GEOLOGIC MAP OF THE KOOSKIA 30 x 60 MINUTE QUADRANGLE, IDAHO

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INTRODUCTION

Geology depicted on this 1:100,000-scale Kooskia 30' x 60' quadrangle is based on previous mapping, extensive fieldwork in 2002, and minor follow up in 2003-2006. The areal extents of the sources used to prepare this map are shown on Figures 1 and 2. The principal sources were 1990 and 1991 mapping by the Idaho Geological Survey (Lewis and others, 1992a and 1992b), a 1:48,000-scale map by Hietanen (1963), unpublished 1981-1992 mapping by Paul Myers, and unpublished 1978-1980 field maps of Rolland Reid and Enid Bittner. Glacial geology is based on mapping by Dingler (1981) and Dingler and Breckenridge (1982). This Digital Web Map is a preliminary report that has not been technically reviewed.

The quadrangle is located at the margin of the Columbia Plateau and the Northern Rocky Mountains physiographic provinces in north-central Idaho. The Columbia Plateau is composed mainly of Miocene flood basalts, whereas the Northern Rocky Mountains are composed of Precambrian to Paleozoic metamorphic rocks intruded by Jurassic to early Tertiary plutonic rocks. Adding to the complexity of the area are the island-arc rocks of the Wallowa terrane, accreted to the North American continent sometime during the Jurassic to Cretaceous. The mountains and plateau are now dissected by the Clearwater River and its major tributaries, the Selway and Lochsa rivers and the South Fork Clearwater River.

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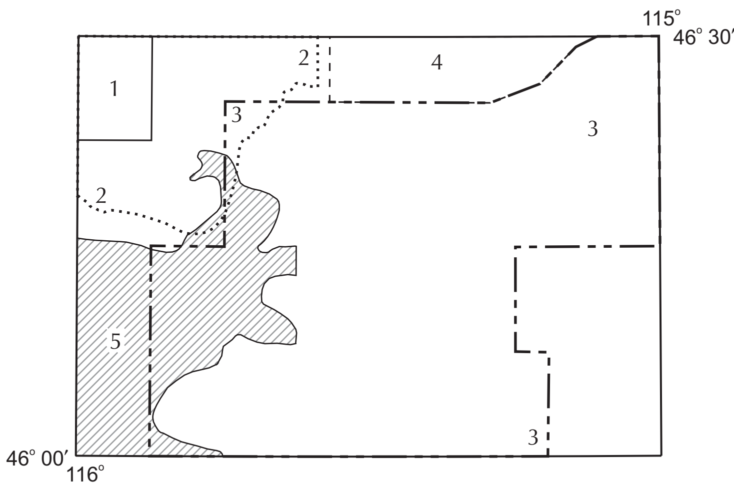
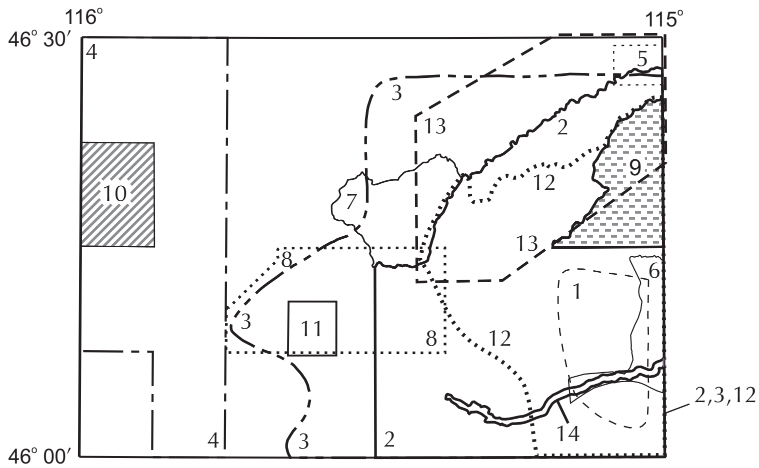


1. Bush and others, 2004.
2. Hietanen, Anna, 1963.
3. Lewis and others, 1992a.
4. Lewis and others, 1992b.
5. Myers, P.E., unpubished mapping 1981-1992.

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



1. Bittner-Gaber, 1983.
2. Dingler,1981.
3. Greenwood and Morrison, 1973.
4. Jenks, M.D. unpublished mapping, 1998, Potlatch Corporation.
5. Kuhns, 1980.
6. Lund, 1980.
7. MacDonald, 1986.
8. Morrison, 1968.
9. Motzer, 1985.
10. Payne, J.D., unpublished mapping, 2004.
11. Pitz, 1985.
12. Toth, 1983.
13. Williams, 1977.
14. Wiswall, 1979.

Figure 2. *Index of previous geologic mapping used as secondary sources of data.*

DESCRIPTION OF ROCK 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). Mineral modifiers are listed in order of increasing abundance for both igneous and metamorphic rocks. Grain size classification of unconsolidated and consolidated sediment is based on the Wentworth scale.

QUATERNARY DEPOSITS

Qal Alluvial deposits (Holocene)–Stream deposits in modern drainages. Primarily channel and flood-plain deposits of the Clearwater River and its major tributaries, but includes local slope-wash and debris-flow deposits from canyon slopes. Most alluvium is composed of laterally discontinuous beds of subrounded to rounded cobbles, pebbles, sand, and silt.

Qaf Alluvial fan deposits (Holocene)–Poorly stratified, poorly sorted gravel in a matrix of granules, sand, silt, and clay. Gravel is composed of subangular pebbles, cobbles, and boulders. Fans form in canyon bottoms at the mouths of steep debris-flow chutes and small tributaries to the major streams.

Qls Landslide deposits (Holocene)–Poorly sorted and poorly stratified angular basalt fragments mixed with silt and clay. Landslide deposits include debris slides as well as blocks of basalt and sedimentary interbeds that have been rotated and moved laterally. Commonly form as a result of slumping of Latah Formation sediments.

Qtg Terrace gravel deposits (Holocene)–Mostly stream alluvium but may include some slope-wash and fan deposits. Differs from *Qal* only in its location on terraces that are well above river level. Primarily coarse channel gravels deposited during high-energy stream flow. Subrounded to rounded pebbles, cobbles, and boulders in a sand matrix. Includes intercalated colluvium and debris-flow deposits from steep side slopes.

Qpg Periglacial deposits (Holocene and Pleistocene)–Coarse angular blocky deposits of felseenmeer (block fields), patterned ground on flat and gently sloping uplands, and stone stripes on slopes, mostly developed in areas above treeline that were free of snow and ice during Pleistocene glaciations.

Qalc Cirque lake deposits (Holocene and Pleistocene)–Lacustrine silt and sand in cirque basins and moraine-dammed lakes. Locally includes mud and organic muck.

Qg Glacial deposits (late Pleistocene)–Brown to grayish, unsorted sandy cobble to boulder till, blocky angular to subangular granitic and metamorphic clasts in a sandy to clayey matrix. Includes deposits of Canteen Creek and Legend Lake glaciations of Dingler (1981) and Dingler and Breckenridge (1982). Forms end, lateral, and ground moraines with immature soil development oxidized less than a meter in depth, weak to moderate B horizon less than 30 cm in depth, and locally covered with loess and volcanic ash as much as 30 cm thick.

Qgow Glacial outwash deposits (Pleistocene)–Unsorted to moderately sorted, sandy pebble to boulder gravel; primarily fluvioglacial deposits. Includes minor amounts of till and postglacial alluvium.

Qgo Older glacial deposits (Pleistocene)–Brown to grayish deposits of cobbly and bouldery silty clay and clayey silt. Includes deposits of the Grave Peak glaciation of Dingler (1981) and Dingler and Breckenridge (1982). Unsorted to moderately sorted. Mostly till(?) with soil development oxidized less than a meter in depth and weak to strong B horizon less than 30 cm in depth; locally covered with loess and volcanic ash as thick as 30 cm.

OLDER SEDIMENTS AND SAPROLITE

Ts Sediment, undivided (Miocene and Oligocene?)–Unconsolidated, poorly sorted, fluvial sediment on upland surfaces. Similar to *Tls* but distant from Columbia River basalt outcrops so age is poorly constrained. Includes beds of gravel, sand, silt, and clay. Typically deeply weathered.

Tsap Saprolite (Miocene and Oligocene?)–Clayey residuum from parent rock weathered in place. Shown as pattern on parent rock.

Latah Formation

Clay, silt, sand and gravel deposits associated with the Columbia River Basalt Group.

Tls Latah Formation sediment (Miocene)–Unconsolidated, poorly sorted, fluvial sediment. Sequences of clay, silt, sand, and minor gravel adjacent to or overlying the Columbia River Basalt Group. Typically deeply weathered. Deposition caused by disruption of stream drainages and related base-level changes during outpouring of basalt lava.

Tli Latah Formation interbed (Miocene)–Sediment interbedded with basalt flows. Deposits range from cobbles to clay, but typically consist of sand; locally contains tuff or arkosic tuff. Commonly erodes forming benches of slumped sediment and basalt that are mapped as *Qls*.

COLUMBIA RIVER BASALT GROUP

The stratigraphic nomenclature for the Columbia River Basalt Group follows that of Swanson and others (1979b) and Camp (1981). In Idaho, the group is divided into four formations. From oldest to youngest, these are Imnaha Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. No Imnaha Basalt was found in the quadrangle, although it may occur at depth (Imnaha Basalt was noted in core from a test hole at the Kooskia National Fish Hatchery; William Rember, verbal commun., 2004). Grande Ronde Basalt, from base upward, has been subdivided into the informal R_1, N_1, R_2, and N_2 magnetostratigraphic units (Swanson and others, 1979b). Of these Grande Ronde units, only basalts from the R_1, N_1, and possibly the R_2 units were identified in the map area. Exposures occur along the incised drainages of the Clearwater River, the South Fork Clearwater River, and their tributaries. The only Wanapum Basalt unit in the map area is the Priest Rapids Member. Saddle Mountains Basalt units, from oldest to youngest, are undivided flows of the Wilbur Creek and Asotin members, the basalt of Weippe, and undivided flows of the Craigmont and Swamp Creek members. Interbedded within and locally overlying the basalt sequence are sediments of the Latah Formation.

Saddle Mountains Basalt

Tcsc Craigmont and Swamp Creek Members, undivided (Miocene)–We have combined these units on the geologic map because of their similarity in chemical signatures, their close physical association, and the scarcity of outcrops. Forms uppermost unit in the Weippe area.

> Craigmont Member –Fine- to medium-grained phyric basalt, common plagioclase phenocrysts 2-5 mm, rarely 7-10 mm; scattered to uncommon olivine about 1 mm; some manganese(?) oxide cavity filling. Normal magnetic polarity, although some field magnetometer readings inconsistent. Outcrops uncommon and generally poorly exposed. Thickness estimated at 15-45 m (50-150 feet), possibly thicker locally. Commonly weathers to red-brown saprolite.

> Swamp Creek Member –Medium- to coarse-grained basalt with common plagioclase phenocrysts, a few as large as 10 mm, and olivine phenocrysts 0.5-1 mm in diameter. Normal magnetic polarity, although some field magnetometer readings inconsistent. Probably fills structural and erosional depressions on older units. Thickness not determined, but probably less than 22 m (75 feet). Commonly weathers to red-orange or red-brown saprolite.

$Tcsc_d$ Craigmont Member dike (Miocene)–A dike sampled by Camp (V.E. Camp, written commun., 1999; map no. 81) southeast of Big Cedar has Craigmont chemistry, but no outcrops of the flow were found in that area.

Twe Basalt of Weippe (Miocene)–Medium- to coarse-grained basalt, some plagioclase phenocrysts; abundant olivine crystals and clots generally visible to the naked eye. Reverse magnetic polarity, although field magnetometer readings are commonly conflicting and weak. Similar chemically to Pomona Member flows. Thickness is generally 30-45 m (100-150 feet), although may locally thicken to more than 60 m (200 feet) in older structural depressions. Commonly weathers to saprolite. Typically overlies Asotin-Wilbur Creek unit (*Taw*) but may lie directly on Grande Ronde Basalt or basement rocks.

> Camp (1981) included the basalt of Weippe in the Pomona Member because of the chemical similarity to Pomona flows, although a physical connection of the two was not confirmed. We also found the chemistry, both major and trace elements, of the Weippe to be nearly identical to the Pomona. However, paleomagnetic directions determined for the basalt of Weippe from two sites near Grangemont, Idaho, reported by Kauffman (2004a) are somewhat different from those determined for Pomona flows by Rietman (1966) and by Choiniere and Swanson (1979) (Table 2), indicating that the two units may not be coeval. Hooper (2000) also noted this discrepancy in paleomagnetic direction, but cited no reference. One whole rock K-Ar age determination on a sample from one of the sites near Grangemont resulted in a date of 12.9 ± 0.8 Ma. This date appears slightly older than, but is probably not significantly different than the “about 12 Ma” age reported by McKee and others (1977).

Twe_d Basalt of Weippe dike (Miocene)–A dike sampled by Camp (V.E. Camp, written commun., 1999; map no. 77) east of Syringa has Weippe chemistry.

Taw Asotin Member and Wilbur Creek Member, undivided (Miocene)–Fine-grained basalt with scattered plagioclase phenocrysts 1-5 mm, and a few olivine phenocrysts 1-3 mm. Occurs throughout the basalt-covered area, but thins across broad structures developed on older basalt units. Upper part of flows commonly very vesicular, with abundant small spherical vesicles, many with a pale bluish lining. Includes basalt of Lapwai of the Wilbur Creek member. Asotin, Wilbur Creek, and basalt of Lapwai all have normal magnetic polarity. Total thickness ranges from about 30 m (100 feet) to over 90 m (300 feet). Locally underlain by arkosic sediment too thin or too poorly exposed to depict on map.

Wanapum Basalt

Tpr Priest Rapids Member (Miocene)–Dark gray, fine- to medium-grained basalt, dense to diktytaxitic, phyric with scattered equant crystals and laths of plagioclase as large as 5 mm and scattered to common olivine crystals 1-3 mm. Reverse magnetic polarity. Rosalia chemical type. Appears to fill a broad north- or northwest-trending trough developed on the Grande Ronde Basalt in the Kooskia-Stites area. Documented by chemistry at several locations east of the South Fork Clearwater River, but not found on the slopes west of the river. Also does not occur on upper Leitch Creek where Asotin lies directly on Grande Ronde (R_2?). A few outcrops near the community of Clearwater at the eastern edge of the Stites 7.5-minute quadrangle are the easternmost remnants of Priest Rapids basalt.

Tpr_d Priest Rapids Member dike (Miocene)–A dike sampled north of Kooskia has probable Priest Rapids chemical composition (map no. 140).

Grande Ronde Basalt

On the Kooskia 1:100,000 quadrangle separation of the Grande Ronde into magnetostratigraphic units was difficult. Field magnetometer readings were commonly contradictory or weak. One location that was thought to be N_1 because of consistent normal fluxgate magnetometer readings (8 readings total) may be R_1 or R_2. Oriented samples processed in the laboratory with alternating field demagnetization and a spinner fluxgate magnetometer yielded a reverse polarity component that was smaller but more stable than the normal polarity component, which is interpreted as a younger overprint. Although Camp previously divided the Grande Ronde in this area into R_1, N_1, and R_2 units (Camp, 1981; Swanson and others, 1979a), his field notes show he also commonly got inconsistent magnetic readings at many locations (V.E. Camp, written commun., 1999). Chemical signatures, while helpful is separating some Grande Ronde units, also tend to overlap between R_1, N_1, and R_2 units, all of which may be present in the area. Without detailed sampling of stratigraphic sections, and collection of numerous oriented cores for laboratory paleomagnetic analysis, Grande Ronde stratigraphy will remain questionable at best. We have attempted to separate magnetostratigraphic units by extrapolating from areas where we feel reasonably certain of the magnetic character or where chemistry supports our unit separation. However, in many areas, we can be certain only that the basalt is Grande Ronde; the interpreted magnetostratigraphic unit is speculative.

Tgr_2 Grande Ronde R_2 magnetostratigraphic unit (Miocene)–Fine-grained basalt, commonly with small 2-3 mm plagioclase laths and a sugary texture. Several samples collected in the quadrangle have chemistry indicative of R_2, and a small area of R_2 has previously been mapped north of Kooskia (Swanson and others, 1979a). Crops out as large stubby columns 1-1.5 m (3-5 feet) in diameter, or as smaller, blocky to hackly columns. Thickness estimated to be 30 m (100 feet) or less.

Tgn_1 Grande Ronde N_1 magnetostratigraphic unit (Miocene)–Texture variable. Mostly fine-grained, dark gray to black, aphyric to plagioclase-microphyric basalt. At least one flow in the Big Tinker Creek area, interpreted to be N_1 based on chemistry, is medium to coarse grained with fairly abundant olivine and pyroxene. Entablature of one flow or series of flows commonly forms tiered cliffs along upper canyon walls. Uppermost flows commonly medium gray, medium grained, with a few plagioclase phenocrysts 2-5 mm, or fine grained but with a sugary texture; diktytaxitic in places. Normal magnetic polarity. Flows vary in thickness from about 15 m (50 feet) for thin flows to 30-60 m (100-200 feet) for thick flows. Thin flows characterized by large stocky columns grading upward into coarsely vesicular flow tops commonly exhibiting crude columnar structure. Thick flows have lower colonnade of columns 0.5-1.5 m (2-5 feet) in diameter with an abrupt change to blocky, hackly thick entablature, becoming vesicular near the flow top. Interpreted to thin and thicken locally, possibly as a result of structural warping or, less likely, erosion on R_1. Contact with overlying R_2 and underlying R_1 interpretative, so locally N_1 may include flows of adjacent units. Appears to be very thin or absent north of Kooskia, yet possibly as thick as 120 m (400 feet) in the Clear Creek drainage southeast of Kooskia.

Tgr_1 Grande Ronde R_1 magnetostratigraphic unit (Miocene)–Typically dense, dark gray to black, fine- to very fine-grained aphyric to plagioclase-microphyric basalt. Less commonly medium grained with scattered small plagioclase phenocrysts. Reverse magnetic polarity. Field magnetometer readings commonly inconsistent and weak. Outcrop characteristics similar to N_1 units. Is in irregular contact with pre-Tertiary rocks. Base of complete sequence not exposed. Appears to be at least 360 m (1200 feet thick) north of Kooskia.

INTRUSIVE ROCKS

Tb Basalt dikes, undivided (Miocene?)–Black, aphanitic, tabular dikes, typically 1-3 m wide, which consist principally of plagioclase, augite, glass, and opaque oxides. Some or all may be related to Columbia River Basalt Group.

Tdu Dike rocks, undivided (Eocene)–Dikes of uncertain composition. Most were located using aerial photographs. May include any of the types of dikes described below, but most are probably either rhyolite (*Tr*) or porphyritic dacite (*Tpd*).

Tr Rhyolite dikes and plugs (Eocene)–Tan-weathering, aphanitic to very fine-grained phaneritic dikes and plugs that contain variable amounts of phenocrysts. Phenocrysts of quartz, alkali feldspar, and plagioclase typically compose about 40 percent of the rock, but are sparse or lacking in dikes in the Lowell area.

Tpd Porphyritic dacite dikes and plugs (Eocene)–Porphyritic dacite with phenocrysts of plagioclase, quartz, biotite, and hornblende in a gray aphanitic groundmass.

Ta Andesite dikes (Eocene?)–Dark gray, nonfoliated dikes characterized by sparse hornblende and plagioclase phenocrysts in an aphanitic groundmass. Plagioclase phenocrysts typically more elongate than those in *Tpd*.

Tg Granite (Eocene)–Equigranular biotite granite. Contains well-developed perthite and 5 percent or less biotite; lacks strongly zoned plagioclase that is characteristic of *Tggd*.

Tpg Porphyritic granite (Eocene)–Gray to pinkish gray, fine- to medium-grained porphyritic hornblende-biotite granite. Phenocrysts are orthoclase feldspar. Mapped as a capping unit of the Whistling Pig pluton (Lund, 1980; Motzer, 1985) at the eastern edge of the map.

Tgf Fine-grained granite (Eocene)–Cream-colored biotite leucogranite. Commonly contains miarolitic cavities. Abundant graphic textures. Mapped as phase of the Whistling Pig and Running Creek plutons (Lund, 1980; Motzer, 1985).

Tgm Medium-grained granite (Eocene)–Pink, medium-grained, biotite-hornblende granite to quartz syenite. Miarolitic cavities are common. Mapped as phase of the Whistling Pig and Running Creek plutons (Lund, 1980; Motzer, 1985).

Tgc Coarse-grained granite (Eocene)–Pink, coarse-grained, biotite-hornblende granite to quartz syenite. Grain size averages >5 mm. Sparse to no miarolitic cavities. Mapped as a phase of the Whistling Pig pluton (Lund, 1980; Motzer, 1985).

Tggd Granite and granodiorite (Eocene)–Light gray, medium- to fine-grained, biotite and hornblende-biotite granodiorite and granite. Typically porphyritic, with potassium feldspar phenocrysts 4-15 mm in length. In the small stock southeast of Stanley Hot Springs biotite and hornblende are concentrated in diffuse clots. Fish Butte stock northeast of Lowell resembles *Tg* in that it weathers to smooth rounded outcrops, contains smoky quartz, and has slightly higher background radioactivity than the surrounding *TKbgd*. However, it contains less magnetite than *Tg*, has strongly zoned plagioclase, contains trace amounts of relatively coarse (primary?) muscovite, and lacks the miarolitic cavities that are characteristic of *Tg*. Easternmost exposures along Highway 12 are hornblende granite or syenite and characteristically deeply weathered to coarse grus. Large exposure northeast of Castle Butte previously mapped as *Tg* (Lewis and others, 1992b) differs from *Tg* in that it lacks the strongly perthitic feldspar, contains hornblende and strongly zoned plagioclase, has Sr in excess of Rb, and has less pronounced negative europium anomalies.

Tdi Diorite (Eocene)–Medium-grained, equigranular diorite and quartz diorite. Largest mass exposed in a small stock east of Stanley Hot Springs. Single sample collected there was a pyroxene-biotite-hornblende quartz diorite. Pyroxene forms cores in hornblende and together they compose about 18 percent of the rock; biotite 10 percent, quartz 8 percent, and potassium feldspar 1 percent. Plagioclase constitutes the remainder and is strongly zoned from calcic core to sodic rim.

TKdi Diorite (Cretaceous or Tertiary)–Fine- to medium-grained, equigranular biotite-hornblende (± pyroxene) diorite and quartz diorite, and minor hornblende-biotite granodiorite and hornblende-pyroxene gabbro. Includes hornblende- and pyroxene-rich diorites and gabbros having a cumulate texture at the mouth of Bald Mountain Creek along Highway 12. Commonly has complex interfingering and locally gradational contacts with *TKbgd* unit. Also occurs as inclusions (or intrusions?) too small to map in *TKbgd*.

TKa Andesite dikes (Cretaceous or Tertiary)–Dark gray, sparsely porphyritic to equigranular fine-grained dikes that consist primarily of plagioclase, biotite, quartz, and hornblende. Distinguished from Ta by a weak to moderate foliation and by cross-cutting pegmatite of probable Cretaceous or Paleocene age.

Plutonic rocks with intermediate to high initial $^{87}Sr/^{86}Sr$ ratios

Intrusive rocks with intermediate to high initial $^{87}Sr/^{86}Sr$ values (>0.706) that reflect formation from, or interaction with, continental crust (Armstrong and others, 1977; Criss and Fleck, 1987). Includes rocks of the Bitterroot lobe of the Idaho batholith in the northeastern part of map and the northern tip of the Atlanta lobe in the southwest part.

TKmg Muscovite-biotite granite (Cretaceous or Paleocene)–Medium-grained, equigranular muscovite-biotite granite and granodiorite. Muscovite present in conspicuous books. The mass south of Mex Mountain is biotite-poor and contains abundant hematite.

TKbgd Biotite granodiorite (Cretaceous or Paleocene)–Medium- to fine-grained, massive to moderately foliated, equigranular to porphyritic biotite granodiorite and granite. Includes lesser amounts of biotite tonalite on the southwest side of the Bitterroot lobe of the Idaho batholith southwest of Old Man Creek and south and west of Big Fog Mountain. Biotite typically 5-11 percent. A few percent or less muscovite, but unlike *TKmg* unit, muscovite is not in conspicuous books. See Reid (1984) for detailed modal data. Weakly zoned plagioclase. Associated pegmatite and aplite dikes and sills are common. Zircon U-Pb TIMS dates of 71 ± 9 Ma and 75 ± 5 Ma from samples along the Lochsa River (Toth and Stacey, 1992) conflict with more recently obtained younger (65-53 Ma) ages obtained by SHRIMP (Foster and Fanning, 1997) and LA-ICPMS analysis (Gaschnig and others, 2007).

TKpgd Porphyritic biotite granodiorite (Cretaceous or Paleocene)–Medium-grained biotite granodiorite and granite that contains euhedral phenocrysts of alkali feldspar 1-3 cm long. Otherwise similar to *TKbgd*.

Kbgd Biotite granodiorite (Cretaceous)–Medium-grained, massive to moderately foliated, equigranular biotite granodiorite and granite. Exposed near southern map boundary. Zircon U-Pb LA-ICPMS date of 86.4 ± 0.6 Ma from an exposure along the South Fork Clearwater River, 12 km south of the map, indicates a Cretaceous age (Lee, 2004).

Kgdf Foliated granodiorite (Cretaceous)–Foliated biotite granodiorite. Includes minor quartz monzonite and may grade into biotite tonalite in exposures near the southern map boundary west of Meadow Creek. Unit includes the porphyritic granodiorite gneiss of Andys Hump, which has been dated at 73 ± 3 Ma (Lund and others, 2005).

Kgdg Granodiorite gneiss (Cretaceous)–Strongly foliated biotite granodiorite gneiss exposed in the southwest part of map. Grades to biotite tonalite gneiss. Relatively abundant epidote (as much as 3 percent) some of which is cored with allanite and interpreted as primary. Sphene is an abundant accessory mineral. Unit extends south of the map where initial $^{87}Sr/^{86}Sr$ values are about 0.708 (Criss and Fleck, 1987).

Kbt Biotite tonalite (Cretaceous)–Moderately foliated, medium-grained biotite tonalite that is similar to, but less deformed than, the *Kbtg* unit.

Kt Biotite tonalite and hornblende-biotite tonalite (Cretaceous)–Medium-grained, equigranular, massive to foliated biotite- and hornblende-biotite tonalite; includes minor quartz diorite and quartz monzodiorite. Lineation (defined primarily by hornblende prisms) plunges steeply down the dip of the foliation. Plagioclase is mostly unzoned. See Reid (1984, 1987) for detailed modal and descriptive data.

Kqd Quartz diorite (Cretaceous)–Medium- to coarse-grained, equigranular, massive to moderately foliated quartz diorite. Invariably hornblende-bearing; biotite typically subordinate.

See Hietanen (1963) for detailed modal and descriptive data. At least two distinct ages of quartz diorite likely. An older phase collected northwest of Headquarters, 18 km north of the map, is 94.6 ± 1.8 Ma based on TIMS U-Pb lower intercept (W.C. McClelland, written commun., 2002). A younger age of 70.0 ± 1.5 Ma has been obtained for quartz diorite collected 7 km east-northeast of Weippe (zircon LA-ICPMS; R.M. Gaschnig, written commun., 2007). The boundary between the two similar-appearing quartz diorite masses is unmapped.

Kgdmg Megacrystic granodiorite (Cretaceous)–Foliated, coarse-grained, porphyritic biotite- and hornblende-biotite granodiorite and subordinate tonalite. Contains potassium feldspar megacrysts as long as 5 cm that commonly form augen. The matrix is tonalitic and most potassium feldspar is in the megacrysts and augen. Exposures along Lochsa River were termed the orthogneiss of Apgar Creek and dated by U-Pb (SHRIMP) method at 94 ± 1 Ma (Lund and others, 2005).

Kbtg Biotite tonalite gneiss (Cretaceous)–Strongly foliated, medium- to fine-grained biotite tonalite gneiss. Quartz typically 20-30 percent and biotite typically 4-20 percent. Muscovite 5 percent or less and not conspicuous in hand samples. Locally contains minor garnet. Strongly foliated varieties difficult to distinguish from paragneiss. Pronounced foliation, fine grain size, and ribboned quartz indicate deformation of intrusion after emplacement. Biotite tonalite orthogneiss from about 13 km southeast of Weippe was dated at 73.3 ± 1.5 Ma (U-Pb zircon SHRIMP analysis; Payne, 2004). Based on the rock description, this sample was likely from a lens of unmapped *Kbtg* within the *Kqdg* unit.

Kbtgc Biotite tonalite gneiss of Coolwater Ridge (Cretaceous)–Same as Kbtg but single large mass (Coolwater Ridge orthogneiss of Morrison, 1968). Has a remarkably well developed planar northwest fabric that parallels the Glade Creek shear zone. Foliation typically dips steeply northeast; local folds of foliation are shallow to steep to the east. Lineation is mostly down dip. This orthogneiss typically has a fine grain size and locally contains ribboned quartz. Has lower initial $^{87}Sr/^{86}Sr$ ratios (0.7066) than plutons east or west of it (Lund and others, 2005). Age estimates for body are 94 ± 1.4 Ma (U-Pb zircon TIMS analysis) from a sample collected immediately east of Lowell (Toth and Stacey, 1992) and 91 ± 2 Ma (U-Pb zircon SHRIMP analysis) from a sample collected along the Selway River southeast of Lowell (Lund and others, 2005).

Kqdg Quartz diorite gneiss (Cretaceous)–Strongly foliated, medium-grained hornblende-biotite orthogneiss. Primarily quartz diorite and tonalite but includes minor diorite and granodiorite. Typically contains 5-19 percent biotite and 3-15 percent hornblende. Dioritic varieties contain about 25 percent hornblende. Epidote, interpreted as primary, present at some localities.

Kmig Migmatite (Cretaceous)–Areas where metamorphic rocks are intermixed with 30-70 percent granitic rocks at a scale of centimeters to decimeters. Metamorphic rocks are typically quartzite, quartzitic gneiss, or schist that retain a common orientation through a given zone. Detailed descriptions of the migmatites are given by Bittner-Gaber (1983) and Bittner (1987).

Plutonic rocks with transitional initial $^{87}Sr/^{86}Sr$ ratios

Intrusive rocks in the western part of the map with initial $^{87}Sr/^{86}Sr$ values that range between low (<0.704) and high (>0.706) from west to east across the unit (see Criss and Fleck, 1987). Values reflect transition from oceanic crust in the west to continental crust in the east (Armstrong and others, 1977; Criss and Fleck, 1987).

Ktt Biotite tonalite and hornblende-biotite tonalite (Cretaceous)–Biotite tonalite and lesser amounts of hornblende-biotite tonalite grading to hornblende-biotite quartz diorite. Contains about 7-15 percent biotite and as much as 10 percent hornblende. Locally foliated but not as deformed as *Kbtg* unit that has a similar composition. Preliminary LA-ICPMS U-Pb zircon age of about 110 Ma obtained from a sample collected near the western boundary of the *Ktt* unit (J.D. Vervoort, written commun., 2006).

Plutonic rocks with low initial $^{87}Sr/^{86}Sr$ ratios

Intrusive rocks in the western part of the map with low initial $^{87}Sr/^{86}Sr$ values (<0.704) that reflect lack of contribution of, or contamination by, continental crust (Armstrong and others, 1977; Criss and Fleck, 1987).

Ktrg Trondhjemite gneiss (Cretaceous)–Strongly foliated biotite-muscovite trondhjemite (leucocratic tonalite) gneiss. Exposed only in a small area south of Lolo Creek at the western map boundary.

Kbtog Biotite tonalite gneiss (Cretaceous)–Fine- to medium-grained, well-foliated biotite tonalite gneiss.

KJqdg Quartz diorite gneiss (Jurassic or Cretaceous)–Medium-grained, equigranular, well-foliated biotite-hornblende quartz diorite gneiss. Similar composition to *KJqd* except biotite locally more abundant than hornblende. In places biotite appears to have replaced hornblende. Foliation and gneissic texture results from deformation along the Orofino shear zone and diminishes southwest into *KJqd*.

KJqd Quartz diorite (Jurassic or Cretaceous)–Medium-grained, equigranular, biotite-hornblende quartz diorite. Includes the Harpster pluton at the southern map boundary (Myers, 1982) and two smaller exposures on the western map border. Contains about 5-10 percent biotite and 10-15 percent hornblende. Hornblende locally cored by pyroxene. Unpublished concordant U-Pb date of 160 Ma by John Stacey (written commun. to Paul Myers, 1982) for the Harpster pluton. Harpster pluton is similar in age to quartz diorite northwest of Kamiah, west of the map area, which has been dated at 157.0 ± 0.5 Ma by U-Pb zircon (W.C. McClelland, written commun., 2003).

KJdg Diorite, gabbro, and ultramafic rocks (Jurassic or Cretaceous)–Medium- to coarse-grained, massive, hornblende- or pyroxene-rich diorite and gabbro; minor ultramafic rocks. Plagioclase content 20 percent or less.

KPi Intrusive rocks, undivided (Permian? to Cretaceous?)–Intrusive complex consisting of a wide variety of rock types. Along Tom Taha Creek includes foliated biotite tonalite, biotite-hornblende quartz diorite or diorite, and hornblende diorite. Also includes gneissic rocks that may be metasedimentary or metavolcanic. Exposure south of Stites is undeformed and porphyritic with a fine-grained groundmass.

CONTINENTAL MARGIN(?) ROCKS

Paragneiss, schist, and calc-silicate rocks previously assigned to the Syringa metamorphic sequence (Lewis and others, 1992b), but now known to be much younger because of the presence of Mesozoic detrital zircons (Lund and others, 2005). Although most detrital zircons are Mesozoic, some are Proterozoic, indicating sources from the continent as well as the Wallowa island-arc terrane. Included are associated ultramafic rocks and amphibolite.

Mzgs Gneiss and schist of Swiftwater Creek (Mesozoic)–Massive weathering, biotite-quartz-plagioclase gneiss and schist. Many exposures contain trace to 2 percent of 5-10 mm long black tourmaline crystals. Notable for high plagioclase content (15-65 percent) relative to other schist in the region and mapped by some workers as orthogneiss (Pitz, 1985). Quartz 15-50 percent, biotite 5-35 percent, muscovite 0-15 percent, garnet 0-5 percent, and potassium feldspar 0-3 percent. Because of high plagioclase content unit is enriched in Sr (>300 ppm), Na_2O (>2.9 percent), and CaO (>2.2 percent) relative to schist of the Syringa metamorphic sequence (*Zss*).

Mzcs Calc-silicate rocks of Swiftwater Creek (Mesozoic)–Thin intervals of calc-silicate-bearing rocks east of Lowell. Primarily plagioclase and quartz, with subordinate garnet, potassium feldspar, hornblende, and pyroxene.

Mzum Ultramafic rocks (Mesozoic)–Small pod-like bodies of medium- to coarse-grained pyroxenite and peridotite associated with the Lowell thrust and the gneiss of Swiftwater Creek. Peridotite, altered to actinolite, talc, and chlorite, crops out at the confluence of Swiftwater Creek and the Selway River. Pyroxenite occurs north of Lowell, and pyroxenite and peridotite occur south and southwest of Stillman Point.

Mzam Amphibolite (Mesozoic)–Fine- to medium-grained plagioclase-hornblende rock. Interpreted to have an igneous protolith on the basis of uniform composition and texture, but may include calc-silicate rock. Restricted to areas with the Coolwater Ridge orthogneiss (*Kbtgc*) and the gneiss and schist of Swiftwater Creek (*Mzgs*).

OROFINO SERIES

Amphibolite-facies metasedimentary (and metavolcanic?) rocks first recognized in the vicinity of Orofino (Anderson, 1930; Hietanen, 1962). Commonly sulfide-rich with iron-stained exteriors. Lithologically varied at outcrop scale. Includes marble commonly associated with dark colored fine-grained garnet-diopside-quartz-plagioclase-hornblende gneiss of fairly uniform appearance. The series appears to belong to the accreted terrane assemblage (Wallowa terrane), but straddles the initial $^{87}Sr/^{86}Sr$ 0.704-0.706 line (Criss and Fleck, 1987) from Orofino to Kooskia. May be equivalent to parts of the Riggins Group (upper part of Squaw Creek schist?) described by Hamilton (1963).

Mzmo Marble of the Orofino series (Mesozoic)–Massive, light gray to white, coarse-grained calcite marble in small lens-like exposures north of the Middle Fork Clearwater River.

Mzgo Gneiss of the Orofino series (Mesozoic)–Fine- to medium-grained hornblende gneiss that grades into and is interlayered with biotite gneiss, hornblende-biotite schist, and calc-silicate quartzite. Exposed north of the Middle Fork Clearwater River west of the Woodrat Mountain fault. Typically well foliated to mylonitic. Contains highly varied amounts of plagioclase, hornblende, and quartz and locally contains pyroxene, zoisite, garnet, biotite, potassium feldspar, and graphite. May be the northern extension of the *Mzrg* unit but appears to be more coarsely crystalline and perhaps higher metamorphic grade.

RIGGINS GROUP

The term Riggins Group was originally assigned by Hamilton (1963) to amphibolite facies metasedimentary and metavolcanic rocks near Riggins, Idaho, south of the map area. Myers (1982) applied the name Riggins Group to similar rocks in the Harpster area. These same rocks extend north into the map area at least as far as the Syringa fault. They may be equivalent to the Orofino series described above.

Mzrg Phyllitic siltite of the Riggins Group (Mesozoic)–Laminated, fine-grained (<0.3 mm) hornblende-quartz-plagioclase phyllitic siltite. Contains variable amounts of plagioclase, quartz, and hornblende and locally epidote, garnet, biotite, and potassium feldspar. Unit contains beds of marble to the south in the area east of Harpster (Myers, 1982). Myers (1982) suggested correlation with the Squaw Creek schist exposed to the south near Riggins (Hamilton, 1963).

SEVEN DEVILS GROUP(?)

TRPc Chlorite-epidote-actinolite schist (Permian to Triassic)–Mylonitic, fine- to medium-grained chlorite-actinolite-epidote schist containing stringers of quartz, plagioclase, and epidote. Exposed at south edge of map. Probably derived from andesitic volcanic and volcaniclastic rocks and correlated with similar rocks of the Seven Devils Volcanic Group exposed to the southwest (Myers, 1982).

TRPsd Seven Devils Group(?), undivided (Permian to Triassic)–Single exposure of greenstone (locally brecciated) and siltstone (possibly hornfels) along the South Fork of the Clearwater River. Probably correlative with volcanic and volcaniclastic rocks of the Seven Devils Volcanic Group exposed to the southwest (Myers, 1982).

SYRINGA METAMORPHIC SEQUENCE

Amphibolite-facies muscovite-biotite schist, clean quartzite, and calc-silicate rocks that are distinct from the Belt Supergroup are widely exposed east of Kooskia. Termed the Syringa metamorphic sequence (Lewis and others, 1992b; Lewis and others, 1998), they are uniformly exposed east of the initial $^{87}Sr/^{86}Sr$ 0.704-0.706 line (Criss and Fleck, 1987) and appear to be part of continental North America. Although Hietanen (1962, 1963) mapped most of the sequence as metamorphosed Belt rocks (either Wallace Formation, St. Regis Formation, or Revett quartzite), the intimate association of pure quartzite and calc-silicate rocks is a characteristic not found in the Belt Supergroup. Also, thin carbonate intervals are present throughout the sequence, in contrast to thicker and more restricted carbonate intervals in the Belt. Lund and others (2005) obtained detrital zircons whose Neoproterozoic age post-dates the Belt. Additional young dates (as young as 680 Ma) were obtained by Lewis and others (2005a).

Zss Schist and gneiss of the Syringa metamorphic sequence (Neoproterozoic)–Medium- to coarse-grained plagioclase-biotite-quartz schist and minor amounts of biotite gneiss, micaceous quartzite, and calc-silicate rocks. Schist typically contains 40-65 percent quartz, 5-15 percent plagioclase, 5-20 percent biotite, and 0-15 percent muscovite. Garnet (typically flattened or stretched) and sillimanite are common, and kyanite is present on Woodrat Mountain (Van Noy and others, 1970), near Lowell, and southeast of Lowell west of Sob Point. Kyanite-rich schist on Woodrat Mountain contains less quartz and plagioclase (<10 percent total) and consists largely of kyanite, garnet, and biotite. Biotite gneiss typically contains more than 25 percent quartz, 20-40 percent plagioclase, 15-30 percent biotite, and locally potassium feldspar. Thin intervals of quartzite similar to *Zqs* and calc-silicate rocks similar to *Zcss* are common throughout.

Zcss Calc-silicate rocks of the Syringa metamorphic sequence (Neoproterozoic)–Varied diopside-, actinolite-, hornblende-, garnet-, and scapolite-bearing granofels, gneiss, quartzite, and minor diopside marble. Locally contains biotite and graphite; rare but locally abundant potassium feldspar (32 percent in exposures in upper O'Hara Creek near the southern map boundary). Plagioclase 10-75 percent. Commonly lacks thin layering or relict bedding that is prevalent in metamorphosed Belt rocks. Gray, medium-grained, pure calcite marble interbedded with relatively fine-grained calcareous diopside quartzite is exposed along the West Fork Clear Creek in the southwest part of the map and tentatively assigned to this unit.

Zqs Quartzite of the Syringa metamorphic sequence (Neoproterozoic)–Coarsely recrystallized quartzite, lesser amounts of biotite schist, and minor calc-silicate rocks. Compositional layering on the scale of decimeters is defined by thin layers of schist alternating with massive quartzite. Quartzite characteristically very pure and coarse grained although some thinner and finer grained layers contain as much as 15 percent feldspar (both plagioclase and potassium feldspar). Resembles vein quartz except typically has large mica flakes fairly uniformly distributed and well aligned between tabular quartz grains. Commonly associated with *Zcss.*

PROTEROZOIC INTRUSIVE ROCKS

Yag Augen gneiss (Mesoproterozoic)–Foliated biotite augen gneiss present only near the southern map boundary. Granitic composition (granodiorite), but not as rich in potassium feldspar as Proterozoic augen gneiss to the south near Elk City. Biotite 10-15 percent. Previously mapped as Cretaceous megacrystic granodiorite (Lewis and others, 1992b), but chemically more similar to Elk City augen gneiss in that it is rich in SiO_2 (74.7-74.8 percent) and poor in Al_2O_3 (11.2-12.0 percent). Appears to be restricted to the Elk City and Golden metamorphic sequences, so probably same age as augen gneiss there (1370-1380 Ma; Evans and Fischer, 1986).

Yam Amphibolite (Mesoproterozoic?)–Fine- to medium-grained plagioclase-hornblende rock. Interpreted to have an igneous protolith on the basis of uniform composition and texture and apparent cross-cutting relations at many places. May include some Cretaceous mafic bodies, but a Mesoproterozoic age is probable for most, if not all, of the amphibolite.

METAMORPHOSED ROCKS OF THE LEMHI BASIN

Southeast of the map area, near the Blackbird Mine, the metasedimentary rocks containing 1370-1380 Ma granites and related mafic intrusives (now mostly augen gneiss and amphibolite) have been correlated with Belt Supergroup units (Winston and others, 1999). Detrital zircon analysis of these rocks shows a large population of approximately 1700 Ma zircons and a smaller "syn-Belt" population of about 1420-1470 Ma (Link and others, 2007). The young age range precludes correlation with older Belt units but does not preclude correlation with younger ones. However, individual units are not easily correlated and we remain unconvinced of proposed correlations. We refer to these and higher grade versions northwest of the Blackbird Mine and near Elk City as part of the Lemhi basin of the Belt following the terminology of O'Neill and others (2007).

Elk City Metamorphic Sequence

The Elk City metamorphic sequence consists of biotite gneiss and biotite schist exposed in the southwestern part of the area. Sequence is distinguished by the abundance of gneiss and the scattered presence of centimeter-scale lenses of sillimanite and muscovite within the schist. Sequence is more widely exposed to the south near Elk City (Lewis and others, 1990; 1998). Appears to be similar in age to some of the younger strata of the Belt Supergroup on the basis of detrital zircon ages (Lund and others, 2005; J.D.Vervoort and P. Oswald, written commun., 2005). Spatially associated with Golden metamorphic sequence; both sequences are intruded by 1370-1380 granitic gneiss (*Yag*; Evans and Fischer, 1986) and are thus distinct from the Belt Supergroup and metamorphosed Belt rocks to the northeast. All three are separated from metamorphosed Belt rocks by the Green Mountain fault, discussed in the structure section below.

Yge Biotite gneiss of the Elk City metamorphic sequence (Mesoproterozoic)–Fine- to medium-grained, biotite-plagioclase-quartz gneiss with apparent relict centimeter-scale compositional layering and lesser muscovite-biotite-plagioclase-quartz schist. Includes minor plagioclase-rich quartzite. More schistose rocks locally contain sillimanite; garnet is rare. Potassium feldspar abundant (as much as 25 percent) in some layers. Locally contains sillimanite and muscovite in lenses 1-4 cm in diameter that resemble flattened pebbles or metamorphosed mudchips.

Golden Metamorphic Sequence

The Golden metamorphic sequence consists of feldspathic quartzite, biotite gneiss, biotite schist, and calc-silicate rocks exposed in the southern part of the area. Sequence is distinguished by the abundance of quartzite in association with gneissic rocks. Previously mapped as part of the Syringa metamorphic sequence (Lewis and others, 1992b) but reassigned here. Quartzite is finer grained and more feldspathic than typical Syringa quartzite. Biotite gneiss predominates over schist whereas the opposite is true in the Syringa sequence. Sequence is named for the hamlet of Golden, south of the area, where one of the quartzite intervals is well exposed (Lewis and others, 1990). Easternmost exposures along and east of O’Hara Creek are more schistose, more similar to Syringa sequence, and only tentatively assigned to the Golden sequence. Appears to be similar in age to some of the younger strata of the Belt Supergroup on the basis of detrital zircon ages (J.D. Vervoort and P. Oswald, written commun., 2005). Spatially associated with Elk City metamorphic sequence; both sequences are intruded by 1370-1380 granitic gneiss (*Yag*; Evans and Fischer, 1986) and are thus distinct from the Belt Supergroup and metamorphosed Belt rocks to the northeast. All three are separated from metamorphosed Belt rocks by the Green Mountain fault, discussed in the structure section below. Differs from the Meadow Creek sequence east of the fault in having less schist and far less muscovite.

Ygg Biotite gneiss of the Golden metamorphic sequence (Mesoproterozoic)–Biotite-plagioclase-quartz gneiss and lesser schist. Layering typically at centimeter to millimeter scale. Gneiss contains about 45-60 percent quartz, 30-40 percent plagioclase, 10-15 percent biotite, and 0-3 percent potassium feldspar. Schist contains less plagioclase, but has garnet, sillimanite, and locally muscovite and kyanite.

Ycsg Calc-silicate rocks of the Golden metamorphic sequence (Mesoproterozoic)–Diopside-plagioclase-quartz gneiss and calc-silicate granofels. Layering typically centimeter to millimeter scale, rarely decimeter. Locally contains hornblende.

Yqg Quartzite of the Golden metamorphic sequence (Mesoproterozoic)–Medium- to coarse-grained biotite-plagioclase quartzite. Quartz 45-90 percent, plagioclase 5-40 percent, potassium feldspar 0-20 percent, biotite 1-15 percent, and muscovite 0-3 percent. Bedding locally preserved south of Pine Knob where it is at a high angle to the foliation. Bedding typically decimeter scale.

MEADOW CREEK METAMORPHIC SEQUENCE

The Meadow Creek metamorphic sequence consists of feldspathic quartzite, muscovitic quartzite, schist, and minor calc-silicate rocks exposed in the southeastern part of the area. The sequence is distinguished by the abundance of quartzite, particularly south of the map where the quartzite of Meadow Creek is more widespread (Lewis and others, 1990), and by the abundance of muscovite. Possibly equivalent to Missoula Group of the Belt Supergroup, but too highly metamorphosed to make a definitive correlation.

Yqm Quartzite of the Meadow Creek metamorphic sequence (Mesoproterozoic)–Light-colored feldspathic quartzite, muscovitic quartzite, and minor fine-grained quartz-muscovite-biotite schist. Partings on micaceous interlayers appear to define "beds" 2-60 cm thick. Quartzite is relatively fine grained. Modal data from Reid (1984) from a ridge immediately south of the map indicates 53.4-85.3 percent quartz, 0.7-24.0 percent plagioclase, 0-26.6 percent potassium feldspar, 0-22 percent biotite, and 0-16.3 percent muscovite. Kyanite is partly replaced by sillimanite on the ridge west of Berry Creek near the southern map boundary.

Ycsm Calc-silicate rocks of the Meadow Creek metamorphic sequence (Mesoproterozoic)–Dark gray, thinly layered, amphibole-diopside-quartz gneiss. Unit is a transition between the quartzite of Meadow Creek and the underlying rocks of the micaceous quartzite unit (*Ymqm*).

Ymqm Micaceous quartzite of the Meadow Creek metamorphic sequence (Mesoproterozoic)–Biotite-muscovite quartzite and quartz-rich schist. Typically 10-30 percent plagioclase; potassium feldspar less abundant. Locally abundant sillimanite, e.g., southwest of Fog Mountain and in schistose rocks on Knife Edge Ridge. Modal data from Reid (1984) from the ridge immediately south of the map area indicates 46.8-72.8 percent quartz, 5.7-36.5 percent plagioclase, 0-8.6 percent potassium feldspar, 8.4-20.0 percent biotite, and 0-40.3 percent muscovite. Less abundant muscovite to northwest, and rocks along and northwest of the Lochsa River are only tentatively assigned to this unit.

METAMORPHOSED BELT SUPERGROUP(?)

Mesoproterozoic Belt formations are widely exposed north of the area (Lewis and others, 1992a; Burmester and others, 1998) and some of the amphibolite facies metasedimentary rocks present in the northern and eastern parts of the Kooskia quadrangle probably have Belt protoliths. Exposures east of Pierce are included in this category, as are metasedimentary rocks from Lowell northeast along the Lochsa River. With increasing metamorphic grade, argillaceous rocks form schist whereas carbonate-bearing quartzitic rocks form calc-silicate quartzite, granofels, and gneiss. This metamorphism destroys original color and fine sedimentary structures, but where penetrative deformation is slight, bedding thickness, general protolith character, and whether protolith was carbonate-bearing are still recognizable. All of the potential Belt rocks were given metamorphic primary names rather than formational assignments.

Ygs Schist and gneiss (Mesoproterozoic)–Sillimanite-plagioclase-biotite-quartz schist that grades into schistose biotite gneiss. Contains 35-85 percent quartz, 0-30 percent plagioclase, 15-30 percent biotite, and as much as 15 percent sillimanite. Locally contains garnet. Unit is spatially associated with calc-silicate gneiss (*Ycg*). Mapped as Wallace Formation by Hietanen (1963). All or part of the unit may be equivalent to the upper Wallace Formation or the upper part of the Ravalli Group (St. Regis Formation).

Ycg Calc-silicate gneiss (Mesoproterozoic)–Includes millimeter- to centimeter-scale layered calc-silicate gneiss or layered calc-silicate granofels, diopside quartzite, amphibolite, quartzite with more than 5 percent garnet, and minor amounts of garnet-biotite schist and gneiss. Contains quartz and plagioclase and varied amounts of diopside and hornblende. Locally contains minor potassium feldspar, sphene, and epidote. Compositional layering or range in grain size of amphibolite distinguishes it from the more homogeneous rock of the metaigneous amphibolite (*Yam*). Unit probably was derived from the carbonate-bearing lower member of the Wallace Formation, but small exposures intimately associated with *Ygs* might be from the middle part of the upper member of the Wallace.

Yqgq Quartzitic gneiss and quartzite (Mesoproterozoic)–Generally medium- to coarse-grained, thin-layered quartzitic gneiss and feldspathic quartzite that contains various amounts of centimeter-layered biotite-feldspar quartz granofels. Grades into quartz-rich biotite gneiss where migmatized. Unit probably represents quartzite-rich portions of the middle member Wallace Formation and perhaps parts of the Ravalli Group.

Yqs Quartzite and schist (Mesoproterozoic)–Thickly layered quartzite, feldspathic quartzite, schist, and rare calc-silicate quartzite. Locally grades into gneiss and migmatite. Includes clean quartzite with 2 percent or less total feldspar and 5 percent or less biotite, feldspathic quartzite with 4 percent or less biotite, and sillimanite-muscovite-biotite schist. Feldspathic quartzite contains as much as 33 percent plagioclase; potassium feldspar is subordinate (0-2 percent) in the large exposure along Dan Lee Ridge southeast of Pierce, but is more abundant in the smaller exposures south and east of the ridge. Muscovite and garnet locally present in minor amounts (2 percent or less) in the quartzites. Most is probably metamorphosed Ravalli Group, but may include quartzitic intervals of the Wallace Formation.

GEOCHEMISTRY

More than 170 volcanic rock samples and 70 intrusive and metamorphic rock samples from the Kooskia quadrangle were analyzed for major oxide and trace element concentrations at the Washington State University GeoAnalytical Laboratory and the U.S. Geological Survey laboratory in Denver, Colorado, as part of this study and from previous work. A selected suite of these samples and their locations are noted on the map. Map numbers 1 through 71 are intrusive or metamorphic rock samples and numbers 72 through 217 are extrusive volcanic rock or dike samples. Information on the volcanic rock samples, including locations and analytical results, can be found in Idaho Geological Survey's Digital Analytical Data 1 (Kauffman, 2004b); information on the intrusive and metamorphic rocks is compiled in Digital Analytical Data 2 (Lewis and Frost, 2005).

STRUCTURE

STRUCTURAL SETTING

The map area includes two major structural boundaries, an important lithologic one, and numerous smaller structures. Figure 3 (on map) shows the distribution of these in a generalized, more regional context. The two major structures can be characterized by geochemical and geophysical data for their extent into the lower crust and perhaps mantle, but are mappable at the surface as zones of deformation or contrast in lithology. One of these is the Salmon River suture (Lund and Snee, 1988), which is expressed in the rapid spatial change in initial strontium isotope ratios in plutonic rocks that intruded it (0.704/0.706 Sr_i line; Figure 3). This is a fundamental convergent plate boundary between arc-affinity rocks of the Wallowa terrane of the Blue Mountains complex and rocks of continental affinity to the north and east. The other is expressed by offset of geologic features, lineaments, and geophysical anomalies. It includes the trans-Idaho discontinuity, described as a major left-lateral, strike-slip fault with several hundred kilometers of offset (Yates, 1968), and as a shear zone with ductile and later brittle deformation with an unknown amount of displacement (Pitz and Thiessen, 1986). This same feature is expressed by aeromagnetic anomalies and referred to as the Clearwater zone (Sims and others, 2005). Some or all of the structures along this trend (e.g., Glade Creek, Yakus Creek and Brown Creek Ridge shear zones; Figure 3) may be part of a 90-70 Ma basement relay system or crustal-scale ramp with basement-cored uplifts on it northeast that extends into southwest Montana (Orofino shear zone of McClelland and Oldow, 2007). Earlier motion along this zone during Belt sedimentation, the East Kootenay orogeny and Neoproterozoic rifting, also is likely. Less easily recognized is the lithologic boundary between Mesoproterozoic metasedimentary rocks from the Belt basin to the northeast and the Lemhi basins to the southwest (Green Mountain fault; Figure 3). For convenience, we'll refer to this boundary as the Belt-Lemhi boundary.

All of these boundaries have been locally intruded and ubiquitously overprinted by deformation, making it challenging to represent them with single lines on the map. Therefore, ductile shear zones, some several kilometers in width, are illustrated schematically in Figure 3. Where we suspect that significant faults are intruded, we show them within these shear zones on the map. Where lithologic contrast is sharp or younger more brittle structures exist, faults are shown on the map. Our current thinking is that the Salmon River suture is now represented by the Woodrat Mountain fault, Syringa fault, and Lowell thrust. The Belt-Lemhi boundary is expressed as the Green Mountain fault. The Brown Creek Ridge and Glade Creek shear zones are part of the trans-Idaho discontinuity (and Orofino shear zone). Descriptions of ductile structures follow this grouping with brittle structures last. Their genesis is discussed in the Geologic History section.

STRUCTURES ALONG THE SALMON RIVER SUTURE

Woodrat Mountain fault

The northwest-striking Woodrat Mountain fault marks the boundary between accreted rocks (Orofino series; *Mzgo, Mzmo*) to the west and continental metasedimentary rocks (Syringa sequence; *Z* units) to the east. Thus, it marks the Salmon River suture in this area. Because the Woodrat Mountain fault separates two major rock units we mapped it as a discrete structure, despite the ductile deformation along it. Foliation along this structure dips 60-70° east-northeast to east. East-plunging lineation defined by quartz rodding and “mica fish” orientation in hanging wall quartzite of the Syringa sequence indicate that the last motion along this structure was top to the west-southwest. Fabric in the orthogneiss east of the fault (*Kqdg* unit) is subparallel to the fabric in the adjacent metasedimentary rocks. Thus, much of the deformation in this zone was synchronous with, or post-dates the intrusion. The suture at depth is recorded by increased (>0.706) initial $^{87}Sr/^{86}Sr$ ratios that record incorporation of more continental sources or contaminants in plutonic rocks toward the east or northeast (Armstrong and others, 1977; Criss and Fleck, 1987). Wallrocks to the plutons change from west to east as well, with the eastern extent of the Orofino series marking the suture in the north, the Riggins Group in the south. The

Woodrat Mountain fault extends under a long-covered interval to the northwest corner of the Kooskia quadrangle.

Syringa Fault

The northeast-striking Syringa fault passes through Syringa and is probably responsible for the bend in the Middle Fork Clearwater River in that area. Foliation is northeast near this fault, in contrast to more north to northwest typical of the region, and dikes have intruded along it indicating that deformation was both ductile and brittle. Although access and exposures are poor south of the river, it appears that the Woodrat Mountain fault is truncated by, or merges with, the Syringa fault. As presently mapped, Syringa metamorphic sequence rocks are offset to the southwest on the southeast side of the fault in apparent right-lateral direction. However, some of the quartzite intervals north of Syringa appear to show left-lateral offset.

Ahsahka thrust

South of the area, the Salmon River suture has been overprinted by a broad (10-15 km wide) zone of shearing referred to as the western Idaho shear zone (McClelland and others, 2000; Tikoff and others, 2001). The western Idaho shear zone can be confidently traced north into the Kooskia quadrangle as far as the Syringa fault. Mylonitic rocks of the Seven Devils Group and Riggins Group at the southern map boundary (Figure 3) are within this zone of ductile deformation. Foliation dips about 70° east-southeast and lineation plunges eastward. Myers (1982) described this zone of deformation in the area immediately south of the map boundary. The Ahsahka thrust is a northwest-striking ductile shear zone in basement rocks in the Orofino quadrangle to the west (Davidson, 1990; Kauffman and others, 2006). We mapped this shear zone extending into the western part of the Kooskia quadrangle, where it is exposed along the lower part of Lolo Creek. Mesozoic rocks southwest of the shear zone lack pervasive gneissic foliation but are cut by numerous northeast-dipping ductile shear zones. Rocks northeast of the thrust are pervasively foliated to form coarse-grained mylonite gneiss. Foliation strikes northwest and dips steeply northeast; lineation plunges steeply down the dip of the foliation. Kinematic indicators in the shear zone in the Orofino quadrangle show consistent northeast-side-up (thrusting) shear sense (Strayer, 1986; Davidson, 1990). Our present interpretation is that the deformation immediately northeast of the Ahsahka thrust is similar in age to that of the western Idaho shear zone, whose activity was waning at 90 Ma. Preliminary U-Pb dating at Orofino indicates that deformation there ended by about 94 Ma, the age of a cross-cutting pegmatite dike (J.D. Vervoort, written commun., 2006).

Lowell thrust

The Coolwater Ridge orthogneiss (*Kbtgc*) and the gneiss and schist of Swiftwater Creek (*Mzgs*) are exposed in a window through a crustal-scale top-to-the west structure termed the Lowell thrust (Lund and others, 2005). As presently mapped, the structure is an antiformal culmination that plunges to the northwest and southeast. The metasedimentary rocks on the northern side of the structure are thought to be Neoproterozoic, but have not been dated. If it is older (Mesoproterozoic), then the geometry of the thrust may be different than depicted here (perhaps lacking continuity from the southwest limb to northeast limb). Ultramafic rocks (*Mzum*) are present along the southern and western parts of the fault, but have not been recognized along the northeast side. Lund and others (2005) reported that the Lowell structure was exposed by normal faults, but we did not find evidence for normal faulting in the area of the thrust.

The Lowell thrust is important in that it places Neoproterozoic rocks of the Syringa metamorphic sequence against Mesozoic rocks derived largely from island-arc sources (gneiss and schist of Swiftwater Creek). In this respect it is analogous to the Salmon River suture and the Woodrat Mountain fault. However, the Swiftwater Creek gneiss is more micaceous than the rocks of the Orofino series that are exposed west of the Woodrat Mountain fault, indicating that it is not a simple eastward continuation of the Woodrat Mountain structure. In addition, the gneiss and schist of Swiftwater Creek contains Proterozoic detrital zircon grains (in addition to numerous Mesozoic grains), indicating mixed source areas during deposition near the western edge of the continent.

BELT-LEMHI BOUNDARY

Green Mountain fault

The Green Mountain fault juxtaposes the Meadow Creek and Elk City metamorphic sequences just to the south of the map area (Figure 3). It has been considered as both a west-directed (Lewis and others, 1998) and an east-directed (Lund and others, 2004a; 2004b) thrust, but our most recent mapping of mylonitic fabrics along the structure east of Elk City shows that it is near vertical. Subhorizontal lineation and kinematic indicators there indicate left-lateral slip during at least one period of motion, similar to the sense of motion suggested for the Great Divide megashear (O’Neill and others, 2007), Clearwater tectonic zone (Sims and others, 2005), and trans-Idaho discontinuity (Yates, 1968). Farther south, rocks that contain 1380 Ma intrusions have been considered part of a single structural block (Hawley Creek thrust plate; Brushy Gulch-Red River thrust slab) by both Skipp (1987) and Lund and others (2004a). The structure that separates strata of the Lemhi and Belt basins appears to cross the southern edge of the map beyond the northern limit of the Elk City sequence, wrap around the east end of the Coolwater orthogneiss where is coincides with the Lowell thrust, and extend north to the Syringa fault. We picture the boundary being offset by the Syringa fault and continuing toward the northwest corner of the map, mostly obliterated by younger intrusions. To what extent this boundary is genetically related to early activity along or just coincident with the Orofino shear zone (sense but not location of McClelland and Oldow, 2007) is unclear.

BROWN CREEK RIDGE SHEAR ZONE AND RELATED NORTHWEST-STRIKING STRUCTURES

Brown Creek Ridge shear zone

This structure is defined by mylonitic intrusive and metasedimentary rocks in the Brown Creek Ridge area. The intrusive rocks have been dated by U-Pb zircon methods at 72 Ma (Payne, 2004; McClelland and Oldow, 2007). The shear zone at Brown Creek Ridge is covered to the southwest but is at least 6 km thick. Foliation is north-northwest and steep (about 75° NE to vertical). Trend and plunge of lineation is about 080° and 60°. Kinematic indicators consistently show northeast side up.

The Brown Creek Ridge shear zone is well inboard of the initial $^{87}Sr/^{86}Sr$ 0.704-0.706 line whereas the western Idaho shear zone is coincident with it. The continental-scale bend in the western Idaho shear zone in the Orofino area has been attributed to a relatively young (90-70 Ma) southwest-vergent structure termed the Orofino shear zone (Payne and McClelland, 2002; Payne, 2004; McClelland and Oldow, 2004, 2007). Although Payne and McClelland (2002) and McClelland and Oldow (2004, 2007) attributed foliation in rocks at Orofino to this structure, recent U-Pb dating of undeformed pegmatite there at 93.8 ± 1.3 Ma (J.D. Vervoort, written commun., 2006) indicates that the deformation at Orofino is older than at Brown Creek Ridge. We speculate that the trans-Idaho discontinuity (and Orofino shear zone) is about 15 km (9 mi) northeast of Orofino (on strike with the Brown Creek shear zone), and that the older fabrics mapped in the northeast part of the Orofino quadrangle and the western part of the Kooskia quadrangle are related to the western Idaho shear zone.

Glade Creek shear zone

A zone of ductile deformation northeast of Lowell previously referred to as the Glade Creek fault (Lewis and others, 1992b; 1998) contains strongly deformed plutonic rocks, many with well-formed augen of potassium feldspar. Foliation is west-northwest (285°) and vertical to steeply north dipping. Although we previously showed a single fault trace (Lewis and others, 1992b), the present map depicts the Glade Creek structure as broad zone of deformation (Figure 3). This shear zone is probably the southeastern continuation of the Brown Creek Ridge structure. Its southeastern extent is unknown. Mylonitic fabrics are sparse in the metasedimentary and igneous rocks west of the Running Creek pluton in the southeast part of the map. It is possible that old fabrics were obliterated by the intrusion of batholithic rocks (*TKbgd*). More likely, the Glade Creek shear zone merges to the southeast with the Green Mountain fault and separates Lemhi basin metasedimentary rocks from those of the main body of the Belt basin.

Yakus Creek shear zone

Strongly deformed rocks along Yakus Creek parallel those across Brown Creek Ridge and may be a southeastern extension of that zone. Foliation within this zone strikes northwest and dips northeast about 70°. Lineation plunges about 70° northeast. Poor exposures southeast of Yakus Creek make it difficult to trace this structure. It may terminate at the Syringa fault, or perhaps continue southeast to Lowell.

BRITTLE STRUCTURES

Several brittle structures have been mapped in the central, north, and northeast parts of the map. They are characterized by gouge zones, chloritic alteration, and topographic lineaments developed along more easily eroded fractures.

Northwest brittle faults near Lowell

Although most of the deformation in the Lowell area was ductile, late brittle shears and undeformed rhyolite dikes have followed the earlier northwest-striking structural grain. Pitz (1985) and Pitz and Thiessen (1987) described brittle northwest-striking faults in this area, several of which we included on the map.

Eldorado Creek and Holly Creek faults

The Eldorado Creek and Holly Creek faults are two of the larger northeast-striking brittle faults in the area. Smaller structures in the intervening area along the northern part of the map have a similar strike. Gouge is developed locally on the Eldorado Creek fault and sericitic alteration is common. Northeast striking Tertiary dikes (presumably Eocene) are parallel to and have intruded along the faults.

GEOLOGIC HISTORY

The fine-grained siliciclastic and carbonate-bearing clastic rocks of the Belt Supergroup were deposited between about 1470 and 1400 Ma during the Mesoproterozoic (Anderson and Davis, 1995; Evans and others, 2000). Bimodal basalt-granitic magmatism at about 1380 Ma near the end of deposition of the Belt Supergroup (Doughty and Chamberlain, 1996) was localized in the Lemhi basin of the Belt. A-type rapakivi granite plutons (*Yag*) and associated mafic intrusions are now found in the southeast part of the area and around Elk City (Evans and Fisher, 1986) and occur as smaller sill-like bodies in the vicinity of Dent in the Potlatch quadrangle to the northwest (Lewis and others, 2005b; 2007b). The 1380 intrusive event was likely related to the East Kootenai orogeny recognized to the north in Canada, which included deformation and metamorphism as well as plutonism (White, 1959; Leach, 1962; McMechan and Price, 1982; Lund and others, 2004a; 2004b).

Deformation and basaltic magmatism in the Neoproterozoic led to accumulation of sedimentary and volcanic rocks of the Windermere Supergroup in northeastern Washington (Miller, 1994) and the Big Creek and Gospel Hump areas of central Idaho (Lund and others, 2003). The Syringa metamorphic sequence (units *Zss, Zqs, and Zcss*) appears correlative with the Umbrella Butte Formation of Lund and others (2003) in the Gospel Hump area. Late Proterozoic rifting (Colpron and others, 2002) that formed a passive plate margin and presumably oceanic crust was followed by shelf and slope sedimentation in the Paleozoic. Preservation of basal Cambrian strata on different Belt units with angular unconformity to the north (Campbell, 1959; Lewis and others, 2002) indicates that the Belt rocks were folded or faulted during one or more of the events above.

Somewhere off the North American coast during the Permian through Triassic, the Blue Mountains composite island-arc terrane formed (Dickinson, 1979, 2004; Avé Lallemant, 1995; Vallier, 1995). Mesozoic sediments with contributions from both the arc and continent (*Mzgs*) may have accumulated on intervening oceanic or arc crust. Emplacement of this terrane against western North America began in late Jurassic or Early Cretaceous (Wernicke and Klepacki, 1988; Selverstone and others, 1992), likely south of its present location (Lund and Snee, 1988; Snee and others, 1995; Wyld and Wright, 2001). Tabular, mostly tonalitic bodies that were emplaced within the zone 118 to 90 Ma appear to be syntectonic with development of the steep fabric of the western Idaho shear zone (Manduca and others, 1993; McClelland and others, 2000), and vertical extrusion of material during transpression could have reduced the width of the suture zone (Giorgis and others, 2005). It seems likely that contraction or transpression that affected the western Idaho shear zone was part of a larger process that caused deformation and plutonism inboard of the suture.

Although one or more Proterozoic metamorphic events is likely, most of the metamorphism, deformation, and plutonism now preserved in the Kooskia quadrangle probably occurred in the Cretaceous. Thrust faulting may have started with the arrival of the Blue Mountains composite terrane. Burial of most rocks to depths of 20-30 km is supported by kyanite in Syringa rocks

(*Zqs*) in the south-central part of the map and in the Meadow Creek unit (*Yqm*) south of the map. This seems to require emplacement of a thick crustal section over most of the area. A remnant of this upper plate may be the little deformed lower Prichard Formation rocks above the Jug Rock detachment fault in the Boehls Butte area of the Headquarters quadrangle (Lewis and others, 2007a). West-vergent thrusting may have placed the Mesozoic strata under the Proterozoic rocks that themselves had to have been tectonically buried. An alternative is that the Mesozoic rocks intruded by the Coolwater body were already inboard relative to other Mesozoic rocks, as if they had accumulated in a reentrant in the continental margin. Plutons, such as along Coolwater Ridge, were emplaced at depth and deformed into orthogneiss (*Kbtgc*) during continuing contraction. Other bodies of *Kgdf* and *Kqdg* dated at 73 Ma are also deformed, indicating that at least local deformation along the Glade Creek and Brown Creek Ridge systems was ongoing then. Intrusion of the main phase of the Bitterroot lobe of the Idaho batholith followed at 65-53 Ma (Foster and others, 2001; Gaschnig and others, 2007). Uplift relative to the composite Blue Mountains arc terrane was focused along and northeast of the Ahsahka thrust. Uplift progressed inboard toward the higher grade terranes. The chilled margins and miarolitic cavities in the Eocene Whistling Pig and Running Creek plutons is consistent with considerable uplift before the Eocene. Some extension likely was accommodated by northeast-striking dikes and normal faults.

Approximately 17 million years ago, extrusion of Columbia River Basalt Group flows began and Grande Ronde Basalt (and possibly the older Imnaha Basalt) inundated the western part of the quadrangle, abutting the older highlands. Streams dammed by these flows deposited sediments in temporary marginal lakes and on the surface of some flows, which were then covered by subsequent flows. The lack of significant interbeds within the thick Grande Ronde sequence indicates very rapid extrusion rates. Following Grande Ronde extrusion, flows of Wanapum and Saddle Mountains basalts invaded the area, filling broad shallow structural depressions that were developing in the Weippe and Stites-Kooskia areas. Extrusion of these flows was less rapid, allowing time for deposition of sediments on one flow prior to eruption of the next flow. Basalt extrusion continued until about 12-11 million years ago when the youngest Saddle Mountains Basalt flows capped the northwest part of the quadrangle in the Weippe area. Streams from the highlands continued deposition of sediments marginal to and over the last basalt flows. Laterally the sediments grade into weathered rock, soil, and colluvium developed on basalt and prebasalt rocks.

During the Pleistocene, glaciation occurred in the eastern part of the quadrangle (Dingler, 1981; Dingler and Breckenridge, 1982). The oldest and most extensive glaciation in the area, the Grave Peak glaciation, was characterized by ice caps and large valley glaciers. The later Pleistocene Canteen Creek glaciation was typified by alpine-type valley glaciers and culminated with the Legend Lake glaciation, which was characterized by cirque headwall glaciers.

The Grave Peak area, located along the arcuate highland between The Crags and the northern Bitterroot Range, was the central accumulation area of a mountain ice cap with piedmont lobes and the extensive valley glaciers. Widespread glacial erratics are evidence of the ice cap and are common on the mountain uplands. The maximum extent of this ice cap is difficult to determine due to subsequent valley glaciation, but on the west, ice flowed down to a stream elevation of 1,403 meters (4,600 feet). To the east, outlet valley glaciers extended to a stream elevation of 976 meters (3,200 feet), the lowest glaciation recognized in the region. The Grave Peak ice cap and its outlet valley glaciers apparently covered an area of approximately 520 square km (200 square miles). The degree of soil development, useful as a relative age-dating method, shows that till deposits have been weathered to a depth of as much as 51 cm (20 inches). This is deeper than any soils recognized on deposits of the younger glaciation, although not all deposits show a uniform degree of development due to the effects of alpine climate, varying topography, and the influence of younger horizons of volcanic ash.

Areas affected by the older Grave Peak glaciation have been topographically modified by a later, less extensive period of alpine-type valley glaciation informally named the Canteen Creek glaciation (Dingler, 1981; Dingler and Breckenridge, 1982). Geomorphic evidence for this latest major glaciation includes an extensive area of glacially carved, youthful alpine topography and numbers of valleys with lateral moraines up-valley from the terminal areas of earlier glaciations. Major drainages with catchment areas above 1,830 m (6,000 feet) were glaciated. A minimum of two advances during the Canteen Creek glaciation are indicated by nested lateral moraines. Soils that have developed on till deposits generally have a thinner B horizon and a thinner cover of loess and volcanic ash than those formed on the older Grave Peak glacial deposits. Soil profiles reveal variations in the different age soils, but it is not clear whether the glaciations were separated by a significant soil-forming episode.

The latest glacial episode in the area was a period of cirque glaciation, as indicated by the ubiquitous cirque lakes dammed by moraines. This glacial episode was informally named the Legend Lake glaciation (Dingler, 1981; Dingler and Breckenridge, 1982). Moraines that formed during the Legend Lake episode occur on cirque lips or a short distance down-valley and are typical Neoglacial positions. Soils on these deposits, although poorly developed, are able to support vegetation. The capacity of these soils to support vegetation may be an effect of the regional climate or may indicate that the deposits are older, because most Neoglacial deposits in the Rocky Mountains do not support substantial vegetation. Mehringer and others (1977) showed that sedimentation in a similar position began approximately 12,000 years ago in the Bitterroot Mountains southeast of map. Because the age is not known, the deposits of Canteen Creek valley glaciation and Legend Lake cirque glaciation are combined on this map, but are mapped separately from the older Grave Peak glacial deposits.

Periglacial processes were active in the higher elevations of the area peripheral to glaciers during the late Pleistocene and Holocene. Sorted stone circles in outwash deposits and debris islands are found on till in The Crags, and a number of rock glaciers are located in alpine cirques. Holocene stream alluvium and fan deposits occur locally in major stream drainages or in broad upland valleys marginal to the Columbia Plateau where streams have not yet become incised.

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