Geologic Map of the John Day Mountain Quadrangle, Idaho County, Idaho

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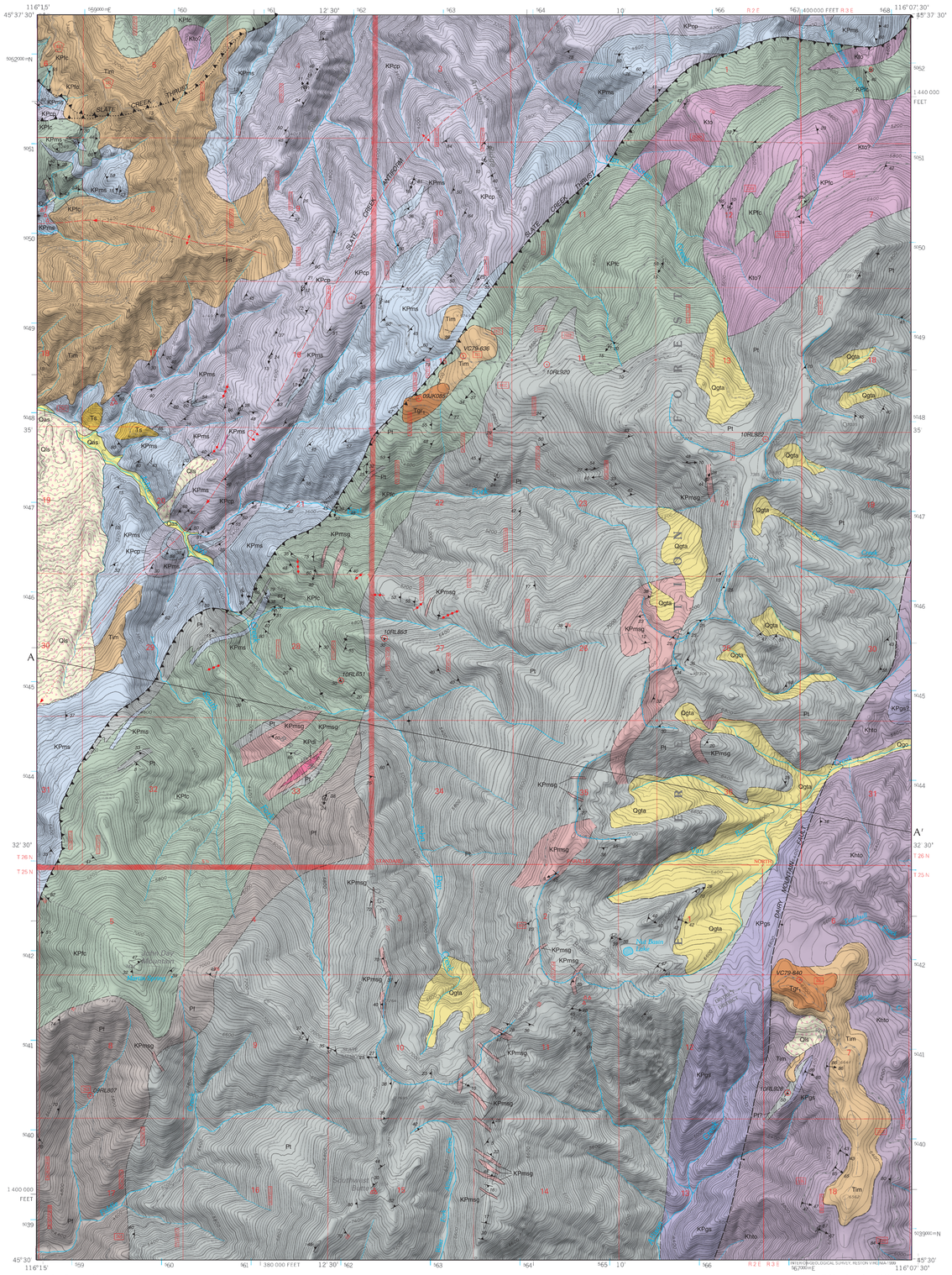
2011



Base digitally scanned from 24,000-scale USGS film separates, 1995.

Shaded elevation from 10 m DEM.

Topography compiled 1962. Planimetry derived from imagery taken 1992. Public Land Survey System and survey control current as of 1995. Partial field check by U.S. Forest Service 1995.

Projection: Idaho coordinate system, west zone (Transverse Mercator). 1927 North American Datum.

10,000-foot grid ticks based on Idaho coordinate system, west zone.

1000-meter Universal Transverse Mercator grid ticks, zone 11.

UTM Grid and 1997 Magnetic North Declination at Center of Map

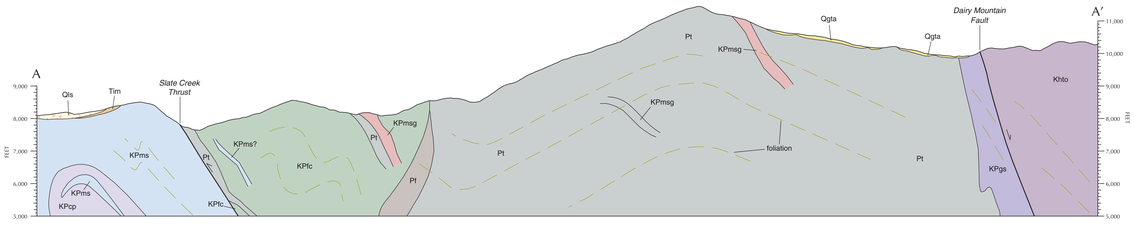
SCALE 1:24,000

Contour interval 40 feet

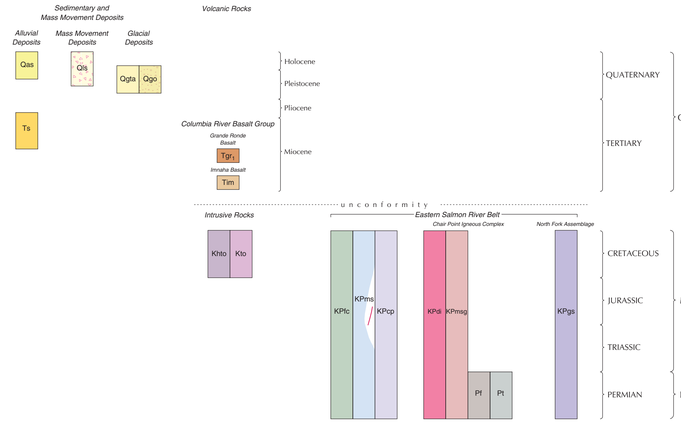
QUADRANGLE LOCATION

ADJOINING QUADRANGLES

Field work conducted 2009-2010.
This geologic map was funded in part by the U.S. Geological Survey National Cooperative Geologic Mapping Program, USGS Award No.G10AC00223.
Digital cartography by Jane S. Freed at the Idaho Geological Survey's Digital Mapping Lab.
Review status: Authors only.
Map version 10-13-2011.
PDF (Acrobat Reader) map may be viewed online at www.idahogeology.org.



CORRELATION OF MAP UNITS



INTRODUCTION

The geologic map of the John Day Mountain quadrangle shows rock units exposed at the surface or underlying thin surficial cover of soil and colluvium. Thicker surficial alluvial, glacial, 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 2009 and 2010 as a continuation of investigations in adjacent quadrangles, as well as compilation of previous research, including that of Edwin Price (unpublished 1976–1977 field work), Onasch (1977, 1987), Lund (1984), McCullough (1984), Lund and others (1993), and reconnaissance mapping from 1978 to 1980 by V.E. Camp (Camp, 1981; Swanson and others, 1981). Some attitudes from previous work are included on this map.

The oldest rocks in the quadrangle are Permian to Cretaceous plutonic and metamorphic rocks. These folded and faulted basement rocks are locally capped by Columbia River Basalt Group lava flows, which are also faulted and tilted by reactivation of older basement structures. The heads of several valleys near Nat Basin were glaciated, forming cirques and depositing till and outwash. A large landslide at the west edge of the map formed near the contact between basalt and basement rocks.

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.

SEDIMENTARY AND MASS MOVEMENT DEPOSITS

Alluvial Deposits

Qas **Channel and flood-plain deposits of Salmon River tributaries (Holocene and late Pleistocene)**—Moderately sorted, stratified to massive, subangular to rounded pebble to boulder gravel in channels, flood plains, and low terraces of John Day Creek. Includes finer grained alluvium immediately upstream of landslide toe. Locally includes poorly sorted debris-flow deposits. The unit is 1.5-9 m (5-30 ft) thick.

Ts **Sediment, undivided (Miocene?)**—Well-rounded pebble to cobble gravels locally mixed with finer grained reddish sediments on the north side of John Day Creek near the west edge of the map. Clasts include vein quartz, porphyry, phyllite, trondhjemite, diorite, and marble. A few blocks are as large as 3 m (10 ft). Basalt clasts were not noted in the deposit, indicating the gravels may predate the basalt.

MASS MOVEMENT DEPOSITS

Qls **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.

GLACIAL DEPOSITS

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. Formed in alpine cirques 2,000 m (6,600 ft) elevation and above, and associated valleys with moraines that extend down to about 1,800 m (5,900 ft) elevation. The thickness of the deposits is highly variable and ranges from 3 to 30 m (10 to 100 ft).

Qgo **Outwash gravel (Holocene and late Pleistocene)**—Subrounded to rounded, moderately sorted sandy cobble to boulder gravel traceable to terminal moraine deposits (Qgta). The unit is 3-9 m (10-30 ft) thick.

VOLCANIC ROCKS

Columbia River Basalt Group

The only Columbia River Basalt Group units in the quadrangle are Imnaha Basalt and small areas of overlying R_2 Grande Ronde Basalt.

Grande Ronde Basalt

Tgr$_2$ **Grande Ronde Basalt, R_2 magnetostratigraphic unit (Miocene)**—R_2 Grande Ronde Basalt is fine grained and aphyric to sparsely plagioclase-phyric or microphyric, and typically forms tiered cliffs with intervening moderately steep to steep slopes. Occurs in two small areas, one in the S½, sec. 15, T. 26 N., R. 2 E., and the other in the southeast part of the map along FS Road 441.

Imnaha Basalt

Tim **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 more than 300 m (1000 ft).

PRE-TERTIARY ROCKS

Rocks older than the Columbia River Basalt Group underlie much of the quadrangle and consist of: (1) Permian to Cretaceous(?) metasedimentary, metaplutonic, and possible metavolcanic rocks of the eastern Salmon River belt throughout much of the map, and (2) plutonic rocks of probable Cretaceous age in the southeastern and northern parts of the map. These units occur within a strongly deformed assemblage of rocks that are presently situated immediately west of the Salmon River suture. They are bounded to the east by Precambrian-Cretaceous rock assemblages of North American origin, and to the west by Permian-Cretaceous rocks of the Wallowa island arc terrane.

Cretaceous Intrusive Rocks

Khto **Hornblende-biotite tonalite (Cretaceous)**—Foliated hornblende-biotite tonalite and hornblende-biotite tonalite gneiss that occurs in a sheeted igneous complex in the southeast part of the map. Includes minor amounts of biotite tonalite, plagioclase-hornblende gneiss, and biotite-feldspar-quartz gneiss and is characterized by considerable outcrop-scale variability and lit-par-lit injection. Contains epidote interpreted to be primary. Includes rocks mapped as the Van Ridge gneiss and Spring Creek tonalite in the adjoining quadrangle to the south (Blake and others, 2009).

Kto **Tonalite and trondhjemite (Cretaceous)**—Biotite tonalite and garnet-biotite-muscovite trondhjemite in northeast part of map. Dated plutonic rocks of similar composition in the region include 113 Ma trondhjemite and tonalite north of Slate Creek (Unruh and others, 2008), one mile north of the map boundary.

Eastern Salmon River Belt

The eastern Salmon River belt (Gray and Oldow, 2005) consists of poorly dated metamorphic rocks east of and in the hangingwall of the Rapid River thrust, which is located about 0.6 km (0.4 mi) west of the western map boundary in the Lucile quadrangle (Lewis and others, in prep). It lies west of the Salmon River suture, a major lithospheric boundary marking the western margin of cratonal North America that has been extensively intruded and sheared by transpressional deformation on the Early Cretaceous Western Idaho shear zone. The Salmon River suture projects northnortheast from the Salmon River to a point immediately east of the southeastern corner of the map (Blake and others, 2009). The Slate Creek antiform is the primary structural feature in this part of the eastern Salmon River belt. From structurally lowest to highest levels it exposes calcareous banded phyllite (*KPcp*), marble of Sheep Gulch (*KPms*), and Fiddle Creek Schist (*KPlc*). We are uncertain of the age or 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 (Lund, 1984; McCullough, 1984), or combined in the redefined Martin Bridge Formation (Lund and others, 1993). The most straightforward interpretation is that the marble of Sheep Gulch is correlative with limestone of the Martin Bridge Formation and the calcareous banded phyllite is correlative with the Lucile Formation. If this interpretation is correct, then the strata in the Slate Creek antiform are upside down, because the marble should underlie, not overlie, clastic rocks of the Lucile Formation (and likely equivalent Hurwal Formation, the unit above the Martin Bridge along the Snake River south of Lewiston, Idaho; Follo, 1994). An alternate scenario is that the rocks in the Slate Creek antiform are upright and that the calcareous banded phyllite (*KPcp*) and marble of Sheep Gulch (*KPms*) are part of, or below, the Riggins Group. The only age constraint of these rocks is that they are intruded by, and thus older than, the 113 Ma *Kto* unit north of the map area (Unruh and others, 2008).

KPlc **Fiddle Creek Schist (Cretaceous to Permian)**—Mafic and felsic schist and minor metaconglomerate in the central and northwestern part of map. Mafic schist in central part of map contains plagioclase, chlorite, muscovite, biotite, quartz, epidote, Fe-carbonate, and opaque minerals. Felsic schist contains muscovite well in excess of chlorite, and abundant plagioclase and quartz, but is otherwise similar. Garnet typically abundant (as much as 20 percent of the rock locally). Late hornblende present on John Day Mountain. Metaconglomerate on the ridge south of the East Fork John Day Creek contains clasts as much as 20 cm across. Light gray mylonitic muscovite-quartz-plagioclase schist and interlayered(?) conglomerate at the western map boundary appear to be lower grade (garnet and hornblende are absent), but are tentatively assigned to this unit. The conglomerate there contains 1-15 cm felsite clasts. *KPlc* unit interpreted to be largely clastic sedimentary in origin, but may include some volcanic or intrusive layers. In the southwestern part of map, Onasch (1977, 1987) mapped this unit as the Fiddle Creek Schist of Hamilton (1963, 1969). Rocks in northwest 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. Name preferred here for both the northern and southern exposures is the Fiddle Creek Schist, the type area of which is 3.2 km (2 mi) southwest of the map (Hamilton, 1963). Like previous workers, we tentatively correlate these rocks with the Seven Devils Group of Vallier (1977).

KPms **Marble of Sheep Gulch (Cretaceous to Permian)**—Informal name applied here to coarsely crystalline light gray marble in the central and northwest parts of the map. Interlayered with, but largely above, the *KPcp* unit. Unit grades downward into *KPcp*. Interpretation here is that this marble is in fault contact with the overlying Fiddle Creek Schist in the central part of the quadrangle, in depositional contact with the schist in the northwest part of the quadrangle, and in both depositional and fault contact with the schist in the Lucile is not as dramatic as in the Lucile quadrangle, the grade change is not as marked, and the thrust appears to continue south without significant folding. Lund and others 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 immediately west of the quadrangle boundary and have mapped it there on the basis of deformation within and east of the Lucile Slate (Lewis and others, in prep.).

WESTERN IDAHO SHEAR ZONE

Foliations in the southeast corner of the map are consistently steeper east dipping and have a down-dip lineation, in contrast to the mostly shallowly dipping foliations in the *Pt* unit to the west.. This fabric may be related to the western Idaho shear zone as mapped on strike to the south (Blake and others, 2009). This shear zone is interpreted as a late Cretaceous structure that formed along the eastern boundary of the eastern Salmon River belt.

DAIRY MOUNTAIN FAULT

A north-northeast trending fault with down-to-the-east normal displacement is present in the southeastern part of the map where it places Columbia River basalts against pre-Tertiary rocks. This fault is the southern continuation of the Dairy Mountain fault mapped to the north (Kauffman and others, in prep.), where it offsets the basalt about 270 m (880 ft). The Dairy Mountain fault may be an older, west-directed reverse fault that has been reactivated following extrusion of the basalts. Similar reactivation is documented to the south near McCall (Giorgis and others, 2006).

LATE FOLDING

A fold orthogonal to the Slate Creek antiform warps the Slate Creek thrust and the general lithologic trends in the northwestern part of the map. This east-west fold deforms the Miocene Columbia River Basalt Group and thus is relatively young.

North Fork Assemblage

Rocks in the North Fork assemblage are roughly coincident with those in the North Fork block of Lund and others(1993) and consist of amphibolite-facies metasedimentary rocks of uncertain age that are immediately west of continental North American rocks. The term "assemblage" is used here because we are not certain they are part of a fault-bounded block as envisioned by Lund and others (1993). We include them here as an eastern subunit within the eastern Salmon River belt. Similar rocks along strike to the northeast have been mapped and described by Myers (1982), Hoover (1986), and Kauffman and others (2008). They may be equivalent to the Orofino series exposed 100 km (60 miles) to the north (Anderson, 1930; Hietanen, 1962) and the Pollock Mountain amphibolite of Selverstone and others (1992) exposed 13 km (8 miles) to the south along the Salmon River. All may be higher grade equivalent rocks of the Squaw Creek Schist of the Riggins Group of Hamilton (1963) and (or) the *KPcp* to the west.

KPgs **Gneiss and schist (Permian to Cretaceous)**—Fine- to medium-grained garnet-plagioclase-hornblende gneiss, biotite-plagioclase quartz schist, and calc-silicate rocks containing garnet, plagioclase, zoisite, hornblende, quartz, and minor potassium feldspar. Present only in southeastern part of map. Although some plagioclase-amphibole gneiss may be metavolcanic in origin, most of the unit is probably metasedimentary.

STRUCTURE

The structural history of this area is complex and long-lived. The area lies within the Salmon River suture zone and includes the west-vergent fold and thrust belt immediately west of the Salmon River suture. It also includes fabrics that are likely related to the Late Cretaceous western Idaho shear zone in the southeastern corner of the map. Early contractional structures include folds and faults that deform Paleozoic-Mesozoic age rocks and are oriented parallel to the regional northeast-southwest structural grain. Final deformation occurred on north-south brittle faults and on east-west folds that cross the regional structural grain.

SLATE CREEK ANTIFORM

Most folds appear to be related to the Slate Creek antiform, mapped by Lund and others (1993) at the north edge of the map, which extends southwest across the John Day Mountain quadrangle and plunges to the southsouthwest. Although it is an open fold near Slate Creek to the north, at John Day Creek it appears to be overturned to the west. 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 heading "Eastern Salmon River Belt", the presence of carbonate rocks (*KPms*) above fine-grained calcareous clastic rocks (*KPcp*) is opposite of the stratigraphy in the Wallowa terrane. Conspicuously low metamorphic grade exhibited by rocks in *KPcp* unit corroborate a deformation history in which the assemblage remained at relatively shallow crustal levels as compared with presently overlying rock assemblages.

SLATE CREEK THRUST

The Slate Creek thrust is an enigmatic structure that appears to be folded by the Slate Creek antiform. 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. The rocks near the fault have a strong foliation and are highly folded. To the north along Slate Creek, this structure also carries amphibolite facies rocks in the hanging wall that are juxtaposed with greenschist facies rocks in the footwall, but rocks there are not as dramatically folded along the fault (Kauffman and others, in prep.). To the west in the Lucile quadrangle, the grade change is not as marked, and the thrust appears to continue south without significant folding. Lund and others 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 immediately west of the quadrangle boundary and have mapped it there on the basis of deformation within and east of the Lucile Slate (Lewis and others, in prep.).

KPcp **Calcareous banded phyllite (Cretaceous to Permian)**—Medium to dark gray calcareous biotite phyllite and schist in the core of the Slate Creek antiform and at the western map boundary. 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. Considering its present structural position beneath *KPms* and *KPlc* units, *KPcp* unit is characterized by conspicuously low-grade metamorphism. We have not found garnet or hornblende in this unit despite an appropriate composition to form these minerals. 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). Rock most closely resembles the 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, the Lucile Slate, and the *KPcp* unit are correlative units..

Chair Point Igneous Complex

Felsic igneous rocks in the southwest part of the quadrangle were recently determined to be Permian in age by U-Pb dating of zircon (Karen Lund, oral commun., 2009). Both a fine-grained phase (felsite, *Pf*) and a more coarsely crystalline biotite trondhjemite (*Pt*) from 0.8 km (0.5 mi) south of the map were dated. Contact relations with the Fiddle Creek Schist (*KPlc*) are unknown. Clasts in *KPlc* are similar to the *Pf* unit, suggesting *KPlc* is younger, but thin lenses of *Pt* in *KPlc* in John Day Creek are suggestive of intrusive sills. 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 igneous rocks (now largely metamorphosed) are also present within the Chair Point complex but have not been dated. As noted below, they may be as young as Cretaceous.

KPdi **Diorite (Cretaceous to Permian)**—Medium-grained hornblende diorite in a single body exposed along Brushy Ridge. Plagioclase and hornblende are the major constituents but minor quartz and potassium feldspar also present. Diorite appears to be rimmed by hornblende gneiss (*KPmsg*) and may be an unmetamorphosed core of an originally more extensive mafic plutonic body.

KPmsg **Mafic schist and gneiss (Cretaceous to Permian)**—Medium- to fine-grained biotite-quartz- hornblende-plagioclase schist and gneiss within *Pt*, *Pf*, and *KPlc* units. Locally contains garnet. May represent metamorphosed mafic dikes or, alternatively, screens of mafic country rock (e.g. *KPgs*).

Pf **Felsite (Permian)**—Massive to foliated light gray to tan felsite, typically iron stained, exposed in southwest part of map. Characterized by fine grain size and lack of layering. Interpreted as shallow intrusive rocks of trondhjemitic composition. Permian age based on U-Pb dating of zircon from a sample near the western map boundary (Karen Lund, oral commun., 2009). Like *Pt*, rock is characterized by low Sr concentrations (< 200 ppm) and low CaO concentrations (< 2.6 weight percent) as shown in Table 1.

Pt **Biotite trondhjemite (Permian)**—Light to medium gray biotite trondhjemite in the central part of the map. Typically foliated and characterized by recrystallized grains of quartz and feldspar. Contains minor amounts of muscovite and epidote. The 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. Plagioclase is sodic (~An_{15}) and relatively free of inclusions. As shown in Table 1, rock is characterized by low Sr concentrations (< 200 ppm) and low CaO concentrations (< 2.6 weight percent) relative to nearby Cretaceous biotite tonalite (> 700 ppm Sr and > 5.0 weight percent CaO), presumably because of the presence of sodic plagioclase. Includes a small mass of biotite trondhjemite east of the Dairy Mountain fault with higher Sr concentrations (typical *Pt* (268 ppm) but lower than nearby Cretaceous tonalites (sample 10RL928; Table 1).

SYMBOLS

- Contact: dashed where approximately located.
- Normal fault: ball and bar on downthrown side; dashed where approximately located; dotted where concealed.
- Thrust fault: teeth on upper plate; dashed where inferred; dotted where concealed.
- Fold axis: arrow indicates direction of plunge; dotted where concealed.
- Anticline.
- Overturned anticline.
- 14 Strike and dip of bedding or volcanic flows.
- 10 Estimated strike and dip of bedding or volcanic flows.
- 81 Strike and dip of foliation.
- 40 Estimated strike and dip of foliation.
- Strike of vertical foliation.
- 60 Strike and dip of mylonitic foliation.
- 66 Strike and dip of compositional layering.
- 70 Strike and dip of cleavage.
- 39 Bearing and plunge of lineation, type unknown.
- 30 Bearing and plunge of mineral lineation.
- 8 Bearing and plunge of small fold axis.
- 15 Bearing and plunge of asymmetrical small fold showing counterclockwise rotation viewed down plunge.
- 38 Bearing and plunge of asymmetrical small fold showing clockwise rotation viewed down plunge.
- 30 Bearing and plunge of crenulation linear.
- Cirque headwall: tics on glaciated side.
- Quartz vein.
- Intensely fractured or brecciated rock.
- 09JK085 Sample location and number.

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Table 1. Major oxide and trace element chemistry of samples collected in the John Day Mountain quadrangle.

Sample number	Latitude	Longitude	Unit name	Map unit	Major elements in weight percent										Trace elements in parts per million															
					SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th	Nd	U
09JK085	45.5865	-116.1954	R_2 Grande Ronde Basalt	Tgr_2	54.68	2.564	14.10	11.66	0.198	3.58	8.07	3.04	1.70	0.409	17	14	33	370	637	48	368	217	41	16.3	22	44	136	8	22	55	5	31	2
09RL807	45.5165	-116.2423	felsite	Pf	76.05	0.456	12.89	2.22	0.036	0.61	1.90	5.47	0.29	0.087	1	4	11	20	89	4	165	152	44	3.0	15	0	9	2	12	26	0	18	0
10RL831	45.5582	-116.2065	felsic schist	KPlc	68.23	0.809	14.76	5.86	0.091	2.40	1.21	4.96	1.47	0.199	1	4	21	74	233	29	74	157	50	5.5	16	3	36	5	11	25	2	18	1
10RL853	45.5624	-116.2003	biotite tonalite	Pt	78.00	0.363	11.71	2.25	0.032	0.53	1.03	4.28	1.75	0.058	0	6	7	28	435	22	82	222	37	8.8	13	1	16	3	13	25	2	11	0
10RL920	45.5899	-116.1771	biotite tonalite	Pt	78.41	0.301	12.16	1.81	0.027	0.41	0.81	3.92	2.08	0.063	3	4	7	25	479	29	86	173	25	6.9	12	8	19	2	22	47	2	21	1
10RL922	45.5824	-116.1458	biotite tonalite	Pt	76.28	0.329	12.59	2.25	0.036	0.65	2.35	3.96	1.53	0.040	2	4	7	39	334	22	154	156	28	3.6	12	8	15	3	10	29	1	17	1
10RL928	45.5168	-116.1427	biotite tonalite	Pt/	75.87	0.285	12.73	3.11	0.102	0.45	2.60	4.22	0.56	0.075	14	4	8	42	231	10	268	90	16	2.0	14	17	41	3	6	11	0	8	1
**VC79-636	45.5915	-116.1902	Imnaha Basalt	Tim	51.01	3.068	14.58	14.04	0.220	4.16	8.32	2.88	1.27	0.441																			
**VC79-640	45.5281	-116.1410	R_2 Grande Ronde Basalt	Tgr_2	57.60	2.314	15.37	8.83	0.190	3.22	6.79	2.98	2.29	0.421																			

* Major elements are normalized on a volatile-free basis, with total Fe expressed as FeO.
** Samples by V.E. Camp, used with permission; no trace element analyses available.
All analyses performed at Washington State University GeoAnalytical Laboratory, Pullman, Washington.

Published and sold by the Idaho Geological Survey
University of Idaho, Moscow, Idaho 83844-3014