GEOLOGIC MAP OF THE MISSOULA EAST 30' x 60' QUADRANGLE, WESTERN MONTANA

INTRODUCTION

The Montana Bureau of Mines and Geology (MBMG), in conjunction with the STATEMAP advisory committee, selected the Missoula East 30' x 60' quadrangle in western Montana (fig. 1) for mapping because: (1) the area lies astride the Lewis and Clark shear zone that has been a focus of recent MBMG studies (Lewis, 1998b; Lonn and McFaddan, 1999; Lonn and Smith, 2005, 2006; Lonn, 2007, 2008, 2009; Lonn and others, 2007); (2) it includes rapidly developing areas along the Interstate 90 corridor and in the Blackfoot River Valley. Completion of this map benefited from 3 years of detailed 1:24,000-scale STATEMAP-funded mapping (Lonn, 2007, 2008, 2009) within a structurally complex area of the Missoula East quadrangle.

STRATIGRAPHY

Mesoproterozoic Belt Supergroup sedimentary rocks underlie much of the area. The Belt stratigraphic section is as much as 4,900 meters thick, although erosion prior to deposition of the middle Cambrian Flathead Formation created a low-angle unconformity that cuts gradually downward through the Belt section from west to east. Paleozoic, Mesozoic, and Cenozoic sedimentary rocks overlie the Belt rocks. Plutons of mostly Cretaceous to early Tertiary age intrude the sedimentary rock, and Tertiary volcanic rocks cover some areas. The sediment-type terminology of Winston (1986b) is used for describing bed thickness and sedimentary structures in the Belt rocks.

STRUCTURE

The Lewis and Clark Line (LCL) which bisects the Missoula East quadrangle, divides much of western Montana into two major thrust slabs that experienced differential rotational movement (Sears and Hendrix, 2004) (Fig. 2). The two major components of the northern slab are the Libby allochthon to the west, and the Lewis-Eldorado-Hoadley (LEH) slab to the east. The two major components of the southern slab are the Sapphire allochthon to the west, and the Lombard allochthon to the east. The LEH slab and the Sapphire allochthon are the parts of the northern and southern slabs, respectively, which are within the Missoula East quadrangle. Sears and Hendrix (2004) proposed that differential rotational movement of the northern and southern thrust slabs drove sinistral transpression along the LCL, forming a flower structure. In their model, the LEH slab was carried northeastward by the underlying LEH thrust system clockwise about a Euler pole near Helena, while the slabs to the south, the Lombard and Sapphire allochthons, moved in a more easterly direction clockwise around a Euler pole in eastern Idaho. The left-lateral and compressive shear created by the slabs interactions formed the complex Cretaceous structures of the LCL (fig. 1). The LEH slab, LCL, and SA were also affected by Tertiary extension that superimposed faults that roughly parallel the earlier compressive structures in each domain.

LEH Slab

The LEH slab is composed of gently dipping sedimentary rocks that are in the hanging wall of the LEH thrust system located to the ENE. The LEH slab is cut by a number of WNW- to NW-striking Tertiary right-lateral normal faults; these faults control the locations of the Tertiary Potomac and Nevada valleys.

Lewis and Clark Line

The Missoula East quadrangle includes a segment of the LCL (Billingsley and Locke, 1941), a wide, 800-km-long, WNW-striking zone of faults and folds that transects the more northerly structural grain of the northern Rockies (fig. 2). Although the original definition of the line was based on geography controlled by Cenozoic strike-slip and normal faults rather than contractional features, most subsequent workers have concluded that Cretaceous compressive or transpressive structures are an important component of the LCL (Smith, 1965; Lorenz, 1984; Hyndman and others, 1988; Griffin, 1989; Wallace and others, 1990; Reid and others, 1993,1995; White, 1993; Yin and others, 1993; Yin and Oertel, 1995; Sears and Clements, 2000; Burmester and Lewis, 2003; Sears and Hendrix, 2004; Lonn and others, 2007). Subsequent Cenozoic extension and/or right-lateral shear (Hobbs and others, 1965; Reynolds, 1979; Harrison and others, 1974; Bennett and Venkatakrishnan, 1982; Sheriff and others, 1984; Winston, 1986a; Doughty and Sheriff, 1992; Yin and others, 1993; Yin and Oertel, 1995; Lonn and McFaddan, 1999; Lonn and others, 2007) superimposed high-angle normal and dextral faults that roughly parallel and obscure the compressional features.

The LCL appears to be a long-lived feature. It forms the southern boundaries of the Cretaceous Libby thrust belt and Late Cretaceous to Paleocene LEH slab, and the northern boundaries of the Mesoproterozoic Helena embayment of the Belt Basin, the Late Cretaceous SA, the Late Cretaceous to Paleocene Lombard allochthon, and the Eocene Bitterroot and Anaconda metamorphic core complexes (fig. 2).

Contractional structures of the LCL on the Missoula East quadrangle include zones of closely spaced, anastomosing reverse and normal faults, WNW- to NW-trending *en echelon* folds, and steep WNW-striking spaced cleavage. Sears and Hendrix (2004) interpreted the LCL as a Cretaceous flower structure that developed in response to sinistral transpression. In flower structures, material at depth is squeezed plastically upward along near-vertical ductile structures that fan outward and dip more gently at higher structural levels. Along this part of the LCL, five major WNW-striking reverse fault systems cross the Missoula East quadrangle: the Blackfoot, Bearmouth, Harvey Creek, North Woodchuck, and Ranch Creek fault zones. Each is a system of anastomosing south-dipping reverse and normal faults, and each contains fault-bounded lozenges or wedges of older strata caught between blocks of younger strata. A wedge of older rock is typically flanked by a south-dipping reverse fault on its north side and a sub-parallel, south-dipping normal fault to its south (fig. 3). This fault geometry is common along the LCL and it has been explained by extensional reactivation of pre-existing reverse faults (Lewis, 1998c; Lonn and others, 2007) or by out-of-sequence thrusting (Wallace, 1987; Lidke and others, 1988). However, this geometry may also result when a wedge of rock is extruded or extracted between two coeval faults with opposite shear sense (fig. 3) (Froitzheim and others, 2006) as has been proposed for western segments of the LCL (Wavra and others,1994; Reid and others, 1993, 1995; Lonn and others, 2007). In other words, these wedges may have been squeezed upward like bars of soap by horizontal contraction. Because most of the faults bounding these wedges dip SW and most associated folds verge NE, we interpret these wedges as "flowers" that droop to the northeast instead of standing straight up. If the LCL does represent a flower structure, then its faults converge with depth and die into zones of ductile deformation. Cross-section A-A' portrays this.

Although most researchers agree that left-lateral shear accompanied the Cretaceous compression, left-lateral faults are difficult to document in the quadrangle. This may be because the strike-slip movement was partitioned into narrow bands that have been obscured by the later Tertiary normal/dextral faults, or because the left-lateral movement was broadly distributed across the LCL as a zone of ductile shear expressed by the sets of NW-striking en echelon folds.

The WNW-striking transpressive structures are cut by steep N-S faults. Some of these are associated with N-S-trending overturned folds, suggesting that they too are reverse faults (Lonn, 2009).

Lastly, a series of WNW-trending normal and dextral faults cut and reactivated the earlier structures. These appear to have developed during Tertiary extensional tectonism, and are represented by the Clark Fork-Ninemile fault. Some normal faults parallel and have probably reactivated the Cretaceous reverse faults, resulting in map patterns that mimic those of the extraction faults described above, but that instead were formed by two superimposed tectonic regimes (Lewis, 1998c). Both Cretaceous shortening-induced normal faults and Tertiary extensional normal faults probably occur along the LCL. A right-lateral component to this Tertiary movement has also been documented along the LCL (Hobbs and others, 1965; Wallace and others, 1990; Lonn and McFaddan, 1999). The relationships of the right-lateral normal faults along the LCL to other Tertiary extensional structures, such as the Anaconda and Bitterroot metamorphic core complexes, are uncertain.

Sapphire Allochthon

The SA is a large thrust slab with significant eastward displacement estimated at 35 km (Lonn and others, 2003) to 60 km (Lidke and Wallace, 1998). The allochthon is characterized by areas of relatively undeformed rocks separated by complex anastomosing NNW-striking fault systems that are the curved southeastern extensions of the LCL fault zones, showing that the large eastward displacement on the SA is kinematically linked to the transpressive structures of the LCL. The major fault systems of the LCL curve southward to become components of the SA: (1) shortening on the Blackfoot thrust is accommodated by tight folds in Mesozoic sediments that bend southward ahead of the leading edge of the Sapphire allochthon; (2) the Harvey Creek fault zone curves southward to become the Georgetown-Philipsburg thrust system that bounds the SA, (3) the North Woodchuck system curves south into the Upper Willow Creek fault zone where it has been reactivated by Tertiary extension; and (4) the Ranch Creek fault zone curves southward into a complex zone partially covered by and probably associated with the Rock Creek volcanic field south of the map area (Lonn and others, 2003). The Bearmouth thrust is buried by volcanic rocks on its eastern end, but it seems likely that it joins the Georgetown-Philipsburg system (Fig 2).

Gently folded, bedding-parallel detachment faults that omit stratigraphic section are also common (and unexplained) on the SA. The Eightmile Creek fault is representative of this type of fault (see cross section A-A'). The youngest sinistral transpressive fault, the Ranch Creek fault, displaces the Eightmile Creek fault, demonstrating that the detachment faults are older than at least some of the transpressive structures.

An area of enigmatic west-verging folds and west-directed reverse faults occurs in the SE part of the area east of and beneath the SA. These are widespread in deep structural levels east of the SA, and are thought to be younger than 75 Ma because they fold both the Georgetown thrust and the detachment faults (Lonn and Lewis, 2009).

Tertiary extension reactivated some thrust faults, created new faults that cut older faults, and formed Tertiary valleys such as the upper Willow Creek Valley.

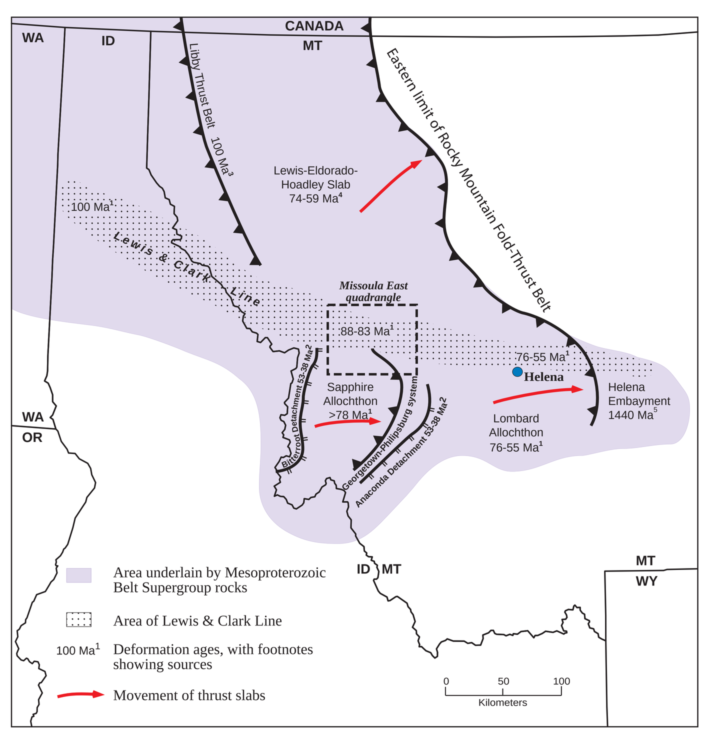


Figure 2. Location of Missoula East quadrangle with respect to major structural features of western Montana. Data sources: [1] Sears & Hendrix, 2004; [2] Foster and others, 2007; [3] Harrison and Cressman, 1993; [4] Sears, 2001; [5] Elston and others, 2002.

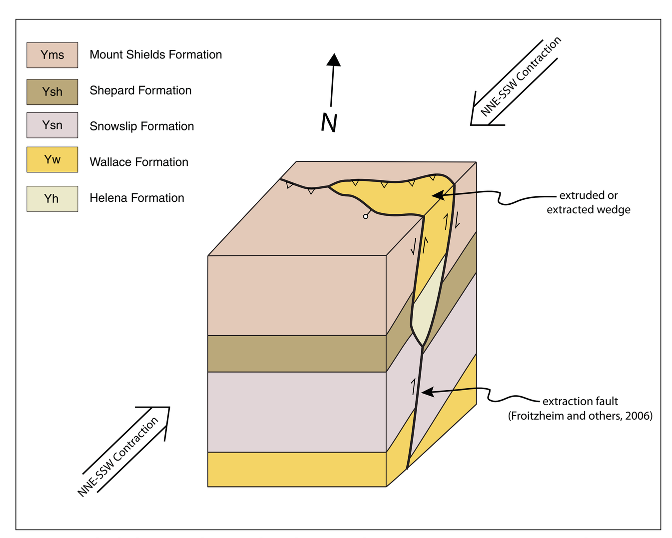
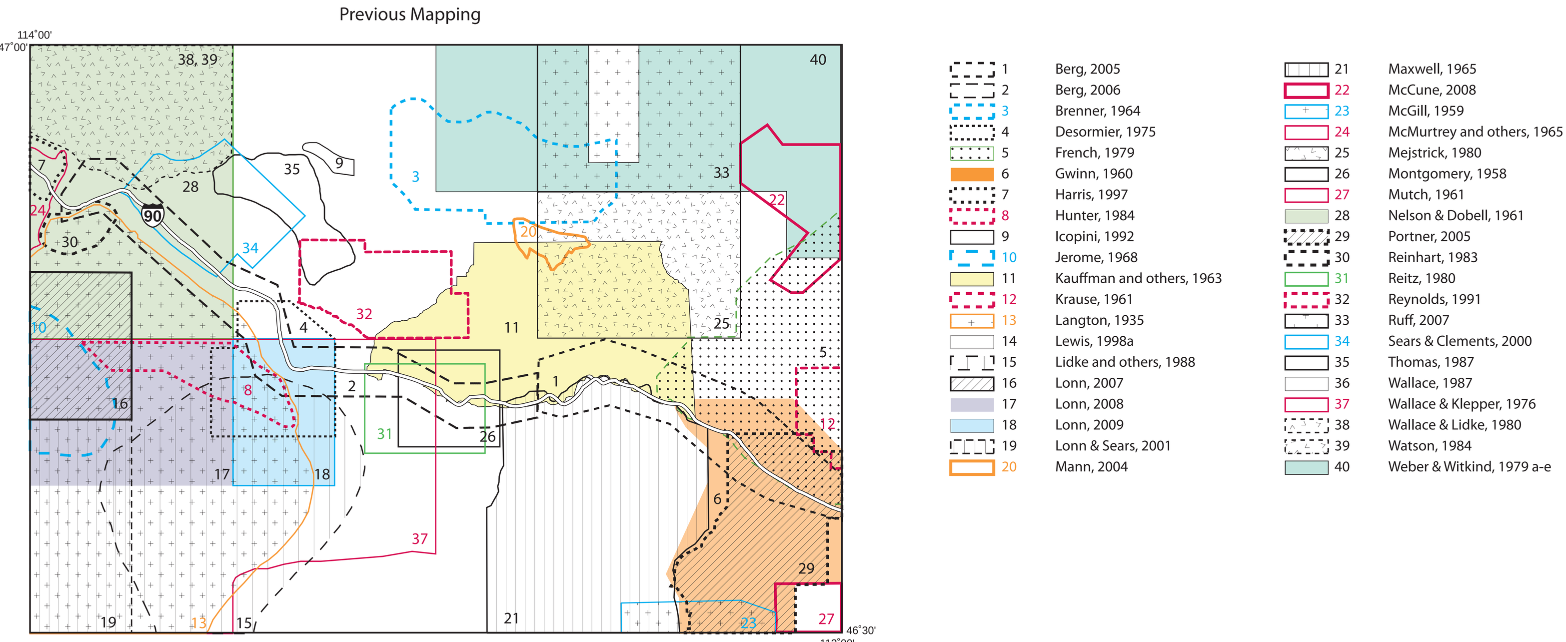


Figure 3. Block diagram showing how horizontal contraction can generate synchronous reverse and normal faults through an extrusion or extraction process. This type of normal fault has been termed a "shortening-induced normal fault" (Ring and Glodny, 2010). Modified from Reid and others (1995).

Previous Mapping



14, 36; entire map at 1:250,000-scale

Montana Bureau of Mines and Geology
Open File MBMG 593, Plate 2

Geologic Map of the Missoula East 30' x 60' Quadrangle, Western Montana

Jeffrey D. Lonn[1], Catherine McDonald[1], James W. Sears[2], and Larry N. Smith[3]

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[1]Montana Bureau of Mines and Geology; [2]University of Montana, Missoula; [3]Montana Tech of The University of Montana

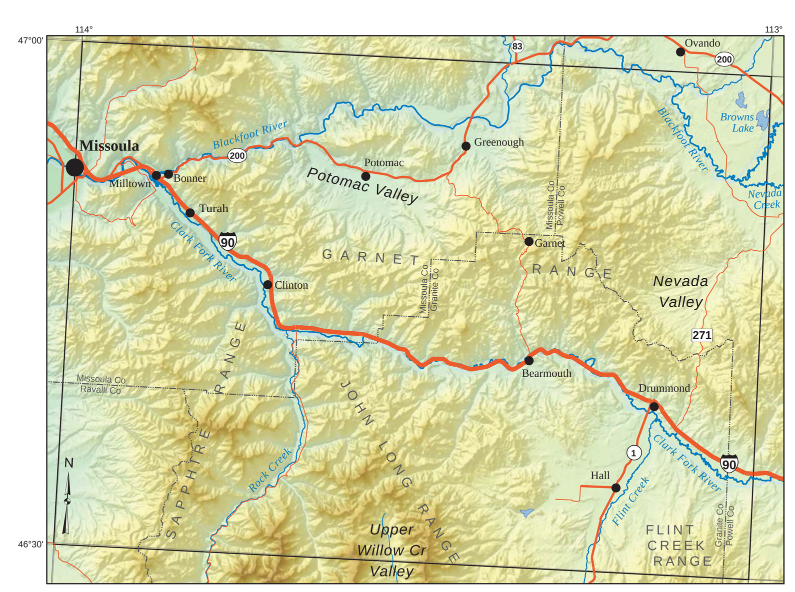

Figure 1. Location of major roads, streams, cities and valleys mentioned in the text.

UNIT DESCRIPTIONS

Qmd MAN-MADE DEPOSITS (HOLOCENE)
Mine dumps, mill tailings, placer mine spoils, and gravel pits. Thickness as much as 10 m.

Qal ALLUVIUM OF MODERN CHANNELS AND FLOODPLAINS (HOLOCENE)
Well- to moderately sorted gravel, sand, and minor silt along active stream channels and on modern floodplains. Thickness 0 to 12 m.

Qaf ALLUVIAL FAN DEPOSITS (HOLOCENE)
Poorly sorted gravel, sand, and silt in distinctly fan-shaped landforms at the mouths of drainages. Thickness as much as 30 m.

Qac ALLUVIUM AND COLLUVIUM (HOLOCENE)
Thin, unconsolidated slope wash and talus deposits and alluvial deposits along small drainages; gravel, sand, and silt. Thickness 2-8 m

Qat ALLUVIUM OF STREAM TERRACES (HOLOCENE AND PLEISTOCENE)
Well-sorted gravel and sand underlying flat benches perched above present river level. Thickness typically 1-10 m.

Qao OLDER ALLUVIUM OF TRIBUTARIES (HOLOCENE AND PLEISTOCENE)
Moderately sorted gravel, sand, and silt underlying benches perched above modern side streams. Typically not as well-sorted as Qat. Up to 10 m thick.

Qls LANDSLIDE DEPOSITS (HOLOCENE AND LATE PLEISTOCENE)
Unsorted mixtures of mud and angular boulders transported by mass movement down slopes; characterized by hummocky topography.

Qdf DEBRIS-FLOW DEPOSITS (HOLOCENE AND LATE PLEISTOCENE)
Poorly sorted subangular boulders, gravel, sand, and silt deposited in steep fans by debris flow processes.

Qlo LOESS DEPOSITS (HOLOCENE AND LATE PLEISTOCENE)
Unconsolidated, very fine- to very coarse grained, poorly sorted sand that lacks cement, includes some matrix-supported gravels (Portner, 2005).

Qgr GRAVEL DEPOSITS (PLEISTOCENE)
Poorly sorted pebbles, cobbles, and rare boulders in a fine-grained, clayey matrix. Deposits on hill slopes above present Clark Fork River flood plain. Forms boulder lag deposits in some areas.

Qgt GLACIAL TILL (PLEISTOCENE)
Unsorted boulders, gravel, sand, silt, and clay. Till makes up lateral and terminal moraines with irregular topography and internally drained associated basins. Thickness as much as 50 m.

Qgl GLACIAL LAKE DEPOSITS (PLEISTOCENE)
Grayish brown, light to dark yellowish brown, gravelly silt, light pink silt and sand, very fine grained sand in cyclic beds, and silty and clayey gravel. Forms flat surfaces. Thickness typically 10-13 m.

Qglf GLACIAL FLOOD DEPOSITS (PLEISTOCENE)
Stratified bouldery gravel, minor sand, and local 12-50-cm-thick interbeds of laminated silty clay and very fine grained sand. Contains large-scale cross beds, as much as tens of meters high. Deposited during the catastrophic draining of Glacial Lake Missoula. Thickness typically about 12 m.

Qgo GLACIAL OUTWASH DEPOSITS (PLEISTOCENE)
Moderately to well-sorted cobble gravel, sand, and silt on dissected terraces and braid plains or in perched valleys. Surfaces are as much as 75 m above modern streams. Thickness 5-25 m.

Qgk GLACIAL KAME AND ESKER DEPOSITS (PLEISTOCENE)
Moderately to well-sorted, sub-rounded to well-rounded, cross-bedded gravel, sand, pebbles, and boulders deposited by streams flowing within, on, and marginal to glaciers. Thickness as much as 50 m.

QTs GRAVEL (PLEISTOCENE OR TERTIARY)
Moderately sorted, well-to sub-rounded, boulder to cobble gravel that forms a thin veneer less than 10 m thick on older units.

QTaf ALLUVIAL FAN DEPOSITS (PLEISTOCENE OR TERTIARY)
Poorly to well-sorted, rounded to sub-angular boulders, cobbles, sand, silt, and clay. Surfaces of these deposits have a distinct fan shape that is more than 15 m above modern deposits.

Ts SEDIMENTARY ROCKS, UNDIVIDED (TERTIARY)

Tsu SEDIMENTARY ROCKS, UPPER MEMBER, INFORMAL (PLIOCENE AND MIOCENE?)
Poorly to moderately sorted conglomerate containing locally derived subangular to subrounded boulders and cobbles in a silty matrix. Probably correlative with the Sixmile Creek Formation. Thickness usually less than 10 m.

Tsl SEDIMENTARY ROCKS, LOWER MEMBER, INFORMAL (MIOCENE AND OLIGOCENE?)
Mostly white to light gray clay and silt deposited in fluvial and lacustrine environments. Probably correlative with the Renova Formation. Thickness unknown, but as much as 50 m exposed.

Tr RHYOLITE AND TUFFACEOUS SEDIMENT (TERTIARY)
White to tan to pink, fine-grained rhyolite often with distinctive small (< 3 mm) black quartz or smaller sanidine phenocrysts. Tuffaceous beds occur within the rhyolite flows. A potassium-argon date on sanidine from near Bearmouth yielded an age of 44.5 ± 2.0 Ma (Williams and others, 1976).

Tab ANDESITE AND BASALT (TERTIARY)
Andesite and basalt flows.

Tl LATITE (TERTIARY)
Dark gray green, porphyritic latite with plagioclase phenocrysts.

Td DACITE (TERTIARY)
Porphyritic dacite and rhyodacite containing plagioclase, biotite, and hornblende phenocrysts. Occurs as both flows and dikes (Reitz, 1980).

Tgd GRANODIORITE (TERTIARY)
Coarse-grained, hornblende-biotite granodiorite. Includes the 48 Ma Clinton stock (Reynolds, 1991) and granodiorite that grades into Tertiary dacite porphyry (Reitz, 1980).

TKgd GRANODIORITE AND GABBRO, UNDIVIDED (TERTIARY OR CRETACEOUS)
Fine- to medium-grained, equigranular biotite-hornblende granodiorite. Contains some gabbroic phases that were not mapped separately. Occurs both as dikes along fault zones of Late Cretaceous to early Tertiary age, and in stocks and plutons in the western part of the map area.

TKgb GABBRO AND DIORITE (TERTIARY OR CRETACEOUS)
Dark weathering, fine-grained gabbro and diorite. In hand sample, difficult to distinguish from unit TKgd. Occurs in small stocks, in dikes, and as a phase within TKgd.

TKt TRACHYTE (TERTIARY OR CRETACEOUS)
Porphyritic trachyte containing plagioclase, biotite, and quartz phenocrysts (Brenner, 1964). Occurs in small stocks.

TKl LAMPROPHYRE (TERTIARY OR CRETACEOUS)
Dark weathering, fine-grained, olivine-pyroxene-rich lamprophyre in a pluton in the northeastern part of the map area (Brenner, 1964).

Kgd GRANODIORITE (CRETACEOUS)
Light gray, hornblende-biotite granodiorite of the Garnet Stock and outliers. Stock has a U-Pb crystallization age of 83 Ma (Sears and Hendrix, 2004).

Ki INTRUSIVE ROCKS, ALKALIC (CRETACEOUS)
Alkalic igneous sills highly weathered to a medium grus. Commonly found along the Blackleaf Fm-Coberly Fm contact and folded along parallel sedimentary bedding planes (Portner, 2005). Age approximately 65 Ma (Sears and others, 2000).

Kcc CARTER CREEK FORMATION (UPPER CRETACEOUS)—Tan to gray and gray green sandstone, siltstone, shale and siliceous mudstones. Basal sandstones are thin-bedded to massive with shaly partings, abundant oyster shells, and some chert pebbles. Interbedded siliceous volcanic-rich beds are common in upper 460 m of formation. On the west limb of the Gold Creek syncline, volcanic-rich interval includes nonfossiliferous, very calcareous, lenticular, variegated beds, some very coarse-grained. On east limb, this interval is characterized by only a few beds of gray green and red gray siltstones and sandstone with some brackish water fossils. Thickness 610-762 m (Gwinn, 1960).

Kj JENS FORMATION (UPPER CRETACEOUS)—Lower part is dark gray to olive, fissile shale and siltstone with minor sandstone and limestone. Middle part is variegated tan, gray, reddish, purplish, and greenish volcanic-rich, siliceous sandstone, siltstone, and silty mudstone. Upper part is predominantly medium gray to tan shale with subordinate thin calcareous beds. Beds are commonly bioturbated but formation is generally unfossiliferous. Thickness as much as 460 m (Gwinn, 1960).

Kc COBERLY FORMATION (UPPER CRETACEOUS)—Predominantly tan, calcareous sandstone with subordinate variegated greenish brown mudstone and siltstone, locally shaly lignite, gray to black, fossiliferous limestone, and sandy coquina. Sandstone has abundant chert and quartz grains giving it a "salt and pepper" appearance. The sandstones in the Coberly differ markedly from sandstones in the Blackleaf and Jens Formations in that they contain much less volcanic detritus and are always calcareous. Limestone beds are dark grayish brown with abundant large gastropods, pelecypods, and oyster coquinas. Thickness as much as 198 m (Gwinn, 1960).

Kbv VAUGHN MEMBER OF BLACKLEAF FORMATION (UPPER AND LOWER CRETACEOUS)—Interbedded grayish green, gray and dark gray tuffs, volcanic and non-volcanic mudstone, siltstone, chert and lithic rich (salt and pepper) sandstone, and several thick conglomerate beds. Abundant light gray, white, and tan porcellanite and siliceous siltstone beds formed from alteration and silicification of the volcanic-rich strata form distinct horizons. Originally mapped as the Dunkleberg Formation by Gwinn (1960). Thickness approximately 460-518 m.

Kbt TAFT HILL MEMBER OF BLACKLEAF FORMATION (LOWER CRETACEOUS)—Lower part is tan to light gray, calcareous, cross-bedded sandstone in gradational contact with dark shale of underlying Flood Member. Upper part is calcareous sandstone, gray to green siltstone and mudstone with lenticular volcanic-rich beds in upper 60 m. Thickness 275-305 m (Gwinn, 1960).

Kbf FLOOD MEMBER OF BLACKLEAF FORMATION (LOWER CRETACEOUS)—Upper part is dark gray to black, noncalcareous, fissile shale with minor thin beds of carbonaceous siltstone and fine-grained, calcareous, ripple-bedded sandstone. Lower part is tan, gray, and yellow brown, often iron-oxide stained, sandy limestone, siltstone, and minor fine-grained sandstone. Sandstone commonly bioturbated with some pelecypod fragments. Upper and lower contacts are gradational. Thickness of upper part approximately 137-152 m; lower part as much as 72 m (Gwinn, 1960).

Kk KOOTENAI FORMATION, UNDIVIDED (UPPER CRETACEOUS)—Predominantly variegated mudstone and siltstone with limestone intervals. Four informal members are recognizable (Kauffman and Earll, 1963). Upper calcareous member is gray, fine- to medium-crystalline limestone with minor interbedded shale, siltstone, and sandstone. Top is marked by the widespread and well-known "gastropod limestone" consisting of 2 to 3 beds of dark brown to dark gray, coarsely crystalline limestone composed almost entirely of gastropod shells. Underlying upper clastic member is green, gray, and maroon siltstone and shale with a few thin calcareous "salt and pepper" sandstone and limestone beds, including a distinctive flat-pebble limestone conglomerate. Lower calcareous member is interbedded dark gray to black, very fine grained limestone, maroon, green, and gray shale and siltstone, and occasional beds of calcareous concretions as much as 1 m across. Lower clastic member is maroon and gray sandstone interbedded with minor shale and siltstone. Base of Kootenai typically marked by lenticular beds of red-brown to gray conglomerate with pebbles and cobbles of black chert and white quartz or hard, silica-cemented vitreous sandstone with distinct red jasper grains (Kauffman and Earll, 1963). Total thickness 275-305 m.

Jm MORRISON FORMATION (UPPER JURASSIC) AND ELLIS GROUP (UPPER AND MIDDLE JURASSIC), UNDIVIDED

MORRISON FORMATION—Poorly exposed olive green, gray to grayish green mudstone, shale, siltstone and minor sandstone. Siltstone near base is calcareous and flaggy bedded. Dense, "salt and pepper" sandstone and minor concretionary limestone in upper part. Contact with Flathead Formation difficult to locate. Thickness varies from 0 m in the east to 360 m in the west.

ELLIS GROUP—Swift Formation–Upper part is brown to yellowish brown, often calcareous and glauconitic, "salt and pepper" sandstone with interbedded siltstone and micaceous shale. Basal sandstone contains lenses of black chert pebble conglomerate. Minor fossils including oyster, belemnite, and wood fragments. Thickness 35-75 m (Kauffman and Earll, 1963). Rierdon Formation–Dark brownish gray to dark gray calcareous shale, shaly limestone and limestone. Shales weather yellowish gray or whitish gray. Fossil fragments and ripple marks are common on bedding planes. Base is marked by brown, oolitic or sandy limestone beds which characteristically weather to a gritty surface. Thickness 18-23 m (Kauffman and Earll, 1963). Sawtooth Formation–Lower part is dark gray to black, fossiliferous, calcareous buff-weathering siltstone, middle part is very calcareous dark gray shale or argillaceous limestone that weathers creamy white, upper part is interbedded calcareous shale, siltstone, and limestone. Estimated thickness as much as 75 m.

PMpa PHOSPHORIA, QUADRANT, AND AMSDEN FORMATIONS, UNDIVIDED (PERMIAN THROUGH MISSISSIPPIAN)

PHOSPHORIA FORMATION (PERMIAN)—Poorly exposed, fine- to medium-grained, white to tan and gray, laterally discontinuous quartzite, fine-grained sandstone with minute phosphate(?) grains, and silty dolomite with ribbons and lenses of black chert. Estimated thickness 0-85 m (Kauffman and Earll, 1963).

QUADRANT FORMATION (PENNSYLVANIAN)—Grayish orange to light gray, massive to irregularly bedded, vitreous quartzite with minor, poorly exposed thin, dolomitic beds at base. Forms resistant ridges, weathers reddish brown, coated with green and black lichen. Thickness about 43 m (Kauffman and Earll, 1963).

AMSDEN FORMATION (PENNSYLVANIAN AND MISSISSIPPIAN)—Upper part is poorly exposed, reddish brown, grayish orange, and grayish yellow dolomite and limestone with a thin zone of pebble conglomerate near top; lower part is moderate reddish brown calcareous siltstone, fine-grained sandstone, and shale. Often weathers with light tan spots. Formation is poorly exposed and usually marked by reddish soil or a recessive interval between underlying Madison Limestone and overlying Quadrant Formation. Thickness 57-92 m (Schneider, 1988; Kauffman and Earll, 1963).

Mm MADISON GROUP, UNDIVIDED (UPPER AND LOWER MISSISSIPPIAN)

LODGEPOLE FORMATION—Dark gray, fossiliferous, thin-bedded limestone and silty limestone. Abundant interbeds of dark gray to black chert nodules, ribbons and beds, especially in lower part of formation. Upper part is more fossiliferous with thicker beds and some breccia. Weathers light to medium gray. Thickness as much as 267 meters (Schneider, 1988; Kauffman and Earll, 1963).

MISSION CANYON FORMATION—Upper part is light to medium gray limestone breccia with interbedded medium-bedded limestone and dolomitic limestone. Breccias contain angular limestone and siltstone clasts in an orange- and red-stained matrix. Lower part is light to dark gray, partly cherty, medium- to very thick bedded limestone and minor dolomite. Commonly very fossiliferous and oolitic. Weathers medium to light gray. Thickness approximately 252 m (Schneider, 1988; Kauffman and Earll, 1963).

MDs THREE FORKS, JEFFERSON, AND MAYWOOD FORMATIONS, UNDIVIDED (MISSISSIPPIAN AND DEVONIAN)

THREE FORKS FORMATION (LOWER MISSISSIPPIAN AND UPPER DEVONIAN)—Siltstone and sandstone; micritic limestone, and local lenses of limestone breccia. Siltstones and sandstones are moderate reddish orange, flaggy bedded, calcareous, with angular gypsum casts on surfaces. Limestone is wavy laminated and weathers grayish pink to grayish yellow, often with moderate reddish orange stain and smooth surfaces. Poorly exposed; recognized by reddish soil and float. Estimated thickness 123 m.

Dj JEFFERSON FORMATION (UPPER DEVONIAN)—Upper limestone member (approximately 245 m thick) is light to dark gray and gray brown, thick-bedded to massive, often brecciated, with poorly preserved fossils. Middle dolomite member (92 m thick) is dark gray, gray brown to black, saccharoidal with a strong petroliferous fetid odor. Lower limestone and dolomite member (183 m thick) is dark gray, fairly strong petroliferous odor, finely crystalline, thin- to thick-bedded, with abundant tan buff or orange yellow stringers and mottling. Stromotoporoidal structures (rounded, concentrically banded algal heads, tubular calcareous algae that weather white or pale orange) are fairly common. Total thickness approximately 520 meters (Kauffman and Earll, 1963).

Dm MAYWOOD FORMATION (UPPER AND MIDDLE DEVONIAN)—Thin-bedded gray, reddish gray, and yellow dolomitic shale and siltstone, silty dolomite, and sparse gray limestone. Upper part contains minor quartzite and dark dolomite beds. Thickness approximately 112 m (Kauffman and Earll, 1963).

Cs SEDIMENTARY ROCKS, UNDIVIDED (MIDDLE CAMBRIAN)—Includes Red Lion, Hasmark, Silver Hill, and Flathead Formations. Near the Garnet Stock, formations metamorphosed to marble, calc-silicates, hornfels, and quartzite.

Crl RED LION FORMATION (MIDDLE CAMBRIAN)—Lower part consists of red, reddish brown, and yellowish brown siltstone and shale, some calcareous, with locally abundant trace fossils. Upper part is light to dark gray micritic limestone with interbedded, discontinuous, thin argillite layers. The argillite stands in relief on weathered surfaces and imparts a wavy, ribbon-like structure to the bedding. Flat-pebble conglomerates, and mottled beds due to burrowing are relatively common. Weathered argillite surfaces often display distinct grayish red and pale red Liesegang banding. Thickness approximately 110 m (Kauffman and Earll, 1963).

Crh RED LION AND HASMARK FORMATIONS, UNDIVIDED

Crhs RED LION, HASMARK, AND SILVER HILL FORMATIONS, UNDIVIDED

Ch HASMARK FORMATION (MIDDLE CAMBRIAN)—Light to medium dark gray, thin to very thickly bedded limestone, magnesium limestone, and dolomite with subordinate calcareous grayish orange and olive green shale. Shale typically separates lower limestone interval from upper dolomite interval and locally contains abundant well-preserved small black brachiopods. Limestone beds are typically massive or laminated with rare oncolites and chert, weathers very light gray to light and dark gray mottled. Laminations visible on weathered surfaces of dolomite beds. Equivalent to Pilgrim, Park, and Meagher Formations mapped by Mann (2004) in the area south of the Garnet Stock. Thickness 365-550 m (Kauffman, 1963).

Csh SILVER HILL FORMATION (MIDDLE CAMBRIAN)—Lower part is poorly exposed, light olive to grayish green micaceous fissile shale with reddish argillite and quartzite near base. Upper part is thin-bedded, medium gray limestone with siliceous wavy laminae that weather reddish brown and stand in relief on weathered surfaces. Beds with oncolites and fossil fragments are fairly common, float typically weathers medium to dark gray with grayish yellow to gold mottling. Thickness as much as 122 m (Kauffman, 1963).

Cshf SILVER HILL AND FLATHEAD FORMATIONS, UNDIVIDED

Cf FLATHEAD FORMATION (MIDDLE CAMBRIAN)—White to pale red, fine- to coarse-grained, friable sandstone and orthoquartzite, locally conglomeratic, cross bedded, and often stained with limonite. Near contact with overlying Silver Hill Formation, dark red argillite, often with abundant trace fossils, is interbedded with thin quartzite beds. Thickness is variable, ranging from discontinuous remnants in the Garnet Range to sections as much as 120 m thick in southeast part of quadrangle (Kauffman and Earll, 1963; McGill, 1959).

Ygb GABBRO AND DIORITE (NEOPROTEROZOIC)
Dark-colored gabbro and diorite sills with diabasic texture. Age based on K-Ar isochronology of a similar sill near Alberton (Obradovich and Peterman, 1968).

Yp PILCHER FORMATION (MESOPROTEROZOIC)
Medium- to coarse-grained, vitreous to feldspathic quartzite with distinctive alternating purple and light gray, trough cross-laminae. Upper contact with Flathead Formation difficult to locate. Thickness varies from 0 m in the east to 360 m in the west.

Ygr GARNET RANGE FORMATION (MESOPROTEROZOIC)
Rusty-brown to yellow weathering, greenish gray, micaceous, hummocky cross-stratified, fine-grained quartzite with olive green to black argillite interbeds. Distinguished by rusty yellow weathered surfaces and abundant detrital mica. Thickness varies from 0 m in the southeast to 1,170 m in the northwest.

Ym McNAMARA FORMATION (MESOPROTEROZOIC)
Dense, interbedded green and red siltite and argillite in micro-laminae and couplets. Mudcracks common. Contains diagnostic thin chert beds and chert rip-up clasts. Coarser grained in the southeast, containing beds of flat-laminated and cross-bedded, fine- to medium-grained quartzite as much as 25 cm thick. Thickness varies from 470 m in the southeast to 1,230 m in the northwest.

Ybo BONNER FORMATION (MESOPROTEROZOIC)
Pink, medium- to coarse-grained feldspathic, crossbedded quartzite. Contains some granule-size grains, and locally includes micaceous, maroon argillite interbeds. Thickness 492 m.

Yms MOUNT SHIELDS FORMATION, UNDIVIDED (MESOPROTEROZOIC)
Includes members 2 and 3; member 1 not mapped.

Yms3 MOUNT SHIELDS FORMATION, MEMBER 3, (MESOPROTEROZOIC)
Red quartzite to argillite couplets and couplets with abundant mud cracks, mud chips, and diagenetic, well-formed, cubic salt casts. Includes green interbeds, and some red microlaminae. Thickness 615-1,046 m.

Yms2 MOUNT SHIELDS FORMATION, MEMBER 2, (MESOPROTEROZOIC)
Pink to gray, flat-laminated to cross-bedded, fine- to medium-grained quartzite. Contains beds of tan-weathering dolomitic cement. Crossbedded intervals are difficult to distinguish from the Bonner Formation. Thickness 1,015 m.

Ysh SHEPARD FORMATION (MIDDLE PROTEROZOIC)
Dolomitic and non-dolomitic, dark green siltite and light green argillite in microlaminae and couplets, and lenticular couplets of white quartzite and green siltite. Poorly exposed, but weathers into thin plates. Dolomitic beds have a characteristic orange-brown weathering rind. Ripples and load casts are common; mudcracks are rare. Thickness 185-307 m.

Ysn SNOWSLIP FORMATION (MIDDLE PROTEROZOIC)
Interbedded intervals of quartzite to red argillite couplets and couplets, and dark green siltite to light green argillite couplets. Desiccation cracks, mud rip-up clasts, and bumps that mimic trace fossils but are probably incipient salt casts are common. Contains diagnostic beds and lenses of well-sorted, well-rounded, quartz-rich, white quartzite. Thickness 923-1100 m.

Yw WALLACE FORMATION (MESOPROTEROZOIC)
Distinctive black and tan, pinch-and-swell couplets and couplets composed of tan weathering, dolomitic, and hummocky cross-stratified quartzite and siltite grading up to black argillite. The quartzite/siltite beds commonly have scoured bases. Load casts, molar-tooth structure, and non-polygonal crinkle cracks are common. Bottom of section not exposed; Thickness at least 1,000 m.

Ywb WALLACE FORMATION, BRECCIA MEMBER, (MESOPROTEROZOIC)
Angular clasts of white, fine-grained quartzite and pinch-and-swell couplets in an orange-weathering, dolomitic and calcitic matrix. Clasts range from 1 cm to 1 m in diameter. Possibly formed by slumping of partially lithified sediments, although in the study area this unit is found only along the Eightmile Creek fault, so a tectonic origin cannot be ruled out. Thickness unknown.

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