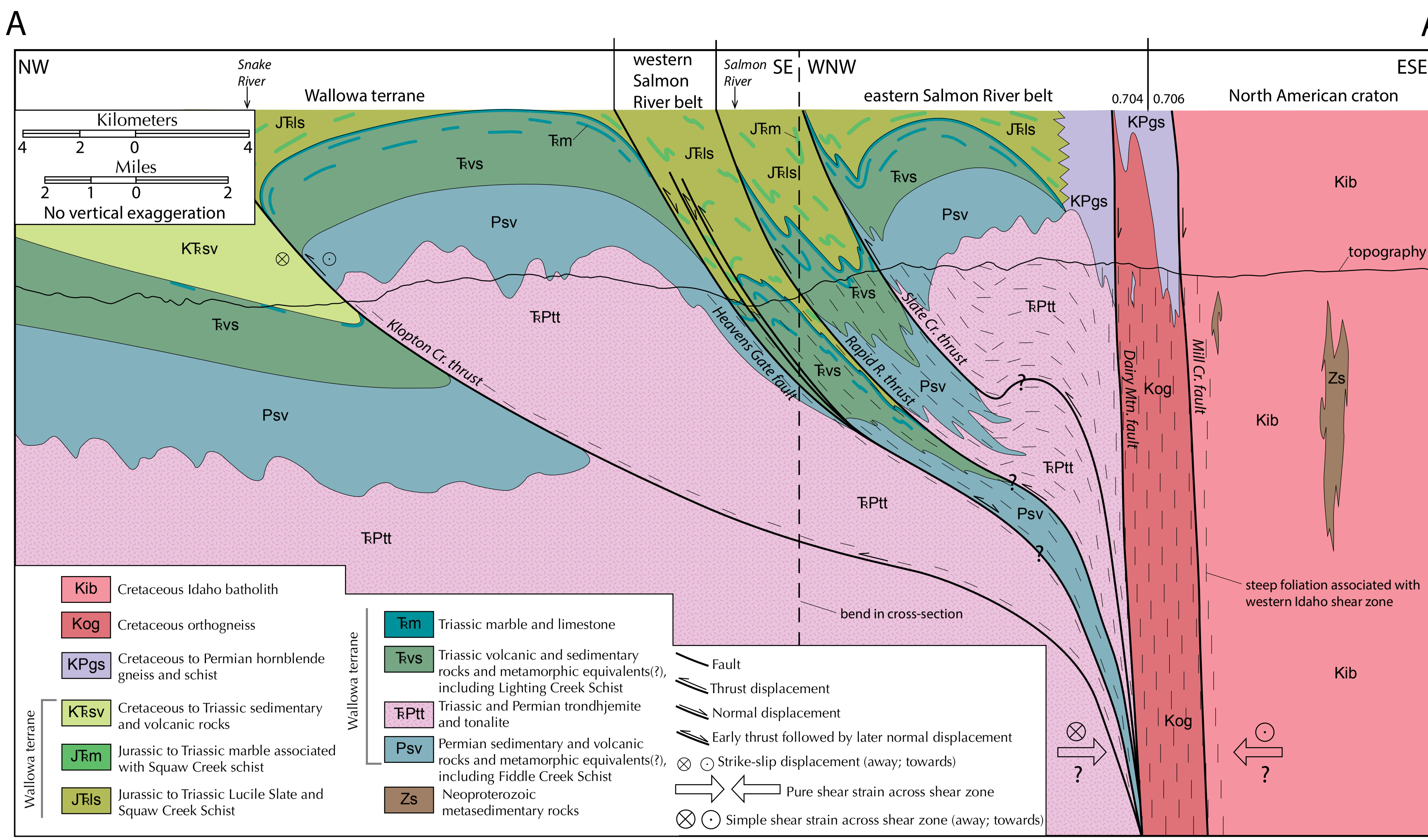


Figure 4. *Schematic cross section across the southern part of the Grangeville 30′ x 60′ quadrangle showing pre-Tertiary rocks only. Line of section is shown on Figure 3.*

from the Salmon River canyon, separating isolated exposures of Triassic-Jurassic volcanic rocks in the west from Permian(?) sedimentary and intrusive rocks in the east under the Camas Prairie north of Grangeville. In this scenario, the northward extension of the Hammer Creek fault represents older, largely thrust deformation along the Klopton Creek-Hammer Creek fault system and the Klopton Creek, southern Hammer Creek, and Mount Idaho segments have experienced subsequent reactivation to accommodate dextral transpression.

HEAVENS GATE FAULT

The Heavens Gate fault was mapped west of Heavens Gate Lookout 15 km (9 mi) south of the map by Gray and Oldow (2005). Gualtieri and Simmons (1978, 2007) mapped the same structure north of Heavens Gate Lookout, just west of the divide between the Snake and Salmon rivers. We believe the fault leaves the divide within the Grangeville quadrangle, crosses the Salmon River 3.2 km (2 mi) north of Lucile, and merges with the Rapid River thrust near Slate Creek. Near Heavens Gate Lookout, the fault separates relatively undeformed volcanic flows and volcaniclastic rocks of the Seven Devils Group in the footwall in the west from strongly deformed volcaniclastic and carbonate rocks of the western Salmon River belt in the hanging wall in the east. Southwest of Lucile, the brittle-ductile fault appears to place less deformed greenstone (*Phc*) footwall rocks against highly foliated and folded greenstone (*Ƭvg*) and marble (*Ƭmg*) hanging wall rocks. Sheared and brecciated rock was noted along the fault south of Cow Creek and on the ridge northwest of Lucile. Along the fault at Slate Creek, older, ductile s-c fabrics showing top-to-the-west thrust kinematics are overprinted by younger, more steeply dipping brittle-ductile shears that indicate top-to-the-east normal kinematics. Our tentative interpretation based on map pattern and these kinematic fabrics is that the Heavens Gate fault is an early thrust fault that has had even more significant later normal motion that has resulted in bringing Permian intrusive and volcaniclastic rocks up in the footwall on the west side (Figure 4).

RAPID RIVER THRUST

The Rapid River thrust was mapped southwest of Riggins by Hamilton (1963, 1969) and at the south edge of the map was shown to place Lucile Slate in the west against Riggins Group (our eastern Salmon River belt) rocks in the east. We have mapped the eastern contact of the Lucile Slate to the north and interpret it as a ductile fault. Much of the Lucile Slate is highly deformed phyllite and most kinematic indicators show top-to-the-west transport. Whether this deformation is exclusively related to the Rapid River thrust is unknown, but it appears that the incompetent nature of the Lucile Slate has localized deformation within this unit. The fault is broadly folded south of Lucile. These folds do not fold the Heavens Gate fault, and we thus consider the Rapid River thrust to be older than the Heavens Gate fault. The Rapid River thrust was thought to truncate metamorphic isograds to the south in the Riggins area (Hamilton, 1963), but not in the Lucile area (Onasch, 1987). If there is a metamorphic grade change across the fault in the Lucile quadrangle, it is apparently not significant.

SLATE CREEK THRUST

The Slate Creek thrust is an enigmatic structure that juxtaposes units within the eastern Salmon River belt along a variably mylonitized shear zone. In the region to the northeast of Lucile, the ductile shear zone thrusts an older(?) hanging-wall assemblage consisting of amphibolite-grade metamorphosed Fiddle Creek schist and the Chair Point basement intrusive complex over a younger(?) footwall assemblage of greenschist grade Lightening Creek and Squaw Creek schists and associated marbles. East of Lucile, footwall rocks are tightly to isoclinally folded with overturning to the northwest, and minor garnet is present in the footwall. South of Lucile, the metamorphic grade change is less marked and greenschist grade metamorphism is apparent in the hanging wall. Tonalite intrusive units associated with the Chair Point complex(?) occur in the hanging wall of the fault in this area. The Slate Creek thrust is covered by Miocene volcanic rocks northwest of Riggins. The thrust either merges with the Rapid River thrust beneath this cover or may continue southeastward along the Salmon River east of Riggins. The Slate Creek thrust is tightly folded by the Slate Creek antiform and is gently folded by the folds that deform the Rapid River thrust south of Lucile. We thus consider the Slate Creek thrust to predate deformation on the Rapid River thrust. Lund and others (1993) mapped our "Slate Creek thrust" as the Rapid River thrust, in part because of the change in metamorphic grade across it. In contrast, we believe the Rapid River thrust is the next major fault to the west and have mapped it there on the basis of deformation within and east of the Lucile Slate.

The western part of the Slate Creek thrust plate contains metamorphosed volcaniclastic rocks of the Fiddle Creek Schist (*Pfc*) whereas the eastern part contains hornblende gneiss (*KPgs*) whose protolith was more likely similar to the Squaw Creek Schist (*JŦsc*, fine-grained calcareous sedimentary rocks). One interpretation is that the *KPgs* unit represents a higher-grade equivalent of the Squaw Creek Schist and possibly correlative Hurwal Formation (zig-zag contact in Figure 4 between *KPgs* and *JŦls*). As reported by Schmidt and others (2013), U/Pb LA-ICPMS detrital zircon analyses of two samples of amphibolite-grade hornblende gneiss (one along upper Slate Creek and one along Gold Springs Creek north of Asbestos Peak) yielded well-defined age modes of 202 Ma (+32, -50 Ma) and 198 Ma (+32, -19 Ma). They interpreted these data as indicating Early Jurassic sedimentary protoliths of the *KPgs* unit. Likely correlative rocks in accreted terranes to the west include the Jurassic Weatherby Formation of the Izee terrane (LaMaskin and others, 2011) or the Triassic–Jurassic Hurwal Formation of the Wallowa terrane.

THREEMILE FAULT

The Heavens Gate fault and Rapid River thrust converge south of Slate Creek in a highly attenuated section of the fold and thrust belt to become the Threemile fault. The Threemile fault continues northwards beneath Miocene cover rocks where we infer that the Slate Creek thrust also joins it. All three of these structures and their continuation as the Threemile fault appear to wrap around the western side of a large (ca. 150 mi2 or 400 km2) tonalite pluton that forms the southwestward, mostly covered, extension of the 111.0 + 1.6 Ma Blacktail pluton along the South Fork of the Clearwater River (U-Pb zircon age; McClelland and Oldow, 2007). A U-Pb zircon age of 113.1 + 0.6 Ma (Unruh and others, 2008) from unfoliated tonalite along Slate Creek corroborates our assumption that a large pluton occurs in this region. This pluton may also be responsible for the Slate Creek anticline that tightly folds the Slate Creek thrust.

An important window occurs in the Miocene basalt near the headwaters of Threemile Creek, south of Grangeville. Amphibolite and hornblende gneiss are exposed in the southeast part of this window that we infer are in the hanging wall of the Threemile fault. Intensely mylonitized chlorite-epidote-actinolite schist and gneiss and quartz-bearing intrusive rocks occur in the northwestern part of the window that we infer are in the footwall of the fault. These same relationships are exposed along strike east of Grangeville along the South Fork of the Clearwater River where we believe the Threemile fault occurs just north of the Blacktail pluton. The pluton displays weak solid-state to magmatic fabrics that parallel the Threemile fault.

The timing relationship between faulting within the fold and thrust belt and intrusion of the ~113-111 Ma Blacktail pluton is not straightforward. Apparent wrapping of faults around the pluton implies that the pluton was emplaced early in the structural development of the fold and thrust belt. Moreover, the presence of magmatic epidote in the Blacktail pluton implies that it was emplaced at mid-crustal depths equivalent to ca. 8 kbar pressures, similar to relationships established for the Round Valley pluton that occupies a similar structural setting to the south (Zen and Hammerstrom, 1984). Metamorphic grade decreases sharply across the fold and thrust belt to the west, and later displacement along thrust faults would help to exhume the deeply seated pluton. However, we note even older fabrics and structures that are cross-cut by the pluton at numerous localities, implying that this zone was deforming for some time prior to intrusion of the Blacktail pluton.

MOUNT IDAHO FAULT

The Mount Idaho fault is exposed south of Grangeville and along the South Fork of the Clearwater River east of Grangeville. This fault has had a protracted history that includes early ductile deformation of basement rocks followed by brittle deformation that has offset Miocene basalts. The early deformation along this zone is apparent in footwall rocks north of the Threemile fault, which display mostly steeply dipping mylonite foliation and shallowly northeast- to east-plunging stretching lineation across a zone as much as 2 km (1.2 mi) wide. Abundant s-c and extension crenulation fabrics indicate consistent dextral, southeast-side-up shear sense across this zone. As discussed above, we think these fabrics formed as part of the Klopton Creek-Hammer Creek-Mt Idaho fault originally proposed by Myers (1982). This fault accommodates dextral transpression that appears to offset the fold and thrust belt, as well as the Salmon River suture and western Idaho shear zone to the east, by several tens of kilometers in a dextral sense. It appears to account for the abrupt change from mostly north-striking structures to the south of the Blacktail pluton to northeast-striking structures north of the pluton. Later reactivation of this ductile structure that also offsets Miocene basalts is discussed below in the "Later Faults" section.

SALMON RIVER SUTURE AND WESTERN IDAHO SHEAR ZONE

The boundary between continental North American rocks and arc-affinity rocks of the Wallowa terrane was originally defined by Lund and Snee (1988) as the Salmon River suture zone. The suture is obscured, however, by later events that include intrusion by numerous Cretaceous plutons, overprinting by ductile fabrics associated with development of the western Idaho shear zone, and brittle extensional faults. Unit *Kog* includes plutons that intrude the suture. These plutons are elongated parallel to the suture and in many cases record the transition in initial $^{87}Sr/^{86}Sr$ ratios from 0.704 to 0.706 that defines the basement boundary between cratonal North America and the accreted Wallowa terrane (Armstrong and others, 1978; King and others, 2007; Fleck and Criss, 2007). The Cretaceous plutons, and associated wall rocks, exhibit steeply dipping mylonitic foliation and steeply pitching mylonitic lineation. Along-strike to the south, these fabrics have been attributed to dextral transpressional shear (dominantly flattening strain; Figure 4) that was focused along the suture zone during development of the relatively late (~100 Ma) transpressional deformation along the western Idaho shear zone (McClelland and others, 2000; Blake and others, 2009). In the southeast part of the map, fabrics occur with similar orientations to those described in the WISZ. These steeply dipping foliations contrast with mostly moderately to shallowly dipping foliations that occur in the fold and thrust belt to the west and may be attributable to the western Idaho shear zone. Later brittle extensional faulting further complicates the suture zone. These faults follow the zone and include, from north to south, the Browns Creek, Mill Creek, Dairy Mountain, and Allison Creek faults (Figure 3). This late movement is described in the subsequent section.

LATER FAULTS

Miocene and possibly younger east-west directed extension that overlaps with and postdates basalt extrusion ensued in the Salmon River corridor, which probably forms a northern arm of Neogene Basin and Range extension. From the Hammer Creek fault east, the geometry of normal faulting that accommodated extension was strongly influenced by the older contractional structures. In some of these structures, later normal faulting reactivated older thrust faults to accommodate extension, some of which is Miocene or younger. For example, along part of the Heavens Gate fault, early penetrative mylonite fabrics containing top-to-the-northwest contractional kinematic indicators are overprinted by more discrete brittle-ductile and spaced-fault fabrics that contain top-to-the-southeast extensional kinematic indicators. The apparent younger-over-older relationships also suggest significant normal motion. Similarly, the Browns Creek, Mill Creek, Dairy Mountain, and Allison Creek faults (Figure 3) have offset Miocene Columbia River basalts, yet parallel older mylonitic fabrics. This relationship is also observed to the south, along the Salmon River suture zone near McCall, where Giorgis and others (2006) observed that Neogene normal faulting has reactivated Cretaceous ductile structures. Normal faults have also developed in the hanging wall of some of the thrust faults. The best example is the White Bird fault, formed in the hanging wall of the Klopton Creek-Hammer Creek thrust (section A-A′ on map).

In general, major north-south-trending faults in the general vicinity of the Salmon River and eastward have down-to-the-east displacement. Displacement of as much as 1,000 m (3,100 ft) is documented across the White Bird fault-Deer Creek detachment zone by offset of the Grande Ronde-Imnaha contact from an elevation of about 1,450 m (4,700 ft) on the east flank of Camp Howard Ridge to less than 450 m (1,500 ft) along the Salmon River south of White Bird. In addition, Grangeville basalt (*Tgv*), which occurs at elevations as high as 1,500 m (4,900 ft) on the north rim of Getta Creek, has also been documented in the White Bird basin and Deer Creek drainage at elevations between 650-750 m (2,100-2,500 ft). Other minor eastern faults, such as the Goodwin Meadows fault, also have down-to-the-east displacement.

In addition to the faults previously mentioned, other Miocene and possibly younger faults offset Columbia River Basalt Group flows. Displacements vary from a few meters (5-10 feet) to as much as several hundred meters (over 1000 ft). On the uplands between the Salmon and Snake rivers, several faults record significant displacement of the basalts. The Grave Creek-Rice Creek fault is a north-south-trending structure that has 100-150 m (300-450 ft) of displacement and changes from down-to-the-east along the Grave Creek segment to down-to the-west along the Rice Creek segment. The Divide Creek fault, previously unmapped, is a west-northwest-trending fault extending west from Wolf Creek to at least the Salmon River; down-to-the-south displacement of as much as 150 m (450 ft) is documented by offset of Tgr_2 and *Tgv*. The Getta Creek fault, which extends from the mouth of Getta Creek north-northeast to Sawmill Gulch, has maximum down-to-the-west displacement of about 100 m (300 ft) and also offsets Tgv. Several other faults, such as the Wolf Creek and Joseph Plains faults, have displacements of 30-60 m (100-200 ft); numerous smaller faults have also been mapped or compiled from previous studies.

LATE FOLDS

Folds orthogonal to the Slate Creek antiform warp the Rapid River thrust and the general lithologic trends in the northern part of the map. These east-west-trending folds also deform the Miocene Columbia River Basalt Group and thus are relatively young. In the northeast part of the map, a series of northeast- and northwest-trending low-amplitude folds warp the basalt surface.

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REFERENCES

Armstrong, R.L., W.H. Taubeneck, and P.O. Hales, 1977, Rb-Sr and K-Ar geochronometry of Mesozoic granitic rocks and their Sr isotopic composition, Oregon, Washington, and Idaho: Geological Society of America Bulletin, v. 88, p. 397–411.

Bard, C.S., 1978, Mineralogy and chemistry of pyroxenes from the Imnaha and lower Yakima basalts of west-central Idaho: Washington State University M.S. thesis, 75 p.

Barker, F., 1979, Trondhjemite: definition, environment, and hypotheses of origin, *in* Barker, F., ed., Trondhjemites, Dacites, and Related Rocks: Elsevier, New York, p. 1-12.

Barker, R.J., 1982, Soil Survey of Idaho County area, western part: U.S. Department of Agriculture, Soil Conservation Service, 266 p., 79 plates.

Blake, D.E., K.D. Gray, Scott Giorgis, and Basil Tikoff, 2009, A tectonic transect through the Salmon River suture zone along the Salmon River canyon in the Riggins region of west-central Idaho, *in* J.E. O'Connor, R. J. Dorsey, and I.P. Madin, eds., Volcanoes to Vineyards; Geologic Field Trips through the Dynamic Landscape of the Pacific Northwest: Geological Society of America Field Guide, v. 15, p. 345-372.

Bond, J.G., 1962, Geology of the Clearwater embayment in Idaho: University of Washington Ph.D. dissertation, 147 p.

Bond, J.G., 1963, Geology of the Clearwater embayment: Idaho Bureau of Mines and Geology Pamphlet 128, 83 p.

Borovicka, T.G., 1988, The pre-Tertiary geology of the lower Salmon River canyon between Packers Creek and Billy Creek, west-central Idaho: University of Idaho M.S. thesis, 178 p.

Camp, V.E., 1981, Geologic studies of the Columbia Plateau: Part II. Upper Miocene basalt distribution, reflecting source locations, tectonism, and drainage history in the Clearwater embayment, Idaho: Geological Society of America Bulletin, Part I, v. 92, p. 669-678.

Chen, Shiahn-Jauh, 1985, Structural geology of the Eureka Complex in the Seven Devils terrane, eastern Oregon and western Idaho: Rice University M.A. thesis, 94 p.

Coffin, Peter, 1967, Geology of the Slate Creek quadrangle, Idaho County, Idaho: University of Idaho M.S. thesis, 57 p.

Criss, R.E., and R.J. Fleck, 1987, Petrogenesis, geochronology, and hydrothermal alteration systems of the northern Idaho batholith and adjacent areas based on $^{18}O/^{16}O$, D/H, $^{87}Sr/^{86}Sr$, and $^{40}Ar/^{39}Ar$ studies, *in* T.L Vallier and H.C. Brooks, eds., Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: The Idaho Batholith and its Border Zone: U.S. Geological Survey Professional Paper 1436, p. 95-138.

Follo, M.F., 1994, Sedimentology and stratigraphy of the Martin Bridge Limestone and Hurwal Formation (Upper Triassic to Lower Jurassic) from the Wallowa terrane, Oregon, *in* T.L. Vallier and H.C. Brooks, eds., Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: Stratigraphy, Physiography, and Mineral Resource of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1439, p. 1-28.

Fleck, R.J., and R.E. Criss, 2007, Location, age, and tectonic significance of the western Idaho suture zone, *in* M.A. Kuntz, and L.W. Snee, eds., Geological Studies of the Salmon River Suture Zone and Adjoining Areas, West-Central Idaho and Eastern Oregon: U.S. Geological Survey Professional Paper 1738, p. 15–50.

Garwood, D.L., K.L. Schmidt, J.D. Kauffman, D.E. Stewart, R.S. Lewis, K.L. Othberg, and P.J. Wampler, 2007, Geologic map of the White Bird quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 101, scale 1:24,000.

Gaschnig, R.M., J.D. Vervoort, R.S. Lewis, and W.C. McClelland, 2010, Migrating magmatism in the northern US Cordillera: in situ U-Pb geochronology of the Idaho batholith: Contributions to Mineralogy and Petrology, v. 159, p. 863-883.

Giorgis, S., B. Tikoff, P. Kelso, and M. Markley, 2006, The role of material anisotropy in the neotectonic extension of the western Idaho shear zone, McCall, Idaho: Geological Society of America Bulletin, v. 118, p. 259-273.

Goldstrand, P.M., 1987, The Mesozoic stratigraphy, depositional environments, and tectonic evolution of the northern portion of the Wallowa terrane, northeastern Oregon and western Idaho: Western Washington University M.S. thesis, 200 p.

Goldstrand, P.M., 1994, The Mesozoic evolution of the northern Wallowa terrane, northeastern Oregon and western Idaho, *in* T.L Vallier and H.C. Brooks, eds., Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: Stratigraphy, Physiography, and Mineral Resources of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1439, p. 29-53.

Grant, P.R., 1980, Limestone units within the Triassic Wild Sheep Creek Formation, Snake River canyon: Washington State University M.S. thesis, 103 p.

Gray, K.D., and J.S. Oldow, 2005, Contrasting structural histories of the Salmon River belt and Wallowa terrane: Implications for terrane accretion in northeastern Oregon and west-central Idaho: Geological Society of America Bulletin, v. 117, p. 687-706.

Gualtieri, J.L., and G.C. Simmons, 1978, Preliminary geologic map of the Hells Canyon Study area, Wallowa County, Oregon, and Idaho and Adams counties, Idaho: U.S. Geological Survey Open-File Report 78-805, scale 1:48,000.

Gualtieri, J.L., and G.C. Simmons, 2007, Reconnaissance geologic map of the Hells Canyon study area, Wallowa County, Oregon, and Idaho and Adams counties, Idaho, *in* G.C. Simmons, J.L. Gualtieri, T.J. Close, F.E. Federspiel, and A.M. Leszcykowski, Mineral Resources of the Hells Canyon Study Area, Wallowa County, Oregon, and Idaho and Adams counties, Idaho: U.S. Geological Survey Scientific Investigations Report 2007-5046, 62 p., 2 plates, scale 1:48,000.

Hamilton, Warren, 1963, Metamorphism in the Riggins region, western Idaho: U.S. Geological Survey Professional Paper 436, 95 p.

Hamilton, Warren, 1969, Reconnaissance geologic map of the Riggins quadrangle, west-central Idaho: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-579, scale 1:125,000.

Holden, G.S., 1973, Chemical and petrographic stratigraphy of the Columbia River Basalt in the lower Salmon River canyon, Idaho: Washington State University M.S. thesis, 93 p.

Hoover, A.L., 1986, Transect across the Salmon River suture, South Fork of the Clearwater River, western

Idaho: Rare earth element geochemical, structural, and metamorphic study: Oregon State University M.S. Thesis, 138 p.

Imlay, R.W., 1981, Jurassic (Bathonian and Callovian) ammonites in eastern Oregon and western Idaho: U.S. Geological Survey Professional Paper 1142, 24 p.

Imlay, R.W., 1986, Jurassic ammonites and biostratigraphy of eastern Oregon and western Idaho, *in* T.L. Vallier and H.C. Brooks, eds., Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: Geologic Implications of Paleozoic and Mesozoic Paleontology and Biostratigraphy, Blue Mountains Province, Oregon and Idaho: U.S. Geological Survey Professional Paper 1435, p. 53-57.

Jones, D.R., 1991, Slope movement hazard evaluation along a portion of the Salmon River and Little Salmon River canyons, Idaho County, Idaho: University of Idaho M.S. thesis, 97 p., 3 plates.

Kauffman, J.D., and D.L. Garwood, 2009, Revised stratigraphy for several Saddle Mountains and Wanapum Basalt units, Columbia River Basalt Group: Geological Society of America Abstracts with Programs, v. 41., no. 7, p. 298.

Kauffman, J.D., and K.L. Othberg, 2007, Geologic map of the Grangeville West quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 85, scale 1:24,000.

Kauffman, J.D., K.L. Schmidt, D.L. Garwood, and K.L. Othberg, 2007, Geologic map of the Fenn quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 87, scale 1:24,000.

Kauffman, J.D., R.S. Lewis, Schmidt, K.L., and D.E. Stewart, 2008a, Geologic map of the White Bird Hill quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 96, scale 1:24,000.

Kauffman, J.D., R.S. Lewis, D.E. Stewart, and K.L. Schmidt, 2008b, Geologic map of the Goodwin Meadows quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 97, scale 1:24,000.

Kauffman, J.D., R.S. Lewis, K.L. Schmidt, D.E. Stewart, D.L. Garwood, and K.L. Othberg, 2011a, Geologic map of the Dairy Mountain quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 129, scale 1:24,000.

Kauffman, J.D., K.L. Schmidt, R.S. Lewis, D.E. Stewart, K.L. Othberg, and D.L. Garwood, 2011b, Geologic map of the McKinzie Creek quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 127, scale 1:24,000.

King, E.M., Beard, B.L., and Valley, J.W., 2007, Strontium and oxygen isotopic evidence for strike/slip movement of accreted terranes in the Idaho batholith: Lithos, v. 96, p. 387-401.

Kleck, W.D., 1976, Chemistry, petrography, and stratigraphy of the Columbia River Basalt Group in the Imnaha River valley region, eastern Oregon and western Idaho: Washington State University Ph.D. dissertation, 203 p.

Kurz, G.A., 2001, Structure and geochemistry of the Cougar Creek complex, northeastern Oregon and west-central Idaho: Boise State University M.S. thesis, 248 p.

Kurz, G.A., 2010, Geochemical, isotopic, and U-Pb geochronologic investigations of intrusive basement rocks from the Wallowa and Olds Ferry arc terranes, Blue Mountains Province, Oregon-Idaho: Boise State University Ph.D. dissertation, 278 p.

Kurz, G.A., and C.J. Northrup, 2008, Structural analysis of mylonitic rocks in the Cougar Creek Complex, Oregon-Idaho, using the porphyroclast hyperbolic distribution method, and potential use of SC'-type extension shear bands as quantitative vorticity indicators: Journal of Structural Geology, v. 30, p. 1005-1012.

Kurz, G.A., M.D. Schmitz, C.J. Northrup, and T.L. Vallier, 2012, U-Pb geochronology and geochemistry of intrusive rocks from the Cougar Creek Complex, Wallowa arc terrane, Blue Mountains Province, Oregon-Idaho: Geological Society of America Bulletin, v. 124, no. 3-4, p. 578-595.

LaMaskin, T.A., R.J. Dorsey, and J.V. Vervoort, 2008, Tectonic controls on mudrock geochemistry, Mesozoic rocks of eastern Oregon and western Idaho, U.S.A.: Implications for Cordilleran tectonics: Journal of Sedimentary Research, v. 78, p. 765–783.

LaMaskin, T.A., J.D. Vervoort, R.J. Dorsey, and J.E. Wright, 2011, Early Mesozoic paleogeography and tectonic evolution of the western United States: Insights from detrital zircon U-Pb geochronology, Blue Mountains Province, northeastern Oregon: Geological Society of America Bulletin, v. 123, no. 9-10, p. 1935-1965.

LeAnderson, P.J., and Scott Richey, 1985, Geology of the Wallow-Seven Devils volcanic (island) arc terrane between the Snake and Salmon rivers near Lucile, Idaho: Part I, Stratigraphy, structure, and metamorphism: U.S. Geological Survey Open-File Report 85-0611, 30 p.

LeMaitre, R.W., 1984, A proposal by the IUGS Subcommission on the Systematics of Igneous Rocks for a chemical classification of volcanic rocks based on the total alkali silica (TAS) diagram: Australian Journal of Earth Sciences, v. 31, p. 243-255.

Lewis, R.S., J.D. Vervoort, R.F. Burmester, and P.J. Oswald, 2010, Detrital zircon analysis of Mesoproterozoic and Neoproterozoic metasedimentary rocks of north-central Idaho: implications for development of the Belt-Purcell basin: Canadian Journal of Earth Sciences, v. 47, p. 1383-1404.

Lewis, R.S., K.L. Schmidt, K.L. Othberg, D.E. Stewart, and J.D. Kauffman, 2011a, Geologic map of the Lucile quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 126, scale 1:24,000.

Lewis, R.S., K.L. Schmidt, D.E. Stewart, K.L. Othberg, J.D. Kauffman, and E.D. Stewart, 2011b, Geologic map of the John Day Mountain quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 128, scale 1:24,000.

Lund, Karen, 1984, Tectonic history of a continent-island arc boundary, west central Idaho: Pennsylvania State University Ph.D. dissertation, 207 p.

Lund, Karen, 2004, Geology of the Payette National Forest and vicinity, west-central Idaho: U.S. Geological Survey Professional Paper 1666, 89 p.

Lund, Karen, W.F. McCollough, and E.H. Price, 1993, Geologic map of the Slate Creek-John Day area, Idaho County, Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-2299, scale 1:50,000.

Lund, Karen, J.N. Aleinikoff, E.Y. Yacob, and S.M. Dee, 2007, SHRIMP U-Pb constraints on age and provenance of the Riggins Group and associated metamorphic rocks west of the Salmon River suture, west-central Idaho: Tectonic implications: Geological Society of America Abstracts with Programs, v. 39, no. 6, p. 289.

Lund, Karen, and L.W. Snee, 1988, Metamorphic and structural development of the continent-island arc juncture *in* west-central Idaho, in W.G. Ernst, ed., Metamorphism and Crustal Evolution of the Western United States (Rubey Volume VII): New York, Prentice-Hall, p. 296-331.

McClelland, W.C., and J.S. Oldow, 2007, Late Cretaceous truncation of the western Idaho shear zone in the central north American Cordillera: Geology, v. 35, no. 8, p. 723-726.

McClelland, W.C., B. Tikoff, and C.A. Manduca, 2000, Two-phase evolution of accretionary margins: examples from the North American Cordillera: Tectonophysics, v. 326, p. 37-55.

McCollough, W.F., 1984, Stratigraphy, structure, and metamorphism of Permo-Triassic rocks along the western margin of the Idaho batholith, John Day Creek, Idaho: Pennsylvania State University M.S. thesis, 141 p.

Morrison, R.F., 1963, The pre-Tertiary geology of the Snake River canyon between Cache Creek and Dug Bar, Oregon-Idaho boundary: University of Oregon Ph.D. dissertation, 195 p.

Myers, P.E., 1982, Geology of the Harpster area, Idaho County, Idaho: Idaho Bureau of Mines and Geology Bulletin 25, 46 p.

Northrup, C.J., M. Schmitz, G. Kurz, and K. Tumpane, 2011, Tectonomagmatic evolution of distinct arc terranes in the Blue Mountains Province, Oregon and Idaho, *in* J. Lee and J.P. Evans, eds., Geologic Field Trips to the Basin and Range, Rocky Mountains, Snake River Plain, and Terranes of the U.S. Cordillera: Geological Society of America Field Guide 21, p. 67-88.

Onasch, C.M., 1977, Structural evolution of the western margin of the Idaho batholith in the Riggins, Idaho area: Pennsylvania State University Ph.D. dissertation, 196 p.

Onasch, C.M., 1987, Temporal and special relations between folding, intrusion, metamorphism, and thrust faulting in the Riggins area, west-central Idaho, *in* T.L. Vallier and H.C. Brooks, eds., Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: The Idaho Batholith and its Border Zone: U.S. Geological Survey Professional Paper 1436, p. 139-149.

Reed, J.C., 1939, Geology and ore deposits of the Florence Mining District, Idaho County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 46, 44 p.

Reidel, S.P., 1978, The stratigraphy and petrogenesis of the Grande Ronde Basalt from the lower Salmon and adjacent Snake River canyons: Washington State University Ph.D. dissertation, 415 p.

Sarewitz, D.R., 1983, Geology of a part of the Heavens Gate quadrangle, Seven Devils Mountains, western Idaho: Oregon State University M.S. thesis, 144 p.

Schmidt, K.L., J.D. Kauffman, D.E. Stewart, K.L. Othberg, and R.S. Lewis, 2007, Geologic map of the Grangeville East quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 86, scale 1:24,000.

Schmidt, K.L., J.D. Kauffman, D.E. Stewart, D.L. Garwood, K.L. Othberg, and R.S. Lewis, 2009a, Geologic map of the Grave Point quadrangle, Idaho County, Idaho, and Wallowa County, Oregon: Idaho Geological Survey Digital Web Map 111, scale 1:24,000.

Schmidt, K.L., J.D. Kauffman, D.E. Stewart, R.S. Lewis, K.L. Othberg, and D.L. Garwood, 2009b, Geologic map of the Slate Creek quadrangle, Idaho County, Idaho: Idaho Geological Survey Digital Web Map 110, scale 1:24,000.

Schmidt, K.L., D.M. Schwartz, R.S. Lewis, J.D. Vervoort, T.A. Lamaskin, and D.E. Wilford, 2013, New detrital zircon ages constrain the origin and evolution of the Riggins Group assemblage along the Salmon River suture zone, western Idaho: Geological Society of America Abstracts with Programs, v. 45, no. 6, p. 66.

Streckeisen, A.L., 1976, To each plutonic rock its proper name: Earth-Science Reviews, v. 12, p. 1-33.

Swanson, D.A., J.L. Anderson, R.D. Bentley, G.R. Byerly, V.E. Camp, J.N. Gardner, and T.L. Wright, 1979a, Reconnaissance geologic map of the Columbia River Basalt Group in eastern Washington and northern Idaho: U.S. Geological Survey Open-File Report 79-1363, sheet 8 of 12.

Swanson, D.A., T.L. Wright, P.R. Hooper, and R.D. Bentley, 1979b, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p.

Swanson, D.A., J.L. Anderson, V.E. Camp, P.R. Hooper, W.H. Taubeneck, and T.L. Wright, 1981, Reconnaissance geologic map of the Columbia River Basalt Group, northern Oregon and western Idaho: U.S. Geological Survey Open-File Report 81-797, 32 p., sheet 3 of 5.

Tumpane, K.P., 2010, Age and isotopic investigations of the Olds Ferry terrane and its relations to other terranes of the Blue Mountains Province, eastern Oregon and west-central Idaho: Boise State University M.S. thesis, 220 p.

Unruh, D.M., Karen Lund, M.A Kuntz, and L.W. Snee, 2008, Uranium-lead zircon ages and Sr, Nd, and Pb isotope geochemistry of selected plutonic rocks from western Idaho: U.S. Geological Survey Open-File Report 2008-1142, 36 p.

Vallier, T.L., 1968, Reconnaissance geology of the Snake River canyon between Granite Creek and Pittsburg Landing, Oregon and Idaho: The Ore Bin, v. 30, no. 12, p. 233-254.

Vallier, T.L., 1974, A preliminary report on the geology of part of the Snake River canyon, Oregon and Idaho: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-6, 15 p., 1 plate.

Vallier, T.L., 1977, The Permian and Triassic Seven Devils Group, western Idaho and northeastern Oregon: U.S. Geological Survey Bulletin 1437, 58 p.

Vallier, T.L., 1995, Petrology of pre-Tertiary igneous rocks in the Blue Mountains region of Oregon, Idaho, and Washington: Implications for the geologic evolution of a complex island arc, *in* T.L. Vallier and H.C. Brooks, eds., Geology of the Blue Mountains Region of Oregon, Washington, and Idaho: Petrology and Tectonic Evolution of Pre-Tertiary Rocks of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1438, p. 125-209.

Vallier, T.L., 1998, Islands &Rapids: a Geologic Story of Hells Canyon: Confluence Press, Lewiston, Idaho, 151 p.

Wagner, W.R., 1945, A geological reconnaissance between the Snake and Salmon Rivers north of Riggins, Idaho: Idaho Bureau of Mines and Geology Pamphlet 74, 16 p.

Walker, G.W., 1979, Reconnaissance geologic map of the Oregon part of the Grangeville quadrangle, Baker, Union, Umatilla, and Wallowa counties, Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I-1116, scale 1:250,000.

Walker, N.W., 1986, U-Pb geochronologic and petrologic studies in the Blue Mountains terrane, northeastern Oregon and westernmost-central Idaho: Implications for pre-Tertiary tectonic evolution: University of California, Santa Barbara, Ph.D. dissertation, 224 p.

White, D.L., 1972, The geology of the Pittsburg Landing area, Snake River canyon, Oregon-Idaho: Indiana State University M.S. thesis, 98 p.

White, D.L., and T.L. Vallier, 1994, Geologic evolution of the Pittsburg Landing area, Snake River canyon, Oregon and Idaho, *in* T.L Vallier and H.C. Brooks, eds., Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: Stratigraphy, Physiography, and Mineral Resources of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1439, p. 55-73.

White, J.D.L., 1985, The Doyle Creek Formation (Seven Devils Group), Pittsburg Landing, Idaho: University of Missouri-Columbia M.S. thesis, 152 p.

White, J.D.L., 1994, Intra-arc basin deposits with the Wallowa terrane, Pittsburg Landing area, Snake River canyon, Oregon and Idaho, *in* T.L. Vallier and H.C. Brooks, eds., Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: Stratigraphy, Physiography, and Mineral Resources of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1439, p. 75-89.

Zen, E-an, and J.M. Hammerstrom, 1984, Magmatic epidote and its petrologic significance: Geology, v. 12, p. 515-518.