

CORRELATION OF MAP UNITS QUATERNARY Columbia River Basalt Group Imnaha Basa Tim -- unconformity Intrusive Rocks Wallowa Terrane Western Salmon River Belt Eastern Salmon River Belt CRETACEOUS **IURASSIC** > MESOZOIC

### INTRODUCTION

The geologic map of the Lucile quadrangle shows rock units exposed at the surface or underlying thin surficial cover of soil and colluvium. Thicker surficial alluvial, colluvial, and landslide deposits are also shown where they mask or modify the underlying rock units or form significant mappable units. The map is the result of our field work in 2008 and 2009 as a continuation of investigations in the adjacent Slate Creek quadrangle (Schmidt and others, 2009b), as well as compilation of previous research, including that of Bond (1963), Hamilton (1963), Edwin Price (unpublished 1976-1977 field work), Onasch (1977, 1987), McCollough (1984), LeAnderson and Richey (1985), Lund and others (1993), and reconnaissance mapping from 1978 to 1980 by V.E. Camp (Camp, 1981; Swanson and others, 1981). Some attitudes from this previous work were included on this map.

The oldest rocks in the quadrangle are Permian to Triassic volcanic, volcaniclastic, sedimentary, and associated intrusive rocks of the Wallowa rocks in the eastern part of the map. These folded and faulted basement rocks are capped by Columbia River Basalt Group lava flows, which are also faulted and tilted by reactivation of older basement structures. The soil survey shows loess parent material on relatively flat surfaces in the Salmon River valley (Barker, 1982), but because loess deposits are thin, they are not included on this map. In addition to modern alluvium, Salmon River deposits form terrace remnants of at least six older regimes of the river. Pleistocene and recent alluvial deposits, both stream sediments and fan deposits, are mostly related to the Salmon River and its tributaries. The map also shows landslide deposits and areas of thick colluvial cover.

### DESCRIPTION OF MAP UNITS

In the following unit descriptions and later discussion of structure, we use the metric system for sizes of mineral or clast constituents of rock units, and also for small-scale features of outcrops, such as thin layering. We use the English system for most thickness and distance measurements to conform to those on the base map. 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.

### ARTIFICIAL DEPOSITS

m Made ground (late Holocene)—Artificial fills composed of excavated, transported, and emplaced construction materials of highly varying composition, but typically derived from local sources. Includes fill along U.S. Highway 95 and in a reclaimed placer mine.

### SEDIMENTARY AND MASS MOVEMENT DEPOSITS

Alluvial Deposits

Alluvium of the Salmon River (late Holocene)—Channel and flood-plain deposits that are part of the present river system. Two grain-size suites are typically present: coarse sand in thin shoreline deposits, and well-sorted and rounded pebble to boulder gravel in river bars and islands. Gravel clasts include indicate flood stage was exceeded less than ten times since 1894. Age is late Holocene to present (see Schmidt and others, 2009b). Thickness varies from

0 to 24 m (0 to 80 ft) because of undulations in scoured surface of bedrock. Qamo Older alluvium of the Salmon River (Holocene)—Primarily stratified sand and well-rounded pebble to boulder gravel. Forms first terrace above the river, which is significantly higher than the average historic peak flow the Salmon River. Maximum age probably middle to early Holocene (see Schmidt and others, 2009b). Gravel clast lithology similar to Qam. May be capped by thin loess and eolian sand. Height above present river level averages 25 feet. Represents the first of a sequence of terraces, but distinguished from Qtg units (see below) by young age and potential for flooding during infrequent but extremely high discharge. Interfingers with or is capped by colluvium and alluvial-fan deposits at toe of canyon slope. Thickness 1-24 m (3-80 ft).

Remnants of gold placer mines common (see *Symbols*). Qas Channel and flood-plain deposits of Salmon River tributaries (Holocene and late Pleistocene)—Primarily stratified and rounded pebble to boulder gravel in channels, flood plains, and low terraces of Cow Creek, John Day Creek, and other tributary streams. Locally includes poorly sorted debris-flow deposits. Thickness 1-9 m (3-30 ft).

Qaf Alluvial-fan deposits (Holocene)—Crudely bedded, poorly sorted brown muddy gravel derived from basalt and basement-rock colluvium on steep canyon slopes. Subangular and angular pebbles, cobbles, and boulders in a matrix of granules, sand, silt, and clay. Primarily deposited by debris flows. Locally includes lenses of Mazama ash. Thickness varies from 1 to 5 m (3 to 50 ft).

Qafo Older alluvial-fan deposits (Pleistocene)—Poorly sorted gravel deposits of incised alluvial-fan remnants. Primarily deposited by debris flows and sheet wash. Texture and lithology similar to Oaf. Commonly interfingers with and caps terrace deposits, but age is undivided. Locally mantled with thin loess.

# Gravel Terrace Deposits

Soils well developed. Thickness varies from 3 to 30 m (10 to 100 ft).

Gravel deposits of high terraces in the Salmon River canyon consist of stratified sand and well-rounded pebble to boulder gravel and form remnants from about 15 m (50 ft) to nearly 245 m (800 ft) above the Salmon River. Gravel clast lithology is similar to *Qam*. Deposits may be capped by thin loess and are locally capped by or interfingered with alluvial-fan deposits (Qafo). Gravel of the lowest observed terrace is mapped as Qamo (see above), rather than Otg..

Qtg, Gravel of second terrace, averaging 18m (60 ft) above Salmon River (**Pleistocene**)—Forms terrace and point bar remnants locally capped by thin loess or alluvial-fan deposits (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 (see

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

Otg. Gravel of fourth terrace, averaging 70 m (230 ft) above Salmon River (**Pleistocene**)—Forms terrace remnants including prominent high benches at Twilegar Bar and across from Johnson Bar. Capped by thin loess and alluvial-fan deposits (Qafo) with well-developed soils. Highly varied thickness ranging from 15 to 61 m (50 to 200 ft), probably owing to buried ancestral river channel.

Qtg<sub>5</sub> Gravel of fifth terrace, averaging 116 m (380 ft) above Salmon River (**Pleistocene**)—Forms terrace remnants including prominent high benches at Squaw Bar and southwest of Lucile. Capped by loess and alluvial-fan deposits (Qafo) with well-developed soils. Overlies bedrock strath at Squaw Bar. Highly varied thickness ranging from 15 to 76 m (50 to 250 ft). Gravel of sixth terrace, 233 m (765 ft) above Salmon River (Pleistocene)— Coarse-grained rounded pebble-cobble gravel with clast lithologies similar to those in the present Salmon River. Deposited on river-cut surface in basement rock at 714 m (2,340 ft) elevation near Dry Gulch (lat 45.57177° N., long 116.29167° W.). Thickness 6-8 m (20-60 ft). Terrace

gravel is conformably overlain by bouldery colluvium (Oc).

#### MASS MOVEMENT DEPOSITS Qlsa Deposits of active landslides (Holocene)—Slumps and slides that have been

active within the last several decades. Includes one landslide along John Day Creek road and one along Cow Creek road. Primary slope-stability factors that control landslide activity are water saturation, steep slopes, and bedrock lithology (lones, 1991). Landslide deposits (Holocene and Pleistocene)—Poorly sorted and poorly

stratified angular to subrounded pebbles, cobbles, and boulders mixed with silt and clay. Deposited by slumps, slides, and debris flows. Landslides range in age from ancient movements that are relatively stable features to those that are more recent and potentially less stable. subrounded colluvial gravel deposits. Deposited by gravity movements of

Qc Colluvial deposits (Pleistocene)—Poorly sorted and poorly stratified angular to various sources, but primarily debris flows. Includes possible landslide deposits that lack landslide morphology. Well-developed soils common. Near Dry Gulch, colluvium capping Quaternary terrace gravels (Qtg<sub>6</sub>) is mostly basalt cobbles and boulders mixed with silt and clay. Above Cow Creek, colluvium is composed of debris from phyllite and greenstone, and includes large boulders of greenstone. East of Squaw Bar, colluvium is composed of debris from marble and schist. Thickness highly varied, but locally 31-61 m (100-200 ft).

## **VOLCANIC ROCKS**

Columbia River Basalt Group

The only Columbia River Basalt Group units in the quadrangle are Imnaha Basalt and a small area of overlying R, Grande Ronde Basalt. Imnaha Basalt caps pre-Tertiary basement rocks along the eastern and southern edges of the map. R, Grande Ronde Basalt caps Imnaha Basalt at survey point "Lucile" west of the Salmon River near the south edge of the map. Grande Ronde Basalt Grande Ronde Basalt, R, magnetostratigraphic unit (Miocene)—The small cap

of Grande Ronde Basalt at survey point "Lucile" was not visited during this project; it was compiled from Swanson and others (1981, sheet 3). The cap on Imnaha Basalt is about 85-92 m (280-300 ft) thick. R, Grande Ronde Basalt is fine grained and aphyric to sparsely plagioclase-phyric or microphyric, and typically forms tiered cliffs with intervening moderately steep to

Imnaha Basalt (Miocene)—Medium- to coarse-grained, sparsely to abundantly plagioclase-phyric basalt; olivine common; plagioclase phenocrysts generally 0.5-2 cm, but some are as large as 3 cm. Typically weathers to sooty brown granular detritus and is poorly exposed except on steep slopes where entablatures and colonnades form tiered cliffs. Maximum exposed thickness is about 214 m (700 ft).

#### PRE-TERTIARY ROCKS

Rocks older than the Columbia River Basalt Group underlie much of the quadrangle and consist of three fault-bounded assemblages: (1) Wallowa terrane in the northwest part of map; (2) western Salmon River belt in the central part of map; and (3) eastern Salmon River belt in the eastern part of the map. The Heavens Gate and Rapid River faults form the boundaries of these assemblages, as they do to the south near Riggins (Gray and Oldow, 2005). Intrusive rocks are present in all three assemblages and most are described below along with the metavolcanic and metasedimentary that they intrude. Exceptions include tonalite (KPt), which is present in more than one of the assemblages and is described separately, as are felsic dike rocks (KPdf) that are present along strike of the KPt unit, and more widespread mafic dikes (KPdm).

### Intrusive Rocks

KPdf / Felsic dike rocks (Cretaceous? to Permian?)—Light gray, medium- to fine-grained dike rocks consisting of quartz and plagioclase ± muscovite ± chlorite ± biotite that are intrusive into the Lucile Slate north of John Day Creek. Weakly to strongly mylonitized. Dikes are as much as several feet thick and most if not all are probably tonalite or trondhjemite. Dated plutonic rocks of similar composition in the region include 260 Ma (Permian) basement tonalite (Pmt) and 113 Ma (Cretaceous) trondhjemite and tonalite north of Slate Creek 4 km (2.5 mi) northeast of the map area (Unruh and others, 2008). A Cretaceous age is most likely, given that the

dikes intrude rocks not thought to be part of a basement complex. **Tonalite (Cretaceous? to Permian?)**—Light gray, medium- to coarse-grained biotite tonalite and medium- to fine-grained muscovite tonalite or trondhjemite in central and northeast part of map. Strongly to weakly mylonitized. Biotite, where present, partly altered to chlorite. May be larger masses of KPdf. As with KPdf, dated plutonic rocks of similar composition in the region include 260 Ma Pmt unit and 113 Ma trondhjemite and tonalite north of Slate Creek (Unruh and others, 2008). A Cretaceous age is most likely, given that the tonalite intrudes rocks not thought to part of a

basaltic, granitic, and metamorphic rocks. Peak-flow gaging-station records | KPdm/| Mafic dike rocks (Cretaceous? to Permian?)—Gray, fine-grained dioritic and andesitic dikes with hornblende phenocrysts in matrix of plagioclase, muscovite, and chlorite. Intrusive into the Lucile Slate north of John Day Creek and south of Wet Gulch as well as into greenstone and metatonalite west of the Salmon River. Dikes are as much as several feet thick. May be

related to *KPdg* unit of the Wallowa terrane.

# WALLOWA TERRANE

The northwest part of the map is underlain by the Permian to Triassic Cougar Creek complex that is interpreted as basement to the Seven Devils Group and the Wallowa terrane (Vallier, 1977; Walker, 1986; Kurz, 2001). The Cougar Creek complex is in the hanging wall of the Klopton Creek thrust, which crosses the Snake River four miles northwest of the map. The complex is dominated by intrusive rocks that are heterogeneous in age, composition, texture, and fabric (KPdg and Pmt units on this map). Greenstones (RPgs) are present along the southeast part of the complex and are interpreted as both metavolcanic and metasedimentary rocks. Most if not all are probably correlative with the Seven Devils Group of Vallier (1977). Metamorphism of *Pmt* and *RPgs* is greenschist facies. Some of the less metamorphosed intrusions (KPdg) probably represent magma chambers and feeders that intruded the basement rocks en route to extrusion as the Seven Devils Group units overlying the complex itself.

Granophrye (Cretaceous? to Permian?)—Conspicuously iron-stained and locally intensely altered fine-grained felsic rocks at western map border. Quartz and plagioclase intergrown in micrographic texture. Nearly devoid of mafic minerals. Locally cut by unmapped fine-grained muscovite granodiorite dikes. May be shallow-level equivalent of *Pmt* and thus similar to *Pf*, or a younger intrusive phase.

**Diorite and gabbro (Cretaceous? to Permian?)**—Composite intrusive body in the northwest part of map consisting primarily of medium to dark gray, medium- to coarse-grained diorite and quartz diorite; also includes small bodies of gabbro. Contains pyroxene, hornblende, and epidote. Plagioclase diorite and gabbro mapped in the Grave Point quadrangle to the northwest (Schmidt and others, 2009a) where a Triassic date of  $229.22 \pm 0.45$  Ma has been obtained for one plutonic phase (G. Kurz, written commun., 2008).

Greenstone (Triassic? to Permian)—Light to dark gray-green, generally

fine-grained rocks of mafic protolith in the northern and central part of the map. Mapped where greenstone dominates over intermixed metatonalite (unit *Pmt*) with mutually cross-cutting relationships. Metatonalite decreases southward and is absent in the Cow Creek drainage. Pervasively metamorphosed to greenschist grade, with the groundmass and many crystals altered to chlorite, sericite, and epidote. At the northern map boundary, some of this unit appears to have been intrusive whereas vesicular mafic flows crop out at 1,281 m (4,200 ft) elevation on Center Ridge. Southward, conglomerate, mafic sandstone, and subordinate red argillite are typical; the sandstones are quartz bearing at two localities near the southern extent of the unit. Rare red chert crops out on the ridge north of Cow Creek near the west map edge. Fabric ranges from strongly foliated to massive but is overall less developed than in the greenstone in the western Salmon River belt (RPvg). Includes unmapped felsic and mafic dikes that are particularly abundant on the ridge north of Cow Creek and north of Fish Dam Spring. Unit is part of the Seven Devils Group of Vallier (1977) but correlation with a specific formation is problematic; it could be equivalent to the Permian Hunsaker Creek Formation (primarily of mafic volcanic sands and silts) or the Triassic Wild Sheep Creek Formation (largely mafic volcanic flows).

Metatonalite (Permian)—Light to medium gray tonalite in northern and central

parts of map that is intimately intermixed with greenstone (unit TPgs described above). Mutually cross-cutting relationships apparent at many outcrops. Quartz composes 20 to 50 percent of the rock and occurs as either light gray to bluish phenocrysts that are locally resorbed and embayed or as a constituent of the groundmass. Altered plagioclase composes from 40 to 80 percent of the rock. Biotite, chlorite, and locally muscovite and hornblende(?) are present. Typically medium grained and porphyritic, with local coarse-grained and fine-grained leucocratic varieties. Micrographic (granophyric) texture developed in groundmass in central part of map. Locally foliated, and in places forms well-developed mylonites. Pervasively metamorphosed, with chlorite and epidote replacing most mafic minerals and plagioclase largely replaced by sericite. Two zircon fractions from a sample described as trondhjemite from along the Salmon River near the northern edge of the map yielded a concordant 260 Ma age (Walker, 1986), and more recently Kurz (2010) obtained a U-Pb age of 268.57  $\pm$  0.07 Ma from tonalite in the same roadcut (sample SAL09-01 on map). These Permian dates indicate that the metatonalite forms part of the basement beneath the Seven Devils Group.

# WESTERN SALMON RIVER BELT

The western Salmon River belt mapped near Heavens Gate Lookout 19 km (12 mi) to the southwest (Gray and Oldow, 2005), extends north into the Lucile quadrangle. Exposed between the Heavens Gate fault and the Rapid River thrust here and to the south, the belt consists of strongly foliated greenstone, phyllite, and marble of uncertain age. All are lower greenschist metamorphic grade and lack metamorphic biotite. The assemblage includes (from structurally lowest to highest levels): greenstone dominated by volcaniclastic rocks (\( \overline{R}Pvg \)), marble within the greenstone (\( \overline{R}Pmg \)), marble of Race Creek (RPmr) and graphitic calcareous phyllite of the Lucile Slate (JPI). Previous correlations in the Lucile quadrangle place the greenstone in the Seven Devils Group and marble in Martin Bridge Formation (Hamilton, 1963; Onasch 1977, 1987), but we have adapted the more

conservative approach of Gray and Oldow (2005) in separating this assemblage from the Wallowa terrane. Although additional mapping and geochronology is required to firmly establish a correlation between the western Salmon River belt and the Wallowa terrane, we do offer tentative correlations below.

JPI Lucile Slate (Jurassic? to Permian?)—Dark gray, graphitic calcareous phyllite, sandstone, and thinly layered marble exposed northeast and southwest of Lucile. Contains quartz and feldspar ± graphite ± muscovite ± chlorite ± biotite ± Fe-carbonate. Zoisite present in northernmost exposures. Sandstones locally contain granules. Highly deformed; commonly displays mylonite foliation or lineation and foliation, which includes s-c and extensional crenulation fabrics. Metamorphosed to lower greenschist grade. Includes gray phyllite near the mouth of John Day Creek that may alternatively be phyllite within the RPvg unit. Named for rocks near Lucile (Lucile series of Wagner, 1945; Lucile Slate of Hamilton, 1963) but no measured section established. Onasch (1977, 1987) used the term Lucile Formation rather than Lucile Slate because of the variety of rock types in the unit. (1993). Lucile phyllite or Lucile Formation possibly more appropriate terms, but usage of Hamilton (1963) maintained on this map. Regional correlation uncertain, but most likely equivalent to the Hurwal Formation (Follo, 1994).

TAPmr | Marble of Race Creek (Triassic? to Permian?)—Informal name applied here to gray marble exposed in the lower part of Wet Gulch and southwest of Lucile. Best exposed along West Fork of Race Creek 2.4 km (1.5 mi) southwest 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 map area) that contains Triassic conodonts (Sarewitz, 1983), but additional mapping is needed to establish continuity. Wagner (1945) reports fragments of Triassic echinoderms in limestone "at Lucile." It is unclear whether the fossils were obtained from the marble of Race Creek or the marble of Sheep

#### Volcaniclastic greenstone (Triassic? to Permian?)—Greenstone intermixed with marble (mapped separately as \( \bar{R}Pmg \)) and minor amounts of argillite and phyllite. Exposed northeast and southwest of Lucile. Greenstone varies from plagioclase-rich sandstone to conglomeratic rocks with stretched clasts of 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 JPI. Foliation and lineation well developed and much of the unit is mylonitic. Entirely volcaniclastic rocks, and thus different from \( \overline{R}Pgs \) unit that includes lava flows with vesicular zones. Previously mapped by Onasch (1977, 1987) as Permian-Triassic Seven Devils Group. Unit may be a clastic-rich facies of the Wild Sheep Creek Formation, which composes

Gulch (KPms), but most likely the former.

the middle part of the Seven Devils Group (Vallier, 1977). Marble within volcaniclastic greenstone (Triassic? to Permian?)—Gray marble exposed in the lower part of Wet Gulch 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 is uncertain, as no fossils have been reported from this unit.

#### EASTERN SALMON RIVER BELT The eastern Salmon River belt of Gray and Oldow (2005) is exposed east of

the Rapid River thrust. It consists of massive to strongly foliated metaconglomerate, mafic and felsic schist, and marble, all of unknown age. The marble is of uncertain metamorphic grade, but the other rocks contain chlorite and muscovite in the west and biotite, garnet, and hornblende in the east. The assemblage includes (from structurally lowest to highest levels): calcareous banded phyllite (KPcp; largely exposed east of the map), marble of Sheep Gulch (KPms), and Fiddle Creek Schist (KPfc). Felsic schist and conglomerate in the northeast corner of the map are tentatively correlated with the Fiddle Creek Schist (Riggins Group). We are uncertain of the stratigraphic position of any of these units and list them below in their structural position. Previous correlations place the calcareous banded phyllite in the Lucile Formation and the marble in the Martin Bridge Formation (McCullough, 1984) or combined in the Martin Bridge Formation (Lund and others, 1993). The most straightforward interpretation is that the marble of Sheep Gulch is correlative with the marble of Race Creek, and that both are higher grade equivalents of the Martin Bridge Formation. If this interpretation is correct, then the strata in the Slate Creek antiform are upside down, because metamorphosed greenstones of the Fiddle Creek Schist (probable Seven Devils Group) overlie the marble of Sheep Gulch, which in turn overlies fine-grained clastic rocks (now phyllite and probable Hurwal Formation equivalent). This interpretation is shown schematically in Figure 1. A less likely scenario is that the rocks in the Slate Creek antiform are upright and that calcareous banded phyllite (KPcp) and marble of Sheep Gulch (*KPms*) are part of, or below, the Riggins Group.

KPfc Fiddle Creek Schist (Cretaceous to Permian)—Green and light gray, massive to

strongly foliated metaconglomerate, metasandstone, and mafic and felsic schist in southern part of map. Metaconglomerate contains light gray felsite clasts in matrix of chlorite and plagioclase ± muscovite ± Fe-carbonate ± guartz ± biotite. Locally contains sandstone and siltstone clasts. Garnet present in southeastern exposures (see garnet isograd on map) and hornblende present locally in easternmost exposures. Metasandstone near southern map boundary contains plagioclase, chlorite, muscovite, biotite, quartz, epidote, Fe-carbonate, and opaque minerals. These same minerals in differing proportions comprise the mafic and felsic schists, which are intermixed at outcrop scale in decimeter- to meter-scale layers. Although micas are generally aligned, most of the schist is relatively massive and may be metasiltstone or tuff. Muscovite and biotite in some of the metasandstone lack alignment. Light gray mylonitic muscovite-quartz-plagioclase schist and interlayered(?) conglomerate in the northeast corner of the map are tentatively assigned to this unit. The conglomerate is similar to that in the southern exposures of the unit but the schist is more muscovite- and quartz-rich relative to schist in the south. Metamorphic grade increases from greenschist facies in the west to amphibolite facies in the east. Unit interpreted to be largely sedimentary in origin, but may include some volcanic or intrusive layers. Normalized SiO<sub>2</sub> concentrations range from 51 to 60 percent (Table 1). In the central and southern parts of map, Onasch (1977, 1987) mapped this unit as the Fiddle Creek Schist of Hamilton (1963, 1969). Some of what we map as Fiddle Creek Schist west of the Salmon River at the south edge of the map was considered Lightning Creek Schist by Hamilton (1969) and Fiddle Creek Schist by Onasch (1977, 1987). We have not been able to distinguish these two units here or elsewhere and have used the term Fiddle Creek Schist exclusively. Rocks in northeast corner of map were assigned by Lund and others (1993) to the Rapid River plate and divided into chlorite schist of mafic volcanic protolith and muscovite schist of intermediate and felsic volcanic protolith. Both were tentatively correlated with the Seven Devils Group. Name preferred here for both the northern and southern exposures is the Fiddle Creek Schist, the type area of which is 1 mile south of the map. The Fiddle Creek Schist is similar compositionally to Seven Devils Group greenstone in the Wallowa

KPms | Marble of Sheep Gulch (Cretaceous to Permian)—Informal name applied here to gray marble exposed in the lower part of Sheep Gulch east of Lucile and as thin layers within KPfc. Crinoid stems present along Wet Gulch (lat 45.5575° N., long 116.2721° W.). Previously mapped by Onasch (1977, 1987) as Triassic Martin Bridge Formation. Interpretation here is that this marble is in depositional contact with the Fiddle Creek Schist and thus part of the Riggins Group. Although marble is reported in the Riggins Group (Onasch, 1977), none of the mapped bodies are as thick as the marble of

might be a separate arc-related sequence of rocks.

terrane (TRPgs) and is probably a higher grade equivalent. Alternatively, it

KPcp Calcareous banded phyllite (Cretaceous to Permian)—Dark gray banded phyllite exposed only in northeast part of map. Phyllite is dense, fine-grained, locally calcareous, and contains small porphyroblasts of chloritoid(?). Unit is structurally below marble interpreted as Marble of Sheep Gulch (*KPms*), a relationship similar to that found along Slate Creek northeast of the map area (Kauffman and others, 2011). Previously mapped by McCullough (1984) as Lucile Formation. Only tentatively correlated here with the Lucile.

#### Chair Point Igneous Complex Igneous rocks in the southeast part of the quadrangle were recently determined to be Permian in age by U-Pb dating of zircon (Karen Lund, oral

commun., 2009). Only a fine-grained phase is present on this map, but

\* Major elements are normalized on a volatile-free basis, with total Fe expressed as FeO

All analyses performed at Washington State University GeoAnalytical Laboratory, Pullman, Washington

more coarsely crystalline biotite tonalite is present immediately east of the map boundary. Contact relations with the Riggins Group (KPfc) are unknown. Although presently mapped as a contact, the igneous complex might be thrust over KPfc, or, less likely, intrusive into it. Clasts in KPfc are similar to the Pf unit, suggesting KPfc is younger. Relationship of these Permian rocks to felsic intrusive rocks of Permian age in the Cougar Creek complex of the Wallowa terrane is uncertain, but similarity of age and composition indicate the Chair Point complex may also be basement to the Seven Devils Group.

Mafic schist (Cretaceous to Permian)—Garnet-plagioclase-hornblende-chlorite schist and granofels intermixed with Pf unit. 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.

Pf Felsite (Permian)—Massive light gray to tan felsite, typically iron stained, exposed in southeast corner of map. Characterized by fine grain size and lack of layering; garnet-bearing immediately east of map. Interpreted as shallow intrusive rocks. Locally cut(?) by rocks tentatively interpreted to have been mafic dikes (KPmsc), now metamorphosed to garnet-hornblendechlorite schist. Permian age based on U-Pb dating of zircon from a sample near the eastern map boundary (Karen Lund, oral commun., 2009).

### STRUCTURE

The structural history of this area is complex and long-lived. Early contractional structures include folds and mylonite shear zones that deform Paleozoic-Mesozoic aged rocks and are oriented parallel to the regional northeast-southwest structural grain. Later extensional brittle-ductile structures parallel, and commonly reactivate, older contractional shear zones and also deform Miocene aged rocks of the Columbia River Basalt Group. Final deformation occurred on a series of folds that cross the regional structural grain.

#### EARLY STRUCTURES

Early structures are likely Mesozoic in age, but could possibly be as old as Permian and as young as Paleogene. These structures include map-scale folds developed in the eastern Salmon River belt that are close to isoclinal, and upright to overturned with west-northwest vergence. Most are related to the Slate Creek antiform, mapped by Lund and others (1993) 5 miles northeast of the map, which extends southwest into the Lucile quadrangle and plunges to the south-southwest. Although it is an open fold near Slate Creek, here it appears to be overturned to the west. The map pattern is suggestive of an overturned synform on western flank of the antiform, but Columbia River basalts cover the area that would confirm continuity of the marble of Sheep Gulch around the nose of the synform and hence folding of a single marble unit as we have shown. This style and intensity of folding is not apparent in assemblages to the west, and we infer that they largely predate juxtaposition with these assemblages on early contractional shear zones described below. The Slate Creek antiform may well fold an earlier fold, highly overturned to the west, that has inverted the stratigraphy immediately east of the Rapid River thrust. As discussed under the headin "Eastern Salmon River Belt", and shown schematically in Figure 1, the presence of carbonate rocks above fine-grained clastic rocks is opposite of the stratigraphy in the Wallowa terrane.

Rocks in much of the western and southern parts of the map area are deformed by mylonite shear zones. Fabrics in these zones include strongly developed mylonite foliation and weaker lineation. Kinematic indicators are variably developed, but consistently indicate contractional strain and northwest vergence. These zones vary from belts that are on the order of miles wide and within which sequences of rock units are recognizable to relatively discrete belts 4.6-9 m (15-30 ft) wide that juxtapose distinct rock assemblages. Several of these discrete shear zones appear to carry significant displacement and are discussed below.

### Heavens Gate Fault

The Heavens Gate fault was mapped west of Heavens Gate Lookout (12 miles southwest of the map) by Gray and Oldow (2005). Gualtieri and Simmons (1978, 2007) mapped the same structure to the north, just west of the divide between the Snake River and Salmon River. We believe the fault crosses the divide about 1.6 km (1 mi) northwest of Round Knob 4.8 km (3 mi west-southwest of map area), enters the Lucile quadrangle south of Cow Creek, and crosses the Salmon River 3.2 km (2 mi) north of Lucile. Near Heavens Gate Lookout the fault separates relatively undeformed volcanic flows and volcaniclastic rocks of the Seven Devils Group in the west from strongly deformed volcaniclastic rocks of the western Salmon River belt (Gray and Oldow, 2005). In the Lucile quadrangle exposures are poor, but the brittle-ductile fault appears to place less deformed greenstone (RPvg) against highly deformed greenstone and marble (RPVg and RPmg). Sheared and brecciated rock was noted along the fault south of Cow Creek and on the ridge northwest of Lucile. Our tentative interpretation based on map pattern and kinematic indicators is that it is an early thrust fault that has had significant later normal motion as discussed in more detail below.

## Slate Creek Thrust

The Slate Creek thrust is an enigmatic structure that appears to flank the east side of the Slate Creek antiform. To the east of the map along John Day Creek it marks a grade change from amphibolite facies rocks in the hanging wall to greenschist facies rocks in the footwall to the west. There it is folded by the antiform. In the Lucile quadrangle, the grade change is not as marked, and the thrust appears to continue south of the map area without

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 rocks in the east. We have mapped the eastern contact of the Lucile Slate to the north across the Lucile quadrangle and interpret it as a ductile fault. Along strike, hanging-wall rocks east of that contact change from Fiddle Creek Schist to the marble of Sheep Gulch. Both the schist and marble are interpreted as Riggins Group. We believe that the marble of Sheep Gulch is removed by faulting near the south edge of the map in an area where the Rapid River thrust is covered by Columbia River basalts. An alternative explanation is that the marble of Sheep Gulch is unconformably overlain by the Fiddle Creek Schist and locally removed along that unconformity. Much of the Lucile Slate is highly deformed 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 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

# Slate Creek Thrust

The Slate Creek thrust is an enigmatic structure that appears to flank the east side of the Slate Creek antiform. To the east of the map along John Day Creek it marks a grade change from amphibolite facies rocks in the hanging wall to greenschist facies rocks in the footwall to the west. There it is folded by the antiform. In the Lucile quadrangle, the grade change is not as marked, and the thrust appears to continue south of the map area without significant folding.

apparently not large.

# Thrusts in Northeast Corner of Map

Two thrust faults were mapped northeast of the Rapid River thrust in the northeast corner of the map. An alternative explanation is that the Rapid River thrust is tightly folded in this area (Lund and others, 1993). We prefer the multiple-thrust model because of the lack of map pattern symmetry of believe that this shear zone continues to the northeast and joins a thrust fault on the northeast limb of the Slate Creek anticline on the McKinzie Creek quadrangle (Kauffman and others, 2011), and strikes to the north to join another shear zone we mapped immediately south of the town of Slate Creek on the Slate Creek quadrangle (Schmidt and others, 2009b).

#### LATER STRUCTURES Miocene and possibly younger east-west directed extension that overlaps

which forms a northern arm of Neogene Basin and Range extension. The geometry of normal faulting that accommodated extension was strongly influenced by the older contractional structural belts, including the Heavens Gate fault. Along part of this 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. Apparently the earlier mylonite shear zones have been reactivated to accommodate Miocene and younger extension. This relationship is corroborated by studies 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.

with and postdates basalt extrusion ensued in the Salmon River corridor,

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 folds deform the Miocene Columbia River Basalt Group and thus are relatively young.

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### SYMBOLS

Normal fault: ball and bar on downthrown side; dashed where

Contact: dashed where approximately located; dotted where concealed beneath younger units.

approximately located; dotted where concealed. Reactivated thrust fault: teeth on upper plate; bar and ball on downthrown

side on reactivated fault segments; dashed where inferred; dotted Fold axis: arrow indicates direction of plunge; dotted where concealed.

Anticline.

→ Syncline.

Overturned anticline.

Overturned syncline. Strike and dip of bedding or volcanic flows.

Estimated strike and dip of bedding or volcanic flows.  $\checkmark^{81}$  Strike and dip of foliation.

★ Strike of vertical foliation.

Strike and dip of mylonitic foliation.  $\int_{30}$  Strike and dip of foliation at an angle to bedding.

 $\int_{0}^{70}$  Strike and dip of cleavage.

→ 29 Bearing and plunge of lineation, type unknown.

→ 15 Bearing and plunge of lineation in L tectonite

Bearing and plunge of small fold axis.

15 Bearing and plunge of asymmetrical small fold showing counterclockwise rotation viewed down plunge.

<sup>16</sup> Bearing and plunge of asymmetrical small fold showing clockwise rotation viewed down plunge.

№25 Bearing and plunge of mylonitic lineation

→ 26 Bearing and plunge of recumbent fold.

≥ 30 Bearing and plunge of crenulation lineation.

Gravel pit.

Limit of historic hydraulic placer mining.

Quartz vein. Intensely tractured or brecciated rock associated with faulting

Sample location and number. - - Garnet isograd: Garnet present on hachured side of line.

Mines and Geology Pamphlet 128, 83 p.

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Table 1. Major oxide and trace element chemistry for rocks collected in the Lucile quadrangle Trace elements in parts per million Major elements in weight percent mber Latitude Longitude Rock name unit SiO, TiO, Al,O, FeO\* MnO MgO CaO Na,O K,O P,O, Ni Cr Sc V Ba Rb Sr Zr Y Nb Ga Cu Zn Pb La Ce Th Nd KPfc 50.80 1.258 19.68 10.25 0.149 5.46 8.40 2.91 0.80 0.300 41 81 30 207 68 10 477 66 18 3.3 16 103 83 1 3 17 1 88 1.687 17.53 13.99 0.148 7.12 2.82 2.56 1.01 0.255 15 18 43 410 225 13 60 85 28 3.5 20 47 115 1 5 19 0 1 .22 1.057 19.68 8.13 0.102 7.61 4.57 4.45 1.93 0.250 56 121 27 228 135 19 334 81 18 4.1 20 73 113 2 6 17 1 1 09RL743b 45.5096 -116.2932 mafic sandstone KPfc 60.35 1.327 17.18 8.05 0.100 4.55 3.74 3.35 1.14 0.209 7 12 30 164 151 16 290 120 42 2.9 19 17 106 5 5 17 1 16 09RL748 45.5074 -116.3644 greenstone TrPvg 46.16 1.107 18.78 11.60 0.212 7.62 12.27 1.79 0.27 0.187 21 35 36 366 56 3 466 36 19 2.4 18 82 78 1 3 8 1 8