Geologic Map of the Idaho Parts of the Orofino and Clarkston 30 x 60 Minute Quadrangles, Idaho

Compiled and Mapped by
John D. Kauffman, Dean L. Garwood,
Keegan L. Schmidt, Reed S. Lewis,
Kurt L. Othberg, and William M. Phillips

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Geologic Map 48
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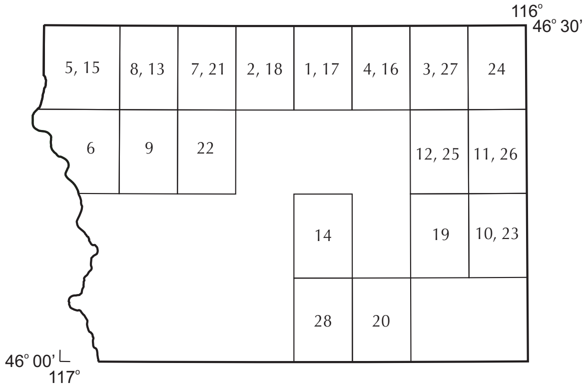
INTRODUCTION

The geology on the Idaho parts of the 1:100,000-scale Orofino and Clarkston 30' x 60' quadrangles is compiled from previous 1:24,000-scale mapping completed by the Idaho Geological Survey between 2000 and 2004 (Figure 1), from supplemental field work in 2005, and from other mapping sources at various scales and areal extent (Figure 2). Sources noted by an asterisk in Figure 2 needed minor modifications after brief field examinations or aerial photographic interpretations.

The eastern part of the region is underlain by basement sequences and intrusive rocks that constitute a North American cratonic assemblage, whereas the western part is underlain by a younger oceanic accreted terrane assemblage. Overlying units consist of Oligocene volcanic rocks, basalt flows of the Columbia River Basalt Group and associated sediments, Pliocene flood deposits, and Quaternary deposits.



SURFICIAL GEOLOGIC MAPS

1. Othberg and Weisz, 2002
2. Othberg and others, 2002a
3. Othberg and others, 2002b
4. Othberg and others, 2002c
5. Othberg and others, 2003d
6. Othberg and others, 2003a
7. Othberg and others, 2003b
8. Othberg and others, 2003c
9. Othberg and others, 2003e
10. Weisz and others, 2003a
11. Weisz and others, 2003c
12. Weisz and others, 2003b

GEOLOGIC MAPS

13. Bush and others, 2005
14. Bush and others, 2004
15. Garwood and Bush, 2005
16. Kauffman and others, 2005a
17. Kauffman and others, 2005b
18. Kauffman, 2004a
19. Kauffman and others, 2004a
20. Kauffman and others, 2004b
21. Kauffman, 2005a
22. Kauffman, 2005b
23. Kauffman and others, 2003b
24. Lewis and others, 2005b
25. Lewis and others, 2004a
26. Lewis and others, 2004b
27. Lewis and others, 2005c
28. Schmidt and others, 2005

Figure 1. *Sources of geologic mapping: STATEMAP*

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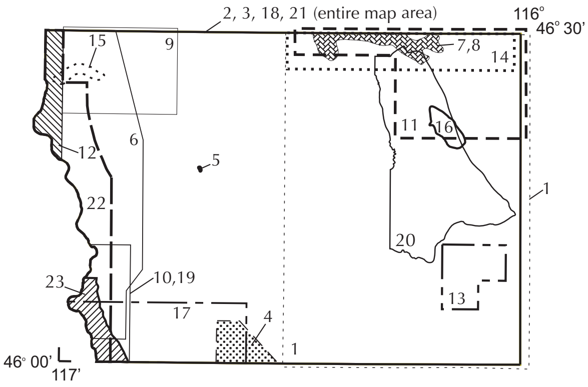

1. Anderson, 1930
2. Bond, 1962
3. Bond, 1963
4. *Borovicka, 1988
5. Bush and McFaddan, 1986
6. Camp, 1976
7. Davidson, 1987-1988 (unpublished geologic mapping)
8. Davidson, 1990
9. Garwood, 2001
10. Glerup, 1960
11. Hietanen, 1962
12. *Hooper and others, 1985
13. Jones, 1982
14. Kopp, 1959
15. Kuhns, 1980
16. Lee, 2001
17. *Reidel, 1978
18. Russell, 1901
19. Savage, 1965
20. Shea, 1970
21. Swanson and others, 1979a
22. Swanson and others, 1980
23. Vallier, 1998

* Primary mapping sources used to compile selected areas of the Idaho parts of the Orofino and Clarkston 30' x 60' quadrangles.

Figure 2. *Sources of geologic mapping: previous geologic mapping*

The oldest basement rocks, amphibolite-facies schist and gneiss of the Neoproterozoic Syringa metamorphic sequence, are restricted to the northeastern part of the map. Late Paleozoic and Mesozoic metasedimentary and metavolcanic rocks include amphibolite facies gneiss, marble, and impure quartzite of the Orofino series; volcanic and volcaniclastic greenschist-facies rocks of the Seven Devils Group; and mostly sedimentary rocks of the overlying Martin Bridge Limestone, Hurwal Formation, and Coon Hollow Formation. Intrusive rocks are predominantly Jurassic and Cretaceous quartz diorite, diorite, and gabbro; Cretaceous biotite tonalite; and Cretaceous trondhjemite. Oligocene volcanic rocks are exposed in the eastern part of the Orofino quadrangle southwest of Kamiah.

Lava flows of the Miocene Columbia River Basalt Group cover much of the area. In the Eagle Creek drainage in the southwest part of the map, the basalt sequence exceeds 1,130 m (3,700 feet) in thickness. These fissure-erupted lavas invaded the area and inundated the paleotopography, leaving a few prominences above the plateau surface. Older rocks are exposed on the steptoes or in canyons where streams have eroded through the basalt. Interbedded with some basalt flows are sediments of the Latah Formation. In the older basalt formations, the interbeds are predominantly near the plateau margin where dammed drainages overflowed the basalt surface and deposited sediments before the next flow was emplaced. Near the top of the basalt sequence, where individual flows are separated by longer periods of time, interbedded sediments are mostly restricted to structural depressions, such as the Lewiston basin.

Quaternary sediments and surficial deposits are shown where they are significant geological units or mask the underlying rock. These units include alluvium, alluvial fan deposits, loess, landslide deposits, and Bonneville and Missoula Flood deposits. Surficial deposits can be found for selected 7.5-minute quadrangles on maps published by the Idaho Geological Survey, as noted in Figure 1.

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). Oligocene and older volcanic rocks are classified by chemical composition (total alkalies versus silica) according to IUGS recommendations (LeMaitre, 1984). The Columbia River Basalt Group contains basalt, basaltic andesite, and andesite by this classification, but the term "basalt" is applied here, as it has been historically. Columbia River Basalt Group stratigraphy is modified from Swanson and others (1979b) and Camp (1981). Wanapum Basalt and Saddle Mountains Basalt units are in part defined by their geochemistry, following Wright and others (1973) and Camp (1981). The magnetic polarity of basalt units was measured by a fluxgate magnetometer in the field or a spinner magnetometer at the Idaho Geological Survey. Whole-rock XRF analyses for both basalt and nonbasalt rocks were done at the Washington State University GeoAnalytical Laboratory. 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 (Wentworth, 1922).

ARTIFICIAL DEPOSITS

m—Made ground (Holocene)—Artificial fills composed of excavated, transported, and emplaced construction materials of highly varying composition, but typically derived from local sources.

SEDIMENTARY DEPOSITS

YOUNGER ALLUVIAL, EOLIAN, AND LANDSLIDE DEPOSITS

Qal—Alluvial deposits (Holocene and Pleistocene)—Channel and flood-plain deposits of mainstreams and tributaries. Primarily Holocene coarse channel gravel. Includes sand bars in the Snake and Clearwater rivers and sand and gravel in low terraces. Subrounded to rounded pebbles, cobbles, and boulders in a sand matrix. Moderately stratified and sorted. Includes intercalated colluvium and debris-flow deposits from steep side slopes, and in places includes small alluvial fan deposits and alluvium of older (Pleistocene) terraces.

Qaf—Alluvial fan deposits (Holocene and Pleistocene)—Crudely 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 small tributaries to the major streams, many of which are steep debris-flow chutes. Commonly includes beds of silt and sand derived from reworked loess, Mazama ash, and Missoula Floods backwater deposits.

Qls—Landslide deposits (Holocene and Pleistocene)—Poorly sorted and poorly stratified angular rock fragments mixed with silt and clay. Landslides include slumps, slides, and debris flows. Slump blocks primarily composed of intact to broken sections of basalt and Latah Formation sediments. Debris flows mainly composed of unstratified, unsorted gravel rubble in a clayey matrix derived from liquified fine-grained sediment or weathered basement rock. Scarp and headwall area of landslide is not included because those features provide some of the best exposures of basalt units. Landslides range in age from relatively stable features of Pleistocene age to those that have been active within the past few years. Landslides are most prevalent along Latah Formation interbeds (*Tli*). Landslide debris is highly unstable when modified through either natural variations in precipitation or artificial means such as cuts, fills, and changes in surface drainage and groundwater infiltration. Even small landslide activity on the upper parts of canyon slopes can transform into high energy debris flows that endanger roads, property, and inhabitants below.

Ql—Loess deposits (Holocene and Pleistocene)—Calcareous wind-blown silt; sandy near deposits of Missoula Floods. Composes the Palouse Formation in the northwest corner of the map where loess is as much as 65 m (200 feet) thick in the Palouse Hills. Elsewhere on the map loess deposits are 1.2-7 m (5-20 feet) thick, lack a geomorphic surface comparable to distinctive Palouse Hills of the eastern Columbia Plateau, and are not correlated with the Palouse Formation (Othberg and others, 2003a, 2003d; Lewis and others, 2005a). The loess becomes a thin veneer eastward and is a common soil constituent over much of the area (Natural Resources Conservation Service, 1999). Thin loess with Holocene soil development caps Missoula Floods backwater deposits and probably represents the rapid deposition that followed the Lake Missoula Floods at the end of the Pleistocene. Loess is shown on the map as a pattern, but is not shown on cross-sections.

OLDER ALLUVIAL DEPOSITS AND SEDIMENTS

Qag—Alluvial gravel (Pleistocene)—Well-rounded pebble and cobble gravel of remnant point bars whose upper surface is about 25-30 m (80-100 feet) above the Clearwater River. Commonly mantled by Missoula Floods backwater deposits (*Qm*). The gravel was deposited by the ancestral Clearwater River before the latest Lake Missoula Floods. Also includes old, incised alluvial fans northeast of the mouth of the Grande Ronde River that contain poorly rounded basalt and limestone boulders, cobbles, and pebbles.

Qtg—Terrace gravel deposits (Pleistocene)—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.

Tclg—Clearwater gravel (late Pliocene?)—Primarily mainstream channel gravel and sand deposits that form a highly dissected terrace. Terrace surface remnants, from east to west, range from 325 to 315 m (1,080-1,050 feet) in elevation; an alluvial fan facies forms remnant slopes graded to the terrace. Gravel clast lithologies, forset cross-bedding, and cobble imbrication indicate a source and current direction similar to the present Clearwater River (Hooper and others, 1985; Othberg and others, 2003d). Gravel clasts include Columbia River basalt, nonbasalt igneous rocks (commonly Idaho batholith), and older metamorphic rocks (Webster and others, 1982). The gravels and sands are more weathered than typical Quaternary deposits, showing yellow to brown iron oxides in the matrix, local cementation, and softening of some gravel clasts. Recent field observations by Othberg and others (2003d) suggest a complex facies in this unit, reflecting an interaction of mainstream and tributary sources. These deposits and their stratigraphic relationships are exposed in two locations: (1) uphill from the site described by Kuhns (1980) in the POE Asphalt gravel pit in North Lewiston (sec. 29, T. 36 N., R. 5 W.), and (2) 5 km (3 miles) to the east in a gravel pit adjacent to Groundcovers, Inc. (Othberg and others, 2003d; sec. 26, T. 36 N., R. 5 W.).

Tch—Clarkston Heights gravel (late Pliocene?)—Primarily mainstream channel gravel and sand deposits equivalent to the Clearwater gravel but deposited by the Snake River rather than the Clearwater River. Characteristics similar to Clearwater gravel, but the common presence of clasts from the Seven Devils Group reflects a southern source area (Webster and others, 1982).

CATASTROPHIC FLOOD DEPOSITS

Qm—Missoula Floods backwater deposits (Pleistocene)—Rhythmites deposited when backwaters of Missoula Floods inundated the Clearwater River and Snake River valleys. Similar depositional environment, sedimentology, and age as Lake Missoula Floods rhythmites of eastern Washington (Smith, 1993; Waitt, 1980, 1985). In eastern Washington, Mount St. Helens tephra forms a 13,000-year time line in Missoula Floods rhythmites. Primarily alternating beds of gray sands and pale brown silts 10-30 cm thick. Cross-bedded, dark gray, basalt-rich granule gravel and coarse sands common at the base. Includes cut and fill structures and sandy clastic dikes. Clastic dikes are common features in the deposits and may follow coarser sand and gravel facies. Where rhythmites mantle Clearwater gravel and basalt, the clastic dikes are cut deep into the gravel and follow joints and normal faults down into the basalt. Rhythmites are typically capped by 0.3-0.9 m (1-3 feet) of loess and commonly reworked into sandy, silty colluvium. Found locally as high as 360 m (1,200 feet) in elevation, the approximate maximum flood level. In the Snake River valley, a veneer of Missoula Floods backwater deposits overlie Bonneville Flood deposits (*Qb*) and in the Clearwater River, Missoula Floods rhythmites mantle Pleistocene alluvial gravel (*Qag*).

Qb—Bonneville Flood deposits (Pleistocene)—Gravel and sandy gravel deposits of the Bonneville Flood that form giant expansion bars and point bars in the Lewiston basin and Snake River canyon. The giant expansion- and point-bar deposits are poorly sorted with bedding consisting of large cross-beds and crude layers of alternating bouldery gravel and sand. Minor calcium-carbonate cementation minimizes erosion in steep exposures. The sand and fine gravel clasts are predominantly very angular basalt fragments probably derived from the Snake River canyon just upstream. Nonbasalt pebbles and cobbles are generally well rounded and reflect a Hells Canyon source; most are granitoids and greenschist facies volcanic and volcaniclastic rocks. The deposits also contain clasts of Sweetwater Creek interbed silt, probably associated with upstream exposures where large landslides are located. Bonneville Flood deposits have not been recognized in the Clearwater River drainage east of Lewiston.

LATAH FORMATION

Sediments of the Latah Formation were deposited by drainages modified during emplacement of the Columbia River Basalt Group. Stratigraphically equivalent to the Ellensburg Formation in Washington (Swanson and others, 1979b).

Tls—Latah Formation sediments (Miocene)—Subangular quartz cobbles, pebbles, arkosic sand, and silt poorly exposed on flat upland surfaces. Typical thickness is <10 m (<30 feet). Poorly sorted sediment deposited marginal to Columbia River Basalt Group. Deposited by streams flowing from the highlands onto the basalt surface.

Tli—Latah Formation interbeds (Miocene)—Clay, silt, sand, pebble, and cobble deposits interbedded between basalt flows or at the basement rock-basalt contact. Sands are typically arkosic. Pebbles and cobbles are usually well rounded; composition varies depending on source area. Interbeds are probably more extensive than mapped. Deposited by streams flowing west as a result of repeated damming of drainages by basalt flows. In the older basalt units, interbeds are mostly restricted to marginal areas near prebasalt basement rocks. In younger units, interbeds are generally associated with developing structures on the basalt surface.

VOLCANIC ROCKS AND ASSOCIATED DIKES

COLUMBIA RIVER BASALT GROUP

Flows of the Columbia River Basalt Group cover much of the area. The thickest exposed sequence occurs along the Salmon River near the mouth of Eagle Creek where the basalt is over 1,120 m (3,700 feet) thick. 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. Imnaha Basalt is exposed in the eastern part of the area along the Clearwater River and in the western part in the canyons of the Salmon and Snake rivers and their tributaries. Grande Ronde Basalt, from oldest to youngest, has been subdivided into the informal R_1, N_1, R_2, and N_2 magnetostratigraphic units (Swanson and others, 1979b). Of these units, flows of the R_1, N_1, and R_2 are exposed throughout the area. Grande Ronde Basalt commonly forms the upland surface or is veneered by one or more flows of the more restricted Wanapum Basalt and Saddle Mountains Basalt. Wanapum Basalt flows cover broad areas where structural depressions were beginning to form on the Grande Ronde Basalt surface. Saddle Mountains Basalt flows, while fairly extensive, are more restricted to structural lows. The youngest Saddle Mountains Basalt units occur only as canyon-filling flows within the Lewiston basin. Table 1 lists average major oxide and trace element concentrations for Columbia River basalt units in the quadrangles.

Saddle Mountains Basalt

Tlm—Lower Monumental Member (Miocene)—Dense, dark gray, very fine-grained basalt with small plagioclase laths 1-2 mm long. Normal magnetic polarity. Occurs in the Lewiston basin as intracanyon flows with thin, blocky irregular columns (Hooper and others, 1985). Age reported as 6 Ma (McKee and others, 1977).

Several dikes in the Snake River canyon have chemistry indicative of the Lower Monumental Member. One was sampled by V.E. Camp (sample CA056, Camp, 1976; Hooper, 2000, Appendix, p.1) and mapped by him as Lower Monumental Member. His correlation was later considered incorrect by Swanson and others (1980) who mapped the dike as queried basalt of Lewiston Orchards. We conclude, however, from major oxide and trace element correlations that Camp was originally correct. Two dikes were found during this study in the Corral Creek drainage, one to the south of the creek and one to the north along the same N. 10°-20° W. trend. These dikes are 1.2-7 m (5-20 feet) wide and in places have small apophyses extending into the adjacent basalt. Both dikes have chemical signatures similar to that of the Lower Monumental Member (samples 05JK211, map no. 101, and 05JK216, map no. 95; Kauffman, 2007).

Tt—Basalt of Tammany Creek (Miocene)—Dense, plagioclase-phyric flow across the mouth of Tammany Creek canyon that fills valleys cut in the Elephant Mountain Member (Hooper and others, 1985). Contains abundant plagioclase phenocrysts and glomeroporphyritic groups of plagioclase, zoned augite, and olivine in intergranular grains and opaque glass (Hooper and others, 1985). The plagioclase phenocrysts and clusters range from 1 mm to 8 mm. Magnetic polarity determinations in the field were strong normal.

An intracanyon flow along Sweetwater Creek is dense, very dark gray and glassy, with common small plagioclase phenocrysts 0.5-2 mm long and a few plagioclase laths and clusters as large as 5 mm. Phenocrysts are not as abundant as in the basalt of Tammany Creek exposures at the mouth of Tammany Creek. A sample collected from this flow (sample 05JK068, map no. 135; Kauffman, 2007) is similar chemically to the Tammany Creek flow (Hooper and others, 1985). Field magnetometer polarity results for this flow were strong normal.

Tem—Elephant Mountain Member (Miocene)—Dark gray, fine-grained, aphyric to microphyric basalt. Occurs as canyon-filling flows on the Idaho part of the Clarkston 30' x 60' quadrangle (Hooper and others, 1985). Normal to transitional magnetic polarity (Choiniere and Swanson, 1979). Dated at 10.5 Ma (McKee and others, 1977).

Tcsc—Basalts of Craigmont and Swamp Creek, undivided (Miocene)—Two flows that form the capping sequence in the northeast part of the Orofino quadrangle, north of Lolo Creek. Northeast of the map near Weippe, the basalt of Craigmont overlies the basalt of Swamp Creek (Bush and others, 2003). We have combined these units in this area because of their similarity in chemical signatures, their close physical association, and the scarcity of outcrops; elsewhere, only the basalt of Craigmont is present, and it is mapped separately. Each unit is described below. Camp (1981) gave both units informal member status, but we have chosen to drop the member status. Mapping and sampling in the Potlatch 30' x 60' quadrangle (Lewis and others, 2005a), as well as for this project, have shown that these two units, and possibly the basalt of Feary Creek (Camp, 1981), are chemically similar, generally occur in close proximity, and should likely be considered separate flows within one member.

> **Tcg—Basalt of Craigmont (Miocene)**—Fine- to medium-grained phyric basalt, uncommon to common plagioclase phenocrysts 2-5 mm long, rarely 7-10 mm long; uncommon olivine about 1 mm in diameter; some dark brown oxide(?) cavity filling. Normal magnetic polarity. Outcrops uncommon and generally poorly exposed. Consists of one flow 15-45 m (50-150 feet) thick, possibly thicker locally. Commonly weathers to red-brown saprolite. Occurs in the northeast part of the map with the basalt of Swamp Creek. Near Craigmont on the Camas Prairie, it locally forms the capping basalt, resting on the basalt of Weippe, the basalt of Grangeville, the basalt of Icicle Flat, or the Grande Ronde Basalt. Distribution of the unit indicates local sources, although none were identified.
>
> **Basalt of Swamp Creek (Miocene)**—Medium- to coarse-grained basalt with common plagioclase phenocrysts as long as 10 mm and olivine phenocrysts 2-3 mm in diameter. Normal magnetic polarity, although some field magnetometer readings inconsistent. Probably fills structural and erosional depressions on older units. Consists of one flow probably less than 25 m (75 feet) thick. Commonly weathers to red-orange or red-brown saprolite. Occurs only in the northeast part of the map where it is combined with the basalt of Craigmont (unit *Tcsc*), but it extends northward and eastward into the Potlatch and Kooskia 30' x 60' quadrangles (Lewis and others, 2005a; Lewis and others, 2007).

Tp—Pomona Member (Miocene)—Fine- to medium-grained basalt with small plagioclase phenocrysts 2-4 mm long and common olivine grains as large as 1 mm. Reverse magnetic polarity (Choiniere and Swanson, 1979). Occurs as canyon-filling flows in the Lewiston area. Has well-developed, commonly radiating or fanning columns that formed perpendicular to the walls of ancestral Salmon River (what is now the Snake River) and Clearwater River canyons. A thick outcrop of welded spatter, hyaloclastite, and associated columnar Pomona Member basalt along Sweetwater Creek, the easternmost known occurrence, has some characteristics of a source vent, although pebbles and sand that underlie this exposure indicate it may be a channel fill rather than a vent. Date reported about 12 Ma (McKee and others, 1977).

Twe—Basalt of Weippe (Miocene)—Medium- to coarse-grained basalt with scattered to common plagioclase phenocrysts 2-5 mm long; abundant olivine crystals and clots generally visible to the naked eye. Reverse magnetic polarity as determined in the laboratory; field magnetometer readings are commonly conflicting and weak. Consists of one flow 15-45 m (50-150 feet) thick. Commonly weathers to saprolite. Similar chemically to Pomona Member (Swanson and others, 1979a) and mapped as part of the Pomona Member by Camp (1981). Kauffman (2004a) suggests the two units may not be coeval on the basis of different paleomagnetic directions. In addition, no physical connection of the two units was found, and they have unique occurrence characteristics. The basalt of Weippe is a plateau-capping unit over part of the Orofino quadrangle that may locally fill shallow structural depressions but was not found filling erosional channels. Conversely, the Pomona Member occurs only as a canyon-filling unit within the Lewiston basin. Although erosion may possibly have removed evidence of a connection, we conclude that the Pomona Member and Weippe basalt are separate time-stratigraphic units. K/Ar age reported as 12.9 ± 0.8 (Kauffman, 2004a).

Tgv—Basalt of Grangeville (Miocene)—Medium to dark gray, fine- to medium-grained basalt with common plagioclase phenocrysts 1-4 mm long and scarce to common olivine grains generally <1 mm in diameter that tend to weather pinkish or orangish. Reverse magnetic polarity as determined in the field and the laboratory. Consists of one flow ranging in thickness from 10 m to 25 m (30-80 feet). The Grangeville flow is the uppermost unit over part of the Camas Prairie near Grangeville where it rests on Grande Ronde Basalt. Where not the capping unit, the basalt of Grangeville overlies the Asotin-Wilbur Creek unit or Grande Ronde Basalt and is capped by either the basalt of Weippe or the basalt of Craigmont, or both. It is restricted in extent in the map to the Camas Prairie area, although it has been documented by chemical analysis in the White Bird basin to the south. Stratigraphic position relative to the basalt of Lewiston Orchards is uncertain, but paleomagnetic directions for the basalt of Grangeville are similar to, although slightly different from, those for the basalt of Weippe (Idaho Geological Survey, unpublished paleomagnetic data). We conclude the basalt of Grangeville was most likely erupted during the same reverse polarity epoch as the Pomona Member and basalt of Weippe, which places it stratigraphically above the basalt of Lewiston Orchards. An age of 12.1 ± 0.4 Ma is reported by Evernden and James (1964) for this unit in the White Bird area.

Twl—Basalt of Lewiston Orchards (Miocene)—Medium gray, medium-grained, plagioclase- and olivine-phyric basalt. Plagioclase phenocrysts typically 2-4 mm long; olivine phenocrysts 0.5-2 mm in diameter. Normal magnetic polarity as determined in the field and from laboratory analysis. Consists of one flow generally less than 15 m (50 feet) thick overlying the Asotin-Wilbur Creek unit or separated from it by a thin, discontinuous sedimentary interbed. Forms the capping unit in the Lewiston Orchards area. Thins eastward and pinches out near Sweetwater Creek. Also mapped at the top of the Lewiston Hill in a northwest-trending shallow syncline. Included in the Weissenfels Ridge Member (Swanson and others, 1979b).

Three dikes with basalt of Lewiston Orchards chemistry occur in the area. Two are associated with anticlinal structures north of the Clearwater River, and one is along the Waha escarpment. The dikes on the Lewiston anticline were intruded parallel or subparallel to the axis. Both are intensely weathered. The dike on the Waha escarpment strikes N. 45° E., again approximately parallel to the structure, and is nearly vertical. The dike, exposed in a roadcut, is about 2 m (6 feet) wide and intrudes the saprolite developed on Grande Ronde Basalt.

Taw—Asotin Member and Wilbur Creek Member, undivided (Miocene)—Dark gray, fine-grained basalt with scattered plagioclase phenocrysts 1-4 mm long and occasional to common olivine grains <1 mm in diameter. Normal magnetic polarity. Entablature forms cliffs or prominent patterned-ground pavement outcrops along upper canyon slopes. Thickness ranges from 30 m to 60 m (100-200 feet) and appears to thin over older structural warps on the basalt surface. Chemistry typical of both members and the intermediate basalt of Lapwai (included in the Wilbur Creek Member; Swanson and others, 1979a; Camp, 1981) is documented in the area (Kauffman, 2004b, 2007). The Asotin-Wilbur Creek unit is the most extensive and lowermost Saddle Mountains Basalt in the area, extending from the Lewiston basin to beyond the eastern edge. It pinches out, except as noted below, against the Waha escarpment and generally thins toward the east along the Clearwater River. It does occur, however, along the eastern edge of the map where it probably flowed into the developing Stites-Kooskia basin. Age is reported about 13 Ma by Tolan and others (1989, Figure 1).

Remnants of a channel fill of *Taw* unit (Asotin chemistry) have been documented on the Craig Mountain uplift and traced nearly 16 km (10 miles) south of Waha. The flow has a maximum thickness of about 30 m (100 feet). Sediments ranging in size from sand to cobble underlie the basalt at several locations. These sediments contain green and purple pebbles and cobbles of Permian to Jurassic metavolcanic units as well as basalt clasts. The basalt apparently flowed into a narrow valley eroded in Grande Ronde R_2 basalt along the present day courses of Lake Creek and West Fork Deer Creek. This valley may have originally drained to the west toward the Snake River. Today, the West Fork Deer Creek drains south to the Salmon River, whereas Lake Creek drains northward toward the Clearwater River. This canyon fill of Asotin basalt south of the Waha escarpment provides an important constraint for the timing and amount of uplift on the escarpment relative to the developing Lewiston basin.

Wanapum Basalt

Tpr—Priest Rapids Member (Miocene)—Medium to dark gray, fine- to coarse-grained basalt with common plagioclase phenocrysts 2-8 mm long and common olivine grains 1-2 mm in diameter. Coarser grained varieties tend to have the larger phenocrysts of both plagioclase and olivine. Reverse magnetic polarity. Consists of one to two flows of Lolo chemical type (Wright and others, 1973) except in the map's northeast part where the Rosalia chemical type (Wright and others, 1973) was documented in a tributary to Jim Ford Creek (Lewis and others, 2005c). Sand, pebbles, and cobbles of the Sweetwater Creek interbed (included in *Tli* unit) are common above the Priest Rapids Member in the Lewiston basin. Age is generally reported as 14.5 Ma (e.g., Tolan and others, 1989, Figure 1).

Several Priest Rapids Member dikes were mapped and sampled by V.E. Camp in 1978 (Swanson and others, 1979b). Some are exposed along a county road just east of U.S. Highway 12 east of the Clearwater River near Greer, and others are southeast of Orofino along Jim Ford Creek road. The dikes along the county road cut Cretaceous plutonic rocks, and those southeast of Orofino cut both Mesozoic Orofino series rocks and R_1 Grande Ronde Basalt.

Tif—Basalt of Icicle Flat (Miocene)—Medium to dark gray, fine- to medium-grained basalt with common plagioclase phenocrysts 4-10 mm long and rare to uncommon olivine grains about 1 mm in diameter. In places, the Icicle Flat texturally resembles the Priest Rapids Member. Normal magnetic polarity as determined in the field and the laboratory. Chemically and paleomagnetically indistinguishable from the basalt of Dodge, Eckler Mountain Member (Kauffman, 2004a). One flow with a maximum thickness of about 30 m (100 feet), but generally 12-18 m (40-60 feet) thick. Probably flowed into structural depressions developed on Grande Ronde Basalt. Previously included in the Saddle Mountains Basalt (Camp, 1981), but was recently found to be older than Priest Rapids (Kauffman, 2005a). During the course of mapping, the Icicle Flat was documented to directly underlie the Priest Rapids Member and overlie R_2 Grande Ronde Basalt at several locations. It was also extended west of Cottonwood Creek near Myrtle and north of the Clearwater River (in the Juliaetta and Lenore quadrangles) where it had not previously been mapped. No vent or source dike was found for the Icicle Flat, but it most likely was extruded somewhere on the Camas Prairie near Craigmont or Grangeville.

The basalt of Icicle Flat extends from the northeastern flank of Cottonwood Butte eastward nearly to Nezperce and northward irregularly to the Gifford area. Northwest of Gifford, it apparently filled a shallow trough in the Cottonwood Creek area where a thin flow rests on R_2 Grande Ronde Basalt and underlies the Priest Rapids Member. This flow extends a short distance north across the Clearwater River and pinches out to the west. Basalt of Icicle Flat is not found in the Lapwai Creek drainage or its eastern tributaries of Tom Beall Creek and Garden Creek where R_2 Grande Ronde Basalt is directly overlain by the Priest Rapids Member.

Grande Ronde Basalt

Grande Ronde Basalt was erupted from about 16.5 to 15.4 million years ago and accounts for over 60 percent by volume of Columbia River basalt (Camp and others, 2003). Although the Grande Ronde Basalt has mappable chemical subdivisions (Reidel and others, 1989; McConnell, 2006; Evarts, 2004), the number of analyses required was not feasible for this project. Therefore, we subdivided the formation on the basis of remanent magnetic polarity. Three of the four Grand Ronde Basalt magnetostratigraphic units occur in the area, R_1, N_1, and R_2. The youngest unit, N_2, pinches out west of the area. The other three units occur throughout most of the map, although R_2 pinches out toward the southeast. The most complete Grande Ronde Basalt sections are in the canyons of the Snake and Salmon rivers. Reidel (1978) measured and sampled several stratigraphic sections in this part of the Salmon River canyon.

The magnetostratigraphic contacts are problematic because most have been established using field magnetometers. We have found that flows near the reverse-normal contacts commonly yield very weak or conflicting results, or results that are extremely sensitive to inclination of the sample, making a definitive location of the magnetostratigraphic break difficult. Samples sensitive to inclination change from normal to reverse or vice versa with minor inclination changes as the magnetometer probe is approached. In other words, normal results do not necessarily mean the unit has normal magnetic polarity, and likewise for reverse results, and may represent basalt eruptions during polarity transitions. In general, we have a contact confidence of plus or minus one or two flows, which can amount to several hundred feet of uncertainty depending on flow thickness. We therefore encourage caution when evaluating stratigraphic thickness of Grande Ronde Basalt magnetostratigraphic units or structure from our mapped contacts for these units.

Tgr$_2$—Grande Ronde Basalt, R$_2$ magnetostratigraphic unit (Miocene)—Medium to dark gray, fine-grained basalt, commonly with a sugary texture. Some flows have uncommon to common 1-2 mm plagioclase phenocrysts. Reverse magnetic polarity, although field magnetometer readings commonly give weak normal or conflicting results, particularly near the top of the R$_2$ section. Consists of four to six flows in the western part of the map with a maximum thickness of about 210 m (700 feet). Most flows have a blocky colonnade jointing character, but a few have well-developed hackly entablatures. Chemical analyses indicate at least four chemical types that are likely equivalent to the Meyer Ridge, Grouse Creek, Wapshilla Ridge, and Mt. Horrible units of Reidel and others (1989), although there is a broad overlap and common repetition of chemical signatures within the R$_2$. There also appear to be three chemical variants of the Meyer Ridge unit, as noted in Table 1, although no relative stratigraphic position of the three is implied. We suspect flows may have repeatedly erupted from different sources, allowing them to interfinger and perhaps inject into and inflate nearby flows, as Reidel (2005) has documented for the N$_2$ Cohassett flow, Sentinel Bluffs Member.

The thickest R$_2$ sequences are in the Lewiston basin, where the unit consists of at least four to six flows totaling 150-210 m (500-700 feet), and on Craig Mountain where it consists of four to six flows totaling 120-150 m (400-500 feet). Eastward from Craig Mountain and the Lewiston basin, the R$_2$ thins in total thickness, and the number of flows decreases. A few isolated reverse field magnetometer readings in the eastern part of the map indicate possible R$_2$ remnants, although these are generally included in the N$_1$ map unit because of their sporadic occurrence and uncertain polarity readings.

One dike, previously mapped as Grande Ronde (Swanson and others, 1980), is included on the map on the Idaho side of the Snake River across from the mouth of the Grande Ronde River, although we were unable to locate the dike during a brief reconnaissance. Reidel and others (1992) map a probable extension of this dike on the Washington side of the Snake River as R$_2$ Grande Ronde Basalt.

Tgn$_1$—Grande Ronde Basalt, N$_1$ magnetostratigraphic unit (Miocene)—Dark gray, fine-grained generally aphyric to plagioclase-microphyric basalt. Normal magnetic polarity. The sequence consists of as many as ten to thirteen flows and is about 240 m (800 feet) thick in the western part of the map and thins eastward. Individual flows range in thickness from 15 m (50 feet) to more than 60 m (200 feet). Flows near the top of the sequence are commonly 15-20 m (50-70 feet) thick and typically sugary textured with scarce small plagioclase phenocrysts 1-3 mm long. Flows lower in the sequence are typically thicker, generally 30-60 m (100-200 feet). Colonnades of thin flows and entablatures of thick flows tend to form tiered cliffs on steep canyon slopes. As noted above, the N$_1$ Grande Ronde Basalt map unit may include remnants of R$_2$ Grande Ronde Basalt in the eastern part of the map.

Tgr$_1$—Grande Ronde Basalt, R$_1$ magnetostratigraphic unit (Miocene)—Mostly dark gray, fine-grained aphyric to microphyric basalt. Very rare plagioclase phenocrysts 2-4 mm long in one or more flows and common to abundant plagioclase phenocrysts 2-8 mm long in the informal Rogersburg unit (Reidel and others, 1989), which is well exposed along the Snake River from Billy Creek to Captain John Creek. Reverse magnetic polarity, although flows near the R$_1$-N$_1$ boundary commonly have inconsistent and weak field magnetometer polarity readings; therefore, the mapped contact is poorly constrained. Outcrop characteristics of flows are similar to those in the N$_1$ unit. Maintains a thickness of 300-360 m (1,000-1,200 feet) across much of the area except where interrupted by topographic highs of older rocks.

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. Flows examined in the field have normal polarity. Outcrops commonly deeply weathered or degraded forming granular detritus. Outcrops of fresh basalt are characterized by well-formed, commonly fanning or radiating columns 0.25-1 m (1-3 feet) in diameter. Best exposures are in the canyons of the Clearwater, Snake, and Salmon rivers and their incised tributaries. At least ten flows with a total thickness of over 460 m (1,500 feet) are exposed in the Eagle Creek drainage. Contact with prebasalt rocks is unconformable and very irregular. Partly indurated sand and silt interbeds, a few of which contain plant fossils, occur locally near contact with basement rocks. These interbeds are not laterally extensive and commonly pinch out within 0.8 km (0.5 mile) of the basalt-basement rock contact.

Several plagioclase-phyric basalt dikes cut the Martin Bridge Limestone near Limekiln Rapids. These dikes, which in places weather as negative-relief features, are mapped as queried Imnaha Basalt. Extensions of these dikes across the Limekiln fault were not found. Some or all of these dikes may possibly be a Columbia River basalt other than Imnaha, or they may be pre-Columbia River basalt in age.

POTLATCH VOLCANICS

Ton—Onaway Member (Oligocene)—Fine- to medium-grained trachyandesite with scarce, mostly clear plagioclase laths as large as 2 mm. Remanent magnetic polarity not determined. Mapped at one location on a northern outlier of Big Butte where one sample (03JK019, map no. 391; Kauffman, 2004b) has a chemical signature more similar to the Onaway Member, Potlatch Volcanics (Kauffman and others, 2003a, 2006), than to the nearby Kamiah volcanics basalt or Columbia River basalt (Tables 1 and 2). The sample has high total alkalis versus silica and elevated values for Al_2O_3, P_2O_5, Sr, Zr, and Nb compared to Columbia River basalt. P_2O_5, Zr, and Nb are also elevated in this sample compared to the Kamiah volcanics basalt. The Onaway Member was previously included in the Columbia River Basalt Group (Camp, 1981), but has since been found to be older, dated at about 26 Ma (Kauffman and others, 2003a, 2006).

KAMIAH VOLCANICS

The Kamiah volcanics consists of basaltic, andesitic, and rhyolitic volcanic rocks exposed on buttes southwest of Kamiah. Originally named by Anderson (1930) and later mapped and described in more detail by Jones (1982). Big Butte and Twin Buttes, along with several smaller outliers, are composed of nearly horizontal basalt, basaltic andesite, and andesite flows overlying dacitic to rhyolitic flows. Total alkalis versus silica for the basalts is greater than in Columbia River Basalt Group but less than in basalt of Onaway. The Kamiah volcanics basaltic rocks also have elevated values for Al_2O_3 and Sr relative to Columbia River Basalt Group, but not for P_2O_5, Zr, and Nb as does the Onaway Member (Tables 1 and 2).

Tak—Andesite (Oligocene)—Subhorizontal andesitic volcanic rocks. Consists of andesite, basaltic andesite, and basalt flows. Includes porphyritic andesite tuff(?) with phenocrysts of plagioclase (about 14 percent) and pyroxene (about 1 percent) in a glassy groundmass, which appears to contain relict welded shards. Jones (1982) reports andesite lava flows and subordinate pyroclastic rocks. The pyroclastic rocks were described as being lower in the section and consisting of lapillistones and tuff breccias. Reported modes from Jones (1982) of the holocrystalline rocks are plagioclase (70-80 percent), pyroxene (10-20 percent), olivine and iddingsite (0-15 percent), and opaques (1-5 percent).

An andesite dike that crosscuts the *Trk* unit probably fed the younger andesite flows. Chemical analysis (sample 02JK633B, map no. 411; Kauffman, 2004b) indicates a composition on the dacite-andesite divide (normalized SiO_2 = 63.27 percent) in the IUGS classification system (LeMaitre, 1984). Nearly identical chemically to sample 02WL040 (map no. 399; Kauffman, 2004b) from the *Tak* unit that has slightly less SiO_2 (62.63 percent) and plots in the andesite field.

Tbrk—Volcanic breccias (Oligocene)—Volcanic breccia layer within *Tak* unit on north flank of Big Butte. May be the tuff breccias noted by Jones (1982), which he reported contain lapilli-size vesicular clasts and bombs of dense andesite.

Trk—Rhyolite (Oligocene)—Subhorizontal rhyolitic volcanic rocks that underlie the *Tak* unit. Jones (1982) referred to this unit as quartz latite. He reported two chemical analyses that plot in the rhyolite field of the IUGS classification system (LeMaitre, 1984). Jones (1982) described these rocks as being mostly vitrophyric lava flows with subordinate air-fall pyroclastic rocks. Reported phenocrysts are plagioclase (10-20 percent), hornblende (0-2 percent), and pyroxene (trace).

The groundmass is glassy and typically partly or entirely devitrified. An $^{40}Ar/^{39}Ar$ date from plagioclase in the unit yielded a weighted mean age of 31.82 ± 0.27 Ma (New Mexico Geochronological Research Laboratory, Richard Esser, written commun., 2005), indicating an Oligocene age.

INTRUSIVE ROCKS

Tab—Andesite and basalt dikes, undivided (Tertiary)—Several dark andesite and basalt dikes cutting *KJqd* and *KJbt* units south of Greer. One dike along the county road on Fivemile Creek (sample VC78-378, map no. 372; Kauffman, 2004b) is chemically similar to andesite of the Kamiah volcanics exposed on several buttes southeast of Nezperce.

Tpd—Porphyritic dacite dikes (Eocene?)—Greenish gray, porphyritic dacite dikes. Two mapped, both along the upper part of Orofino Creek, 18 km (11 miles) east of Orofino. Phenocrysts are euhedral plagioclase laths 5-10 mm long. Age uncertain, but textures and compositions are similar to dated dikes of the Challis magmatic event.

Kpeg—Pegmatite dikes (Cretaceous)—Dikes of pegmatite cross-cutting Cretaceous units, mapped only locally. They are typified by coarse plagioclase, quartz, and muscovite grains (Lee, 2001). Includes a large biotite tonalite pegmatite along the slope east of the Clearwater River 3 km (2 miles) southeast of Orofino. A U/Pb zircon laser-ablation ICPMS age of 93.8 ± 1.3 Ma from an undeformed pegmatite is too small to show on map that cross-cuts mylonitic quartz diorite (*KJqdg*) at sample locality 29 (J.D. Vervoort, written commun., 2006).

INTERMEDIATE INITIAL $^{87}SR/^{86}SR$ INTRUSIONS

Ktt—Biotite tonalite and hornblende-biotite tonalite (Cretaceous)—Biotite tonalite and lesser amounts of hornblende-biotite tonalite grading to hornblende-biotite quartz diorite. Typically foliated. Includes one exposure of biotite granodiorite along the road west of Cedar Creek at the map's northeast edge. Contains about 7-15 percent biotite and 0-10 percent hornblende. Initial $^{87}Sr/^{86}Sr$ values are transitional between low (<0.704) and high (>0.706) from west to east across the unit in the Orofino Creek drainage (Criss and Fleck, 1987). Northern part of intrusion separates Neoproterozoic Syringa metamorphic sequence (*Zss*) from Mesozoic Orofino series (*Mzgo*) and has intruded along the folded northern extension of the Salmon River suture (Lund and Snee, 1988).

LOW INITIAL $^{87}SR/^{86}SR$ INTRUSIONS

Ktr—Biotite-muscovite trondhjemite (Cretaceous)—Medium-grained, equigranular biotite-muscovite trondhjemite (leucocratic oligoclase-bearing quartz diorite and tonalite). Generally massive. Contains 1-7 percent muscovite, 2-10 percent biotite, 1-3 percent epidote, and minor amounts of magnetite and garnet. Single small exposure west of the mouth of Big Canyon Creek contains 63 percent plagioclase, 25 percent quartz, 7 percent potassium feldspar, 3 percent biotite, and 2 percent muscovite. Intrudes quartz diorite (*KJqd*). No isotopic data are available, but an initial $^{87}Sr/^{86}Sr$ value of <0.705 is likely based on close spatial and age association with *Kbto* unit. Zircons from a sample collected along the Clearwater River have been dated by the laser-ablation ICPMS U-Pb method at 115.7 ± 2.7 Ma (Lee, 2004).

Kbto—Biotite tonalite (Cretaceous)—Medium-grained, massive to foliated, equigranular biotite tonalite. Grades into muscovite-biotite tonalite towards the contact with *Ktr*. Contains 0-3 percent muscovite, 5-10 percent biotite, and 0-3 percent epidote. The epidote is interpreted as magmatic by Lee (2001, 2004), and some is cored by allanite. Lee (2001, 2004) reported deformed plagioclase twinning and quartz recrystallization. An initial $^{87}Sr/^{86}Sr$ value of 0.7034 was obtained by Criss and Fleck (1987). Zircons from a sample of the muscovite-bearing phase collected along the Clearwater River have been dated by laser-ablation ICPMS U-Pb method at 119.1 ± 1.5 Ma (Lee, 2004).

Kbtog—Biotite tonalite gneiss (Cretaceous)—Fine- to medium-grained, well-foliated biotite tonalite gneiss. Grades to biotite quartz diorite gneiss and contains small areas of biotite-hornblende quartz diorite gneiss, amphibolite, and paragneiss not mapped separately. Well-developed foliation masks original igneous textures, but unit is relatively homogeneous and interpreted as mostly igneous in origin. Contains 5-10 percent biotite and 1-5 percent epidote. Locally muscovite-bearing.

Accessory allanite cores in some epidote grains. Epidote is conspicuous in hand specimens, and at least some is likely primary. An initial $^{87}Sr/^{86}Sr$ value of 0.7037 was obtained by Criss and Fleck (1987).

KJpeg— Pegmatite and aplite dikes (Cretaceous or Jurassic)—Undeformed dikes of pegmatite cross-cutting Jurassic or Jurassic-Cretaceous units. Mapped only locally.

KJhqdt—Hornblende quartz diorite and tonalite (Cretaceous? or Jurassic)—Three moderately heterogeneous stocks east-northeast of Cottonwood Butte, in the southeast part of map consist of mostly medium-grained, slightly plagioclase porphyritic, hornblende quartz diorite. Some fine- and coarse-grained varieties are also present, and compositions locally range to tonalite. Rocks generally contain no observable fabric. Consists of 30-40 percent hornblende occurring in clots as large as 1 cm and about 55 percent plagioclase in subhedral to euhedral grains as long as 6 mm. Quartz ranges from 15 to 25 percent and forms grains that are 0.5-4.0 mm. No potassium feldspar was observed. The westernmost stock is notably leucocratic, slightly plagioclase porphyritic, and highly recrystallized in places; it consists of 5-7 percent hornblende in clots as large as 1 mm in diameter, 58-65 percent plagioclase as subhedral to euhedral grains as long as 6 mm, and 30-35 percent quartz as equant grains that range from 0.5 to -4.0 mm. No isotopic data are available, but an initial $^{87}Sr/^{86}Sr$ value of <0.705 is likely from its position west of rocks with values <0.705.

KJqd—Biotite-hornblende quartz diorite and quartz diorite (Cretaceous or Jurassic)—Medium- to coarse-grained, equigranular, massive to foliated quartz diorite that generally occurs southwest of the Ahsahka thrust fault. Includes minor amounts of granodiorite, hornblende gneiss, and dioritic rocks. Contains 8-32 percent hornblende, 0-20 percent biotite, 0-5 percent epidote, 10-25 percent quartz, and 0-5 percent K-feldspar. Apatite is a conspicuous accessory mineral, and sphene, allanite, and rutile (in biotite) were noted in some of the samples. Hornblende is locally cored by pyroxene in the Kamiah area. An outcrop in Big Canyon Creek, south of Peck, contains 8-10 percent microcline. Most samples within 10 km (6 miles) of the Ahsahka thrust along the map's northern and northeastern boarders contain a few percent epidote, some of which is cored by allanite and appears to be primary. At several locations, mutually cross-cutting relationships and mingling textures are observable between quartz diorite and hornblende diorite and gabbro (*KJdg*), suggesting that *KJqd* and *KJdg* are, at least in part, comagmatic units. These relationships are particularly evident along Cold Spring Creek west of Craigmont, along the Greencreek road 5 km north of Cottonwood, and in Meadow Creek due south of Ferdinand, where spectacular exposures of microgabbroic enclave swarms occur. At a location 1.5 km (~1 mile) north of Greencreek, a transitional margin was observed in which mafic quartz diorite containing about 40 percent hornblende and 5 percent quartz grades into normal quartz diorite across a distance of ~200 m (~600 feet). Initial $^{87}Sr/^{86}Sr$ values in this unit are low (0.7033-0.7037; Criss and Fleck, 1987). Dates from both U-Pb zircon and $^{40}Ar/^{39}Ar$ hornblende systematics indicate a Jurassic to Cretaceous range for the quartz diorite unit. A U-Pb TIMS zircon age of 157.0 ± 0.5 Ma was obtained from a quartz diorite exposure northwest of Kamiah (sample locality 21 on map; W.C. McClelland, written commun., 2003), and another sample from near Greer had a U-Pb zircon laser-ablation ICPMS age of 88.8 ± 1.2 Ma (J.D. Vervoort, written commun., 2006). However, a sample from the quartz diorite near Snow Hole Rapids on the Lower Salmon River along the map's southern border area had a slightly discordant U/Pb TIMS zircon age of about 220 Ma from two fractions (Borovicka, 1988), indicating that some of the quartz diorite may be as old as Triassic in age, although the data for this analysis are unavailable. A sample from northwest of Kamiah had a hornblende $^{40}Ar/^{39}Ar$ plateau age of 157.9 ± 2.8 Ma (Criss and Fleck, 1987), and two samples from exposures south of Peck had plateau ages of 138.0 ± 0.4 Ma and 134.4 ± 0.5 Ma (Davidson, 1990; Criss and Fleck, 1987). A younger hornblende $^{40}Ar/^{39}Ar$ plateau of 121.9 ± 0.5 Ma was obtained from the quartz diorite exposed along the Clearwater River east of the mouth of Big Canyon Creek north of Peck (Davidson, 1990).

KJqdg—Quartz diorite gneiss (Cretaceous or Jurassic)—Medium-grained, equigranular, well-foliated quartz diorite gneiss that occurs northeast of the Ahsahka thrust fault. Similar composition to quartz diorite unit (*KJqd*) except biotite locally more abundant than hornblende. Contains 3-40 percent hornblende, 0-15 percent biotite, 1-2 percent epidote, and <1 percent apatite. At least some of the epidote appears to be primary. In places, biotite has replaced hornblende. This unit grades southwest into *KJqd* across the Ahsahka thrust.

Initial $^{87}Sr/^{86}Sr$ values are low (0.7031-0.7034; Criss and Fleck, 1987). A quartz diorite gneiss from west of Ahsahka, immediately north of the map, had a U-Pb zircon laser-ablation ICPMS age of 115.8 ± 1.3 Ma (J.D. Vervoort, written commun., 2006).

KJfqd—Fine-grained hornblende quartz diorite (Cretaceous? or Jurassic)—Fine- to medium-grained, equigranular biotite-hornblende quartz diorite with weak magmatic foliation. Contains 10-15 percent biotite ranging from 0.1 to 2 mm in length, 8-13 percent hornblende as long as 2 mm, and 15-18 percent quartz occurring in grains 0.1-1 mm. Plagioclase constitutes about 60 percent of the rock and is as long as 4 mm. A few percent potassium feldspar and epidote occur in anhedral grains as large as 2 mm. No isotopic data are available, but an initial $^{87}Sr/^{86}Sr$ value of <0.705 is likely from its position west of rocks with values <0.705.

KJdg—Diorite and gabbro (Cretaceous or Jurassic)—Hornblende-rich, typically very heterogeneous, igneous and meta-igneous rocks, primarily diorite and gabbro. Exposures west of Big Canyon Creek are dominated by medium- to coarse-grained hornblende and plagioclase and contain abundant secondary epidote and minor quartz. Minor hornblendite and pyroxene-bearing ultramafic rocks are also present. Exposures along the east side of Big Canyon Creek are finer grained, typically gneissic, and include abundant amphibolite. Exposures along the Clearwater River east of the mouth of Big Canyon Creek are less metamorphosed, generally medium grained, and dominated by rocks that are clearly plutonic in origin. Compositions there include hornblende-pyroxene diorite or gabbro, hornblende quartz diorite, and hornblendite that are cut by numerous narrow, discreet mylonitic shear zones. An initial $^{87}Sr/^{86}Sr$ value of 0.7030 was obtained by Criss and Fleck (1987) near Peck. Hietanen (1962) gives detailed descriptions for this unit in the Orofino area. In exposures north and east of Cottonwood Butte in the map's southern part, the unit is strongly heterogeneous and consists of fine- to coarse-grained, equigranular to porphyritic, hornblende diorite, gabbro, anorthositic gabbro, and gabbroic anorthosite. Magnetite is a common oxide mineral. Samples typically contain as much as 10 percent biotite and minor pyroxene. Fabrics are mostly massive with uncommon, weak igneous foliation. Igneous layering and mylonitic fabrics occur rarely adjacent to contacts with metavolcanic host rocks. Diorite to the west of Cottonwood Butte shows an apparently gradational contact along its eastern border with andesite porphyry (*JPap*) that forms a border phase. A hornblende diorite from east of Peck yielded a U-Pb zircon laser-ablation ICPMS age of 125.2 ± 1.2 Ma (J.D. Vervoort, written commun., 2006). Two samples of hornblende gneiss from the Peck area yielded hornblende $^{40}Ar/^{39}Ar$ plateau ages of 123.9 ± 0.7 Ma and 119.4 ± 1.2 Ma (Davidson, 1990).

KPd—Dike rocks, undivided (Cretaceous? to Permian?)—Compositionally diverse unit consisting of dikes and sills that intrude mostly metavolcanic and metasedimentary rocks as well as the *KPi* unit. Lithologies include plagioclase-hornblende andesite porphyry, fine-grained hornblende diorite and quartz diorite, and plagioclase-quartz dacite porphyry.

KPi—Plutonic rocks, undivided (Cretaceous? to Permian?)—Compositionally diverse igneous unit; includes gneissic rocks that may be metasedimentary or metavolcanic. Exposures west of the Clearwater River south of Kamiah are primarily foliated biotite tonalite with lenticular plagioclase and quartz grains, which no longer reflect original igneous textures, and abundant secondary epidote. Exposures northeast of Kamiah are less deformed and include quartz diorite, tonalite, diorite, and fine-grained hornblende-plagioclase rocks that may be meta-andesite. Along Cottonwood Creek in the southeast part of map, includes biotite tonalite and hornblende-biotite quartz diorite. Some biotite in the tonalite is in fine-grained masses and may be secondary. Exposures northeast of Cottonwood include altered, massive, medium-grained, leucocratic, hornblende-bearing, porphyritic tonalite with prominent quartz phenocrysts. No isotopic data are available, but an initial $^{87}Sr/^{86}Sr$ value of <0.705 is likely from its position west of rocks with values <0.705.

JPap—Andesite porphyry (Jurassic to Permian)—Amphibole-plagioclase andesite porphyry occurring mostly as stocks, although some may be extrusive. Typically contains 10-40 percent phenocrysts of mostly plagioclase ranging from 0.5 mm to 2 cm in length with subordinate hornblende <2 mm in length, which is commonly replaced by actinolite. Groundmass is dark to medium gray and felty to trachytic. Unit commonly weathers greenish gray owing to abundant chlorite and epidote that occur as lower greenschist-grade metamorphic minerals. Cleavage development varies in this unit, indicating intrusion may have occurred over an extended time. Probably represents hypabyssal intrusions. No isotopic data are available, but an initial $^{87}Sr/^{86}Sr$ value of <0.705 is likely from its position west of rocks with values <0.705.

Several amphibole-plagioclase andesite porphyry dikes are intruded into the andesite porphyry. Similar in appearance to *JPap* and may have fed andesite porphyry lava flows within the volcanic sequence.

ISLAND-ARC METASEDIMENTARY AND METAVOLCANIC ROCKS

Island-arc metasedimentary and metavolcanic rocks consist of Permian to Jurassic metasedimentary, metavolcanic, and intrusive rocks of the exotic (accreted) Wallowa island-arc terrane; amphibolite facies rocks of uncertain age near Orofino (Orofino series); and lower amphibolite facies metasedimentary and metavolcanic(?) rocks near Peck that are either Wallowa terrane or part of the Orofino series.

WALLOWA TERRANE

The Wallowa terrane includes volcanic and sedimentary strata of the Permian and Triassic Seven Devils Group and sedimentary rocks of the Triassic Martin Bridge Limestone, Jurassic-Triassic Hurwal Formation, and Jurassic Coon Hollow Formation (Vallier, 1977). Strata are intruded by rare to abundant (as much as half of the outcrops in some locations) sills, dikes, and stocks of plagioclase-hornblende andesite porphyry, fine-grained diorite, and plagioclase-quartz dacite porphyry. In places where the intrusions are most abundant, the rocks are mapped as *JPap* (andesite porphyry) and *KPd* (dike rocks, undivided); they are commonly difficult to distinguish from volcanic flow rocks. All rocks are metamorphosed to lower greenschist grade and commonly contain metamorphic epidote, albite, actinolite, and chlorite. Locally, near contacts with large intrusive bodies, upper greenschist-grade metamorphism is apparent with the appearance of garnet and calc-silicate minerals.

Jch—Coon Hollow Formation (Jurassic)—Thinly bedded to thickly laminated, intercalated black shale and gray siltstone, with less common lithic sandstone and pebble conglomerate. Poorly sorted cobble conglomerate occurs in discontinuous lenses <1 m in thickness. Clasts, mostly chert and rarely limestone, are commonly rounded and 0.5-5 cm long, but locally 10 cm. Hornblende andesite sills are abundant between Corral Creek and Cave Gulch, but less abundant elsewhere. Uncommon fossils include plant hash and tree bark from exposures along the Snake River and an ammonite from exposures in Deer Creek (lat 46.0572°N, long 116.7219°W). The ammonite is likely an outer whorl fragment of *Lilloettia*, which would suggest an early Callovian age, but the fragment is also possibly from a juraphyllitid and would have little chronologic value for these rocks (David Taylor, written commun., 2007). The Callovian (late Middle Jurassic) age is typical for the fault-bounded, structurally highest part of the Coon Hollow Formation (Turbidite Unit) in the Pittsburg Landing area 50 km south of Deer Creek (Imlay, 1981; White and Vallier, 1994), but in the type area immediately south of the map, the oldest known beds are Oxfordian (early Late Jurassic; Morrison, 1964, Imlay, 1986). Lies in angular unconformity on rocks of the Wild Sheep Creek Formation.

JPr—Rhyolite tuff (Jurassic to Permian)—Distinctive red-purple to gray-blue porphyritic rhyolite tuff that shows little metamorphism. The groundmass is devitrified with abundant welded(?) ghost glass fragments, about 75 percent compacted pumice(?) fragments 1-3 cm long, and scarce small volcanic fragments. Phenocrysts compose about 18 percent of the rock and consist of nearly equal amounts of euhedral to slightly embayed quartz 0.1-1 mm in diameter and plagioclase 0.2-2 mm long, and a lesser amount of euhedral sanidine 0.3-0.7 mm. Layering strikes east-northeast, and cleavage is poorly developed. Exposed only on the hill about 2.4 km (1.5 miles) east of Keuterville. Age and correlation to other units are uncertain. Chemical composition of the tuff (map no. 65, sample 03JK141; Lewis and Frost, 2005) is similar in major oxides and trace elements to a sample of quartz keratophyre south of the map along the lower Salmon River reported by Borovicka (1988), which he tentatively correlated with the Permian Windy Ridge Formation. Recent mapping in the White Bird area to the south, however, identified similar rocks which appear to be part of a less metamorphosed volcanic sequence younger than the Seven Devils Group and likely Jurassic in age (Idaho Geological Survey, unpublished mapping). Additional study is needed to determine the proper stratigraphic position of the tuff.

JTRh—Hurwal Formation (Jurassic and Triassic)—Thinly bedded, phyllitic, fine-grained graywacke, siltstone, and shale with less common pebble conglomerate and thin limestone beds. Mostly calcareous. Common sedimentary structures include load casts and graded bedding. Gradational contact with underlying Martin Bridge Limestone is ill-defined because upper part of Martin Bridge unit consists of similar thinly bedded calcareous clastic rocks. Occurs in Billy Creek, where it is in contact with the Martin Bridge Limestone, in Captain John Creek, and in a northeast-trending set of isolated erosional windows along the uplifted side of the Waha escarpment. The Hurwal Formation has been defined as Late Triassic to Early Jurassic in age in the Wallowa Mountains of northeastern Oregon (Follo, 1994).

TRmb—Martin Bridge Limestone (Triassic)—Limestone and marble, mostly recrystallized massive sparite and micrite with chert lenses and uncommon thinly bedded calcareous siltstone and shale. Lower 5-10 m (15-30 feet) interval consists of gray-green colored thinly bedded calcareous graywacke and siltstone, and argillaceous limestone. In Mission Creek, light gray to black high-calcium, steeply dipping marble and limestone are exposed in a quarry (Bush and McFadden, 1986). Near the confluence between the Snake and Grande Ronde rivers, the unit is also steeply dipping, and the base of the Martin Bridge Limestone appears to be sheared in the contact area with underlying Doyle Creek Formation. No fault was mapped because little of the stratigraphic section is missing. Considered to be Late Triassic by the fossil assemblage and similar in character to carbonate rocks of the Martin Bridge Limestone in eastern Oregon and western Idaho. Stanley (1979) considered the Mission Creek limestones to be slightly younger.

Seven Devils Group

TRPsd—Seven Devils Group, undivided (Triassic and Permian)—Strongly heterogeneous phyllitic to schistose, quartzo-feldspathic, calcite-actinolite-epidote-chlorite greenstone and uncommon actinolite amphibolite of mostly volcanic and volcaniclastic protolith. Common recognizable protolith lithologies include the following: (1) plagioclase-quartz dacite(?) lava flows and possibly tuff that include 10-30 percent phenocrysts of quartz and plagioclase ranging in length from 0.05 to 3 mm and volcanic clast fragments as large as 3 mm; (2) medium to dark gray plagioclase porphyritic basalt and andesite and aphyric basalt and andesite lava flows that are lithologically similar to rocks of the intrusive andesite porphyry unit (*JPap*); (3) medium- to thin-bedded argillite and immature siltstone and sandstone; and (4) clast-supported conglomerate with round to subangular clasts as large as 10 cm that consist of both tuffs(?) and porphyritic volcanic rocks. In exposures south of Kamiah, the unit is apparently metamorphosed to higher grade, and one sample contains plagioclase (58 percent), hornblende (27 percent), quartz (10 percent), biotite (2 percent), epidote (2 percent), opaque oxides (1 percent), and minor amounts of secondary potassium feldspar. Metadacite(?) tuff and fine-grained volcanic siltstone are included with rocks at this location. Most likely correlatives are the Wild Sheep Creek or Doyle Creek formations of the Seven Devils Group of Vallier (1977).

TRdc—Doyle Creek Formation (Triassic)—Greenschist metamorphosed, dominantly reddish to purplish, thin- to medium-bedded, mostly epiclastic rocks consisting of arkosic pebble conglomerate and sandstone, graywacke, siltstone, and argillite. Mud rip-up clasts are common. Volcanic flows, volcanic breccias, and dikes and sills are less common. Fine-grained rock (chert? or tuff?) west of Soldiers Meadow Reservoir is tentatively assigned to the Doyle Creek (*TRdc?* on map). Unit also occurs along the Snake River south of confluence with Grand Ronde River, northwest of Soldiers Meadow Reservoir west of Webb Creek, and in upper Corral Creek and Cave Gulch along the Snake River, where it is inferred to lie in fault contact with the Coon Hollow Formation. Base of formation is poorly defined and appears gradational with rocks of the underlying Wild Sheep Creek Formation. Inferred Late Triassic age determined by fossil assemblages in bounding formations (Vallier, 1977).

TRws—Wild Sheep Creek Formation (Triassic)—Greenschist metamorphosed, dominantly green to greenish gray volcaniclastic, volcanic, and epiclastic rocks. Recognizable protoliths include plagioclase-pyroxene(?) porphyritic volcanic flow and intrusive rocks (mostly sills), volcanic breccias, and epiclastic conglomerate, graywacke and arkose, siltstone, and argillite. Epiclastic rocks contain common feldspar crystals in addition to volcanic lithic fragments. Occurs along the east side of the Snake River north of Corral Creek and along the northwest side of the Waha escarpment-

Limekiln fault structure north of the confluence with the Grand Ronde River where it is in fault contact with Hurwal Formation. A small area of the unit was also mapped in lower Deer Creek where it lies in unconformable contact with the Coon Hollow Formation. Considered latest Middle to early Late Triassic in age on the basis of fossil assemblages (Vallier, 1977).

TRwsm—Wild Sheep Creek Formation, marble (Triassic)—Massive marble with rare layering that may represent bedding. Occurs in Chimney Creek, where it lies in fault contact with greenstone rocks of the Wild Sheep Creek Formation. Possibly Martin Bridge Limestone, but this correlation would require kilometers of displacement on the west-bounding fault, which is not apparent to south.

OROFINO SERIES

The Orofino series consists of amphibolite-facies metasedimentary (and metavolcanic?) rocks first recognized near Orofino (Anderson, 1930; Hietanen, 1962). Commonly sulfide-rich with iron-stained exteriors. Lithologically varied at outcrop scale. Includes marble commonly associated with dark gray, fine-grained, garnet-diopside-hornblende gneiss of fairly uniform appearance. These metamorphic rocks with a carbonate-rich protolith may belong to the Wallowa accreted terrane assemblage, but could alternatively be part of another terrane, or a younger suite deposited east of the Wallowa terrane as they straddle the initial $^{87}Sr/^{86}Sr$ 0.704-0.706 line defined by isotopic values in plutonic rocks (Criss and Fleck, 1987) from Orofino to Kooskia. May be equivalent to parts of the Riggins Group (upper part of Squaw Creek schist?) exposed 100 km (60 miles) to the south and described by Hamilton (1963).

Mzao—Amphibolite (Mesozoic)—Foliated or lineated plagioclase-hornblende rocks with less than 10 percent quartz. Locally contains garnet and biotite. Probably meta-igneous rocks (metamorphosed mafic sills or lava flows). Described in more detail by Hietanen (1962).

Mzgo—Gneiss and schist (Mesozoic)—Fine- to medium-grained hornblende gneiss that grades into biotite gneiss, schist, and amphibolite. Consists of quartz (3-63 percent), plagioclase (20-69 percent), hornblende (0-35 percent), and biotite (0-35 percent). Locally contains garnet (0-5 percent), diopside (0-12 percent), epidote (0-4 percent), graphite (0-3 percent), sphene (1 percent or less), and scapolite. Includes minor calc-silicate quartzite containing about 50 percent quartz, 35 percent plagioclase, and various amounts of biotite, pyroxene, actinolite, epidote, graphite, and sphene. Uncertain protolith. Quartz-rich and calc-silicate parts of unit are clearly metasedimentary, but may include some metavolcanic rocks. Hietanen (1962) provides a detailed description of exposures along the railroad track north of Orofino Creek, east of the mouth of Whiskey Creek, where quartz-plagioclase-anthophyllite-garnet-kyanite rocks are present in addition to more abundant hornblende-biotite gneiss, biotite schist, and calc-silicate lithologies. Biotite-quartz-plagioclase schist, sampled by R. Fleck (written commun., 2002; Criss and Fleck, 1987, sample 837-24F), had a relatively low initial $^{87}Sr/^{86}Sr$ ratio (0.7048 calculated at 80 Ma), indicating affinity with the Wallowa terrane rather than with the continental metasedimentary rocks to the northeast.

Mzcso—Calc-silicate gneiss and granofels (Mesozoic)—Calc-silicate gneiss and granofels containing various amounts of diopside, epidote, zoisite, clinozoisite, scapolite, calcite, amphibole, garnet, quartz, plagioclase, biotite, and wollastonite. Wide range of layering thickness and grain size; some very fine to medium grained and thinly layered (millimeter to centimeter scale), and others coarse grained (skarnlike) and thickly layered (decimeter to meter scale). Hietanen (1962) reported An_{37-40} plagioclase compositions. The garnet is locally abundant, in places constituting as much as half of the rock, light brownish red, and mainly grossularite (Hietanen, 1962). Small grains of graphite rare.

Mzmo—Marble (Mesozoic)—Tan-weathering, white to light bluish gray graphitic marble in discontinuous lenses. Layers are decimeter to meter scale and concentrated in sections as much as 20 m (60 feet) thick. Most layers are pure calcite (grains 0.5-5 mm in diameter) with only a few small grains of pyrite, tremolite, diopside, quartz, and sphene (Hietanen, 1962). Kopp (1959) reported plagioclase, mica, and graphite.

Mzqo—Quartzite (Mesozoic)—Small exposures of biotite-plagioclase quartzite in the northeastern part of map. Described as thin-bedded, fine- to medium-grained gray quartzite with some layers rich in biotite and others in plagioclase (Hietanen, 1962). Exposures southeast of Orofino Creek are mylonitic biotite quartzite and biotite-plagioclase-quartz schist. Contains 50-80 percent quartz, 10-35 percent plagioclase feldspar, and 0-7 percent biotite. Locally present are minor garnet, hornblende, pyroxene, actinolite, muscovite, graphite, and sillimanite.

ISLAND-ARC ROCKS, UNASSIGNED

The unassigned island-arc rocks include metasedimentary and metavolcanic(?) rocks near Peck mapped by Hietanen (1962) as part of the Orofino series. Davidson (1990) distinguished these rocks from the Orofino series and called them “island arc rocks” and postulated affinities with the Wallowa terrane south of the map area. Hietanen (1962) also noted that the metamorphic rocks near Peck differ in appearance, texture, and mineralogy from the metasedimentary rocks near Orofino. Davidson (1990) noted that the rocks near Peck are lower metamorphic grade (lower amphibolite facies) and farther outboard from the initial $^{87}Sr/^{86}Sr$ 0.704/0.706 line. They may be, however, similar in age to the Orofino series. Also includes garnetiferous hornfels west of Winchester.

JPg—Gneissic and hornfelsic rocks (Jurassic? to Permian?)—Mixed unit that near Peck in the north-central part of map consists of biotite-quartz-plagioclase gneiss, biotite-hornblende gneiss, calc-silicate hornfels, muscovite-quartz schist, and lenses of gabbro and amphibolite. The biotite-quartz-plagioclase gneiss is dark gray and fine grained and contains 15-50 percent quartz and a similar range of plagioclase. Biotite content is 15 percent or less. Those rocks with high quartz content do not have igneous compositions and are assumed to be metasedimentary. The calc-silicate hornfels contains epidote, diopside, actinolite, quartz, plagioclase, garnet, and cordierite(?). Minor marble is associated with the hornfels. The hornfels west of Winchester occurs as roof pendants in a quartz diorite pluton. It is dark greenish gray and contains quartz, plagioclase, and biotite. Garnet, sillimanite, and muscovite are present locally. More quartz-rich than other units in the Wallowa terrane.

CONTINENTAL METASEDIMENTARY ROCKS

SYRINGA METAMORPHIC SEQUENCE

The Syringa metamorphic sequence consists of amphibolite-facies metasedimentary rocks first recognized east of Kooskia near Syringa (Lewis and others, 1992; Lewis and others, 1998). Regionally, the sequence contains muscovite-biotite schist, relatively pure quartzite, and calc-silicate rocks. Typically, it is exposed east of the initial $^{87}Sr/^{86}Sr$ 0.704-0.706 line (Criss and Fleck, 1987) and is thought to be part of continental North America. The Syringa sequence appears to be Neoproterozoic on the basis of detrital zircon analysis (Lund and others, 2005). At the map’s northeast edge, the Syringa sequence is farther outboard (southwestward toward the accreted terranes) than elsewhere. This outboard position may result from folding of the Syringa-Orofino series contact or from fault slivers of Syringa rocks intercalated with Orofino series rocks. Biotite tonalite (*Ktt* unit) has intruded along the contact, obscuring the boundary relationships.

Zss—Schist and gneiss (Neoproterozoic)—Medium-grained garnet-plagioclase-sillimanite-biotite-quartz schist. Exposed only in the northeast part of map north of Orofino Creek. Garnet porphyroblasts are as large as 1 cm in diameter.

STRUCTURE

Major structural features (see illustration on map) are (1) the Salmon River suture (Woodrat Mountain fault) at the northeast corner and east of the map, (2) the Ahsahka thrust in the northeast part of the map, (3) the Orofino shear zone north and east of (and within?) the map, and (4) the Lewiston basin and associated bounding structures in the northwest part of the map. Several less prominent structures are also discussed, including the Cottonwood Creek and Grave Creek faults. In addition, cleavage, bedding, and other outcrop-scale features are outlined below.

SALMON RIVER SUTURE

The Salmon River suture forms the boundary between accreted island-arc terranes of western Idaho and continental North America (Lund and Snee, 1988). Along much of its length, the suture is intruded by plutonic rocks that postdate accretion and have subsequently been deformed. South of the area, between McCall and Riggins, it strikes north-south (Lund and Snee, 1988). East of Grangeville, it bends from north-south striking to northeast striking where offset by the Mt. Idaho-Syringa fault system. The suture continues northwest from the Syringa fault as the Woodrat Mountain fault where mylonitic Neoproterozoic metasedimentary rocks of the Syringa metamorphic sequence are faulted against Mesozoic metasedimentary (and metavolcanic?) rocks of the Orofino series. East-northeast-dipping foliations, down-dip lineations, and kinematic indicators along this zone indicate a period of west-southwest-directed thrusting, but the age of this deformation is unknown. The Woodrat Mountain fault extends under a long covered interval to the northeast corner of the map, where it swings west, perhaps at the intersection with the Orofino shear zone discussed below. Although partly covered by basalt and intruded by tonalite (*Ktt*), the suture extends into the northeast corner of the map where it has been either folded or complexly faulted. The folding, or fault slivers, account for the anomalous "outboard" (southwestward toward the accreted terranes) position of the Syringa sequence. The suture then continues west, mostly covered by basalt, across Dworshak Reservoir and to the base of the Lewiston Hill, where the relatively young Wilma thrust fault (Camp, 1976; Kehew, 1977; Garwood, 2001) places basalt over younger gravels and is the likely surface expression of the reactivated structure.

AHSAHKA THRUST

The Salmon River suture has been overprinted by a broad zone of shearing, 10-15 km (6-10 miles) wide, referred to as the western Idaho shear zone (McClelland and others, 2000; Tikoff and others, 2001). The Ahsahka thrust is a northwest-striking ductile shear zone in basement rocks that forms the southwest edge of the western Idaho shear zone in the Orofino quadrangle and marks a major change in deformational style, metamorphic grade, and ^{40}Ar/^{39}Ar ages in the region (Davidson, 1990). Near Orofino, the Ahsahka thrust is characterized by a zone about 250 m (700 feet) wide of moderately to steeply northeast-dipping banded gneiss consisting of both mafic hornblende-rich bands and more felsic tonalite bands (Davidson, 1990). 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 show consistent northeast-side-up (thrusting) shear sense (Strayer and others, 1989; Davidson, 1990). Rocks southwest of the Ahsahka thrust lack the pervasive gneissic foliation but are cut by numerous discrete ductile shear zones centimeters to meters in width. These discrete shears have a variety of orientations and shear sense, including reverse and normal motion, but most are northeast-side up. The discrete shears cut a more pervasive foliation fabric oriented nearly orthogonal to the Ahsahka thrust. This foliation strikes northeast, dips nearly vertical, and is interpreted to predate deformation along the Ahsahka thrust.

OROFINO SHEAR ZONE

The bend in the western Idaho shear zone in the Orofino area has been attributed to a relatively young (80-60 Ma) southwest-vergent structure termed the Orofino shear zone (Payne and McClelland, 2002; Payne, 2004; McClelland and Oldow, 2004). Coincident with the trans-Idaho discontinuity (Yates, 1968), this structure is defined by mylonitic rocks in the Brown Creek Ridge area east of the map that have been dated by U-Pb zircon methods at 72 Ma. Although Payne and McClelland (2002) and McClelland and Oldow (2004) attribute 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 older deformation at Orofino than at Brown Creek Ridge. We speculate that the trans-Idaho discontinuity (and Orofino shear zone) is northeast of Orofino and that the fabrics mapped in the northeast part of the map at Orofino are related to the western Idaho shear zone.

LEWISTON BASIN

The Lewiston basin is a broad asymmetrical synclinal trough with complex, poorly understood bounding structural zones—the east-northeast-trending Lewiston Hill escarpment to the north and northeast-southwest-trending Waha escarpment-Limekiln fault to the south. A major component of these two bounding structures is the downwarping of the Columbia River basalt sequence into the basin axis, located along the westward-plunging Lewiston syncline. On the map, the syncline extends east from about the Snake River south of Lewiston Orchards to Lapwai Creek where the axial trace bends to the northeast and follows Tom Beall Creek. The syncline bifurcates into opposing monoclines in the upper forks of Tom Beall Creek; the monoclines are then disrupted by the Cottonwood Creek fault. East of the fault, a westward-plunging syncline extending eastward up Magpie Creek is likely the continuation of the Lewiston syncline. The structure dies out near the head of Magpie Creek. Several northwest-trending, low-amplitude anticlines and synclines crosscut the Lewiston syncline nearly parallel to Columbia River Basalt Group dike trends.

LEWISTON HILL ESCARPMENT

North of the confluence of the Clearwater and Snake rivers, the Lewiston Hill escarpment is underlain by an asymmetrical east-trending anticline with an undulating crest developed in the Columbia River basalts. Fold geometry is complicated by syntectonic extrusion, evident as changes in the thickness of Wanapum and Saddle Mountains basalt flows across structures, and by postextrusion northwest-trending, low-amplitude, long-wavelength cross folds, which cause the undulating crest of the anticline. Because several faults are associated with the main anticline beneath the escarpment, geologists disagree on the relative roles of folding and faulting in disrupting the basalt sequence (Garwood and Bush, 2005). Camp (1976) and Swanson and others (1980) depict a major east-west fault, the Vista fault, a few hundred feet below and south of the crest of Lewiston Hill. Hooper and others (1985) show this same fault in Washington across the eastern part of the Clarkston 15-minute quadrangle. We show the fault on the Idaho part of the Clarkston 30' x 60' quadrangle but do not continue it into the Orofino 30' x 60' quadrangle. Detailed mapping across the projected fault zone in Idaho, using geochemical, paleomagnetic, and stratigraphic methods, demonstrates that stratigraphic offset is less than 8 m (25 feet; Garwood and Bush, 2005). Garwood and Bush (2005) interpret breccias, slickensides, and minor faults exposed in roadcuts on the Lewiston Hill as related to anticlinal deformation and the intrusion of Lewiston Orchards basalt dikes. In Washington, the structure becomes more complex, and faulting appears to play a more important role.

The east-striking Wilma thrust fault near the base of the Lewiston Hill escarpment is exposed in a small cut north of the Clearwater River near Hatwai Creek (Garwood and Bush, 2005). At this location, R_2 Grande Ronde Basalt has been thrust over late Pliocene(?) Clearwater gravel on a fault dipping 25-30 degrees to the north. Kehew (1976) describes a similar exposure about 1.6 km (1 mile) west of this location. From about Hatwai Creek eastward, the thrust fault appears to be absent and is replaced by an anticline-syncline couplet that continues along the same trend as the fault to the northern edge of the map. The syncline is a subtle, low-amplitude feature, whereas the anticline is asymmetrical with a shallow-dipping northern limb and a steeply dipping southern limb. Near Myrtle, the anticline is probably faulted. The thrust and anticline-syncline pair may represent reactivation of basement structures, such as those in the Orofino area. The Lewiston Hill escarpment lies along the westward projection of the initial $^{87}Sr/^{86}Sr$ 0.704-0.706 line of Armstrong and others (1977) and Fleck and Criss (2004).

WAHA ESCARPMENT AND LIMEKILN FAULT

WAHA ESCARPMENT

The Waha escarpment extends from about Gifford on the northeast nearly to the Snake River on the southwest, a distance of about 40 km (27 miles). The structural zone begins on the northeast as a broad series of low-amplitude monoclinal flexures that gradually increase in amplitude to the southwest. From Lapwai Creek southwestward, the escarpment becomes a more prominent feature. From Rock Creek southwestward, the structural zone appears to be bounded on the southeast by a steeply dipping fault, the Waha fault, with an adjacent zone about 5 km (3 miles) wide to the northwest of mostly northwest-dipping, in places broken, monoclinal flexures. This northwest flank of the structure also has northwest-trending, low-amplitude cross folds that are not present on the uplifted southeast side. The linear expression of the fault indicates a steep dip, although it is unclear whether a normal or reverse sense of motion. The overall displacement across the escarpment is down-to-the-northwest. In Webb Creek and drainages to the southwest, nearly horizontal R_1 Grande Ronde Basalt on the structurally higher southeast side of the escarpment is juxtaposed with slightly northwest-dipping N_1 Grande Ronde Basalt on the downthrown northwest side. Stratigraphic displacement across the structure is about 180 m (600 feet). Near the community of Waha, the structure becomes more complex with multiple fault splays and folds, and we suspect many others are unrecognized. Grande Ronde Basalt flows are tilted as much as 25 degrees northward at the base of the escarpment northwest of Waha. A steptoe of metavolcanic rocks of the Triassic Wild Sheep Creek Formation forms the escarpment west of Waha to the Snake River canyon. R_2 Grande Ronde Basalt flows cap the eastern end of the steptoe, dip northwestward on the northern flank, and appear to dip southwest on the southern flank; R_1 Grande Ronde Basalt flows near the Snake River north of Captain John Creek also dip southwest. The steptoe may be a westward-plunging antiform that dies out at the Snake River, because flows west of the river are nearly horizontal. This prebasalt basement remnant is also at the juncture of the Waha fault of the Waha escarpment and its continuation to the south-southwest as the Limekiln fault, discussed below, which contains many of the same structural features. The present expression of these faults probably reflects reactivation along an original Mesozoic structure.

LIMEKILN FAULT

The Limekiln fault is another complex structure whose extent and displacement are not fully understood. The fault forms the south-southwestward continuation of the south-bounding fault of the Waha structural zone. The Limekiln fault has down-to-the-west displacement in Columbia River basalt units and is likely a reactivated Mesozoic strike-slip or oblique-slip fault with kilometers of displacement in basement rocks. The linear nature of the fault trace suggests the fault is nearly vertical at present erosional levels. We have depicted the fault as steeply west-dipping on cross section C-C′, suggesting it is a normal fault; however, we note that typical extensional-related features such as back rotation of hanging-wall sequences are absent along the fault. An alternative explanation, favored by Jones (2003), is that the fault dips steeply east at depth and that the latest movement was compressional or transpressional. The presence of Wild Sheep Creek Formation rocks on the northwest side of the fault, north of Madden Creek, and younger Hurwal Formation rocks on the southeast side, with a considerable intervening stratigraphic section missing, may signify far greater (kilometers) displacement in basement rocks than is apparent in the Miocene basalts. Stratigraphic reconstructions across the fault would require 5 km (3 miles) or more of throw in a down-to-the-east sense if the fault were strictly dip-slip, a sense opposite to that shown in Miocene units and an unreasonable amount of throw considering the similarity in metamorphic grade in rocks on either side of the fault. Alternatively, and more likely, the fault accommodated 10-20 km (6-12 miles) of displacement in a dominantly right-lateral sense before basalt emplacement and reactivation. A gently (20 degrees) southwest-plunging lineation along the fault north of Madden Creek is consistent with strike-slip motion along this structure, but the age of this fabric is unknown.

West of the Snake River in Washington, R_2 Grande Ronde Basalt occurs on the northwest side but not on the southeast side of the fault (Reidel and others, 1992), suggesting movement on the structure in Grande Ronde Basalt time. Younger displacement occurred after the eruption of the 13 Ma Asotin-Wilbur Creek unit of the Columbia River basalt with a relative sense of motion down-to-the-northwest. The Asotin-Wilbur Creek unit occurs only as a valley-filling remnant on the uplifted block southeast of the Waha escarpment-Limekiln fault at an elevation of 1,400 m (4,600 feet), but is a continuous unit on the north flank of the escarpment and west of the Snake River at about 850 m (2,800 feet). Basalt units younger than the Asotin-Wilbur Creek unit do not cross the structure, indicating sufficient relief existed to contain those flows in the Lewiston basin.

FAULTS IN COLUMBIA RIVER BASALT

COTTONWOOD CREEK FAULT

The Cottonwood Creek fault (Bond, 1963; Bush and others, 2001) is a northwest-trending structure extending from 16 km (10 miles) northwest of the map boundary north of Myrtle to about 6 km (4 miles) southeast of the Clearwater River. The fault crosses the Clearwater River near Myrtle and follows Cottonwood Creek. At both ends, the fault gradually dies out, changing to monoclinal flexures. Displacement is down-to-the-east with about 400 m (1,200 feet) of maximum offset of Grande Ronde, Wanapum, and Saddle Mountains units (Kauffman, 2005a). The fault, therefore, is younger than 13 Ma, the age of the Asotin-Wilbur Creek unit, the youngest Saddle Mountains Basalt unit in the area. We interpret the fault to be near vertical on the basis of its linear trace.

GRAVE CREEK FAULT

The Grave Creek fault is a steep north-south-striking structure that extends from the town of Cottonwood southward along the west side of Grave Creek and continues south beyond the map, where it was mapped as the Rice Creek fault by Holden (1973). North of Cottonwood, the fault either bends to the northeast or splits into two segments, one northeast-striking and the other north-striking. The northeast segment appears to change to a monoclinal flexure several kilometers northeast of Cottonwood. The north-south segment is suggested by a topographic linear that extends northward several kilometers from Cottonwood, but no physical evidence of a fault was found along that segment. Displacement along the segment south of Cottonwood is difficult to determine because the exposed basalt on either side of the structure is N_1 Grande Ronde Basalt. South of the map, Holden (1973) reported as much as 150 m (500 feet) of offset. Initiation of this fault, possibly originally as a monoclinal flexure, is likely post-R_2 Grande Ronde Basalt extrusion and prebasalt of Grangeville extrusion, because the Grangeville flow is restricted to the east side of the structure.

CLEAVAGE, BEDDING, AND SMALL-SCALE STRUCTURAL FEATURES

The Permian to Jurassic metavolcanic and metasedimentary rocks of the accreted Wallowa terrane southwest of the Clearwater River show a moderately to strongly developed, spaced to penetrative cleavage that is mostly steeply dipping and northeast to north striking. Microcrystalline, lower greenschist-grade metamorphic minerals, such as chlorite, epidote, and actinolite, mostly define cleavage. Most intrusive rocks show only minor solid-state fabric development, or the fabrics are absent. The southern boundary of the map appears to coincide with the location of a north-to-south cleavage intensity gradient. The basement rocks north of the map boundary have generally much better developed cleavage, commonly to the point that many primary volcanic and sedimentary features have been obliterated. To the south, other geologists' mapping and our own reconnaissance suggest that cleavage is developed to a much lesser degree. This is true in the Snake River canyon (Goldstrand, 1994) and in the lower Salmon River canyon, where Borovicka (1988) noted a distinct lack of cleavage south of the river and a northward-increasing gradient in cleavage intensity north of the river.

Bedding in metavolcanic and metasedimentary rocks is mostly northeast striking and moderately to steeply northwest dipping. Much of the Triassic to Permian section is exposed as a nearly contiguous northwest-dipping panel along the Snake River canyon and upper Waha escarpment. The section is intensely and tightly folded in places, such as in China Garden Creek along the Snake River at the southwestern margin of the map, but folding occurs at a scale of meters to hundreds of meters and is intraformational. We have not determined if the northwest-dipping panel of section is actually a limb of a much larger fold set.

The units exposed on Cottonwood Butte in the southeastern part of the map contain bedding orientations that are more complicated. Northeast-striking bedding is common, but anomalous west- and northwest-striking bedding is also present. A well-developed mylonite zone (denoted by mylonitic foliation symbols) occurs in septa of metavolcanic strata between quartz diorite and diorite plutons west-southwest of Ferdinand. The limited exposure of the mylonite zone prevents us from establishing its extent or importance.

GEOCHEMISTRY

More than 650 volcanic rock samples and 40 intrusive and metamorphic rock samples from the quadrangles were analyzed for major oxide and trace element concentrations at the Washington State University GeoAnalytical Laboratory 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 30 are intrusive or metamorphic rock samples, and numbers 31 through 470 are extrusive volcanic rock or dike samples. Information on the volcanic rock samples, including locations and analytical results, can be found in Kauffman (2004b, 2007); information on the intrusive and metamorphic rocks is compiled in Lewis and Frost (2005) and in Table 3.

Most volcanic rock samples are from the Columbia River Basalt Group, but a few are from the Kamiah volcanics and other volcanic rocks. Tables 1 and 2 list average values of major oxide and trace element concentrations for Columbia River Basalt Group units (Table 1) and for Kamiah volcanics units and one sample of possible Potlatch Volcanics, Onaway Member basalt (Table 2). Most of the analyses of Columbia River basalt units match well with previously published results (Swanson and others, 1979b; Wright and others, 1973, 1979, 1980; Reidel and others, 1989). Chemistry of Grande Ronde Basalt units should be used with caution in making stratigraphic determinations, unless a partial or complete stratigraphic section is measured and sampled. Compositions for the Grande Ronde Basalt magnetostratigraphic subdivisions commonly overlap, which may be caused by flows interfingering from several sources over time, by eruptions continuing from one source across magnetostratigraphic breaks, by a flow of one chemistry invading and inflating a flow of a different chemistry, or by a unit being misidentified because of false or conflicting magnetic polarity readings.

Samples of pre-Tertiary units include several gneissic and a few basaltic to andesitic rocks, but most samples are from intrusive units (Lewis and Frost, 2005; and Table 3). Quartz diorite is a common intrusive rock in the area with ages that range from 157 Ma to 89 Ma in units that are similar mineralogically. Analyses of five samples of quartz diorite (Table 3) indicate similar major-element compositions for the Jurassic and Cretaceous plutons. Concentrations of Sr are lower, and Cu higher, in the Jurassic sample (02RL983), but more samples from dated outcrops are needed to confirm this relationship. Quartz diorite near Headquarters, 20 km (12 miles) northeast of the map, has a high initial $^{87}Sr/^{86}Sr$ ratio (>0.706) relative to the quartz diorite in the area (<0.704) and also some differences in major and trace element concentrations, as shown in Table 3 (sample 90TF038). Relative to the Headquarters sample, the quartz diorite is enriched in FeO* (total Fe as FeO) and MgO, and depleted in P_2O_5, Zr, Nb, La, and Ce.

GEOLOGIC HISTORY

The oldest event in the quadrangles is the deposition of the argillaceous protoliths of the Syringa metamorphic sequence in the Neoproterozoic. During the late Paleozoic and early Mesozoic, volcanic and volcaniclastic rocks of the Wallowa island-arc terrane were forming off the continental margin somewhere west or south relative to their present-day position in North America. In the Mesozoic, the Wallowa terrane was accreted to continental North America along the Salmon River suture zone (Lund and Snee, 1988). The mechanics of this accretionary event are unclear, in part because of continued deformation along the suture zone following accretion. Deformation subsequent to suturing (as late as 72 Ma) may play a strong role in the present configuration of the boundary and the “bend” in the initial $^{87}Sr/^{86}Sr$ 0.704/0.706 line at the latitude of the Orofino quadrangle (McClelland and others, 2000; Payne and McClelland, 2002; Payne, 2004). The Orofino series has an unclear role in the accretion history. Rocks of this series straddle the 0.704/0.706 line in the Orofino Creek area and contain minor amounts of quartzite, suggesting some continental affinity, yet they have chemical and lithologic affinities with the arc complex. The series must be older than its metamorphic age of about 80 Ma (Davidson, 1990).

Mesozoic magmatism began in the Jurassic in the island-arc terrane. By the Cretaceous, magmatism was widespread throughout the northeast part of the area. Plutons near Orofino formed at depth; they contain primary epidote, a mineral indicative of pressures in excess of 9 kb (Zen and Hammarstrom, 1984). The Cretaceous also accommodated much of the metamorphism in the area, although an earlier (Proterozoic?) metamorphic history in the Syringa metamorphic sequence cannot be

Table 1. Average major oxide and trace element concentrations for Columbia River Basalt Group units in the Idaho parts of the Orofino and Clarkston 30 x 60 minute quadrangles.

Average major oxide concentrations (weight percent).

Unit	n	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
SADDLE MOUNTAINS BASALT											
Lower Monumental Member	2	50.35	2.979	13.77	13.94	0.227	5.05	8.76	2.75	1.50	0.665
Lower Monumental dikes	2	50.51	2.788	13.94	13.36	0.212	5.33	9.45	2.84	0.97	0.605
Basalt of Tammany Creek	2	53.72	3.090	13.43	13.03	0.202	3.72	7.65	2.91	1.77	0.480
Elephant Mountain Member	3	51.90	3.746	13.03	13.77	0.219	4.28	8.64	2.50	1.32	0.592
Basalt of Craigmont	13	53.38	3.064	13.83	13.11	0.213	3.42	7.73	3.02	1.72	0.504
Basalt of Swamp Creek	2	51.95	2.767	13.57	13.74	0.268	4.51	8.85	2.74	1.23	0.377
Pomona Member	3	52.20	1.709	14.70	10.38	0.180	6.63	10.95	2.33	0.66	0.260
Basalt of Weippe	31	51.76	1.828	14.80	10.80	0.190	6.33	11.00	2.55	0.51	0.232
Basalt of Grangeville	18	53.16	1.375	15.46	9.16	0.180	6.32	10.98	2.49	0.71	0.168
Basalt of Lewiston Orchards	12	49.33	2.390	14.71	11.62	0.200	7.03	11.27	2.43	0.47	0.553
Asotin-Wilbur Creek Members											
Asotin Member	54	50.44	1.454	16.32	9.47	0.159	7.73	11.46	2.28	0.50	0.183
Wilbur Creek Member	9	54.06	1.890	14.67	10.95	0.175	4.58	8.77	2.72	1.70	0.496
Basalt of Lapwai	8	52.28	1.719	15.22	10.93	0.166	5.93	9.66	2.51	1.21	0.375
Asotin-Wilbur Creek mix?	3	52.74	1.706	15.99	9.67	0.156	5.05	10.55	2.60	1.19	0.345
WANAPUM BASALT											
Priest Rapids Member											
Lolo chemical type	32	50.00	3.254	13.67	13.59	0.235	5.29	9.36	2.67	1.14	0.800
Rosalia chemical type	5	50.26	3.694	12.96	15.10	0.270	4.20	8.69	2.73	1.30	0.800
Priest Rapids mix?	2	50.24	3.557	14.28	12.98	0.226	4.04	9.93	2.73	1.13	0.894
Basalt of Icicle Flat	23	52.00	1.429	15.41	11.33	0.217	5.54	9.92	3.05	0.78	0.324
GRANDE RONDE BASALT											
Grande Ronde R2											
Meyer Ridge 1	7	53.86	1.670	14.70	10.32	0.192	5.32	9.71	2.86	1.09	0.268
Meyer Ridge 2	15	54.21	1.783	14.55	10.74	0.207	4.92	9.16	2.94	1.18	0.293
Meyer Ridge 3	9	55.08	1.751	14.50	10.52	0.189	4.69	8.63	3.13	1.24	0.273
Grouse Creek/Mt. Horrible	40	55.25	2.109	14.07	11.45	0.200	3.96	7.88	3.19	1.52	0.382
Wapshilla Ridge	64	55.58	2.479	14.04	11.53	0.199	3.40	7.23	3.21	1.85	0.476
Grande Ronde N1	124	55.21	2.115	14.10	11.47	0.202	4.00	7.89	3.17	1.49	0.363
Grande Ronde R1	47	55.31	2.211	13.90	11.62	0.192	3.91	7.72	3.15	1.65	0.340
IMNAHA BASALT	2	50.18	2.589	15.26	12.43	0.189	5.43	9.67	3.05	0.84	0.361

Table 1. (Continued).

Average trace element concentrations (ppm).

Unit	n	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th
SADDLE MOUNTAINS BASALT																		
Lower Monumental Member	2	11	38	30	327	482	33	347	181	36	26.9	21	13	138	4	33	76	6
Lower Monumental dikes	2	42	77	38	370	576	20	319	207	42	20.9	21	26	129	4	31	69	1
Basalt of Tammany Creek	2	14	16	28	335	714	47	273	239	45	24.3	23	21	132	10	41	85	7
Elephant Mountain Member	3	13	36	35	426	518	32	234	260	52	25.8	24	22	154	7	39	74	5
Basalt of Craigmont	13	22	25	32	354	783	42	290	262	51	27.2	24	28	141	11	49	81	7
Basalt of Swamp Creek	2	34	46	35	370	561	27	288	215	46	23.6	24	43	129	7	33	76	3
Pomona Member	3	46	107	38	279	305	14	235	137	31	11.8	19	51	97	4	15	42	3
Basalt of Weippe	31	35	68	38	292	302	9	243	127	30	13.2	19	56	94	4	20	40	3
Basalt of Grangeville	18	34	135	36	229	397	15	251	130	27	14.4	19	61	81	3	22	41	4
Basalt of Lewiston Orchards	12	73	268	40	309	464	7	249	177	40	19.4	18	56	112	4	25	65	1
Asotin-Wilbur Creek Members																		
Asotin Member	54	128	283	32	253	262	9	253	110	26	9.7	18	84	81	3	15	31	2
Wilbur Creek Member	9	39	59	31	275	846	37	283	234	43	17.1	21	27	119	12	39	77	7
Basalt of Lapwai	8	75	139	29	266	601	25	263	186	37	14.4	19	48	103	8	32	61	6
Asotin-Wilbur Creek mix?	3	71	175	33	275	542	24	277	181	35	13.4	19	62	104	8	25	61	2
WANAPUM BASALT																		
Priest Rapids Member																		
Lolo chemical type	32	43	100	39	367	539	26	291	186	46	15.8	22	39	141	5	23	59	3
Rosalia chemical type	5	17	33	42	437	633	29	294	218	52	18.8	22	21	150	5	36	55	3
Priest Rapids mix?	2	34	99	39	387	641	25	309	200	49	16.9	22	38	152	6	26	67	4
Basalt of Icicle Flat	23	35	99	43	364	451	11	347	103	33	7.5	19	115	108	5	13	27	2
GRANDE RONDE BASALT																		
Grande Ronde R_2																		
Meyer Ridge 1	7	39	114	40	323	494	24	313	135	32	10.4	19	67	103	4	17	35	3
Meyer Ridge 2	15	27	76	38	333	526	27	308	145	34	11	20	59	111	5	20	41	4
Meyer Ridge 3	9	10	26	36	322	508	30	331	148	33	10.3	21	30	108	6	15	39	4
Grouse Creek/Mt. Horrible	40	12	25	36	365	609	37	329	171	38	12.3	22	33	125	6	20	48	4
Wapshilla Ridge	64	13	18	34	376	817	47	336	198	42	14.1	22	25	134	9	27	56	5
Grande Ronde N_1	124	10	23	37	365	632	36	328	170	38	11.9	21	25	123	7	20	45	4
Grande Ronde R_1	47	14	28	34	349	585	42	327	193	38	13.6	21	49	119	7	22	48	4
IMNAHA BASALT	2	73	109	35	355	304	19	358	185	40	13.4	21	140	124	6	16	49	2

n = number of samples analyzed.

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

Table 2. Average major oxide and trace element concentrations for Kamiah volcanics and one Potlatch volcanics unit sample in the Idaho parts of the Orofino and Clarkston 30 x 60 minute quadrangles.

Average major oxide concentrations (weight percent).

Unit	n	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
KAMIAH VOLCANICS											
Basalt	2	50.09	1.653	18.17	10.31	0.164	5.93	8.82	3.74	0.80	0.332
Basaltic andesite	4	54.49	1.299	18.05	8.27	0.136	4.31	8.03	4.00	1.09	0.329
Andesite	7	59.42	1.058	17.26	6.62	0.117	3.21	6.11	4.13	1.70	0.369
POTLATCH VOLCANICS											
Onaway Member**?**	1	52.71	1.874	16.99	10.57	0.222	3.22	6.03	5.34	1.78	1.261

Average trace element concentrations (ppm).

	n	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th
KAMIAH VOLCANICS																		
Basalt	2	53	29	27	241	274	8	545	140	27	12.9	20	52	85	2	17	33	2
Basaltic andesite	4	51	29	21	197	502	13	566	150	26	12.0	18	48	83	4	19	41	2
Andesite	7	34	60	20	122	536	26	477	194	27	12.3	19	27	75	5	20	42	3
POTLATCH VOLCANICS																		
Onaway Member?	1	20	36	14	88	458	14	1305	444	49	42.7	22	33	141	5	48	116	3

n = number of samples analyzed.

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

Table 3. Whole-rock analyses of selected intrusive rocks from the Orofino 30 x 60 minute quadrangle. Includes one sample from Headquarters 30 x 60 minute quadrangle (90TF038; Lewis and Frost, 2005) for comparison. Units listed as "KJ" may include intrusives of Cretaceous or Jurassic age; ages listed in the table are for specific locations within the unit from dated samples. All analyses by XRF except La and Ce in 90TF038, which were analyzed by neutron activation analysis. Total Fe expressed as FeO.

Map no.	26	27	28	29	30	21	
Sample no.	05RL321	06RL400	06RL401	06RL403	06RL404	02RL983	90TF038
Mineralogy	hornblende-biotite	epidote-biotite-hornblende	epidote-biotite-hornblende	epidote-biotite	biotite-hornblende	biotite-hornblende	hornblende-biotite
Lithology	quartz diorite	quartz diorite	quartz diorite	tonalite	quartz diorite	quartz diorite	quartz diorite
Form	pluton	pluton	pluton	sill	pluton	pluton	pluton
Unit	KJqd	KJdg	KJqdg	Kbtog	KJqd	KJqd	Kqd
7.5′ quad.	Waha	Peck	Orofino West	Orofino West	Orofino East	Woodland	Headquarters
Latitude	46.18225	46.49719	46.4955	46.4955	46.38517	46.2650	46.6498
Longitude	-116.87125	-116.40630	-116.27713	-116.27713	-116.17344	-116.0903	-115.8254
Age	uncertain	Cretaceous	Cretaceous	Cretaceous	Cretaceous	Jurassic	Cretaceous
Initial $^{87}Sr/^{86}Sr$	<0.704	<0.704	<0.704	<0.704	<0.704	<0.704	>0.706
				Major elements (weight %)			
SiO_2	63.90	57.76	59.84	72.15	52.44	58.81	63.50
TiO_2	0.577	0.746	0.889	0.165	0.825	0.654	0.62
Al_2O_3	16.73	17.91	16.64	16.29	20.70	16.32	17.00
FeO*	4.06	6.22	6.39	1.22	7.11	7.60	3.56
MnO	0.074	0.116	0.111	0.029	0.148	0.150	0.06
MgO	2.98	4.27	3.21	0.44	4.05	3.85	1.91
CaO	4.88	7.24	6.05	3.36	8.37	7.45	6.37
Na_2O	4.68	3.95	3.88	5.43	4.99	2.75	4.04
K_2O	1.49	1.26	1.46	0.63	0.18	1.30	1.31
P_2O_5	0.180	0.193	0.258	0.066	0.213	0.099	0.46
Total	99.56	99.66	98.72	99.78	99.03	98.98	98.84
				Trace elements (ppm)			
Ni	42	43	16	6	17	13	10
Cr	95	75	24	4	25	30	<20
Sc	10	21	19	3	20	27	
V	103	170	161	24	170	197	
Ba	600	399	695	557	94	398	670
Rb	25	25	33	13	0	31	38
Sr	1061	562	666	905	918	331	670
Zr	82	131	216	60	128	78	245
Y	8	18	23	6	19	21	22
Nb	2.5	3.4	5.5	1.8	3.0	3.4	12
Ga	19	19	20	18	21	16	
Cu	9	52	31	13	63	96	14
Zn	54	73	87	23	86	73	66
Pb	8	5	6	10	4	4	
La	12	17	12	6	4	9	26.3
Ce	23	31	33	16	21	15	62.8
Th	3	2	0	2	1	4	
Nd	15	19	21	7	17		

discounted. Amphibolite-grade conditions progressed northeast from late Cretaceous in the island-arc terrane to early Paleocene toward the northeast, as the uplift and cooling of rocks presently at the surface progressed in that direction (Davidson, 1990).

Oligocene volcanism is recorded in the Kamiah volcanics and the minor occurrence of the Onaway Member of the Potlatch Volcanics exposed on Twin Buttes, Big Butte, and a small unnamed butte, collectively referred to locally as Kamiah buttes. Sources for these units and the original extents are unknown, but the presence of rhyolitic lava flows, bombs, and dikes suggests a local source. Volcanic rocks of similar age have been reported from northern Idaho (Kauffman and others, 2006), southern Idaho (Norman and others, 1986), and several locations in Oregon (Walker and Robinson, 1990; Robinson and others, 1990; Ferns, 2002), which suggest the rocks on Kamiah buttes may be remnants of more widespread regional volcanism during the Oligocene.

About 17 million years ago, extrusion of Columbia River Basalt Group flows began as Imnaha Basalt inundated the area. Streams dammed by these flows deposited sediments in temporary marginal lakes and on flow surfaces; these sediments were covered by subsequent flows. Rapid extrusion of Grande Ronde Basalt began shortly after the Imnaha Basalt eruption ended. Contacts of Imnaha and Grande Ronde basalts are conformable, with little indication of weathering or erosion on the Imnaha surface. The lack of significant interbeds within the Grande Ronde sequence, except at the eastern margin of the plateau, indicates very rapid extrusion rates. Throughout Grande Ronde magmatism, the Pasco basin was forming to the west and causing a gentle westward tilt to the region. Before R_2 extrusion, subtle warping began along the Waha escarpment, as indicated by thinning of the R_2 over the crest and thickening in the Lewiston basin. The Limekiln fault was also developing at this time, as indicated by the absence of R_2 flows southeast of the fault (Reidel, 1982). Regional tilting to the west continued and caused the N_2 to pinch out in the west part of the Lewiston basin in Washington. The exposed R_2 and N_1 surfaces then had sufficient time before eruption of Wanapum Basalt to develop significant saprolite surfaces.

Following this period of volcanic quiescence, Wanapum Basalt flows began to be extruded. The basalt of Icicle Flat was probably extruded from local vents and filled subtle structural depressions that had developed on the Grande Ronde surface. The Icicle Flat basalt flowed toward the Lewiston basin from the Camas Prairie, but pinched out west of Lapwai Creek, suggesting either the volume was insufficient to flow farther or the Lewiston basin was not the lowest area at that time. The later Priest Rapids Member, however, is thickest within the Lewiston basin and thins significantly or is absent east of Cottonwood Creek near Gifford. It also pinches out against the Waha escarpment, documenting the continued development of the structure, and thins but covers the Lewiston anticline and extends northward to Genesee and Moscow. The Priest Rapids marked the end of Wanapum Basalt extrusion.

Following Priest Rapids extrusion, streams became established and supplied sediment into the developing basins, although evidence of significant downcutting is absent. Within the Lewiston basin, sediments of the Sweetwater Creek interbed were deposited. These sediments are more than 30 m (100 feet) thick near the center of the basin but thin outward rapidly. They were deposited on the Priest Rapids Member or, where that unit is absent, on R_2 Grande Ronde Basalt. The distribution of the interbed indicates continued and possibly slightly accelerated downwarping of the Lewiston basin. Eruption of Saddle Mountains Basalt then began with the extrusion of the Asotin-Wilbur Creek unit flows, possibly from sources east of the map. This extensive unit lapped against the Waha escarpment-Limekiln fault structure and partly filled a narrow valley eroded about 90 m (300 feet) into R_2 Grande Ronde Basalt south of the escarpment. The presence of this eroded valley indicates at least 90 m (300 feet) of uplift along the escarpment at this time. To the north, however, the Asotin-Wilbur Creek unit and the later basalt of Lewiston Orchards were able to override the Lewiston anticline, although both thin across this structure. The tilting of Asotin-Wilbur Creek basalt along the base of the Waha escarpment and the restriction of Lewiston Orchards basalt to the north side of the escarpment indicate continued and probably increased post-Asotin subsidence. The Lewiston Orchards basalt may have been extruded from dikes along the Lewiston anticline and Waha escarpment. Other Saddle Mountains Basalt units — the basalt of

Grangeville, basalt of Weippe, basalt of Craigmont, and basalt of Swamp Creek — were then erupted and spread across a slightly warped upland surface in the eastern half of the Orofino quadrangle. These flows, which were most likely erupted from dikes south or east of the area, did not reach the Lewiston basin. About 12 million years ago, the ancestral Salmon River began cutting its canyon in the Lewiston area. The Pomona Member filled the developing channel, followed sequentially by the Elephant Mountain Member, the basalt of Tammany Creek, and the Lower Monumental Member. Major development of the Lewiston basin and associated structures, therefore, probably began about 13 to 12 Ma and likely continued into the Pliocene, as indicated by the thrusting of Grande Ronde Basalt over Clearwater Gravel deposits along the Wilma fault.

By 6 Ma, the ancestral rivers at the west edge of the area had cut canyons to a level similar to today's as determined from elevations at the base of the Lower Monumental Member, which was emplaced into a stream channel. Sometime later, the valley was aggraded with gravel, probably in response to a rising base level downstream. As described by Kehew (1977), Webster and others (1982), and Hooper and others (1985), the Clearwater gravel and its downstream correlative, the Clarkston Heights gravel, represent major aggradation in which the ancestral valleys were filled to about an elevation of 345 m (1,150 feet). Webster and others (1982) suggest the Clarkston Heights gravel, and therefore the Clearwater gravel, predate the capture of the Snake River drainage into the Columbia River drainage. They also suggest equivalency with the Middle Ringold Formation, which is early to middle Pliocene and formed in response to a base level event near the outlet of the Pasco basin in Washington state. Therefore, the Clearwater and Clarkston Heights gravels are probably Pliocene in age.

In late Pliocene or early Pleistocene, the ancestral Snake River cut Hells Canyon and captured the drainage of the western Snake River Plain (Wheeler and Cook, 1954; Malde, 1991; Othberg, 1994). The capture coincided with, and was probably augmented by, the change toward glacial climates that characterized the Pleistocene worldwide. Increased stream discharges and the erosion of downstream nickpoints resulted in renewed downcutting to the present river levels. However, late Pleistocene gravel terraces document that the Clearwater and its tributaries were somewhat aggraded before the Lake Missoula Floods. During the Holocene, the Clearwater and Snake rivers varied their levels as shown by deposits in point bars and terraces that are above modern stream levels. Dworshak and Hells Canyon dams have contributed to some of the change, but the evidence also exists on the Clearwater River upstream of its confluence with the North Fork.

The warm, moist climate that characterized the Miocene in the region continued into the Pliocene and promoted weathering that formed deep, brightly colored, highly leached soils whose kaolinitic clay mineralogy contrasts with the shallow, dull, illite-vermiculite soils of the Quaternary. Many nearly flat basalt surfaces in the eastern part of the map show evidence of spheroidal weathering and saprolite formation. The cooler and drier glacial climate of the Pleistocene changed the weathering processes and brought on the cyclical deposition of wind-blown silt that forms the thick loess of the Palouse Formation in the northwest part of the map. Being southeast of the primary source area for wind-blown dust, the Lewiston basin has only a thin mantle of loess on gently sloping basalt surfaces. Eastward, loess forms a thin discontinuous mantle on the basalt plateau and mountain foothills.

In the late Pleistocene, the Snake and Clearwater rivers were inundated by both Bonneville and Missoula Floods. Giant gravel bars deposited by the Bonneville Flood are prominent features along the Snake River. Multiple catastrophic floods from the emptying of Glacial Lake Missoula reversed the flow of the rivers depositing silt, sand, and ice-rafted cobbles and boulders in the valleys up to an elevation of 360 m (1,200 feet). Rhythmically bedded sediments typical of Missoula Floods backwater deposits mantle parts of the landscape in the lower elevations of the canyons. Kamiah was the approximate upstream limit of the floods and is the location of a delta built into the backwater by the Clearwater River and Lawyer Creek.

Large slumps of late Pleistocene- and Holocene-age landslide deposits form the valley sides in many locations along the Snake and Clearwater rivers and their tributaries. These large landslides occur where sedimentary interbeds have been exposed along valley sides. Smaller landslide deposits are common on steep canyon slopes, and many have been historically active.

GASCOME GASCO COTTONWOOD NO. 1-26 EXPLORATION WELL

In late 1981, Gascome Oils, Inc., began drilling a wildcat gas exploration well several miles northwest of the town of Nezperce. The location is shown on the geologic map, and cross-section A-A′ intersects the well. Surface elevation at the wellhead was 3,267 feet (the metric system was not used on the well log), and the total depth was 5,701 feet. The lithologic log reports fine-grained basalt with a few tuffaceous or sand interbeds to a depth of 1,119 feet where a "microgabbro dyke" is reported from 1,119 to 1,331 feet. We are uncertain what this microgabbro unit is, but interpret the base of the Columbia River Basalt Group (probably all Grande Ronde Basalt) to be at 1,119 feet. The microgabbro unit could be Imnaha Basalt, which would place the base of the Columbia River Basalt Group at 1,331 feet. Below the microgabbro dike to a depth of 2,581 feet is a sequence of interlayered basalt flows, tuffs, sandstones, and pyroclastic deposits. These units may correlate with the nearby Kamiah volcanics, but could include Potlatch Volcanics or other unknown volcanic deposits. From 2,581 to 2,602 feet, the log records "shale with marble interbeds" that may be equivalent to the Hurwal Formation, or alternatively may be part of the Martin Bridge Limestone. From 2,602 to 4,724 feet, the drill hole intersected marble with minor quartzite bands below 2,880 feet. We interpret this marble as the Martin Bridge Limestone. Actual thickness cannot be determined because the attitude is unknown, but Follo (1994) reports a thickness of 200-350 m (600-1,000 feet) for the unit in Oregon. Unit attitude and thickness depicted on the cross-section are speculative, although the reported thickness of over 2,000 feet in the drill hole log suggests the unit has a moderate to steep dip or is folded. At 4,724 feet, the hole passes into metavolcanic rocks, probably meta-andesite, with a few marble bands. We show this as Seven Devils Group, undivided, on the cross-section, but the lithologic description is similar to the Wild Sheep Creek Formation we map farther to the west.

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