Geologic Map of the Grave Point Quadrangle, Idaho County, Idaho, and Wallowa County, Oregon

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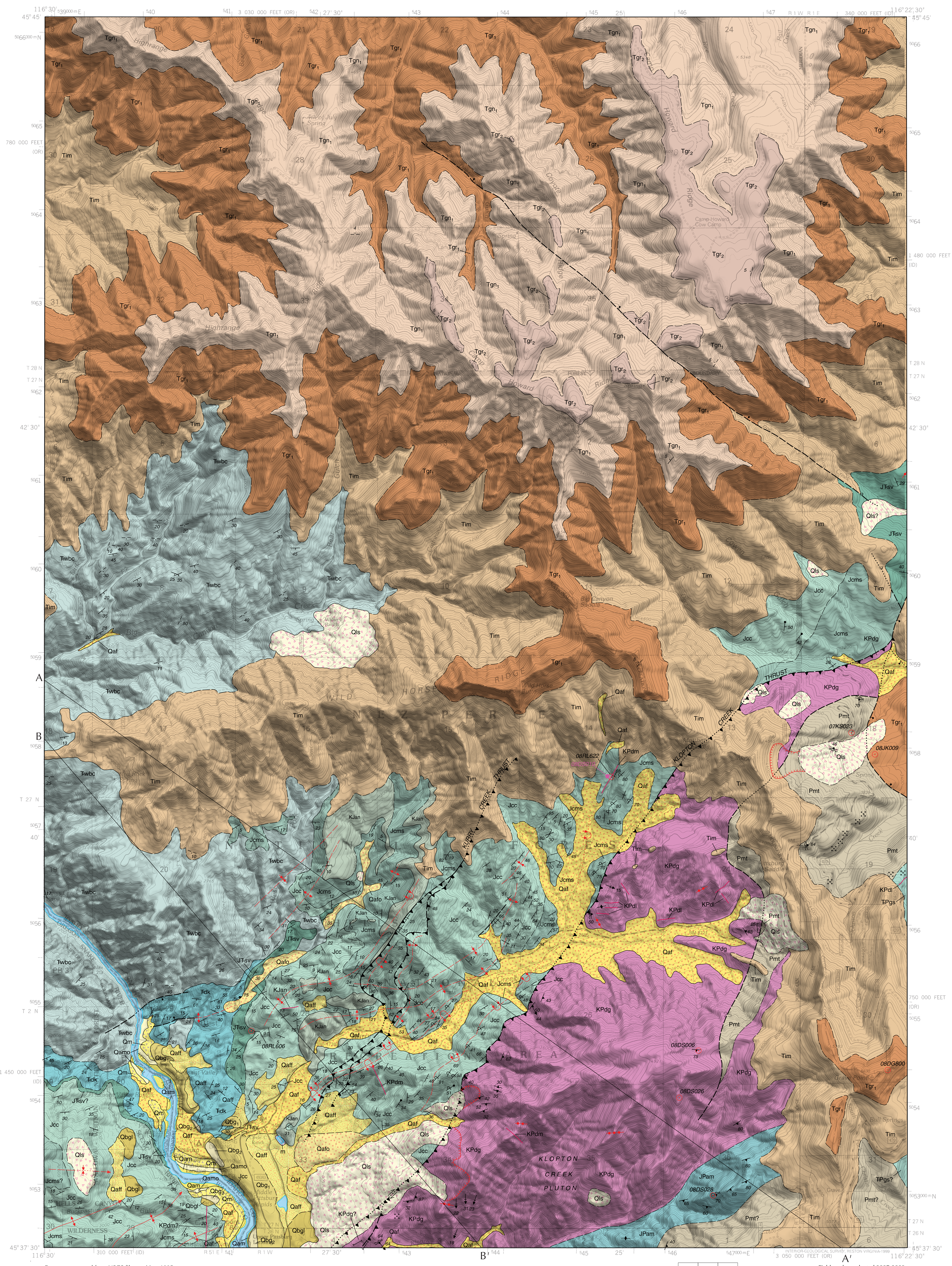
2009



Base map scanned from USGS film positive, 1995.

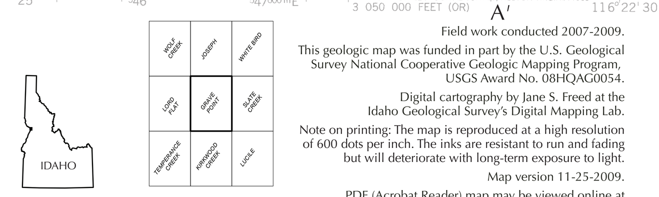
Shaded elevation from 10 m DEM, vertically exaggerated 1.5x.

Topography by photogrammetric methods from aerial photographs taken 1961. Planimetry derived from imagery taken 1992. Partial field check by U.S. Forest Service 1995.

Transverse Mercator projection. 1927 North American Datum.

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

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



Field work conducted 2007-2009.

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Digital cartography by Jane S. Freed at the Idaho Geological Survey's Digital Mapping Lab.

Note on printing: The map is reproduced at a high resolution of 600 dots per inch. The inks are resistant to run and fading but will deteriorate with long-term exposure to light.

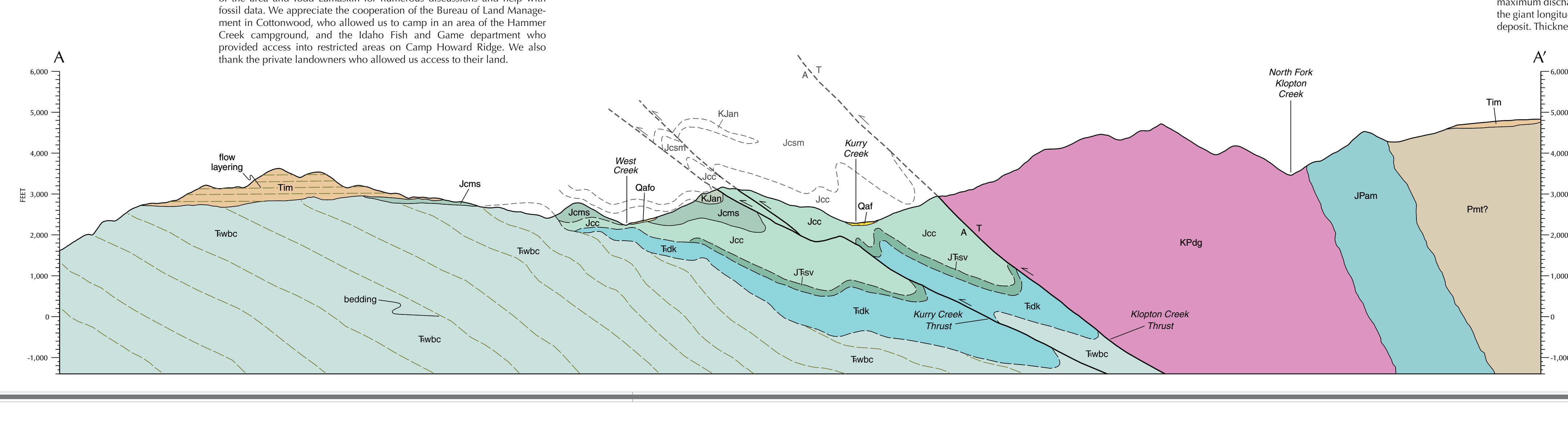
Map version 11-25-2009.

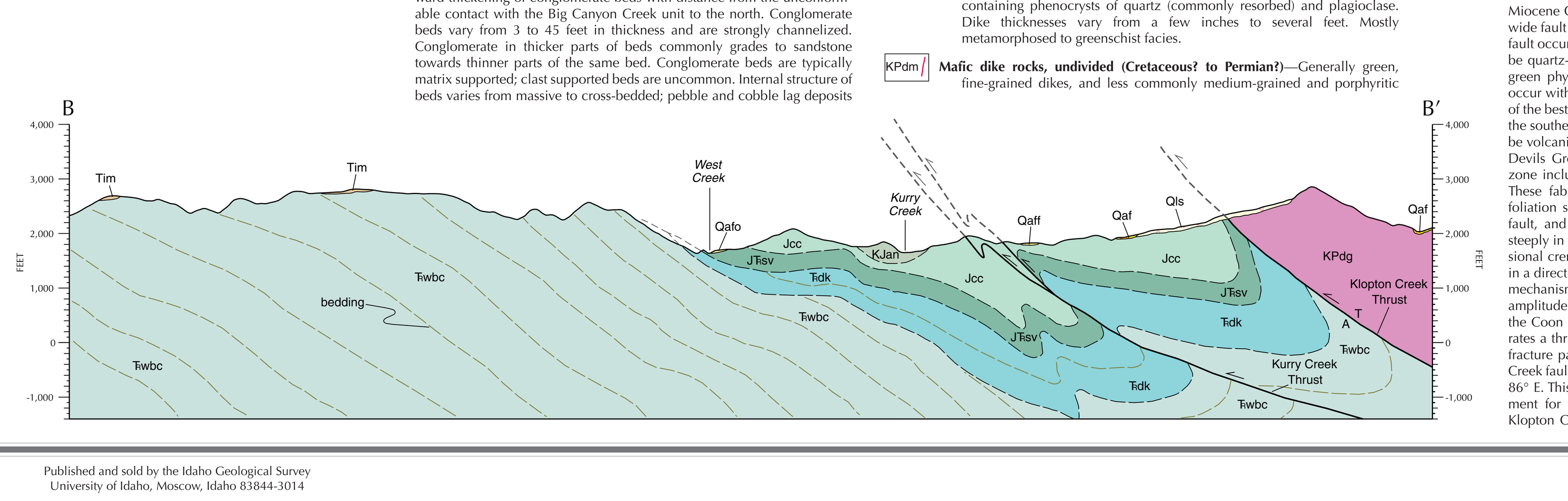
PDF (Acrobat Reader) map may be viewed online at www.idahogeology.org.

ACKNOWLEDGMENTS

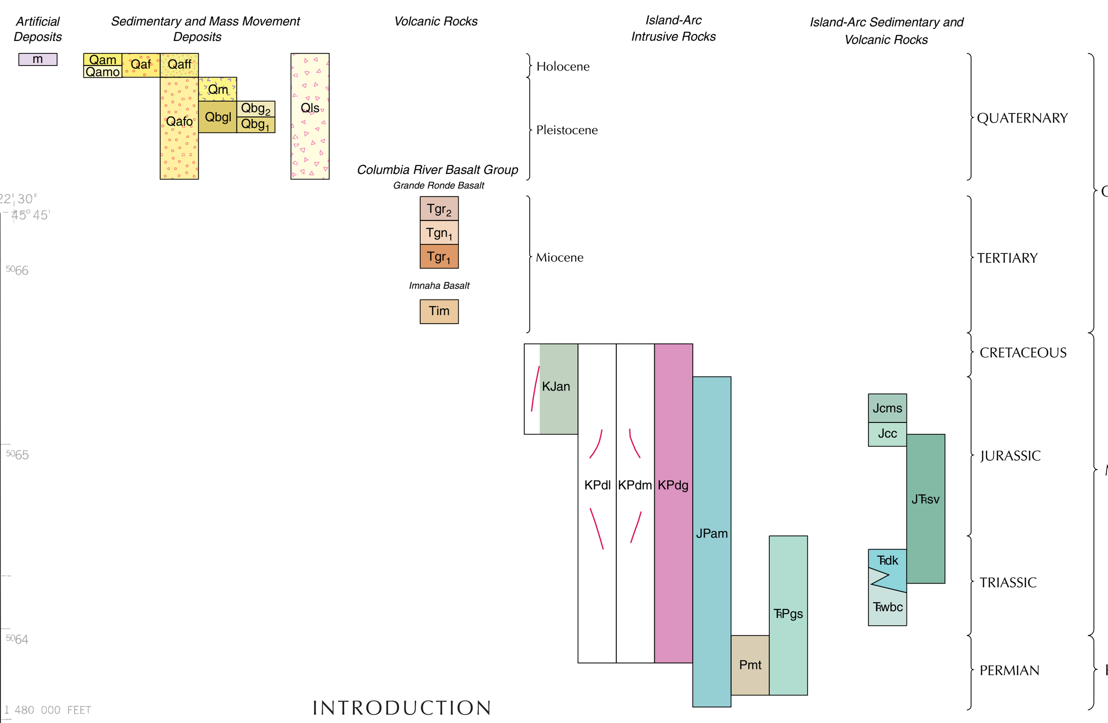
David White and Tracy Vallier produced the pioneering mapping in the Pittsburg Landing area and helped considerably with the construction of this map. In addition to providing field maps, time spent in the field with the authors established a firm basis for our follow-up work. Gene Kurz and Kyle Tumpane kindly provided preliminary results from their geochronologic work. We thank V.E. Camp for providing copies of his field notes and map of the area and Todd Lamaskin for numerous discussions and help with fossil data. We appreciate the cooperation of the Bureau of Land Management in Cottonwood, who allowed us to camp in an area of the Hammer Creek campground, and the Idaho Fish and Game department who provided access into restricted areas on Camp Howard Ridge. We also thank the private landowners who allowed us access to their land.

Disclaimer: This Digital Web Map is an informal report and may be revised and formally published at a later time. Its content and format may not conform to agency standards.





CORRELATION OF MAP UNITS



INTRODUCTION

The geologic map of the Grave Point quadrangle identifies rock units exposed at the surface or underlying thin surficial cover of soil and colluvium. Thicker surficial alluvial, colluvial, and landslide deposits are also shown where they mask or modify the underlying rock units and form significant mappable units. The area is characterized by steep, rugged canyon slopes with intervening plateau surfaces. Main access into the area is the Pittsburg Landing road; additional access is on Forest Service roads and BLM or private jeep trails. The map is the result of our field work from 2007-2009, as well as compilation of previous research, including that of Bond (1963), Vallier (1968, 1974), Walker (1986), White (1972), White (1994), White and Vallier (1994), Kurz (2001), and reconnaissance mapping from 1978 to 1980 by V.E. Camp (Camp, 1981; Swanson and others, 1981). T.L. Vallier provided unpublished mapping that was also used in compilation (T.L. Vallier, written commun., 2008).

The southern part of the quadrangle is underlain by island-arc rocks of the accreted Wallowa terrane, including Triassic Seven Devils Group units, Jurassic sedimentary and volcanic rocks, and Permian to Cretaceous(?) intrusive rocks basement to or intruding the Seven Devils Group. These folded and faulted rock assemblages accreted to the North American continent during Jurassic to Cretaceous and are capped by Miocene Columbia River Basalt Group lava flows in the northern and southeastern part of the map. The basalts have a gentle northwestward dip but are otherwise little deformed and are not cut by the major basement structures, except for a small area on the east edge of the map where a major down-to-the-east fault displaces the basalt at least 1,500 feet. In the late Pleistocene, the lower part of the Snake River canyon was inundated by the Bonneville Flood, forming prominent giant gravel bars. Later, at least one of the Missoula Floods backwatered the Snake River 40-60 feet deep in the Pittsburg Landing area and deposited fine-grained sediments. Holocene and Pleistocene colluvial and alluvial deposits form a surficial cover in the Pittsburg Landing area and in side-stream drainages. Quaternary landslide deposits are mapped at several locations.

DESCRIPTION OF MAP UNITS

In the following unit descriptions and later discussion of structure, we use the metric system for sizes of mineral or clast constituents of rock units. We use the English system for thickness and distance measurements to conform to those on the base map. Intrusive rocks are classified according to IUGS nomenclature using normalized values of modal quartz (Q), alkali feldspar (A) and plagioclase (P) on a ternary diagram (Streckeisen, 1976). Pre-Miocene volcanic rocks are classified by total alkalies versus silica chemical composition according to IUGS recommendations (LeMaitre, 1984). The Miocene Columbia River Basalt Group contains basalt, basaltic andesite, and andesite by that classification, but the term "basalt" is applied here, as it has been historically.

ARTIFICIAL DEPOSITS

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

SEDIMENTARY AND MASS MOVEMENT DEPOSITS

Alluvial Deposits

Qam **Alluvium of the Snake River (late Holocene)**—Channel and flood-plain deposits that are part of the present river system. Predominantly well-sorted and rounded pebble to boulder gravel in river bars and islands, and coarse sand in thin shoreline deposits. Gravel clasts primarily metamorphic and plutonic rocks from Hells Canyon. Thickness variable, ranging 1 to 10 feet.

Qamo **Older alluvium of the Snake River (early Holocene)**—Primarily stratified sand and well-rounded pebble to boulder gravel of point-bar remnants that are above modern levels of the Snake River. Gravel clast lithology similar to Qam. May be capped by thin loess and eolian sand. Height above the river is 20-40 feet. Interfingers with colluvium and alluvial-fan deposits at toe of canyon slope. Thickness ranges from 5 to 20 feet.

Qaf **Alluvial-fan deposits (Holocene)**—Crudely bedded, poorly sorted dark-brown muddy gravel deposited primarily by debris flows from steep canyon slopes. Debris-flow deposits form fans and compose drainageways upstream from fans. Gravel is composed of subangular to subrounded pebbles, cobbles, and boulders in a matrix of sand, silt, and clay. May include beds of silt and sand reworked from loess and Mazama ash. Thickness highly variable, ranging 5 to 50 feet.

Qaff **Alluvial-fan deposits, fine-grained (Holocene)**—Crudely bedded, poorly sorted brown sand and pebble gravel deposited primarily by sheet wash and debris flows. Derived primarily from erosion of Triassic and Jurassic sedimentary rocks. Forms broad fans composed of thin deposits that cap bedrock and overlie Bonneville Flood gravels. Includes light brown silt and sand reworked from loess and Mazama ash. Thickness highly variable, ranging 5 to 25 feet.

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

Lake Missoula Floods Deposits

Qm **Lake Missoula Floods backwater deposits (Pleistocene)**—Pale brown silty sand deposited when one or more Lake Missoula Floods backwatered the Snake River canyon. Forms terrace remnant at and just below 1,200 feet in elevation that is partly buried by Holocene fan debris-flow deposits. This may be the farthest upstream recorded Missoula Flood deposit. Thickness 10-20 feet.

Bonneville Flood Deposits

Qbg$_1$ **Sand and gravel in giant flood bars, maximum flood stage (Pleistocene)**—Stratified deposits of boulders, cobbles, and pebbles in a matrix of coarse sand deposited during highest-energy, maximum stage that flooded the Pittsburg Landing reach of the Snake River valley to nearly 1,700 feet in elevation (O'Connor, 1993). Forms giant, bouldery surfaced longitudinal bar in the south end of the reach, and coarse-grained deltaic gravel in the north end of the reach; both have large-scale crossbeds. Thickness highly variable, ranging 20 to 200 feet.

Qbg$_2$ **Sand and gravel in large flood bars and terraces, lower flood stages (Pleistocene)**—Stratified deposits of boulders, cobbles, and pebbles in a matrix of coarse sand deposited during later, lower stages of flood. Forms smaller gravels bars and remnants of gravel terraces. Thickness variable, ranging 20 to 80 feet.

Qbgl **Sand and gravel in eddy deposits and lower-energy bars (Pleistocene)**—Stratified coarse sand and gravel. Gravel typically characterized by angular granules and small pebbles; open-work texture. Deposited in eddies and side-channel positions associated with higher positions of maximum stage and also in eddies formed during later, lower stages of the flood. Thickness variable, ranging 10 to 60 feet.

Mass Movement Deposits

Qls **Landslide deposits (Holocene and Pleistocene)**—Poorly sorted and poorly stratified angular to subrounded pebbles, cobbles, and boulders mixed with silt and clay. Deposited by slumps, slides, and debris flows. In addition to the landslide deposit, the map may also show the landslide scarp and the headwall (steep area adjacent to and below the landslide scarp) from which material broke away (see Symbols). Location of landslide deposits is often controlled by interface between rock units of contrasting lithologies. Landslides vary in age from ancient, relatively stable features, to those that have been active in the Holocene. Most landslide deposits are Pleistocene, suggesting that mass movements occurred during times of greater snow packs and soil moisture. Judging from the blocks of fault gouge exposed in the large landslide mass just east of Upper Pittsburg Landing, it probably broke away from the mountain along the Klopton Creek thrust. The steepness of the mountain slope and the form of the landslide mass suggest that it moved as a relatively fast debris slide, possibly triggered by an earthquake. The landslide toe was scoured by the Bonneville flood during maximum discharge, and many of the boulders of diorite and gabbro within the giant longitudinal bar may have been flood-reworked from the landslide deposit. Thickness highly variable, ranging 20 to 100 feet.

VOLCANIC ROCKS

Columbia River Basalt Group

Flows of the Columbia River Basalt Group cover most of the northern half of the quadrangle and cap basement rocks along the southeastern map edge. Only flows of Imnaha Basalt and Grande Ronde Basalt occur in the area. Latah Formation sediments, which commonly form interbeds in the basalt sequence in other areas, were not found in the quadrangle. As much as 1,200 feet of Imnaha Basalt is exposed on Wild Horse Ridge. Grande Ronde Basalt appears to conformably overly Imnaha Basalt and includes flows of the informal R$_1$, N$_1$, and R$_2$, magnetostratigraphic units (Swanson and others, 1979). Maximum thickness of Grande Ronde Basalt is 1,200-1,300 feet. Basalt units were identified using hand sample characteristics, paleomagnetic signatures, geochemical signatures, and compilation of previous data. Representative samples were collected for chemical analysis. Sample locations are identified on the map, and analytical results are listed in Table 1. Samples were analyzed at Washington State University's GeoAnalytical Laboratory.

Grande Ronde Basalt

Tgr$_2$ **Grande Ronde Basalt, R$_2$ magnetostratigraphic unit (Miocene)**—Medium to dark gray, fine-grained basalt, commonly with a sugary texture, and uncommon to common plagioclase phenocrysts 1-2 mm long. Reverse magnetic polarity, although field magnetometer readings commonly give weak normal or conflicting results. Unit consists of one to three or possibly four flows locally, which form a thin cap on Camp Howard Ridge. Maximum thickness is about 200 feet.

Tgn$_1$ **Grande Ronde Basalt, N$_1$ magnetostratigraphic unit (Miocene)**—Dark gray, fine-grained generally aphyric to plagioclase microphyric basalt. Normal magnetic polarity. Consists of four to six flows with a total thickness of about 600 feet. Individual flows range from 50 to 150 feet in thickness. Flows near the top of the sequence are commonly 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 100-200 feet, and commonly have thick entablatures and basal colonnades that form tiered cliffs on steep canyon slopes.

Tgr$_1$ **Grande Ronde Basalt, R$_1$ magnetostratigraphic unit (Miocene)**—Mostly dark gray, fine-grained aphyric to microphyric basalt. Uncommon to common plagioclase phenocrysts 2-4 mm long in one or more flows near the base of the section. Lowermost flow(s) is very coarse grained and weathers to sooty brown, fine granular detritus, which is very similar to weathering characteristics of the underlying Imnaha Basalt. Reverse magnetic polarity, although flows near the R$_1$-N$_1$ boundary commonly have inconsistent or weak field magnetometer polarity readings. Outcrop characteristics of flows are similar to those in N$_1$ Grande Ronde Basalt. Consists of five to seven flows with a maximum thickness of 600-700 feet.

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 long, but some are as large as 3 cm. Normal magnetic polarity. Weathers to sooty brown granular detritus. Commonly has welll-developed fanning or irregular columns 1-2 feet in diameter. Maximum exposed thickness is about 1,200 feet on the south flank of Wild Horse Ridge; number of flows not determined. Thick hyaloclastic deposits occur locally in the unit near its contact with the older basement rocks.

ISLAND-ARC SEDIMENTARY AND VOLCANIC ROCKS

Coon Hollow Formation

Jcms **Marine mudstone, sandstone, and conglomerate unit of the Coon Hollow Formation (Jurassic)**—Dark gray to tan, massive to thin-bedded mudstone and sandstone in the lower part of the section, and conglomerate and sandstone in the upper part. Mudstone and sandstone are interbedded throughout the lower sequence, but the sediments grade upwards from mostly sandstone in the lower 30-60 feet of section to >150 feet of mostly mudstone above. The tan sandstone is thin to medium bedded, fine to coarse grained, and typically poorly sorted, calcareous, and immature; feldspar grains and volcanic-derived lithics are the common clasts. The mudstone is thinly bedded to massive, breaks in hackly fracture, and occurs with less common thinly bedded light gray to tan siltstone. Carbonate concretions are locally common in the mudstone. Both the sandstone and mudstone locally contain abundant fossil plant fragments; fossil pelecypods are uncommon and occur mostly in the lower sandstones.

The conglomerate in the upper part of the section is medium to thickly bedded and massive, and matrix to clast supported with subrounded to well-rounded clasts as large as 5 cm. Chert clasts are the dominate lithology in most coarse conglomerate beds exposed in upper Kurry Creek; however, clasts in sandstone beds are in places chert-rich and elsewhere dominated by volcanic and volcaniclastic lithologies. One pebbly sandstone contained 65 percent subangular to well-rounded volcanic clasts, 20 percent subangular to subrounded chert clasts, and 15 percent angular plagioclase and quartz fragments in a mica and silica matrix. Mudstone immediately west of the chert-pebble conglomerate beds contains pelecypod and ammonite fossils (latitude 45.67345 N., longitude 116.41852 W., sample 08DS010). Pebble conglomerate beds in the northeasternmost exposures of the *Jcms* unit in the footwall of the Kurry Creek thrust have clasts consisting of mostly volcanic and volcaniclastic lithologies; sandstones at this location are similar to those in the lower part of the section, except that micrite clasts dominate over chert and volcanic-derived clasts. The sandstone and conglomerate beds in this part of the section locally contain coral, pelecypod, and ammonite fossils (latitude 45.66453 N., 116.44124 W.). White and Vallier (1994) suggest that the unit is about 300 feet thick and represents a marine transgressive sequence that closely followed deposition of the underlying conglomerate-sandstone (*Jcc*) unit. The sandstone and conglomerate beds exposed in upper Kurry Creek that we include in *Jcms* are not mentioned in White and Vallier (1994), and we believe these beds overlie the sandstone-mudstone transgressive sequence they mapped in lower Kurry Creek and West Creek.

The marine unit conformably overlies the conglomerate, sandstone, and mudstone unit of the Coon Hollow Formation (*Jcc*), and to the northwest unconformably overlies the Big Canyon Creek unit of the Wild Sheep Creek Formation (*₮wbc*). The top of the marine unit is not exposed because it is either covered by the overlying Miocene basalts or is truncated by Mesozoic thrust faults.

At several localities along the West Fork of West Creek, preserved bioherms (too small to show at map scale), consisting of Bajocian (Middle Jurassic) shallow-water coral, pelecypod, and brachiopod fossils, occur at the unconformable contact between the marine unit and the underlying Big Canyon Creek unit (Stanley and Beauvais, 1990). Because the contact is a buttress unconformity, the age of the marine unit sequence is poorly constrained. The oldest marine unit beds along this part of the unconformity, therefore, can only be Bajocian age or younger. Included in our *Jcms* unit is mudstone located on the west side of the Snake River that was originally called the "Turbidite unit of the Coon Hollow Formation" by White and Vallier (1994). The northern contact with the lower part of the Coon Hollow Formation is covered and could be depositional or faulted. Ammonite varieties from this section include *Grossouvria*, giving these strata an early Callovian age (late Middle Jurassic; Imlay, 1981). Therefore, the age of these rocks is younger than the Bajocian bioherm fauna found along the unconformity below the marine unit in West Creek and is consistent with our interpretation that the bioherm assemblage either predates or represents the oldest age for the marine unit.

The upper sandstone and conglomerate sequence of the *Jcms* unit, which contains the pelecypod and ammonite fossils, clearly lies stratigraphically above the Bajocian bioherm assemblage. We are currently pursuing identification of the fossils from the two new localities noted above to better constrain the age of this sequence.

Jcc **Conglomerate, sandstone, and mudstone unit of the Coon Hollow Formation (Jurassic)**—Tan to dark gray, thick- to medium-bedded conglomerate, sandstone, and mudstone. All three lithologies are interbedded throughout the sequence, but overall the unit grades upward from dominantly conglomerate-sandstone at the base to dominantly mudstone-sandstone at the top. Tuffaceous sandstones, welded and unwelded quartz-biotite ryolite tuffs, and hornblende andesite tuffs are common towards the base of the unit. Thicknesses of beds, particularly conglomerates, change dramatically over distances of hundreds of feet, and there is a pronounced southeastward thickening of conglomerate beds with distance from the unconformable contact with the Big Canyon Creek unit to the north. Conglomerate beds vary from 3 to 45 feet in thickness and are strongly channelized. Conglomerate in thicker parts of beds commonly grades to sandstone towards thinner parts of the same bed. Conglomerate beds are typically matrix supported; clast supported beds are uncommon. Internal structure of beds varies from massive to cross-bedded; pebble and cobble lag deposits are common. Conglomerate clasts are subrounded to well rounded, commonly range in size from 0.5 to 20 cm (White and Vallier, 1994, report clasts as large as 1 m), and consist of mostly volcanic and volcaniclastic lithologies. Other clast lithologies are locally abundant and include plutonic and clastic sedimentary rocks and chert. White and Vallier (1994) suggest that many of the plutonic clasts were derived from lithologies in the Cougar Creek complex to the south. Sandstone is typically poorly sorted, locally calcareous, and immature, with feldspar crystals and volcanice-derived clasts as the most common constituents. Sandstone beds range from 4 inches to 15 feet in thickness. Internal bedding structure varies from massive to cross-bedded; graded bedding is common. Load casts occur where sandstone has been deposited on mudstone. Mudstone is dark gray and massive to thinly bedded. Plant fossils and petrified wood are locally common in sandstone and mudstone beds. The fossils represent a rich assemblage of Jurassic flora that includes ferns, lycopods, horsetails, seed ferns, ginkgoes, and conifers (Ash, 1991). Unfortunately these fossils yield little age control for the unit beyond the Jurassic Period. The unit unconformably overlies sedimentary and volcanic rocks (*J₮sv*), Kurry (*₮dk*), and Big Canyon Creek (*₮wbc*) units. It is conformably overlain by the marine Coon Hollow unit (*Jcms*).

Other Sedimentary and Volcanic Rocks

J₮sv **Sedimentary and volcanic rocks (Jurassic to Triassic?)**—Mixed unit of conglomerate, sandstone, tuff, limestone, mudstone, and volcanic flow rocks. Unit mostly conglomerate and tuff in the Pittsburg Landing area in the southwest corner of the map and mostly calcareous sandstone and limestone in the vicinity of Poe Creek in the eastern part of map. In the southwest corner, red to tan conglomerate and tuffaceous sandstone occur between Kurry Creek and West Creek on the eastern side of the Snake River and at one limited area south of Pleasant Valley on the western side of the river. In places, the sediments were deposited in channels that are cut into strata of the underlying Kurry unit (*₮dk*). Conglomerate is typically matrix supported and contains rounded to well-rounded 0.5 to 50 cm clasts of mostly volcanic lithologies; sandstone and limestone clasts are less common. Plagioclase-porphyritic basalt and basaltic andesite clasts similar to the Big Canyon Creek unit (*₮wbc*) are common. Sandstones are coarse- to medium-grained, immature, and contain subrounded to angular grains of feldspar and quartz, as well as lithic clasts of mostly volcanic origin. Opaque oxide replacement of grains is common. One sample contained 50 percent feldspar, 25 percent volcanic clasts, and 15 percent chert clasts; approximately 15 percent of grains were replaced by opaque oxide. Welded rhyolite tuff is present higher in the unit (locality 08RL606). Flattened pumice is present and phenocrysts include quartz and feldspar. One sample contained 5 percent embayed quartz, plagioclase crystals, and uncommon lithic rock fragments in a devitrified(?) groundmass. White and Vallier (1994) report a low-K rhyolite composition (70.59 percent SiO_2, 0.14 percent K_2O, normalized). Sample 08RL606 also has low-K rhyolite composition (78.35 percent SiO_2, 0.21 percent K_2O, normalized; Table 1). This assemblage was originally mapped by White and Vallier (1994) as the "Red Tuff unit" of the Coon Hollow Formation and was estimated to be 0 to 150 feet thick.

Also in the Pittsburg Landing area on the north side of West Creek, and to a limited extent on the western side of the Snake River across from the Lower Pittsburg Landing boat ramp, are sandstone, mudstone, cobble and pebble sandstone and mudstone, and uncommon conglomerate and mafic volcanic rocks. This subunit includes medium to thick-bedded, brown, calcareous, immature sandstone and tan to dark gray mudstone that contain fossil plant fragments. Brown to tan cobble and pebble sandstone and mudstone contain feldspar grains and heterolithologic clasts of volcanic and sedimentary origin as large as 20 cm. Some beds are dominated by cobbles of clastic sedimentary protolith rather than volcanic clasts. Matrix-supported conglomerate is an uncommon lithology and contains similar clast lithologies. Many of these sedimentary and volcanic beds are yellow-orange weathering and probably saprolitic. This assemblage was originally mapped by White and Vallier (1994) as part of their "Conglomerate unit" of the Coon Hollow Formation (our *Jcc* unit). However, we consider these rocks to be a facies variation of their "Red Tuff unit" described above because in several localities we note interfingering relationships among lithologies in the two units.

Rocks of the *J₮sv* unit that occur in the vicinity of Poe Creek on the eastern side of the map include calcareous sandstones, siltstones, and breccias as well as thin limestone beds. Clasts are epiclastic in origin. The breccias in upper Poe Creek are similar to the distinctive proximal channel breccia deposits that occur in the Kurry unit (*₮dk*) in West Creek. The calcareous breccias vary from 1 to 5 feet in thickness and are matrix to clast supported. Clasts typically range from 0.5 to 5 cm and consist mostly of plagioclase porphyritic basalt and basaltic andesite, some of which is lithologically identical to rocks in the Big Canyon Creek unit; less common clasts are other volcanics and peperites(?), immature sandstone, and limestone. These breccia beds are commonly underlain by thinly bedded quartz- and feldspar-bearing micritic limestone and calcareous immature sandstone beds that are folded, scoured, ripped-up, and entrained in the overlying breccia. Also distinctive is thinly bedded gray chert that occurs just south of Poe Creek. Interbedded with the sedimentary lithologies are volcanic lithologies, which include red to green weathered, thick-bedded plagioclase ± amphibole ± quartz lithic tuffs(?), breccias, and lava flow rocks of probable rhyolitic to basaltic andesite composition. Strongly weathered volcaniclastic beds with a distinctive spotted appearance also occur that we interpret as either saprolitic volcanics or peperite deposits.

Only plant fossils, which yield little age control beyond the Jurassic Period, have been found in the sedimentary beds, but a Lower Jurassic age of 196.86 ± 0.06 Ma (U-Pb zircon) was obtained from welded tuff near locality 08RL606 (Tumpane and Schmitz, 2009; Tumpane written comm., 2009). The presence of apparent saprolitic volcanic and sedimentary rocks indicates that the unit was deposited over an extensive interval of time. Overall, the unit may be more or less time-equivalent to the Hurwal Formation, but a coarser facies. In the Pittsburg Landing area, the unit unconformably overlies the Kurry unit (*₮dk*) and, along a short contact to the northwest, it lies unconformably above the Big Canyon Creek unit (*₮wbc*). It is unconformably overlain by the conglomerate-sandstone unit of the Coon Hollow Formation (*Jcc*). In the Poe Creek area, contact relationships with other stratigraphic units are poorly exposed and uncertain. Lithologies are similar to parts of the Kurry unit (*₮dk*) in the quadrangle and to a thick package of volcanosedimentary rocks that occur to the north in the Slate Creek and White Bird quadrangles. The latter package consists of mostly volcanic sequences, with sedimentary lithologies increasing toward the south. The age of that sequence is currently unknown, but we suspect it is Late Triassic or younger because of the relatively low degree of metamorphism compared to the older units and because lithologies do not correlate well with older units described from other localities.

Seven Devils Group

₮dk **Kurry unit of Doyle Creek Formation (Triassic)**—Tan to green thinly bedded tuffaceous(?) calcareous sandstone and mudstone, and argillaceous limestone. Towards the buttress unconformity with the underlying Big Canyon Creek unit, massive, wedge-shaped channel breccia deposits 3-9 feet thick become common. These breccias vary from matrix to clast supported. Clasts typically range from 0.5 to 5 cm and consist of mostly plagioclase porphyritic basalt and basaltic andesite that are the same as in the Big Canyon Creek unit; other clasts consist of immature sandstone and less common limestone. White and Vallier (1994) report one deposit that contains 1-2 m limestone clasts. The massive breccia deposits are commonly underlain by thin-bedded sediments that are scoured, ripped-up, and entrained in the overlying breccia. Soft sediment folding of the thin-bedded sediments is also evident where they are in contact with overlying breccia. The Kurry unit is at least 300 feet thick (White and Vallier, 1994). The lower, northern section of the unit interfingers with volcanic and volcanic breccia beds of the Big Canyon Creek unit. In places, this contact is difficult to determine. The Kurry unit is considered Carnian (Late Triassic) in age on the basis of the occurrence of the flat clam *Halobia* sp. Other fossils include ammonites and plant fragments. Interfingers with, and unconformably overlies, the Big Canyon Creek unit (*₮wbc*) and is unconformably overlain by the sedimentary and conglomerate-sandstone unit of the Coon Hollow Formation (*Jcc*).

₮wbc **Big Canyon Creek unit of Wild Sheep Creek Formation (Triassic)**—Mostly green volcaniclastic and volcanic rocks. Massive and pillow lavas typically contain abundant plagioclase phenocrysts ranging from 0.5 to1.0 cm in length. Plagioclase compositions range from labradorite to albite depending on the degree of metamorphism (White, 1972). Volcanic rock lithologies include mostly basalt and basaltic andesite with rare andesite and dacite (White and Vallier, 1994). Volcaniclastic units are massive, mostly matrix supported, and characterized by 1-10 cm angular to rounded clasts of porphyritic basalt or basaltic andesite in a strongly recrystallized greenstone matrix. Interpreted by White and Vallier (1994) as pillow lava and pillow breccia, features that distinguish this unit from the rest of the Wild Sheep Creek Formation. Also contains uncommon, moderately to welll-bedded, immature tuffaceous(?) sandstone and mudstone, and rare limestone and calcareous mudstone. Typically extensively metamorphosed to greenschist grade, with abundant albite, chlorite, and epidote growth. The Big Canyon Creek unit is considered to be at least Ladinian (late Middle Triassic) in age on the basis of fossils of *Daonella* sp. found at Jones Creek, the headwaters of which reach the western margin of the map (White, 1972). *Daonella* is common elsewhere in the Wild Sheep Creek Formation, but in some areas the fossil *Halobia* sp. of Carnian age (Late Triassic) occurs in addition to contemporaneous ammonites (White and Vallier, 1994).

ISLAND-ARC INTRUSIVE ROCKS

Dike And Sill Rocks

KJan **Mafic sills and stocks (Cretaceous? to Jurassic)**—Porphyritic andesitic or basaltic sills that intrude rocks of the Coon Hollow Formation and are only found in the footwall of the Kurry Creek thrust. Contains plagioclase and minor hornblende phenocrysts in a strongly recrystallized chlorite and epidote groundmass. Intrusion into the Coon Hollow Formation indicates a Jurassic or possibly younger age.

KPdl **Leucocratic dike rocks, undivided (Cretaceous? to Permian?)**—Light colored dike rocks, probably tonalite, consisting largely of quartz and plagioclase. Textures range from coarse grained to aphanitic, with porphyritic samples containing phenocrysts of quartz (commonly resorbed) and plagioclase. Dike thicknesses vary from a few inches to several feet. Mostly metamorphosed to greenschist facies.

KPdm **Mafic dike rocks, undivided (Cretaceous? to Permian?)**—Generally green, fine-grained dikes, and less commonly medium-grained and porphyritic bodies with plagioclase and hornblende phenocrysts. Most have been metamorphosed to greenschist facies, with groundmass and phenocrysts largely recrystallized to chlorite and epidote. Dikes are as much as several feet thick.

Cougar Creek Complex

The Cougar Creek complex, which occupies the hanging wall of the Klopton Creek thrust south of Pittsburg Landing on the Snake River, is dominated by intrusive rocks that are interpreted as basement to the Seven Devils Group (Walker, 1986; Kurz, 2001). This package of rocks is heterogeneous in age, composition, texture, fabric, and metamorphism. The complex is long-lived, with U-Pb zircon plutonic rock ages ranging from Permian to Triassic; one discordant Pennsylvanian U-Pb zircon age has been obtained on a quartzofeldspathic layer of uncertain protolith (Walker, 1986). The complex is compositionally diverse, ranging from mafic through silicic and intrudes rocks of probable volcanic protolith that may predate the Seven Devils Group. Metamorphism varies from lower greenschist to amphibolite facies, but is predominantly greenschist facies. Much of the material that makes up the complex probably represents magma chambers and feeders that intruded the basement rocks en route to extrusion as the Seven Devils Group units overlying the complex itself.

KPdg **Diorite and Gabbro (Cretaceous? to Permian?)**—Composite intrusive body consisting primarily of diorite and quartz diorite, but also includes small bodies of gabbro and aplite dikes. The diorite and quartz diorite are medium to dark gray with light-colored plagioclase and black pyroxene and hornblende, and typically contain a few percent quartz. The diorite weathers readily to a fine, dark brown soil. Mostly medium to coarse grained, but very fine grained in places. Subhedral plagioclase varies in size from 0.1 to 3.0 mm and is typically zoned. Orthopyroxene and clinopyroxene is anhedral, varies from 0.1 to 2.5 mm, exhibits exsolution lamellae, and is rimmed by deuteric hornblende and biotite. Quartz is anhedral and as large as 1.5 mm. Metamorphism is generally not apparent in these rocks, but deformation twins are apparent in feldspar and subgrains occur in quartz. The quartz diorite stock located north of Klopton Creek contains weakly foliated zones within it and, at its southern boundary, is well foliated where it is in contact with a well-foliated amphibolite (*JPam*). We interpret these textural relationships to indicate that the quartz diorite stock intruded relatively late in the deformation history of the Cougar Creek complex. This unit is equivalent to diorite and gabbro mapped on the White Bird quadrangle to the northeast (Garwood and others, 2008). Kurz (written commun., 2008) reports a Triassic U-Pb zircon age of 229.22 +/-0.45 Ma for one sample from this unit (sample CC-7-17-1 on map). We believe most or all of this unit is Triassic, but we cannot exclude the possibility of Cretaceous or Permian intrusions.

JPam **Amphibolite (Jurassic? to Permian)**—A band of gneissic amphibolite and quartz diorite crops out along the southeastern margin of the *KPdg* body in the southern part of the map. The rocks are black to dark gray and consist of as much as 70 percent blocky anhedral hornblende as large as 5 mm, subordinate anhedral plagioclase as long as 2 mm, and minor quartz. Texture is generally fine grained and completely recrystallized, but medium- to coarse-grained elongate lenses as thick as 10 cm are locally present. Gneissic compositional and grain-size segregation is locally developed, including <3 mm discontinuous plagioclase-rich bands. The rocks are pervasively foliated, and are relatively resistant to weathering, forming bold outcrops. Metamorphosed to amphibolite facies. Weathered rock produces a fine, dark soil. The amphibolite includes bands of leucosome that resemble the metatonalite unit described below, and that locally appear to intrude the amphibolite. Walker (1986) analyzed a sample from a structurally concordant quartzo-feldspathic layer within similar amphibolite gneiss located outside the map area to the south. Two zircon fractions from this sample yielded discordant data, giving an upper intercept Late Carboniferous (309 Ma) date interpreted to be the original crystallization age of the suspected plutonic protolith of the gneiss. Within the map area, the amphibolite is only found in contact with the diorite body (*KPdg*) and metatonalite (*Pmt*). The foliation in the amphibolite parallels the margin of the quartz diorite, and deformed diorite segregations are common within the amphibolite body; much of the deformation and metamorphism in the amphibolite also predates intrusion of the diorite. All of these characteristics suggest that the amphibolite represents an older gneissic unit that was intruded by the diorite. It also differs chemically from the diorite (Table 1). Relationship to the metatonalite is less certain because the contact is poorly exposed.

Pmt **Metatonalite (Permian)**—Light to medium gray rocks that occur as an intrusive package with varied composition and texture. Compositions range from hornblende(?) biotite tonalite with as much as 15 percent altered mafic minerals to leucocratic tonalite with less than 3 percent altered mafic minerals. At many outcrops, the metatonalite is intimately intermixed with greenstone (unit *₮Pgs* described below), and mutually cross-cutting relationships are apparent. Quartz composes 20 to 50 percent of the rock and occurs both as light gray to bluish phenocrysts as large as 1 cm that are locally resorbed and embayed and as a component of the groundmass. Altered plagioclase as much as 6 mm long composes from 40 to 80 percent of the rock and also occurs in the groundmass. Biotite and locally hornblende are present. Texture is generally medium grained and porphyritic, with locally occurring coarse-grained and fine-grained leucocratic varieties. The rocks are pervasively metamorphosed, with chlorite and epidote replacing most mafic minerals and plagioclase largely replaced by sericite. The metatonalite is locally foliated, and in places forms well-developed mylonites. South of the map area, this unit displays mylonite fabrics along the contact with *JPam*. The metatonalite could be a deeper-level equivalent to the quartz keratophyre rocks Vallier (1977) describes from the lowest exposed portion of the Hunsaker Creek Formation, or could be related to his quartz keratophyre-dominated Windy Ridge Formation, both of which consist of high silica quartz-porphyritic volcanogenic rocks.

₮Pgs **Fine-grained greenstone (Triassic? to Permian)**—Small area in southeast corner of map, where greenstone dominates over intermixed metatonalite (unit *Pmt*) with mutually cross-cutting relationships. Projected into the area from exposures mapped to the east that consist of light to dark gray-green, generally fine-grained rocks of mafic protolith, which locally display mediumm-grained and relict porphyritic textures. Pervasively metamorphosed to greenschist grade, with the groundmass and many crystals altered to chlorite, sericite, and epidote. Most of this unit appears to have been intrusive; however, some relict volcanosedimentary features, such as breccias and conglomerates, are locally present. Portions of this unit, if once sedimentary and volcanic rocks, could be equivalent to the Permian Hunsaker Creek Formation of Vallier (1977), which is composed primarily of mafic volcanic sands and silts.

STRUCTURE

The structural history of this area is complex and several episodes of faulting and folding are evident. Basement rocks of the Cougar Creek complex were initially modified by the formation of ductile shear zones. Later deformation included successive tilting of Triassic and Jurassic cover units to form angular unconformities with small bedding discordances. Folding and faulting are then evident with the formation of the Klopton Creek thrust and its associated fault splays. Finally, syn- to post-Miocene normal faulting is evident along the east edge of the map, although most of the basalt sequence has little deformation other than regional northwest tilting.

PRE-MIOCENE STRUCTURES

Triassic metavolcanic rocks of the Big Canyon Creek unit are overlain to the southeast by the Jurassic-Triassic volcanosedimentary sequence that includes the Kurry unit, mixed sedimentary and volcanic rocks, and the Coon Hollow Formation along a buttress unconformity. The volcanosedimentary sequence pinches out to the northwest and thickens dramatically to the southeast. The farthest southeast part of the map is underlain by older and originally deeper plutonic rocks of the Cougar Creek complex, which have been obliquely thrust westward over the metavolcanic-volcanosedimentary sequences along the northeast-striking Klopton Creek thrust.

Two major sets of pre-Miocene structures are apparent on the map: older, mostly ductile shear zones that occur in rocks of the Cougar Creek complex; and younger, complex faulting and folding associated with the brittle-ductile Klopton Creek thrust fault system. In the Cougar Creek complex, the older mylonite fabrics are developed in the elongate amphibolite body (*JPam*) in the southeast part of the map. Farther southwest, outside of the map area, metatonalite adjacent to the southeast contact with the amphibolite is also intensely mylonitized and joins a series of anastomosing mylonite belts that intersect the Snake River. We interpret the amphibolite body in the quadrangle as a recrystallized mylonite shear zone that is part of the same system exposed to the southwest. On the map, this belt is 0.2-0.4 mile wide and contains east-northeast-striking mylonite and gneissic foliation that parallels the outcrop trace of the belt and dips moderately to steeply south-southeast. Kinematics were not determined in the map area, but farther south along the continuation of this belt Kurz (2001) determined both oblique sinestral and dextral sense of shear on mylonite shear zones within the Cougar Creek complex. These zones contain a mylonitic foliation that strikes more northeasterly, dips steeply to moderately northwest and southeast, and contains a mostly shallowly to moderately southwest-plunging stretching lineation. Other regions of brittle-ductile deformation that do not appear to be associated with the later Klopton Creek thrust fault include exposures of intensely sheared quartz diorite along switchbacks in the road west of Pittsburg Saddle that are part of a north-northeast-striking high-angle shear zone. The age of these older shear zones has been constrained to the south. Walker (1986) obtained a U-Pb zircon age on a sample of the deformed Triangle Mountain pluton of ~246 Ma. Balcer (1980) determined $^{40}Ar/^{39}Ar$ hornblende and biotite ages of ~239-226 Ma from samples of the Cougar Creek complex. Thus, this period of deformation is loosely constrained to postdate 246 Ma intrusion of the Triangle Mountain pluton and, assuming that the biotite ages are at the lower temperature limit of ductile deformation, mostly predate the 226 Ma time at which biotite closure temperatures were attained (Kurz, 2001).

The younger Klopton Creek fold and thrust fault system (White and Vallier, 1994) is the dominant structure in the map area. The main strand of this fault system juxtaposes partially migmatized plutonic rocks of the Cougar Creek complex in the hanging wall with lower greenschist metamorphosed rocks of the Seven Devils Group and little-metamorphosed overlying Triassic? strata in the footwall. The structure does not deform the overlying Miocene Columbia River basalt sequence. Rocks in the 300- to 600-foott-wide fault zone are mylonites of mostly uncertain lithology even where the fault occurs at the margin of the *KPdg* unit. Protoliths in this zone appear to be quartz-rich metatonalite, diorite, and quartz diorite. Slivers of red and green phyllite, that in places appear to contain relict phenocrysts, also occur within the fault zone and form a distinctive "candystripe" rock. One of the best exposures of this lithology occurs where the fault zone intersects the southern border of the map along Klopton Creek. These rocks appear to be volcanic in origin, and we speculate that they may be part of the Seven Devils Group overlying the Cougar Creek complex. Fabrics in the fault zone include intensely developed mylonite overprinted by brittle shears. These fabrics are generally more brittle toward the footwall. Mylonite foliation strikes north to northeast, generally parallel to the strike of the fault, and dips moderately east to southeast; mylonite lineation pitches steeply in the foliation. Kinematic indicators, such as SC fabrics and extensional crenulations, consistently indicate top-to-the-northwest shear sense in a direction parallel to mylonitic lineation and consistent with a thrusting mechanism for development of fault rocks. A well-developed 300-foot amplitude overturned syncline with northwest vergence occurs in rocks of the Coon Hollow Formation in the footwall of the thrust, which corroborates a thrust mechanism for the fault. However, Kurz (2001) performed a fracture pattern analysis study in brittlely deformed zones of the Klopton Creek fault and determined a mean fault-slip vector plunging 39 degrees, S. 86° E. This implies a significant component of dextral strike-slip displacement for the thrust fault. An oblique-dextral thrust mechanism for the Klopton Creek fault explains the apparently large difference in structural level between footwall and hanging wall assemblages, because less throw is required if volcanosedimentary sequences in the footwall of the thrust originally occurred farther to the southwest of their present position. Significant oblique-dextral displacement on the order of tens of miles has also been determined for the northeastern continuation of the Klopton Creek fault system where it joins the Hammer Creek (Garwood and others, 2008) and Mount Idaho (Schmidt and others, 2007) fault segments.

A second thrust, the Kurry Creek thrust, that we believe merges with the Klopton Creek thrust at depth, also occurs in the Pittsburg Landing area. Stratigraphically lower parts of the Coon Hollow Formation in the hanging wall have been thrust northwest over stratigraphically higher parts in the footwall. Andesite sills and small stocks that intrude the Coon Hollow Formation appear to be restricted to the footwall of this fault. The fault generally strikes northeast and dips shallowly (20-40 degrees) to the southeast. Fault rocks include gouge and breccia. A subsidiary splay occurs in the hanging wall. Vertical separation along the Kurry Creek thrust, determined from the elevation of the *Jcc-Jcms* contact on either side of the fault, appears to be about 2,000 feet. However, as constrained from cross-section construction, displacement on this fault is more likely about 1,000 feet, because the *Jcc* unit in the hanging wall is not thick enough to permit 2,000 feet of vertical separation. It is thus apparent that the strata were likely not horizontal when this fault was active, and we speculate that some of the folding apparent in Coon Hollow Formation rocks occurred before this fault initiated. Later folding associated with this fault is complex and long-lived. A series of overturned footwall synclines and anticlines occurs along the Kurry Creek thrust and its subsidiary thrust. The thrust faults and their associated overturned folds have subsequently been folded by a series of shallowly northeast-plunging folds that in map view tighten and have shorter wavelengths in the vicinity of Kurry Creek, but open and lengthen in wavelength as they continue to both the southwest and northeast. The apparent constriction on the map where folds tighten near Kurry Creek coincides to the northwest with a protruding bend in the map trace of the buttress unconformity between rocks of the Triassic Big Canyon Creek unit and overlying younger units. We speculate that during the regional contraction that produced oblique thrusting and folding in the area, the Big Canyon Creek unit northeast of the buttress unconformity behaved as a semi-rigid mass, causing the younger and weaker rocks to form a keel-shaped body between the unconformity and rocks of the Cougar Creek complex to the southeast. The age of the Klopton Creek-Kurry Creek oblique-thrust system is broadly constrained to postdate deposition of the Jurassic marine unit (*Jcms*; presently constrained to Bajocian age or younger) and to predate Miocene basalt extrusion.

MIOCENE AND LATER STRUCTURES

Synbasalt and postbasalt structure in most of the quadrangle consists of regional tilting and minor faulting. From Grave Point to the north edge of the map, the basalt units have a fairly consistent northwesterly dip of 4 to 7 degrees. This attitude contrasts sharply with the underlying complexly folded and faulted pre-Tertiary accreted Wallowa terrane rocks. A minor northwest-trending fault, with several hundred feet of down-to-the-northeast displacement, cuts the basalt sequence on Camp Howard Ridge just south of Camp Howard cow camp. Along the eastern side of the quadrangle, however, a strongly curved major normal fault barely enters the map. This fault, which is part of a series of trough-shaped normal faults that occur in the Slate Creek quadrangle to the east, accommodated eastward hangingwall transport along the Salmon River extensional corridor.

Table 1. Major oxide and trace element chemistry of samples collected in the Grave Point quadrangle.

Sample number	Latitude	Longitude	Unit name	Map unit	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce	Th	Nd
					Major elements in weight percent										Trace elements in parts per million																	
08JK009	45.6751	-116.37965	R1 Grande Ronde Basalt	Tgr$_1$	54.41	2.580	13.88	12.00	0.222	3.90	7.79	3.22	1.61	0.389	5	11	32	370	567	41	346	218	37	14.0	21	30	130	7	28	47	4	28
08DG800	45.64305	-116.37783	R1 Grande Ronde Basalt	Tgr$_1$	53.22	2.262	14.01	12.05	0.223	5.09	8.80	2.85	1.17	0.319	23	64	33	323	487	26	338	182	32	12.2	21	47	123	8	26	45	5	27
08DS006	45.64502	-116.40524	quartz diorite	KPdg	52.69	0.793	19.03	9.63	0.207	4.80	9.45	3.03	0.31	0.062	0	8	35	333	144	3	346	19	13	0.0	19	22	83	0	1	3	0	5
08DS026	45.64024	-116.40803	quartz diorite	KPdg	51.99	0.835	19.28	9.78	0.218	4.59	9.75	3.11	0.26	0.177	0	4	34	323	132	3	381	16	14	0.0	19	33	96	0	3	5	0	5
08DS028	45.63032	-116.40315	amphibolite	JPam	50.95	0.970	16.31	9.58	0.195	8.31	10.53	2.79	0.23	0.139	101	325	40	298	59	3	205	52	22	1.0	13	58	68	0	4	15	0	10
08RL606	45.64702	-116.47001	rhyolite tuff	J₮sv	78.35	0.377	10.27	4.19	0.182	1.61	1.83	2.82	0.21	0.160	0	4	17	46	58	3	71	99	40	2.1	10	4	114	0	10	22	0	16
08RL622	45.67283	-116.4179	basaltic andesite dike	KPdm	53.13	0.637	19.06	9.38	0.187	6.27	9.45	1.80	0.04	0.034	21	36	32	283	59	1	323	16	6	0.0	15	110	66	0	5	3	0	4
07KS023	45.67729	-116.38306	metatonalite	Pmt	65.30	0.493	14.63	6.24	0.123	3.15	6.87	2.67	0.42	0.096	11	43	29	171	156	7	154	56	23	0.9	15	5	45	0	8	12	2	8

* Major elements are normalized on a volatile-free basis, with total Fe expressed as FeO.
All analyses performed at Washington State University GeoAnalytical Laboratory, Pullman, Washington.

SYMBOLS

- Contact: dashed where approximately located.
- Fault: bar and ball on downthrown side; dashed where inferred; dotted where concealed.
- Thrust fault: teeth on upper plate; dashed where inferred; dotted where concealed.
- Oblique thrust fault: teeth on upper plate; arrows indicate direction of motion; dashed where inferred; dotted where concealed.
- Fold axis: arrow indicates direction of plunge, dotted where concealed.
- Anticline.
- Syncline.
- Overturned anticline.
- Overturned syncline.
- 14 Strike and dip of bedding or volcanic flows.
- 10 Estimated strike and dip of bedding or volcanic flows.
- 42 Strike and dip of bedding known to be upright.
- Strike of vertical bedding.
- 70 Strike and dip of overturned bedding.
- 51 Strike and dip of bedding known to be overturned.
- 81 Strike and dip of foliation.
- Strike of vertical foliation.
- 30 Strike and dip of foliation that varies at outcrop scale.
- 65 Strike and dip of mylonitic foliation.
- 70 Strike and dip of cleavage.
- Strike of vertical cleavage.
- 29 Bearing and plunge of lineation, type unknown.
- 50 Bearing and plunge of mineral lineation.
- 15 Bearing and plunge of lineation in L tectonite.
- 15 Bearing and plunge of asymmetrical small fold showing counterclockwise rotation viewed down plunge.
- No fabric.
- Quartz vein.
- Breccia.
- Headwall scarp of landslide.
- 08JK057 Sample location and number.
- 08DS010 Fossil sample location and number.

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