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Geologic Map of the Canyon Ferry Dam 30´× 60´ Quadrangle, West-Central Montana

By Mitchell W. Reynolds and Theodore R. Brandt

Canyon of the Missouri River above the Gates of the Rocky Mountains is incised through beds of the Upper and Lower Mississippian Mission Canyon Formation (Mm). *On July 19, 1805, the Lewis and Clark expedition named the Gates of the Rocky Mountains, as the cliffs first appeared as a closed gate, then appeared to open as expedition boats changed course approaching the canyon mouth. Mann Gulch is the site of the infamous forest fire that took the lives of 13 U.S. Forest Service fire fighters in August 1949. View is north-northeast toward the Adel Mountains from Upper Holter Lake in the northwest corner of the Canyon Ferry Dam quadrangle. Unit labels as on map explanation.*

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Pamphlet to accompany
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Contents

Conversion Factors

To convert	Multiply by	To obtain
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
square kilometer (km^2)	0.3861	square mile (mi^2)

Discussion

Introduction

The Canyon Ferry Dam quadrangle, scale 1:100,000, in west-central Montana, lies at the junction of four major tectonic elements: the Lewis and Clark tectonic zone, the Montana disturbed belt, the Boulder batholith and related intrusive bodies, and the continental autochthon (figs. 1 and 2, sheet 1). Basin and range structures overprint those tectonic elements. The quadrangle encompasses about 4,200 km^2 in the northeastern part of the northern Rocky Mountains. Four mountain ranges dominate the map area: the Big Belt Mountains, which form the northwest-trending high backbone across the west-central part of the map area; the Elkhorn Mountains in the southwest corner; the west end of the Little Belt Mountains in the northeast corner; and the Adel Mountains in the northwest corner (fig. 1, sheet 1). Boulder Baldy, the highest peak in the Big Belt Mountains is 2,726 m high, and Woods Mountain in the western Little Belt Mountains is 2,294 m high. Local relief is as much as 1,065 m in the Big Belt Mountains (fig. 3, sheet 2, and Boulder Baldy area), and 800 m in the Tenderfoot Creek area (T. 14 N., R. 5 E.) of the Little Belt Mountains. Helena Valley and the north end of Townsend Valley lie west of the Big Belt Mountains, and the north end of the Smith River Valley lies east of those mountains (fig. 1, sheet 1).

Drainage west from the crest of the Big Belt Mountains, from the Elkhorn Mountains, and from the western part of the Adel Mountains is to the Missouri River, which flows north-northwest across the western part of the quadrangle. Drainage east from the crest and from the Little Belt Mountains is to the Smith River, which flows north across the eastern part of the quadrangle. The Missouri River is dammed from south to north to form successively Canyon Ferry Lake, Hauser Lake, and Upper Holter and Holter Lakes. Northwest of Canyon Ferry, meanders of the Missouri River are deeply incised through the northwest end of the Big Belt Mountains (see map jacket). Similarly, about 48 km directly east of the meandering reach of the Missouri River, meanders of the north-flowing Smith River are incised through the west end of the Little Belt Mountains and bedrock ridges south of those mountains (fig. 7, sheet 2). The lowest elevation in the quadrangle is 1,090 m where the Missouri River leaves the quadrangle (sec. 9, T. 14 N., R. 3 W.); by comparison, the Smith River flows from the quadrangle at an elevation of 1,208 m (sec. 6, T. 14 N., R. 4 E.).

Helena, the State capital city, lies adjacent to the west-southwest edge of the quadrangle; the communities of East Helena, Canyon Ferry, and York are the main settlements within the quadrangle, all in the southwestern part. Urban growth is expanding rapidly across the south flank of Helena Valley, north, east, and southeast of East Helena. Similar growth is occurring across the north flank of the valley, west-northwest of Lake Helena. Principal transportation routes include U.S. highways 12-287 and Interstate 15 in the southwest corner of the map area. State road 360 (mostly unpaved) and unpaved county roads serve the eastern part of the quadrangle.

The geologic map was made as part of the Montana Investigations Project to provide new information on the stratigraphy, structure, and geologic history of the geologically complex area. Because of the geologic complexity, number of geologic units mapped, and detail mainly of new information gathered, the geology is presented in three formats. Sheet 1 contains the geologic map, structure sections, correlation and list of map units, and index to major sources of geologic information incorporated on the map. Sheet 2 displays the geology on a base of shaded topographic relief, supplemented with selected color photographs, in order to aid interpretation of relations between geology and physiography and to enhance the understanding of the geology by visitors to an area known for its scenic beauty (map jacket; figs. 3, 4, 7, and 8), for its historic significance (pamphlet cover), and for its well-exposed spectacular geologic structure (figs. 3–8). The tectonic map (fig. 2) on sheets 1–3 presents an interpretation of relations among tectonic elements in the area. Sheet 3 emphasizes the principal geologic structures and provides selected structural point data, including dips and strikes of stratified rocks, layering in igneous rocks, and foliation or layering in metamorphic rocks, in context of the regional geology.

Geologic Units

Rocks and sediments in the Canyon Ferry Dam quadrangle are assigned to 129 map units, described in the "Description of Map Units" section, on the basis of rock or sediment type and age. The discussion here only highlights stratigraphic relations among some strata and clarifies age designations or nomenclature for other units.

Paleoproterozoic units are metamorphic crystalline rocks, including mainly granite gneiss and three other locally restricted units of metasedimentary, metavolcanic, or sodic metaintrusive origin. These rocks are part of the continental autochthon, exposed in the northeast quarter of the quadrangle, which plunges west under the southeast terminus of the Montana disturbed belt (fig. 2, sheets 1–3). None of the units within the map area has been dated radiometrically, but in the Neihart and Sheep Creek areas of the White Sulphur Springs 1:100,000-scale quadrangle that adjoins the Canyon Ferry Dam quadrangle on the east, Vogl and others (2004, p. 20, 30) reported a maximum age of about 1,810 Ma for rocks equivalent to the granite gneiss and ages ranging from about 1,867 to 1,842 Ma for older metamorphic rocks of the area.

A thick succession of strata of Mesoproterozoic age in six formations in the Belt Supergroup includes the lowest strata of the supergroup known in the eastern part of the Belt depositional basin. Within the Canyon Ferry Dam quadrangle, the Belt Supergroup is everywhere faulted against the Paleoproterozoic metamorphic rocks (secs. 31, 32, T. 12 N., R. 6 E.) along a high-angle fault or, across the north-central and west edge of the quadrangle, is faulted against Phanerozoic sedimentary rocks along high-angle or thrust faults. The Neihart Quartzite, lowest stratigraphic unit included in the supergroup, is exposed only in very thin structural slices between Paleoproterozoic granite gneiss and strata of the Newland Formation in secs. 31 and 32, T. 12 N., R. 6 E., although it crops out more widely northeast of the quadrangle. The Newland Formation is structurally truncated from bottom to top, southeast to northwest, by the Moors Mountain thrust fault, and is not known from either surface outcrop or drill core northwest of sec. 7, T. 12 N., R. 1 W. The Spokane Formation is truncated by post-Mesoproterozoic–pre-Middle Cambrian erosion in successively higher thrust plates along a west-northwest-trending line from sec. 14, T. 11 N., R. 4 E. to sec. 3, T. 12 N., R. 2 W. That line of truncation is within, and approximately parallel to, the trend of the Lewis and Clark tectonic zone (fig. 2, sheets 1–3). The stratigraphically highest exposed formations of the Belt Supergroup (Empire and Helena Formations) are present only along the west flank of the Big Belt Mountains between Confederate Gulch (sec. 16, T. 9 N., R. 2 E.) and Oregon Gulch (sec. 22, T. 11 N., R. 1 W.). The Empire Formation is present beneath the Middle Cambrian Flathead Sandstone on the flanks of the Spokane Hills; the Helena Formation is absent there. Across all other exposures of the Belt Supergroup in the quadrangle, the Empire and Helena are absent as a result of post-Mesoproterozoic–pre-Middle Cambrian erosion.

Diorite sills and dikes of Neoproterozoic age intrude rocks of the Belt Supergroup. One such dike in sec. 4, T. 11 N., R. 1 W. has an apparent age of 741.3±32.2 Ma (Reynolds, 2003). Marvin and Dobson (1979, p. 20) reported a similar age (744±37 Ma) for the diorite sill intruded in the Empire Formation in NE¼SW¼ sec. 1, T. 10 N., R. 1 E. A major diorite dike intruded in the Newland Formation in SE¼ sec. 9, T. 11 N., R. 1 E. has a somewhat older apparent age of 826±41 Ma (Marvin and Dobson, 1979, p. 20), an age nearly within the margin of error of the other dated dike and sills so that they can be considered part of the same intrusive episode. Intrusion of the dikes during early Neoproterozoic time seems to have accompanied deformation of Belt Supergroup strata, which led to unconformable relations of the Middle Cambrian Flathead Sandstone to truncated edges of Belt strata described above (Harrison and Reynolds, 1976).

Paleozoic rock units are of sedimentary origin and are assigned to 29 units that range in age from Middle Cambrian through Permian. Ordovician and Silurian strata are absent. Middle Cambrian, Upper Mississippian, and most Pennsylvanian strata are predominantly of terrigenous clastic origin. Upper Cambrian, Devonian, Lower Mississippian, and lower Upper Mississippian strata are mainly marine carbonate rocks. The Middle Cambrian Flathead Sandstone, basal Paleozoic unit, rests unconformably across gently folded rocks of the Belt Supergroup in the southwestern part of the Big Belt Mountains. The Flathead overlies progressively lower strata of the Belt Supergroup north across the Lewis and Clark tectonic zone where the Flathead rests unconformably on the middle and upper lower part of the Greyson Formation. North and east of the fault zone that bounds the Dry Range and extends east across the south edge of T. 12 N., Rs. 5 and 6 E., the Flathead rests directly on Paleoproterozoic metamorphic rocks; the Belt Supergroup is absent as a result of Neoproterozoic–pre-Middle Cambrian erosion. Clearly the ancestral fault, parallel to the margin of the Lewis and Clark tectonic zone, was active as a normal fault along which the north side was uplifted and generally eroded as deeply as the Paleoproterozoic crystalline rocks relative to the south side. Along the north side of the ancestral fault, the Flathead Sandstone contains pebble to boulder conglomerate that fills channels in the sandstone (for example, southeast corner sec. 24, T. 12 N., R. 4 E., and locally east into the adjacent White Sulphur Springs quadrangle). Well-rounded cobbles and boulders as large as 35 cm in the conglomerate are Neihart Quartzite, including granule pebble quartzite, and resistant rock types from the Greyson and Spokane Formations. The Flathead Sandstone laps onto ancestral islands of Paleoproterozoic granite gneiss (sec. 2, T. 12 N., R. 4 E.; secs. 5, 8, T. 12 N., R. 5 E.). Sandstone and granule pebble laminae in the Flathead dip radially away from the islands. Across most of the northeastern part of the quadrangle, the Flathead rests on the crystalline Paleoproterozoic rocks on an erosion surface that generally has less than 1.5 m of relief.

Stratigraphic relations among Upper Mississippian and Pennsylvanian formations document both ancestral tectonic movement in the Canyon Ferry Dam area and important effects of the stratigraphic succession on development of the Late Cretaceous Montana disturbed belt. The Upper Mississippian Kibbey Formation rests on a surface eroded across carbonate strata of the Lower and Upper Mississippian Mission Canyon Limestone. Basal beds of the Kibbey locally contain pebbles of the underlying formation, and Kibbey red beds containing carbonate rock rubble fill local karst depressions in the uppermost part of the Mission Canyon Limestone. Red beds with interbedded sandy and silty limestone in the lower part of the Kibbey are overlain by an interval of gypsum and anhydrite. In turn, the evaporite beds are overlain by a succession of sandy siltstone, lenticular sandstone, and calcareous sandy siltstone. The original thickness of the evaporite interval is not known, for the gypsum with anhydrite flowed and deformed during Late Cretaceous folding and faulting (figs. 5 and 6, sheet 2). The interval of evaporite beds forms the detachment zone, herein called the Black Canyon decollement fault, that separates the strongly folded and faulted rocks of the Montana disturbed belt above from gently west- or southwest-tilted, but otherwise little deformed, rocks of the continental autochthon beneath (fig. 5, sheet 2). Small folds in secs. 32 and 33, T. 14 N., R. 3 E. and secs. 4 and 5, T. 13 N., R. 3 E. are cored by brecciated remnants of the evaporite interval admixed with pale-grayish-yellow siltstone of the uppermost part of the Kibbey. From Antelope Creek and Rock Creek on the south (T. 12 N., R. 2 E.) northeast to Black Canyon and Cat Creek (western part of T. 13 N., R. 3 E. and southwestern part of T. 14 N., R. 3 E.), thrust faults above the decollement surface follow the evaporite interval, so that generally the sandy siltstone unit at the top of the Kibbey forms the lower part of hanging walls of the thrust faults. Brecciated anhydrite is commonly present along the thrust faults and separates faulted sequences in drill holes (Hunt Oil Co., Galt No. 13-1, sec. 23, T. 13 N., R. 1 E., and Fortuna (U.S.) Inc., Sieben 29-1, sec. 29, T. 14 N., R. 1 E.; sheets 1–3). The interval of evaporite beds is present in the upper part of the Kibbey Formation only from the present trace of the Moors Mountain thrust fault on the west to the Black Canyon decollement fault on the east and southeast. The interval is not present in the Kibbey across the quadrangle on the upper plate of the Moors Mountain thrust fault, nor is it present in the Kibbey south and southeast of the decollement fault in Antelope Creek (center T. 12 N., R. 2 E.).

The Upper Mississippian Tyler Formation rests unconformably on the Big Snowy Group across a limited area in the disturbed belt extending from Antelope Creek on the south (center T. 12 N., R. 2 E.) northwest to the North Fork of Wickiup Creek (northwest corner T. 13 N., R. 1 E.). A basal pebble conglomerate contains clasts derived from the underlying Heath and, rarely, Otter Formations as well as silica-rich pebbles derived presumably from older sedimentary units farther west. Tongues of lithic arenite and local white and ferruginous reddish-brown quartz arenite are present in the dark-gray to black siltstone and silty mudstone of the Tyler Formation. The mudstone and silty mudstone beds locally served as intervals of folding and local detachment during Late Cretaceous thrust faulting. The Tyler Formation thins to a wedge edge in Antelope Creek (center T. 12 N., R. 2 E.), where it seems to lap onto, or abut, an ancestral structural high that coincided with the trend of the Lewis and Clark tectonic zone. The Tyler was subsequently truncated southeast and northwest by erosion that produced the unconformity at the base of the Pennsylvanian Amsden Formation. The Tyler is not known in the upper Paleozoic stratigraphic succession either above the Moors Mountain thrust fault or across the remainder of the Canyon Ferry Dam quadrangle where the Amsden Formation rests unconformably on units of the Big Snowy Group.

Across the southwestern part of the quadrangle on the upper plate of the Moors Mountain thrust fault, the Pennsylvanian Quadrant Formation is about 105 m thick. East of the surface trace of the thrust fault, the Quadrant is 4–5 m thick. West and southwest above the Moors Mountain thrust fault, remnants of the Phosphoria Formation are preserved in stratigraphic succession above the Quadrant. Truncation of the Phosphoria Formation and dramatic thinning of the Quadrant resulted mainly from uplift and erosion of the crustal block on the north flank of the Lewis and Clark tectonic zone prior to deposition of the Jurassic Ellis Group.

Mesozoic rocks include 44 mapped units of sedimentary, volcanic, and intrusive igneous origin. Several stratigraphic and age relations are significant for this summary. The Jurassic Sawtooth Formation, present at the base of the Ellis Group in the western part of the quadrangle, is truncated east of the Moors Mountain thrust fault by erosion that preceded deposition of the overlying Jurassic Swift Formation. The apparent ancestral high from which the Sawtooth Formation was eroded was coincident with crustal block on the north flank of the Lewis and Clark tectonic zone. The Swift rests on a wedge edge of the Pennsylvania Quadrant Formation northeast of the trace of the Moors Mountain thrust fault and above the Black Canyon decollement fault. Channels filled with pebble conglomerate are common at the base of the Swift. In secs. 31 and 32, T. 14 N., R. 2 E. and secs. 5 and 6, T. 13 N., R. 2 E., a notable basal conglomerate bed is as thick as 5 m and contains well-rounded small boulders as much as 32 cm across. The pebbles, cobbles, and boulders are mainly black and dark-gray chert, medium-gray siliceous siltite and chert, polycrystalline quartz, and minor quartz. Upper Paleozoic fusulinids were observed in several chert clasts. The source was likely Pennsylvanian and Permian chert-bearing strata eroded from developing uplands to the southwest and west.

In this report, the age of the overlying Morrison Formation is considered to be Late Jurassic and Early Cretaceous. The Morrison consists of two contrasting rock successions: the lower succession is greenish-gray to grayish-red siltstone and minor mudstone, thin grayish-orange sandstone, and discontinuous silty and sandy limestone beds. The upper part, exposed east of the present trace of the Moors Mountain thrust fault and locally near the mouth of White Gulch (sec. 19, T. 10 N., R. 2 E.), is dark-gray to grayish-black carbonaceous siltstone and mudstone, coaly siltstone, and low-grade coal. Barnett (1916) described the Morrison and Kootenai Formations in the Hound Creek district, Montana, which included part of the Canyon Ferry Dam quadrangle (T. 14 N., R. 1 E., and northwest corner of T. 14. N., R. 2 E.). Barnett (1916, p. 217, 220–222) included the variegated beds in the Morrison(?) Formation but assigned the dark-gray to black siltstone, coaly siltstone, mudstone, and coal to the lower part of the Kootenai Formation and described a conformable relation between the units. Barnett considered the age of the dark-gray and black silty and coaly sequence to be Early Cretaceous. Subsequently, Brown (1946, p. 240–241) summarized the history of assigning the silty and coaly sequence to either the Jurassic or Lower Cretaceous and noted that coaly beds at the top of Morrison Formation near the type section in Colorado had been included in the Morrison and assigned a Jurassic age. Brown's paleobotanic collections did not resolve the age issue. On the basis of the established age of the Morrison Formation in other western States, the formation was subsequently presumed to be Jurassic in west-central Montana as well. During mapping of the Canyon Ferry Dam quadrangle, samples for palynologic analysis collected at two localities from the dark-gray siltstone, mudstone, and coaly unit at the top of the Morrison Formation yielded palynomorphs of Early Cretaceous age (sec. 9, T. 13 N., R. 1 W.; R.H. Tschudy, U.S. Geological Survey, oral commun., 1977; sec. 7, T. 17 N., R. 3. E., R. Spanish Coulee School quadrangle, Montana; Robert Cushman, Loma Linda University, written commun., 1999). In a separate study, Vuke (2000, map pamphlet, p. 2) reported that palynomorphs from drill core from the carbonaceous shale in the upper part of the Morrison Formation north of the Canyon Ferry Dam quadrangle are of Neocomian (Early Cretaceous) age. Thus, on the basis of all available palynologic evidence, stratigraphic position, and correlation with units farther north in Montana and adjacent Alberta, Canada, a Late Jurassic and Early Cretaceous age is here assigned to the Morrison Formation in the Canyon Ferry Dam quadrangle.

Stratigraphic relations between the Kootenai Formation and underlying Morrison Formation differ across the Canyon Ferry Dam quadrangle. In much of the western part of the map area, sandstone beds at the base of the Kootenai rest conformably or with local slight erosional discordance on the Morrison. In T. 14 N., Rs. 1 and 2 E., granule pebble conglomerate rests on the silty and coaly sequence of the Morrison Formation. Local scour is evident at the base of the Kootenai where the conglomerate is present, but evidence of discordance diminishes as the conglomerate grades laterally into sandstone. Northeast from secs. 2–5, T. 14 N., R. 2 E., sandstone beds characteristic of the Kootenai interfinger with the dark-gray mudstone and siltstone at the top of the Morrison.

Upper Cretaceous rocks of volcanic, volcaniclastic, and sedimentary origin are mainly associated with three Cretaceous volcanic centers: the Elkhorn Mountains Volcanics in the southwest corner of the map area, the area of the Two Medicine Formation in the northwest corner, and the distinct Adel Mountain Volcanics at the northwest central edge of the quadrangle. The Elkhorn Mountains Volcanics were erupted between about 81 and 76 Ma, in part predating and in part synchronous with emplacement of the associated Boulder batholith (Rutland and others, 1989, p. 17). Schmidt (1978, p. 41–43, pl. 2) considered that volcanic rocks of the Two Medicine Formation are equivalent to, and represent a northern extension of, the Elkhorn Mountains Volcanics, although the different volcanic assemblages are separated geographically by about 35 km and separated geologically by the major Eldorado thrust fault (fig. 2, sheets 1–3). Schmidt (1978, pl. 2) assigned an age of about 82.5–72.5 Ma to both the western and eastern facies of the Two Medicine Formation in the Wolf Creek area, north of the Canyon Ferry Dam quadrangle. Schmidt (1978, p. 43) recognized that the age of the units could be several million years older than the young ages obtained from glassy volcanic rocks of the formation. Rogers and others (1993, p. 1072) reported an age of 80–74 Ma for the formation. Recently, Harlan and others (2005) reported, with some reservation, an age of about 82 Ma for the Two Medicine Formation, which would seem to equate the formation with the oldest part of the Elkhorn Mountains Volcanics. The age reported by Harlan and others is consistent with the oldest ages determined by Rogers and others (1993, p. 1070–1071) for crystal tuff beds in the lower part of the formation. Harlan and others (2005) established that the Adel Mountain Volcanics were emplaced between about 76 and 73 Ma. The Adel Mountain Volcanics are clearly distinct in age, petrology, and tectonic setting with respect to the Elkhorn Mountains Volcanics and the Two Medicine Formation.

The principal Cretaceous intrusive bodies are in the southwestern part of the Canyon Ferry Dam quadrangle, south of the Lewis and Clark tectonic zone (fig. 2, sheets 1–3). Rocks of the Boulder batholith (T. 9 N., Rs. 2, 3 W.), including the Butte Quartz Monzonite and associated monzodiorite and granodiorite, range in age from about 81 to 68 Ma (Tilling, 1973, p. 3880–3881; Rutland and others, 1989, p. 17; du Bray and Snee, 2002). Snee and others (1999) concluded that the main body of the Butte Quartz Monzonite was emplaced at about 75.6 Ma. Monzonite exposed as three bodies and numerous thin sills and dikes along the axis of the Spokane Hills (Ts. 9, 10 N., R. 1 W.) likely is part of a single pluton that underlies those hills. Conventional K-Ar ages for biotite from the largest exposed monzonite body are about 81 and 79 Ma (G.D. Robinson, U.S. Geological Survey, written commun., 1977), which suggests that the Spokane Hills intrusive is somewhat older than the main body of the Butte Quartz Monzonite. Quartz monzonite and associated intrusive rocks of the Boulder Baldy pluton in the Big Belt Mountains were likely emplaced later than the main body of the Butte Quartz Monzonite. The outer part of the Boulder Baldy pluton in Little Camas Creek (SW¼NE¼NW¼ sec. 21, T. 9 N., R. 4 E.) has a cooling age of 73.8–72.1 Ma (Snee and others, 2002). From $^{40}Ar/^{39}Ar$ analyses of hornblende from quartz monzonite within the core of the pluton and from the Miller Mountain stock to the north (sec. 13, T. 10 N., R. 2 E.), du Bray and Snee (2002, p. 9) suggested an emplacement age between 70 and 69 Ma. The older cooling age for the Boulder Baldy pluton determined during the course of the present study suggests that emplacement occurred between 74 and 69 Ma and overlapped intrusion and eruption of the potassium-rich basalt and andesite of the Adel Mountain Volcanics at the northern margin of the Canyon Ferry Dam quadrangle. The age of the Bilk Mountain pluton (secs. 32–34, T. 11 N., R. 2 E., and secs. 3–5, 8–10, T. 10 N., R. 2 E.; fig. 2, sheets 1–3) has not yet been determined, but we consider it to be of Late Cretaceous age and of the same general intrusive sequence as the Boulder Baldy pluton and Miller Mountain stock. The plutons in the Big Belt Mountain are younger than thrust faulting in the area.

Hornblende diorite sills intrude Upper Mississippian strata widely across the frontal fold and thrust belt (fig. 2, sheets 1–3) as far east as SW¼NW¼ sec. 27, T. 14 N., R. 3 E. Similar sills and a small stock (secs. 3, 4, T. 12 N., R. 2 W.) intrude lower Paleozoic rocks on the upper plate of the Moors Mountain thrust fault north of Beaver Creek. The sills are folded and broken by the thrust faults. Attempts to determine the radiometric age of the sills have been unsuccessful because of alteration of the rocks, but we consider that they are likely Late Cretaceous, possibly about 76–75 Ma and related to widespread igneous activity that resulted in volcanic rocks and shallow intrusive bodies in the Two Medicine Formation. The sills predate not only the thrust deformation but also development of the Adel Mountain Volcanics. Dikes and sills of more silicic composition are widespread in the central southern part of the quadrangle, east and northeast of the Boulder Baldy pluton. These intrusive bodies both predate some folding and thrust faulting and are younger than some faulting and are likely related to the Late Cretaceous plutonism in the central Big Belt Mountains.

Tertiary rocks include igneous intrusive rocks of Eocene age, andesitic basalt of Oligocene age, and successions of Oligocene to Pliocene rocks of sedimentary, volcaniclastic, and volcanic origin, preserved in fault-bounded valleys in the southwestern and eastern parts of the quadrangle. Eocene intrusive rocks form laccoliths and sills intruded along and south of the Tenderfoot Creek fault zone in the northeastern part of the quadrangle (fig. 8, sheet 2), and sills and scattered dikes intrude Paleozoic rocks from the Smith River (east edge of T. 12 N., R. 4 E.) south and east to sec. 32, T. 11 N., R. 6 E. Floors of the laccoliths are mainly in the lowest part of the Middle Cambrian Flathead Sandstone or at the unconformity between the Flathead and Paleoproterozoic granite gneiss and schist. Paleozoic rocks are domed over the laccolith; usually mudstone and siltstone beds of the Wolsey Formation or Park Shale form the basal cap rock. Relief between the floor and Cambrian rocks on the crests of the laccoliths is about 155 m on the Devils Footstool laccolith and about 760 m on the Woods Mountain laccolith (fig. 2, sheets 1–3). Based on $^{40}Ar/^{39}Ar$ determinations, the radiometric age of the Devils Footstool laccolith is 51.3±0.16 Ma, and the age of the Woods Mountain laccolith is 53.07±0.28 Ma (L.W. Snee and D.P. Miggins, U.S. Geological Survey, written commun., 2005).

A hornblende biotite dacite body, intruded in the major fault along which the Mesoproterozoic Newland Formation is faulted against Middle Cambrian strata in secs. 3–6, T. 11 N., R. 5 E., has an age of 54.4±0.2 Ma. That intrusive body and sills of similar composition to the southeast in the Newland and Greyson Formations document active crustal extension during early Eocene time and, together with the laccoliths, represent widespread magmatism that accompanied extension following thrust faulting in the Western United States (Snee and others, 2002). In secs. 1–2, T. 10 N., R. 5 E., secs. 5–8, T. 10 N., R. 6 E., and sec. 12, T. 10 N., R. 5 E., rhyolite bodies that intrude a fault along which the Mesoproterozoic Spokane Formation is thrust over lower Paleozoic strata have an $^{40}Ar/^{39}Ar$ age of 48.69±0.07 Ma (L.W. Snee and D.P. Miggins, U.S. Geological Survey, written commun., 2002). In the adjacent White Sulphur Springs quadrangle (sec. 9, T. 10 N., R. 6 E.), an associated major rhyolite intrudes the older hornblende biotite dacite sills.

Flows and intrusive necks of trachybasalt are widespread in the Canyon Ferry Dam quadrangle mainly within and on the north margin of the Lewis and Clark tectonic zone (fig. 2, sheets 1–3). Across much of the north-central part of the quadrangle, accumulations of basalt rest on a nearly flat or gently rolling surface eroded across folded and faulted pre-Tertiary rocks (section *A–A'*, sheet 1). That surface seems to be graded toward the west end of the Little Belt Mountains. The outcrop pattern of the basalt suggests that the current distribution in the north-central area locally represents inverted topography resulting from erosion of less-resistant rock units originally adjacent to or overlying the basalt that filled shallow valleys when extruded. Basalt is interbedded with pebble and cobble conglomerate, siltstone, and tuffaceous siltstone in the valley of Eagle Creek (secs. 26, 27, T. 13 N., R. 5 E.) and locally rests on sedimentary rocks of Oligocene age [for example, in Rock Creek (secs. 5, 6, T. 12 N., R. 3 E.), above Dry Creek (secs. 4, 5, T. 13 N., R. 4 E.), and in the Big Belt Mountains]. Along the crest of the Big Belt Mountains, basalt at the heads of Cooney and Culp Gulches (sec. 2, T. 11 N., R. 1 E.) and capping Bilk Mountain (sec. 34, T. 11 N., R. 2 E.) documents the extent of relative downward displacement by faulting of the north end of Townsend Valley on the west and the Smith River Valley on the east, inasmuch as basalt at the crest of the mountains rests on Tertiary strata that can be correlated with sedimentary sequences as much as 920 m topographically below in the valleys. Basalt plugs are present in fault zones such as in Hilger Valley (sec. 35, T. 13 N., R. 3 W.), in Helena Valley near the Black Butte fault zone (fig. 2, sheets 1–3; sec. 34, T. 10 N., R. 3 W.), and in Rock Creek (secs. 35, 36, T. 13 N., R. 2 E.). The maximum thickness of trachybasalt is about 175 m (secs. 13, 24, T. 13 N., R. 2 E.; secs. 19, 30, T. 13 N., R. 3 E.). Whole rock $^{40}Ar/^{39}Ar$ ages on basalt across the quadrangle from Bilk Mountain northeast to Eagle Creek and the Smith River define a narrow interval of basaltic volcanism from 32.8 to 30.4 Ma (Reynolds and others, 2002).

Sedimentary rocks of Oligocene and Miocene age are widely exposed in the Smith River Valley and its northeastern tributaries, along the eastern margin of Helena Valley, and in the northern part of Townsend Valley. Tertiary strata in the Smith River Valley were first described by Grinnell and Dana (1876) in the general area of Camp Baker (T. 12 N., R. 4 E.) on the Smith River (then known as Deep River). They noted the presence of similar beds as far as 30 km southeast of Camp Baker, west across the mountains near Helena, and more widely north and south of the Smith River area (Grinnell and Dana, 1876, p. 128). They described the thickness of the beds as about 65 m and concluded from fossil vertebrates that the beds were Miocene and Pliocene in age (Grinnell and Dana, 1876, p. 127). Subsequently, Dall and Harris (1892) referred to the strata as the “Deep River beds.” On the basis of mammalian fossils, Douglass (1904, p. 150) concluded that the lower part of the “Deep River beds” are upper Oligocene and named the lower part “Fort Logan beds” after the frontier Fort Logan near the Smith River (unsurveyed area, east of secs. 25, 35, T. 11 N., R 4 E.). Douglass (1904, p. 150) restricted the name “Deep River beds” to the upper part of the succession, but did not assign an age to that part. However, he suggested that they might not be Pliocene as previous authors had concluded. Like Grinnell and Davis before him, Douglass (1904, p. 150, 153) recognized the similarity of the “Fort Logan beds” to strata at Canyon Ferry west of the Big Belt Mountains. Koerner (1940, p. 838–853) named the main part of the succession “Fort Logan formation” and assigned an early Miocene age to it and a late Miocene age to the overlying “Deep River formation.” As a result of the limited continuity of exposures and absence of marker beds that can be traced across the area, subsequent authors have not applied the name “Deep River beds,” but have instead included all the strata in the Fort Logan Formation (see Runkel, 1986, for an extended summary of the development and application of the formation names). The

U.S. Geological Survey has applied the name Fort Logan Formation to lithologically similar strata that extend about 65 km south of the Fort Logan area along the Smith and upper Shield River valleys (McGrew, 1977a–d; Green, 1999). In the present study the name Fort Logan Formation is applied to interbedded clayey siltstone, tuffaceous siltstone, poorly to moderately welded ash-flow tuff, thin sandstone and conglomerate beds, and clayey vitric tuff in the Smith River Valley south of both Whitetail Deer Creek (secs. 6–9, 15, 16, T. 11 N., R. 5 E.) and Beaver Creek (north edge T. 11 N., Rs. 3, 4 E.). The formation is as thick as 85 m. Strata north and northeast of that area are in part contiguous with the Fort Logan Formation; however, they are mainly pebble conglomerate and interbedded tuffaceous siltstone and sandstone. Clasts in the conglomerate beds were derived from different source terranes than many intervals in the Fort Logan Formation, and basal beds locally contain well-rounded boulders of Paleoproterozoic, Cambrian, Devonian, and Mississippian rocks as large as 1.5–3 m across. The unnamed beds are as thick as about 120 m in secs. 4, 5, 9, 15, and 16, T. 13 N., R. 4 E., and the lower part of the succession is interbedded with trachybasalt flows that range in age from 34.7 Ma (NW¼ sec. 4, T. 13 N., R. 4 E.) to mainly 32.8–30.4 Ma (D.P. Miggins and L.W. Snee, U.S. Geological Survey, written commun., 2001); the age of the upper part is not yet known but is likely Miocene.

Vertebrate fossils and radiometric ages establish the age of the Fort Logan Formation as Oligocene and Miocene. Runkel (1986) concluded from vertebrate fossils that the age of Fort Logan Formation beds along the Smith River in T. 10 N., R. 5 E. is Arikareean (Oligocene and Miocene); locally along the eastern margin of Smith River Valley and in Camas Creek, the age is Barstovian (Miocene). South of the Canyon Ferry Dam quadrangle, McGrew (1977a–d) assigned the Fort Logan Formation to the lower Miocene apparently following the age designation by Koerner (1940, p. 843–858). A pumice tuff, collected during the present geologic mapping study in SE¼SW¼ SW¼ sec. 18, T. 12 N., R. 5 E., interbedded with rocks equivalent to the lower part of the Fort Logan Formation, has an $^{40}Ar/^{39}Ar$ age of 32.3 Ma [(early Oligocene), D.P. Miggins and L.W. Snee, U.S. Geological Survey, written commun., 2001]. We consider that the age of the Fort Logan Formation is Oligocene and Miocene.

A succession of Tertiary sedimentary, volcaniclastic, and volcanic rocks is widely present in the eastern part of Helena Valley, at the southeast end of the Spokane Hills, and on the east side of Canyon Ferry Lake south from Canyon Ferry to the edge of the quadrangle in the northern part of the Townsend Valley. Exposures are generally limited to small areas on the colluvial-covered flanks of dissected pediment and terrace surfaces. The rocks are tilted east and repeated by faulting. The lower part of the succession is primarily interbedded vitric tuff, tuffaceous sandstone, and tuffaceous siltstone and mudstone with interbedded pebble conglomerate; very thin lahar bodies and devitrified poorly welded ash-flow tuff are present locally. The upper part of the succession is mainly pebble and small boulder conglomerate. Pardee (1925) and Mertie and others (1951) reported that the succession is Oligocene and Miocene. On the basis of extensive collections of vertebrate fossils, White (1954) concluded that the Tertiary strata in the area adjacent to, and now partly flooded by, Canyon Ferry Lake are lower and middle Oligocene and lower and middle Miocene. Sandy vitric tuff and pebbly sandstone beds with conglomerate lenses are similar to beds at the crest of the Big Belt Mountains that are overlain by Oligocene basalt. The succession is broadly similar to strata of equivalent age east of the Big Belt Mountains in the Smith River Valley. The distribution of ages at White's (1954, fig. 51) fossil localities is consistent with the mapped repetition and eastward tilting of the Helena and Townsend Valley successions on faults that flank the Spokane Hills and Big Belt Mountains and a fault zone identified beneath Canyon Ferry Lake by geophysical surveys (Davis and others, 1963).

Sheets 1–3 show the distribution of 24 units of surficial deposits of Quaternary or late Tertiary and Quaternary age. The "Description of Map Units" describes the units and identifies the characteristics by which the units are distinguished. Two categories of units, pediment gravels and glacial deposits, are described further here. Gravel deposits, here termed pediment gravel, veneer extensive surfaces of low relief that slope southwest and northeast from the flanks of the Big Belt and Elkhorn Mountains. We infer that the gravel deposits are of Pliocene and Pleistocene age because they rest on surfaces that truncate gently tilted Tertiary strata as young as late Miocene, which crop out in limited exposures on the flanks of the dissected surfaces. Gravel on adjacent broad erosional surfaces of approximately the same general elevation and slope, or the highest gravel veneer in an area of more than one such surface, is designated QTp. On the east flank of the Big Belt Mountains between Camas Creek and the Smith River, gravel veneers rest on adjacent broad surfaces eroded at successively lower elevations from southeast to northwest. We distinguished gravel veneers on adjacent eroded surfaces at different elevations with subscript numbers QTp_2 for the higher gravel and QTp_1 for the next lower gravel veneer. A gravel veneer on a yet lower broad surface is designated Qp. The succession of eroded surfaces suggests west tilting of the area toward the Camas Creek fault (fig. 2, sheets 1–3) during latest Tertiary and Quaternary time.

Glacial deposits shown on the geologic map of the Canyon Ferry Dam quadrangle include products of alpine glaciation in the Boulder Baldy and Boulder Mountain area, south-central part of the Big Belt Mountains, and deposits of glacial lake Great Falls in the northwestern part of the quadrangle. Neither the northeast flank of the Elkhorn Mountains nor the west end of the Little Belt Mountains was glaciated, although alpine glaciers covered adjacent areas in those mountains southwest and northeast, respectively, of the Canyon Ferry Dam quadrangle. Glacial deposits are preserved mainly on the east side of Boulder Baldy or confined to Boulder Creek and the upper reaches of Middle Fork of Duck Creek between Boulder Baldy and Boulder Mountain. At least two and possibly three Pleistocene and Holocene glacial stages are represented most clearly by deposits in the valley of Big Birch Creek (T. 9 N., R. 4 E.). Till likely of Pinedale age forms two terminal moraines (NW¼ sec. 25, and bounding Gipsy Lake, NW¼NE¼ sec. 34, T. 9 N., R. 4 E.) and a series of lateral moraines and ground moraine in between. Till of Holocene age comprises small terminal moraines at the base of cirques and ground moraines high in valleys adjacent to Boulder Mountain (secs. 9, 10, 15, 16, T. 9 N., R. 3 E.) and east of Boulder Baldy (secs. 2, 11, 12, T. 9 N., R. 3 E.). Deposits interpreted as till on high surfaces adjacent to the upper reaches of Indiana Creek (secs. 24, 25, T. 10 N., R. 3 E., and secs. 19, 29, 30, T. 10 N., R. 4 E.), and locally of upper Big Birch Creek south of the quadrangle boundary, might be as old as Bull Lake (Pleistocene).

Remnant sequences of clay, silt, and sand with rare lenses of vitric ash deposited in glacial lake Great Falls crop out discontinuously along the Missouri River from the northwest edge of the quadrangle as far southeast as sec. 1, T. 10 N., R. 2 W., and along the northeast shoreline of Lake Helena in secs. 18 and 19, T. 11 N., R. 2 W. The highest glacial lake deposits are generally at elevations ranging from about 1,116 to 1,119 m along reaches of the Missouri River in the northwestern part of the quadrangle. However, along and on the north side of the Helena Valley fault zone, Schmidt (1986, pl. 2) mapped glacial lake deposits on the northeast corner of Lake Helena at an elevation of about 1,120 m and at an unusual height of about 1,140 m (secs. 14, 24, T. 11 N., R. 2 W.) along the trace of the Spokane Hills fault in NW¼ sec. 1, T. 9 N., R. 2 W., adjacent to Hauser Lake. We conjecture that the lake deposits could be at higher elevations in these local areas as a result of lacustrine deposition upstream of a temporary landslide dam in the upper narrows of the glacial lake, or could be elevated by subtle crustal warping at the junction of the Helena Valley and Spokane Hills faults that have shown response during Holocene earthquakes (M.W. Reynolds, U.S. Geological Survey, and M. McKeown, U.S. Bureau of Reclamation, written commun., 1977; Schmidt, 1986, p. 15–18).

Geologic Structure

The Canyon Ferry Dam quadrangle lies at the junction of major crustal structures of the northern Rocky Mountains. The Montana disturbed belt (figs. 1, 2, sheet 1) terminates in the north-central part of the quadrangle. The surface expression of west-trending structures of the Little Belt Mountains and the ancestral central Montana uplift ends in the quadrangle as those structures intersect the predominantly north-northwest trending structures of the thrust belt in the northern Rocky Mountains. Basin and range structure that characterizes a major part of the Western United States ends at the southeast corner and along a west-northwest-trending zone across the middle of the quadrangle (Reynolds, 1979, p. 188, 189). Recurring movement on the principal structural elements together with igneous activity through geologic time have resulted in the complex structure present in the quadrangle.

The continental autochthon, cored by Paleoproterozoic crystalline rocks (fig. 2 and sections *A–A'* and *B–B'*, sheet 1), is exposed across the northeast quarter of the quadrangle. The crystalline core, overlain unconformably by a succession of lower and middle Paleozoic sedimentary rocks, plunges gently west under folds and thrust faults of the disturbed belt (section *A–A'*, sheet 1). A major fault zone, termed the Dry Range fault zone, bounds the crystalline rocks on the south. The long history and complex character of recurrent movement along the Dry Creek fault zone suggests that it overlies and is part of a fundamental shear zone deeper in the Earth's crust.

The principal fault along the south margin of the Dry Range fault zone (secs. 35, 36, T. 12 N., R. 4 E., secs. 3–5, T. 11 N., R. 5 E., secs. 35, 36, T. 12 N., R. 5 E., and secs. 31, 32, T. 12 N., R. 6 E.) juxtaposes the Mesoproterozoic Newland Formation on the south against Middle and Upper Cambrian rocks that rest unconformably on Paleoproterozoic crystalline rock. In sec. 31, T. 12 N., R. 6 E., the fault splays to form a narrow wedge enclosing Paleoproterozoic granite gneiss between Middle Cambrian strata on the north and Newland Formation on the south. Thin selvages of Mesoproterozoic Neihart Quartzite are caught between subordinate faults along the principal fault between the Newland Formation on the south side of the wedge and Paleoproterozoic granite gneiss on the north side. Farther east in the adjacent White Sulphur Springs quadrangle, the principal fault between Belt Supergroup rocks on the south and either Paleoproterozoic crystalline rocks (M.W. Reynolds, U.S. Geological Survey, unpub. mapping, 1979) or Paleozoic strata on the north has been named the Volcano Valley fault (Weed and Pirsson, 1900, p. 305). On the north side of the principal fault in the Canyon Ferry Dam quadrangle, the Flathead Sandstone and younger rocks rest directly on Paleoproterozoic crystalline rocks, whereas on the south side of that fault, the Flathead Sandstone rests unconformably on a sequence, nearly 4,800 m thick, of Mesoproterozoic Belt Supergroup strata (west-center T. 11 N., R. 5 E.; section *B–B'*, sheet 1). Normal movement on the fault was down to the south during Neoproterozoic to Middle Cambrian time, during which the upthrown north block was eroded as deep as the Paleoproterozoic crystalline rocks. Movement on the fault reversed, south side up, during Late Cretaceous–pre-Eocene time, as evidenced by the lower part of the Mesoproterozoic sedimentary succession now juxtaposed against Paleozoic strata that were deposited originally across both the crystalline rocks on the north and the Belt Supergroup rocks on the south (section *B–B'*, sheet 1). The reactivated fault was subsequently intruded by an Eocene sill (secs. 3–5, T. 11 N., R. 5 E.), during a period of crustal relaxation that followed the reverse fault movement.

Displacement along faults at the west end of the Dry Range fault zone was yet more complex. In addition to the displacements described above, in secs. 20–22 and 25–27, T. 12 N., R. 3 E. and sec. 30, T. 12 N., R. 4 E., Mesoproterozoic and Paleozoic strata are folded, thinned by shearing, and displaced eastward by right lateral shear along the fault zone. Separate fault strands continue west where, as they curve northwest, they flatten northeast to become basal bounding thrust faults of the Avalanche Butte structural block (fig. 2, sheets 1–3). To the south in the Wagner Gulch–Beaver Creek area (secs. 31–36, T. 12 N., R. 2 E. and sec. 31, T. 12 N., R. 3 E.), a parallel major fault displaces folded Mesoproterozoic and Paleozoic units about 1 km east by right-lateral separation. The fault flattens westward to become a structurally higher thrust fault within the Avalanche Butte structural block. The higher fault and displaced fold are en-echelon southwest, also in a right-lateral sense, with respect to the displaced fold along the bounding fault of the Dry Range fault zone. Southeast from Wagner Gulch, the higher fault is concealed by old alluvium and Miocene and Oligocene strata but emerges (sec. 33, T. 12 N., R. 3 E.) as a thrust fault with a component of oblique shear. The fault displaces the lowest part of the Greyson Formation and the limestone-bearing sequence at the top of the Newland Formation over the principal fold adjacent to the Dry Range. We interpret the age of the deformation that produced the faults and displaced folds as Late Cretaceous, likely between about 75 and 73 Ma.

Subsequent to the Late Cretaceous faulting and Eocene extension, described in the preceding, the west end of the Dry Range was faulted up on the north along the fault zone with respect to the crustal block on the south (sec. 25, T. 12 N., R. 3 E. and secs. 28–30, T. 12 N., R. 4 E.). The faulting occurred during the late Miocene or Pliocene. Beds of Oligocene and Miocene age, including a distinctive pumice- and basalt-fragment tuff unit, dip 25° south from the Dry Range fault zone toward Beaver Creek. Much of the area adjacent to the fault zone seems to have sagged gently during the late Miocene or Pliocene from the Dry Range and west end of the Little Belt Mountains toward a structural low along the fault zone: the pre-Tertiary bedrock surface on which Oligocene strata lie slopes south from Dry Canyon (secs. 4, 5, T. 13 N., R. 4 E.) toward Sheep Creek (secs. 12, 13, T. 12 N., R. 4 E.) and Beaver Creek in the fault zone. The direction of apparent slope is opposite that predicted if the Oligocene-Miocene drainage from the ancestral Smith River Valley area was generally north similar to Holocene drainage. The dip of bedding in the pumice- and basalt-fragment tuff declines south from the fault zone to outcrops in sec. 28, T. 12 N., R. 4 E., to as far south as secs. 6 and 7, T. 11 N., R. 5 E., where the unit is flat lying.

Few faults displace rocks in the main block of the autochthon. East-northeast-trending normal faults in the valley of Sheep Creek (center T. 12 N., R. 5 E.) and on Sheep Creek Bar (secs. 5–7, 18, T. 12 N., R. 5 E.) splay from the Dry Range fault zone to displace Middle Cambrian rocks down on the north with respect to equivalent strata that cap Rocky Ridge to the south. Farther north, the major east-trending Tenderfoot Creek fault zone generally displaces Paleozoic units of the autochthon down on the north with respect to the same units on the south. Several lines of evidence suggest that the Tenderfoot Creek fault zone reflects crustal shear at depth. The linear fault zone is the northeast limit of deformation in the frontal fold and fault belt above the Black Canyon detachment fault. North of the fault zone, middle Paleozoic rocks are tilted west but generally not strongly deformed. Only north of Mud Creek (secs. 3–5, 8–10, T. 14 N., R. 3 E.) is the Mississippian Mission Canyon Limestone deformed in an elongate dome, likely over a small laccolithic intrusion at depth. Along the Tenderfoot Creek fault zone east from sec. 29, T. 14 N., R. 3 E., lower and middle Phanerozoic units are displaced by right-lateral oblique slip, down on the north. Fault-bounded wedges of the same strata are juxtaposed across faults in the zone in secs. 27 and 28, T. 14 N., R. 3 E., secs 24, 26, and 27, T. 14 N., R. 4 E., and sec. 30, T. 14 N., R. 5 E. Near the east end of the fault zone, Paleoproterozoic crystalline rocks are faulted up on the south against Paleozoic strata on the north. The fault zone ends at the Woods Mountain laccolith. During Eocene time, faults in the zone might have served as conduits for rising magma that formed the laccolith. At the west end, displacement on faults that form a graben along the zone diminishes west to Whitetail and Crooked Creeks (section *A–A'*, sheet 1). We conjecture that the circular fault enclosing faulted Pennsylvanian, Jurassic, and Cretaceous units intruded by dikes related to the Adel Mountain Volcanics (secs. 16, 17, T. 14 N., R. 1 E.) is a failed bysmalith along the trace of the deep crustal shear zone. The projected westward trace of the zone also marks the approximate southern extent of small intrusive bodies of the Adel Mountain Volcanics outside the main volcanic center.

The Montana disturbed belt, a zone of folded and thrust-faulted post-Mississippian rocks along the east front of the northern Rocky Mountain thrust belt, terminates in the northeast quarter of the Canyon Ferry Dam quadrangle (fig. 2, sheets 1–3). Folds and faults in the belt rise up plunge southeast to their termination along the Black Canyon decollement fault (Ts. 12–14 N., Rs. 2–3 E.). The decollement is in the evaporite succession in the lower upper part of the Upper Mississippian Kibbey Formation (figs. 5, 6, sheet 2). Underlying interstratified red beds and thin carbonate beds of the Kibbey are in continuous, little deformed succession with the underlying rocks of the autochthon. Faults immediately above the decollement generally juxtapose Upper Mississippian Heath and Otter Formations and uppermost part of the Kibbey Formation against folded rocks of the same units (fig. 5, sheet 2). Down plunge to the northwest, rocks as young as Late Cretaceous are preserved mainly in synclines above, or faulted over, tight disharmonic anticlinal folds that are strongly broken internally by faults. Generally the faults are nearly vertical or dip steeply southwest, although locally faults dip at low angles southwest (secs. 29, 31, 32, T. 14 N., R. 1 E.). Mudstone and siltstone beds of the Tyler or Heath Formations core most of the broken folds (section *A–A'*, sheet 1). Hornblende biotite sills intruded in the Tyler and Heath Formations and lower part of the Amsden Formation are folded, locally to dip at high angles, and faulted with those sedimentary units.

Northwest from the up-dip termination of the frontal fold and fault belt along the Black Canyon decollement fault, erosion has exposed different structural levels along the western part of the belt. Between the north margin of the Moors Mountain thrust fault klippen (northwestern part T. 13 N., R. 1 E., and secs. 31, 32, T. 14 N., R. 1 W.), erosion has exposed successive thrust slices that displace Pennsylvanian through Cretaceous strata east over folded and thrust rocks of the same ages. Thrust faults at this structural level are more tightly imbricated than in adjacent areas and flatten in exposures northwest to bottom generally in either the upper part of the Heath Formation or the Amsden Formation (secs. 29–31, T. 14 N., R. 1 W.). Displacement on the faults diminishes in folds in Mesozoic rocks southeast toward, and under, the klippen of the Moors Mountain thrust fault; the structure emerges southeast up plunge from beneath the klippen as a broad syncline exposed across the basin of Calamity Gulch (N½ T. 12 N., R. 2 E.).

From the upper reaches of Elkhorn Creek (southwest corner T. 14 N., R. 1 W.) to the northwest edge of the quadrangle, erosion to a deeper structural level has exposed folded strata of the Upper Mississippian Big Snowy Group. The upper part of the Kibbey Formation and the Otter Formation core tight upright or overturned anticlines. Beds of the Heath Formation core the intervening synclines (T. 14 N., R. 2 W.; sheets 1, 3). Generally, the tight folds are not broken by faults. Only two significant thrust faults with limited stratigraphic separation displace beds at the lower structural level. On the west margin of the exposed deeper structural level (sec. 18, T. 14 N., R. 2 W.), the Amsden Formation is preserved locally in a tight syncline. Along the east margin, Pennsylvanian through Lower Cretaceous strata, in fault contact with the older rocks, are folded in an asymmetrical to eastward-overturned syncline (secs. 13, 14, 24, T. 14 N., R. 2 W.). The younger rocks project northwest and, down plunge to the north, are faulted over the folded Upper Mississippian rocks (Schmidt, 1977), to appear on the upper plate of the Moors Mountain thrust fault and a subthrust fault in secs. 18, 19, 29, and 32, T. 14 N., R. 2 W. None of the tight folds or faults across the lowest exposures involves rocks of the Mission Canyon Limestone. Similarly, southeast across the highest exposed structural levels to the bounding decollement fault, none of the imbricate thrust faults or broken folds involves Mission Canyon strata. From these relations we infer that the decollement fault within the Kibbey Formation is present under the frontal fold and fault belt northwest across the Canyon Ferry Dam quadrangle nearly to the current trace of the major overlying Moors Mountain thrust fault (fig. 2, sheets 1–3; section *A–A'*, sheet 1).

Intrusive relations among rocks and structures of the frontal fold and thrust belt and the Adel Mountain Volcanics establish the approximate age of deformation in the belt. In the north-northwestern part of the Canyon Ferry Dam quadrangle, the Upper Cretaceous Two Medicine Formation is locally thrust over the Adel Mountain Volcanics, but southeast along strike, the Adel Mountain volcanic rocks, in turn, intrude the thrust fault (secs. 12, 13, T. 14 N., R. 2 W. and secs. 17, 18, T. 14 N., R. 1 W.). Overlapping thrust faulting and volcanism are documented also at the south end of the Adel Mountain Volcanics in the Middle Creek Lake area. There, latite stocks intrude Lower and Upper Cretaceous strata that were earlier deformed during thrust faulting (secs. 23–26, 35, 36, T. 14 N., R. 1 W.; fig. 4, sheet 2). A nearby thrust fault, which ends on the north against Adel Mountain Volcanics, seems to displace Pennsylvanian though lower Upper Cretaceous rocks against a small outlying stock of the Adel Mountain complex (sec. 19, T. 14 N., R. 1 E.). The age of the Two Medicine Formation, youngest stratigraphic unit involved in thrust faulting in the frontal fold and fault belt, is about 80–74 Ma and that of the Adel Mountain Volcanics is 76–73 Ma. The age of thrust faulting seems to be limited between about 75 and 73 Ma.

A complex sequence of thrust sheets is present southwest and west structurally above the frontal fold and fault belt. The lowest, and demonstrably the oldest, structural block in the thrust sequence is the Avalanche Butte block (fig. 2, sheets 1–3). Mesoproterozoic strata on the faulted south side of the Dry Range fault zone form the core of the Avalanche Butte block as far west as Beaver Creek and Wagner Gulch (secs. 1, 2, T. 11 N., R. 2 E., and secs. 35, 36, T. 12 N., R. 2 E.). Overlying Paleozoic units, contiguous east-northeast across faults with rocks of the autochthon, are broadly folded, but faulted, in up-plunge exposures of the structural block (secs. 25–28, T. 12 N., R. 2 E.). The southwest limb of the broader fold, including Cambrian through Mississippian units, is overturned in a northeast-verging recumbent syncline (secs. 33, 34, T. 12 N., R. 2 E. and secs. 3–5, T. 11 N., R. 2 E.). The Mission Canyon and Lodgepole Limestones on that limb are progressively more deformed northwest along the block: exposed in a window in Trout Creek Canyon (secs. 17, 19, 20, 29, 30, T. 12 N., R. 1 E.), the units are recumbently folded and imbricated in thin sheets by thrust faults (Reynolds, 2003). Farther northwest, between Soup Creek and Hunters Gulch (Ts. 12, 13 N., R. 1 W. and T. 13 N., R. 2 W.), successive structural levels of the Avalanche Butte thrust block are exposed: Middle Cambrian through lower Upper Mississippian rocks are stacked in a complex of recumbent and asymmetric folds separated by folded thrust faults (fig. 3, sheet 2; Reynolds and Hays, 2003). The structurally higher Hogback Mountain and Moors Mountain thrust sheets override the complex.

The Hogback Mountain thrust sheet overlies and is younger than the Avalanche Butte structural block (fig. 2, sheets 1–3). Exposures of the sheet are limited to the southwest margin of the Avalanche Butte block, and in erosional windows on the east flank of the Avalanche Butte block from Sunshine Basin (west edge T. 12 N., R. 2 E.) northwest across Beaver Creek (T. 13 N., R. 1 W.). At the surface, Mesoproterozoic rocks of the Greyson Formation and Paleozoic rocks as young as the Mission Canyon Limestone are generally overturned in the Hogback Mountain thrust sheet (section *A–A'*, sheet 1; sheet 3). In limited exposures between Nary Time Gulch and upper Avalanche Creek (northwest corner T. 11 N., R. 2 E.), fault slices of overturned Middle Cambrian rocks form the base of the Hogback Mountain thrust sheet. In wider exposures east of Nelson in Beaver Creek (secs. 6–8, T. 12 N., R. 1 W.; sec. 31, T. 13 N., R. 1 W.; secs. 1, 2, T. 12 N., R. 2 W.; and sec. 36, T. 13 N., R. 2 W.), overturned Greyson Formation and Flathead Sandstone override the westerly recumbent syncline limb of the Avalanche Butte block. The Beaver Creek area is critical for distinguishing between the Hogback

Mountain thrust sheet and the overlying Moors Mountain thrust sheet, for there the Greyson Formation on each sheet is juxtaposed across the Cenozoic Soup Creek normal fault (fig. 2, sheets 1–3). On the Hogback Mountain sheet, the Flathead Sandstone is stratigraphically unconformable on, but structurally beneath, the lower and lower middle part of the Greyson Formation. By contrast, on the Moors Mountain thrust sheet directly to the west, the Flathead is unconformable on beds of the Spokane Formation that, in turn, conformably overlies a thick succession of middle and upper Greyson strata.

Along the east flank of Hogback Mountain, the Greyson Formation and overlying succession of Paleozoic rocks on the upper plate of the Hogback Mountain thrust fault rest on steeply east dipping rocks of the Mission Canyon Limestone. The thrust fault (fig. 2, sheets 1–3) dips steeply east then flattens beneath a broken recumbent syncline on the upper plate. In sec. 20, T. 13 N., R. 1 W., the overturned Hogback Mountain thrust fault is overridden by the Moors Mountain thrust fault (fig. 3, sheet 2; Reynolds and Hays, 2003; Reynolds, 2003). Southeast of Beaver Creek, the Hogback Mountain thrust sheet is overfolded, and the recumbent fold is refolded so that the youngest involved units, the Mission Canyon and Lodgepole Limestones, crop out dipping radially under older rocks along a sinuous overturned synclinorium (sheet 3; Reynolds, 2003). In the Sunshine Basin area, the overturned Flathead Sandstone, exposed over a wide area in secs. 11–13, T. 12 N., R. 1 E., is overlain by the structurally inverted middle and lower part of the Greyson Formation. A large klippen of the Moors Mountain thrust sheet, comprised of a north-dipping upright succession of the Newland and Greyson Formations, rests on the complexly overfolded rocks of the Hogback Mountain thrust sheet (T. 13 N., Rs. 1, 2 E.; north edge T. 12 N., R. 1 E.; fig. 2, sheets 1–3). Along the east edge of the Hogback Mountain thrust sheet, formations are overturned against the Avalanche Butte block or the frontal fold and fault belt.

We interpret that the Hogback Mountain thrust sheet is the folded and detached southwest and west limb of the deformed fold system of the Avalanche Butte thrust block (section *A–A'*, sheet 1). Displacement on the thrust is likely at least 6–10 km, but movement was likely more internally complex with thin detached intraplate sheets moving differentially with respect to the basal thrust and in response to the overriding Moors Mountain thrust sheet. The greatest complexity within the Hogback Mountain thrust sheet spatially coincides with, but is disharmonic on, the greatest structural complexity in the underlying Avalanche Butte thrust block. This structural complexity lies obliquely across the projected west-northwest trace of the Lewis and Clark tectonic zone (fig. 2, sheets 1–3).

The Moors Mountain thrust fault extends from northwest to southeast across the Canyon Ferry Dam quadrangle. In sec. 14, T. 14 N., R. 3 W., the fault emerges as a high-angle fault with little displacement from an anticlinal fold in the Lower Cretaceous Kootenai Formation. The Kootenai and underlying formations are folded across the trace of the fault and are in stratigraphic continuity with older Mesozoic and upper Paleozoic units that are tightly folded and continue down plunge northwest of the quadrangle in the frontal fold and fault belt (Schmidt, 1977). Southeast from its emergence, the Moors Mountain fault cuts structurally down through the stratigraphic section on the hanging wall, and the dip of the fault gradually flattens west. In exposures about 19.7 km southeast on the north flank of Moors Mountain, the fault dips west at a low angle beneath the Mesoproterozoic Greyson Formation (NE¼ sec. 9, T. 13 N., R. 1 W.) and overrides a northeast-verging recumbent syncline in upper Paleozoic and Mesozoic strata in the shared limb of the Hogback Mountain and Avalanche Butte thrust blocks. The thrust fault continues west at a low angle from Moors Mountain to the Cenozoic Soup Creek normal fault along which the Moors Mountain thrust plate is displaced down to the west (secs. 26, 35, T. 13 N., R. 2 W.; Reynolds and Hays, 2003). About 6 km farther south in Bridge Creek (east edge sec. 12, T. 12 N., R. 2 W.), the Moors Mountain fault emerges east from the Soup Creek fault and descends structurally at a low angle east and southeast through the Greyson and Newland Formations that comprise the upper plate. The thrust-truncated contact between the Greyson and Newland Formations in sec. 7, T. 12 N., R. 1 W. on the upper plate provides the stratigraphic relation and piercing point to correlate the Moors Mountain thrust fault with the same point and relation (secs. 35, 36, T. 13 N., R. 1 W.) in the large klippen of the thrust sheet about 8 km east (fig. 2, sheets 1–3; Reynolds, 2003). Neoproterozoic diorite sills in the Newland Formation on the klippen (secs. 10, 11, T. 12 N., R. 1 E.) are in the same stratigraphic sequence as sills in the Moors Mountains thrust plate to the south-southwest (secs. 28–30, 34, T. 12 N., R. 1 E.). The principal trace of the Moors Mountain thrust fault[1] continues southeast across the east-central part of the Big Belt Mountains.

Displacement along the Moors Mountain thrust fault is a minimum of about 19 km as calculated from the projected

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[1]Pardee and Schrader (1933, p. 129; pls. 2, 15) named the thrust fault at the mouth of Trout Creek Canyon (secs. 29, 30, T. 12 N., R. 1 E.) the "Scout Camp overthrust fault." The name "Scout Camp thrust" was subsequently applied by several workers (for example, Woodward, 1982) variously to the same fault or strands of lower faults farther southeast without knowledge of relations northwest and northeast of the original limited site. Inasmuch as application of the name "Scout Camp thrust" has been inconsistent, correlation of the fault has been uncertain, and the name came from a temporary human site (the original location of which is not certainly known and has not existed for more than six decades), the name is here abandoned. The Moors Mountain fault was previously considered a different, presumably higher fault (Woodward, 1982), the southeasterly trace of which was apparently mistaken for the late Tertiary Soup Creek normal fault, identified by Reynolds and Hays (2003). The Moors Mountain thrust fault is named for Moors Mountain (secs. 9, 16, T. 13 N., R. 1 W.), below which the fault crops out continuously northwest, south, and west (east edge fig. 3, sheet 2). The continuity of structural relations along the fault is here documented from emergence of the fault from a fold in Cretaceous rocks in the northwest corner of the map area across the known extent of the fault in the Canyon Ferry Dam and adjacent quadrangles (sheets 1–3). The name Moors Mountain thrust fault applies also to the outlier of the same low-angle fault at the base of the large klippen of Mesoproterozoic rocks across Jim Ball Basin and upper reaches of Rock Creek (Ts. 12, 13 N., R. 1 W.; Ts. 12, 13 N., Rs. 1, 2 E.).

subsurface cutoff of the contact between the Greyson and Newland Formations and the northeast extent of the Greyson Formation on the klippen of the thrust plate at Elk Ridge (sec. 16, T. 13 N., R. 1 E.; section *A–A'*, sheet 1). Depending on the extent of folding, now concealed, before thrust faulting, displacement might be as much as about 30 km. The northeast extent of the upper plate is not known beyond exposures of the Moors Mountain klippen in sec. 31, T. 13 N., R. 2 E. Between Avalanche Butte on the southeast and down-plunge exposures northwest near Candle and Moors Mountains, the thrust plate is warped along a northwest-trending axis over both the Hogback Mountain plate and Avalanche Butte block by post-thrust arching of the block (section *A–A'*, sheet 1). The linearity of the trace of the Moors Mountain thrust fault from the upper part of Beaver Creek (sec. 11, T. 11 N., R. 2 E.) as far east as the Smith River (secs. 31, 32, T. 11 N., R. 5 E.) suggests that the fault dips more steeply southwest along that segment than farther northwest and has a component of left-lateral shear. In the southeast corner of the quadrangle, the dip of the fault surface declines southwest as the trend of the fault trace curves southeast.

The Eldorado thrust fault is structurally the highest major thrust fault in the Canyon Ferry Dam quadrangle. Along the fault, Mesoproterozoic rocks of the Spokane and Greyson Formations on the upper plate have been transported east and northeast over folded and imbricated rocks ranging in age from Mesoproterozoic through Late Cretaceous in the lower plate. Stratigraphic and structural separation along the Eldorado thrust fault decrease south and east. In the northwest corner of the quadrangle, the lower part of the Greyson on the upper plate is thrust over imbricated sheets of Upper Cretaceous Two Medicine Formation and associated shallow igneous intrusive rocks (Ts. 13, 14 N., R. 3 W.). Northwest and south of Upper Holter Lake, the thrust fault juxtaposes the Greyson Formation over tightly folded upper Paleozoic and Lower Cretaceous strata. Farther southeast along Hauser Lake, the thrust fault cuts downward across Mississippian through Middle Cambrian rocks of the lower plate into strata of the Spokane Formation. From near Eldorado Bar (secs. 11–14, T. 11 N., R. 2 W.) south to the Metropolitan Bar area (secs. 25, 36, T. 11 N., R. 2 W.; secs. 30, 31, T. 11 N., R. 1 W.), as the fault cuts stratigraphically downward on rocks of the lower plate, the thrust rises stratigraphically in the upper plate from the middle to the uppermost part of the Greyson Formation. The change in stratigraphic position of the thrust fault between the upper and lower plates suggests that the throw on the fault decreases southeast. We infer that the stratigraphic and structural separation between the plates decrease nearly to zero in the subsurface between lower Magpie and Little Hellgate Gulches (secs. 12, 13, T. 10 N., R. 1 W., and secs. 7, 18, T. 10 N., R. 1 E.). Thus, Paleozoic rocks and the Mesoproterozoic Empire and Spokane Formations in the Spokane Hills were likely folded but structurally contiguous with equivalent rocks now exposed along the southwest side of the Big Belt Mountains prior to middle and late Cenozoic extension by normal faulting (section *C–C'*, sheet 1). As stratigraphic and structural separation decrease southeast on the Eldorado thrust fault, stratigraphic and structural separation on the next lower Moors Mountain thrust fault increase southeast.

Relations among the major thrust faults document times of thrust faulting and folding and convey implications for patterns of crustal deformation. The Hogback Mountain thrust sheet overrides and is younger than the moderately to intensely deformed Avalanche Butte block. Both the Hogback Mountain and Avalanche Butte plates were folded anticlinally before emplacement of the Moors Mountain thrust sheet that truncates the folded Hogback Mountain thrust fault and rests on the deformed Avalanche Butte thrust block. In turn, the Moors Mountain thrust is warped over both the Hogback Mountain and Avalanche Butte sheets, thus documenting successive, but distinct, episodes of folding associated with the thrust faulting. Structural relations among the three plates document clearly that the thrust faults are successively younger from east to west.

Northwest of the Canyon Ferry Dam quadrangle, strata of the upper plates of the Avalanche Butte and Hogback Mountain sheets are deformed under the Eldorado thrust fault (Schmidt, 1977; R.G. Schmidt, U.S. Geological Survey, written commun., 1982, map scale 1:48,000; Mudge and Earhart, 1983). We infer that movement on the Eldorado thrust plate is in part older than, and in part contemporaneous with, displacement on the Moors Mountains fault.

The succession of major thrust plates is folded across strike by the east-southeast-trending Beartooth Ranch syncline (sec. 34, T. 14 N., R. 3 W., east-southeast to sec. 15, T. 13 N., R. 1 W.). Folding that produced the syncline was not only transverse to and began later than initial phases of folding across the Avalanche Butte thrust block, but also recurred after emplacement of all the thrust sheets. About 18 km south of the syncline, the strike of the Eldorado thrust fault changes abruptly from north to mainly east to produce an apparent left-lateral bend in the trace of the fault (north edge T. 11 N., Rs. 2, 3 W.). Rocks along the east trend of the Eldorado fault are crushed and intensely sheared (Schmidt, 1986, p. 20), likely as a result of strike-slip movement. As displacement on the Eldorado thrust fault decreases east-southeast and south along the south margin of the bend, subordinate thrust faults emerge from beneath the principal thrust fault (sec. 6, T. 11 N., R. 2 W.) to cut east and south through the stratigraphic succession as deeply as the Mesoproterozoic Spokane Formation. Stratigraphic separation on the subordinate faults also diminishes east and south.

The major east bend in the trace of the Eldorado thrust fault is on structural strike with the younger Helena Valley fault zone to the west (fig. 2, sheets 1–3; north edge T. 11 N., Rs. 2, 3 W., and south edge T. 12 N., Rs. 2, 3 W.) and the Dry Range fault zone on the east. That general structural trend, together with other spatially coincident structural and stratigraphic changes, defines a major structural boundary in the Earth's crust that crosses the center of the Canyon Ferry Dam quadrangle. We interpret the boundary as the eastern extension of the Lewis and Clark tectonic zone (fig. 2, sheets 1–3; Reynolds, 1977; Reynolds and Kleinkopf, 1977).

Deformation along and adjacent to the zone has been complex and recurrent through time.

Several structural relations define the trace of the Lewis and Clark tectonic zone across the Canyon Ferry Dam quadrangle. Within the inferred trace of the tectonic zone, the Moors Mountain thrust fault ramps up section from the lower part of the Newland Formation north through the lowest part of the Greyson Formation. Recumbent folding with folded internal thrust faults in the Avalanche Butte thrust block increases north within the zone. Cross folds in overturned rocks of the upper plate of the Hogback Mountain thrust sheet and in the Avalanche Butte sheet as well as the later Beartooth Ranch syncline are within and parallel to the westerly trend of the zone (Ts. 12, 13 N., R. 1 W.; sheet 3; Reynolds, 2003; Reynolds and Hays, 2003). The major fault along which the Paleoproterozoic crystalline basement block is faulted against Mesoproterozoic and younger strata follows the eastern trace of the tectonic zone. That major fault projects west beneath the area of greatest structural complexity in the Hogback Mountain and Avalanche Butte thrust sheets (section *A–A'*, sheet 1). We infer that the structural complexity resulted from crustal shortening by folding and thrusting in stratified rocks with concurrent shear along the structural boundary between crystalline basement rocks on the north and a thick sequence of Mesoproterozoic strata on the south. The southern up-dip termination of the frontal fold and fault belt in the Antelope and Rock Creek areas (Ts. 12, 13 N., R. 2 E.) lies within the tectonic zone. Stratigraphic separation on the Eldorado thrust fault decreases to an end along the south margin of the belt. In the eastern part of the quadrangle, extensional normal faults of middle and late Cenozoic age, including the Camas Creek fault and the southeastern extension of the Moors Mountain fault, along which Smith River Valley has been faulted down against adjacent bedrock hills, extend south from the tectonic zone (Reynolds, 1978, p. 191; fig. 3, p. 189). Within the eastern part of the Lewis and Clark tectonic zone, no Cenozoic normal faults are known north of the Dry Range fault zone (fig. 2, sheets1–3).

Stratigraphic relations that document the trend and recurrent structural movement along the tectonic zone include (1) the onlap by the Middle Cambrian Flathead Sandstone from a thick sequence of Belt Supergroup strata on the south across the principal fault onto Paleoproterozoic granite gneiss north of the fault; (2) the east to west and north truncation across the tectonic zone of the Spokane Formation and upper part of the Greyson Formation by pre-Flathead uplift and erosion; (3) the truncation of the Mesoproterozoic Helena and Empire Formations along the south margin of the zone; (4) the apparent southern margin of the evaporite facies of the Upper Mississippian Kibbey Formation within the zone; (5) the southern extent of the Tyler Formation prior to erosion and deposition of the Pennsylvanian Amsden Formation; and (6) the northern extent of Late Cretaceous plutons of the Boulder batholith suite, Spokane Hills, and Big Belt Mountains.

The Helena Valley fault zone (fig. 2, sheets 1–3) marks the trace of the Lewis and Clark tectonic zone across the central western part of the quadrangle. Faults including the Spokane Bench, Spokane Hills, Regulating Reservoir, and Big Belt Mountains frontal fault zones splay south and southeast from the Helena Valley fault. A major fault, defined beneath Canyon Ferry Lake by gravity and aeromagnetic studies (sheets 1–3; Davis and others, 1963), is likely also a splay from the Lewis and Clark tectonic zone. These faults generally displace narrow segments of the crust systematically down to the west, and movement on the faults is generally younger than middle Miocene. The Bald Butte fault zone along the southwest margin of Helena Valley (fig. 2, sheets 1–3) is a major splay from the Lewis and Clark tectonic zone. Displacement on faults in Helena Valley and on faults along the east side of the Big Belt Mountains, together with the long history of recurrent movement and major offset along faults in the Lewis and Clark tectonic zone, suggest that it is a major intraplate transform fault zone (Reynolds, 1979; Reynolds and Kleinkopf, 1977, p. 1140). The normal faults that splay south from the zone accommodate extension as the crustal block on the south side of the transform extends west with respect to the crustal block north of the Lewis and Clark zone (Reynolds, 1979). Recurring present-day earthquakes along faults such as the Helena Valley, Spokane Bench, and Black Butte fault zones (Schmidt, 1986, p. 13, 16, 17), and along the Big Belt Mountains frontal fault zone and the Camas Creek fault (M.W. Reynolds, interpreted from Reviewed Earthquake Locations, Montana Bureau of Mines and Geology), document active crustal movement on faults across much of the south half of the Canyon Ferry Dam quadrangle.

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DESCRIPTION OF MAP UNITS

Qa **Alluvium (Holocene)**—Unconsolidated stratified to unstratified sand, gravel, silt, and clay, deposited primarily by streams; locally includes some colluvium and some gravel on low terraces in stream valleys. Thickness as much as 18 m

Qc **Colluvium (Holocene)**—Unconsolidated rock fragments and finer sediment that have moved by sheetwash or slow creep down hillsides to accumulate in downward-thickening wedge on the slope. Includes talus cones on steep mountainsides. Thickness as much as 20 m

Qac **Alluvium and colluvium, undivided (Holocene)**—Unconsolidated stratified to unstratified rock fragments, blocks, gravel, sand, and silt deposited by gravity and sheet wash in cones and fan-shaped deposits on valley sides; includes alluvium and colluvium along eroding narrow shoreline of Canyon Ferry Lake

Ql **Landslide deposit (Holocene and Pleistocene)**—Angular rock fragments, blocks, and soil that have moved down slope as a single unit. Generally chaotic and unstratified fragments, locally weakly stratified; supports hummocky topography. Superimposed or immediately adjacent deposits of different ages shown locally by common internal map contacts. Thickness as much as 60 m

Qlb **Landslide deposit of basalt fragments (Holocene and Pleistocene)**—Major loose accumulations of angular basalt fragments that have broken from and moved down slope from basalt flows OGb that cap high erosion surfaces in north-central part of map area. Thickness as much as about 45 m

Qd **Debris flow deposit (Holocene and Pleistocene?)**—Angular rock fragments and some blocks in a matrix largely of mudstone-derived clay, silt, and soil that have moved down slope as a unit, usually by abrupt slumping. Generally chaotic and unstratified fragments, locally weakly stratified; supports hummocky topography generally with an arcuate scarp at the top and a bulbous base. Thickness as much as about 20 m

Qdt **Dredge tailings (Holocene)**—Cobbles, pebbles, and small boulders with some interstitial sand and silt, mostly in arcuate, concentric windrows produced by discharge from floating dredges. Present along banks of Missouri River in west-central part of map area. Thickness estimate 15 to locally 25 m

Qt **Terrace gravel (Holocene and Pleistocene)**—Rounded pebbles and cobbles with sand and silt matrix of fluvial origin. Gravel rests on an erosion surface that slopes gently downstream and is separated from the floodplain of an adjacent stream by a steeper slope that rises from the stream bottom. Thickness as much as 5 m

Qp **Pediment gravel (Holocene? and Pleistocene)**—Thin accumulation of cobbles, pebbles, and scattered small boulders with sand and silt matrix, which rests on a widespread surface of low relief eroded across underlying bedrock. As mapped between lower Camas Creek and Smith River, unit rests on broad surface cut adjacent to one or more topographically higher, broad surfaces that are also mantled with thin, locally cemented gravel (QTp_1, QTp_2). Thickness as much as about 5 m

Qpw **Pediment gravel with windblown silt and sand (Holocene? and Pleistocene)**—Thin accumulations of cobbles, pebbles, and scattered small boulders with sand and silt matrix discontinuously covered by a veneer of eolian silt and very fine sand, which rest on a widespread surface of low relief eroded across underlying bedrock. Surface slopes gently from base of mountain range into adjacent valley. Mapped on west flank of Spokane Hills and on east side of Hauser Lake adjacent to Big Belt Mountains. Thickness as much as about 5 m

Qbg **Boulder gravel (Holocene or Pleistocene)**—Rounded to well-rounded cobbles and boulders of Paleozoic and Mesozoic rock types derived by erosion from upstream in drainage in which deposits occur. Boulders commonly as large as 1.5–2 m across. Deposits rest on local surfaces cut across bedrock at elevation 5–15 m above adjacent stream channels. Thickness as much as 4 m

Qoa **Old alluvium (Holocene or Pleistocene)**—Unconsolidated stratified to unstratified sand, gravel, silt, and clay at heads of streams now eroding into adjacent bedrock, or which mantle irregular slopes that rise above modern alluvial channels. Deposited primarily by streams and sheetflow. Thickness as much as 10 m

Qog **Old gravel (Holocene or Pleistocene)**—Generally unconsolidated weakly stratified gravel, containing mainly small cobbles and pebbles with minor sand and silt; deposited by streams; clasts rounded to subrounded; at several elevations above recent stream channels. Generally, unit does not contain common boulders as does unit Qbg. Thickness 0–4 m

Qgt **Glacial till (Pleistocene)**—Unsorted deposits of sand, pebbles, cobbles, and boulders generally suspended in a matrix of silt, clay, and sand; occupies glacially eroded valleys in Boulder Baldy area of Big Belt Mountains, south-central edge of map area. Deposits occur as ground moraine and arcuate end moraines. Thickness as much as about 45 m

Qgo **Glacial outwash deposit (Pleistocene)**—Stratified to weakly stratified deposit mainly of sand and gravel, which accumulated beyond end moraine of Birch Creek glacier. Mapped in valley of Big Birch Creek in southeast corner of map area. Thickness as much as about 15 m

Qgl **Glacial lake Great Falls deposit (Pleistocene)**—Silt, sand, and clay; very thin bedded, locally laminated like glacial varves; rare thin lenses of vitric volcanic ash; light yellowish gray, very light gray, and very pale grayish orange. Deposited in glacial lake Great Falls. Present discontinuously along shoreline of Missouri River from northwest corner of quadrangle southeast to upper part of Hauser Lake. Thickness as much as 18 m

QTa **Older alluvium (Pleistocene or Pliocene)**—Unconsolidated to weakly consolidated sand, pebble and cobble gravel, silt, clay, and local minor volcanic ash; stratified; local cut-and-fill channels; includes some colluvium; in fan-shaped accumulations now separated from adjacent stream systems by erosion. North of Lake Helena (secs. 1, 2, 3, and 11, T. 11 N., R. 3 W.), unit might represent alluvium deposited by ancestral Missouri River and its local tributaries. Unit mapped also in drainage of Middle Creek, north-central part of map area, in secs. 4, 5, 8, and 9, T. 11 N., R. 3 E., and in sec. 7, T. 14 N., R. 6 E. Thickness as much as 11 m

QTl **Older landslide deposit (Pleistocene or Pliocene)**—Angular rock fragments, and blocks that have moved down slope as a single unit, likely as a single event. Deposit is chaotic and unstratified, locally weakly stratified; supports hummocky topography. Chaotic rock fragments and blocks are now separated topographically by incised channels and valleys from bedrock units from which the fragments were derived. Thickness as much as 60 m

QTt **Older terrace gravel (Pleistocene or Pliocene)**—Thin deposits of cobbles and pebbles in matrix of sand and some silt; locally indurated by silt and clay in matrix; rests on narrow erosional surfaces above young terraces but below extensive surfaces capped by pediment gravel. Mapped adjacent to Canyon Ferry Lake near south-central edge of quadrangle; south of Louisville in sec. 7, T. 9 N., R. 1 W.; in secs. 1 and 12, T. 11 N., R. 4 E.; and in Elk Creek drainage, secs. 22 and 27, T. 14 N., R. 1 E. Thickness as much as 6 m

QTp **Older pediment gravel, undivided (Pleistocene and Pliocene)**—Thin accumulations of cobbles, pebbles, and scattered small boulders with sand and silt matrix, locally cemented by carbonate cement and containing rare carbonate veinlets, which rest on a widespread surface of low relief eroded across underlying bedrock; local shallow channels filled with gravel at base of unit. Gravel mantles a surface, common between drainages, which slopes gently from the base of a mountain range into the adjacent valley. Thickness as much as about 5 m

QTp_1 **Older pediment gravel, lower level overlying rocks of Miocene and Oligocene age (Pleistocene and Pliocene)**—Thin accumulations of cobbles, pebbles, and scattered small boulders with sand and silt matrix, locally cemented by carbonate cement and containing rare carbonate veinlets, which rest on a widespread surface of low relief eroded across underlying bedrock, generally Miocene and Oligocene rocks. Gravel mantles a broad eroded surface topographically lower than adjacent deposits of unit QTp_2, but higher than unit Qp. The surface on which unit QTp_1 was deposited slopes gently from the base of a mountain range into the adjacent valley. Thickness as much as about 5 m

QTp_2 **Older pediment gravel, upper level overlying rocks of Miocene age (Pleistocene and Pliocene)**—Thin accumulations of cobbles, pebbles, and scattered small boulders with sand and silt matrix, locally cemented by carbonate cement and containing rare carbonate veinlets, which rest on a widespread surface of low relief eroded across underlying bedrock, generally Miocene strata. The broad surface is topographically higher than the surfaces on which units QTp_1 and QTp rest. Gravel is on a surface that slopes gently from the base of a mountain range into the adjacent valley. Thickness as much as about 6 m

QTbg **Older boulder gravel (Pleistocene or Pliocene)**—Boulders as large as 1.2 m across and cobbles with minor sand and silt matrix; well-rounded to subrounded clasts; mantles topographic spurs or forms narrow linear deposits high on hillsides, separated from source areas for contained clasts and from young deposits of alluvium, colluvium, and boulder deposits by erosion. Thickness as much as about 6 m

QTg **Older gravel (Pleistocene and Pliocene)**—Gravel, sand, and some silt; unconsolidated to weakly consolidated; stratified and weakly stratified; deposited predominantly by streams; might include minor colluvium; clasts in silty or clayey silty matrix; clasts rounded to subrounded, subangular and locally angular; pebbles and small cobbles; deposits generally rest on uneven high erosional surfaces; clasts derived from nearby bedrock sources some of which are now separated by erosion from the deposit. Thickness as much as 18 m

PoMis **Sedimentary rocks, undivided (Pliocene and Miocene)**—Interbedded sandstone, pebble and boulder conglomerate, and scattered very thin lenses of lithic vitric tuff; pale grayish orange to yellowish gray; pebbles, cobbles, and boulders well rounded, most derived from bedrock units not now in the local drainage in which deposit occurs; contains scattered rounded and subrounded clasts derived from Oligocene ash-fall, ash-flow, and sandstone deposits; weathers to rounded slopes. Mapped in lower Black Butte Creek (secs. 11 and 12, T. 12. N., R. 5 E.), Horse Prairie (sec. 35, T. 12 N., R. 5 E.), and on divide between Clarks and Oregon Gulches (sec. 22, T. 11 N., R. 1 W.). Thickness as much as about 15 m

MiOgf **Fort Logan Formation (Miocene and Oligocene)**—Interbedded clayey siltstone, tuffaceous siltstone, poorly to moderately welded ash-flow tuff, tuffaceous diamictite, thin sandstone and conglomerate beds, minor claystone, and scattered clayey vitric tuff; pale yellowish gray, pale grayish orange, grayish orange, and locally pale pinkish red; laminated to very thin bedded; some ash-flow tuff beds and tuffaceous diamictite beds, which originated as tuffaceous lahars, are thick bedded; formation supports low cliffs and steep slopes from which the strata slake readily; contains scattered to abundant vertebrate remains; rests unconformably on strongly deformed pre-Oligocene rocks. Formation name applied in valley of Smith River from southeast corner of map area north to Beaver Creek (north edge T. 11 N., Rs. 3 and 4 E.) on west side of river, and to Whitetail Deer Creek (secs. 6, 7, 8, 9, 15, and 16, T. 11 N., R. 5 E.) on east side of river; grades north into unit MiOgs. Thickness as much as 85 m

MiOgs **Sedimentary rocks, undivided (Miocene and Oligocene)**—Interbedded clayey siltstone, sandstone, conglomerate, tuffaceous clayey siltstone, and lithic pumice tuff; very light gray, pale yellowish gray, pale grayish orange, and grayish orange; locally clay-rich matrix derived from vitric ash, and local calcareous matrix; well-rounded pebbles, cobbles, and local small boulders of resistate pre-Devonian rocks, and of carbonate rock clasts with admixed resistate rock types in northeastern part of map area; in northern

Townsend Valley, contains some thin beds of vitric lithic tuff and pumice vitric tuff; unit laminated to predominantly very thin and thin bedded; weathers to rounded slopes with ledges supported by tuffaceous bed and scattered pebbly sandstones. Remnants of unit are present on south flank of Bilk Mountain in secs. 2–4, 8, and 9, T. 10 N., R. 2 E. Thickness as much as 170 m in northern Townsend Valley and about 80 m in northeastern part of quadrangle

OGs **Sedimentary rocks, undivided (Oligocene)**—Interbedded pale-yellowish-gray, very light gray, light-grayish-orange, and locally pinkish gray sandstone, vitric lithic tuff, sandy tuff, pebble and cobble conglomerate, and clayey siltstone; lenses of carbonaceous siltstone near base southeast of Lake Helena; mainly laminated to very thin and thin bedded; thick beds of crossbedded pebble and cobble conglomerate support east-dipping cuestas on Spokane Bench; mapped west of Missouri River, Spokane Hills; at crest of Big Belt Mountains (sec. 2, T. 11 N., R. 1 E.; and adjacent to Buffalo Canyon, secs. 7 and 8, T. 12 N., R. 3 E. Thickness about 80–225 m

OGts **Tuff and tuffaceous sedimentary rocks (Oligocene)**—Interbedded very light gray, locally white, and light-yellowish-gray vitric tuff, vitric lithic tuff, and subordinate tuffaceous sandstone and sandy pebble conglomerate; local very thin carbonate-clast breccia; very thin and thin bedded, locally thick bedded; thin base-surge deposits locally exposed in excavations; unit forms smooth slopes mostly covered with a veneer of alluvium or colluvium; differs from unit OGs in dominant tuffaceous volcanic content, and likely originally interfingered with unit OGs east across the site of present Helena Valley

Ts **Sedimentary rocks (Miocene, Oligocene, and Eocene(?))**—Interbedded pale-grayish-yellow, very light gray, to pale-red lithic and feldspathic lithic sandstone and pebble conglomerate; minor vitric and vitric feldspathic tuff; very thin and thin bedded; local moderate-reddish-brown matrix of clayey siltstone on drainage divide north of Soup Creek (secs. 35 and 36, T. 12 N., R. 2 W., and sec. 2, T. 11 N., R. 2 W.); poorly exposed adjacent to Soup Creek fault (secs. 29, 30, and 32, T. 12 N., R. 1 W.). Exposed thickness 10–75 m

Tsb **Sedimentary breccia with pumice- and basalt-fragment tuff bed (Miocene or Oligocene)**—Interbedded pale-grayish-yellow, pale-brownish-gray, and pale-red sedimentary breccia with conspicuous very pale yellowish gray and white pumice lithic tuff; fragments in breccia are angular to subangular, comprised mainly of Upper and Lower Mississippian carbonate rock fragments with scattered well-rounded pebbles and rare cobbles of older silicic rocks; pumice fragments 1–5 cm across and basalt fragments 0.5–3 cm across in matrix of shards and comminuted pumice; some biotite and smoky quartz crystals; tuff bed is 2–2.5 m thick; unit dips south off Dry Range at angles as high as 26° in secs. 25 and 36, T. 12 N., R. 3 E. Thickness about 10–60 m

Tl **Landslide deposit (Miocene or Oligocene)**—Interleaved, intensely brecciated but coherent rock masses derived from the Three Forks Formation (Lower Mississippian and Upper Devonian), Jefferson Formation (Upper Devonian), and Pilgrim Formation (Upper Cambrian) associated with reddish-orange clayey sandy siltstone and silty conglomerate all resting with bedding at high angles on siltstone of the Wolsey Formation (Middle Cambrian) (secs. 19 and 30, T. 12 N., R. 5 E.). Brecciated masses are 3.2–9.6 km from present-day outcrops of parent bedrock units. Estimated thickness 0–20 m

Tr **Sedimentary rock rubble (Pliocene?)**—Angular blocks of brecciated and rehealed and unbrecciated Flathead Sandstone resting on the Mesoproterozoic Spokane and Greyson Formations along extended trace of Helena Valley fault zone (secs. 32 and 33, T. 11 N., R. 1 W.), and angular blocks of Flathead Sandstone and lower Paleozoic rocks on Paleozoic carbonate rocks beneath Eldorado thrust fault (secs. 34 and 35, T. 12 N., R. 2 W., and secs. 2 and 3, T. 11 N., R. 2 W.). As mapped in secs. 20 and 30, T. 12 N., R. 4 E., unit is likely an exhumed karst-fill deposit that consists of angular fragments of units Mm and Ml in matrix of pale-red and grayish-orange calcareous siltstone. Estimated thickness 0–7 m

OGb **Basalt (Oligocene)**—Trachybasalt; very dark gray to black, locally reddish orange; microcrystalline, generally equicrystalline; local phenocrysts of olivine, and rare fine dikes of biotite pegmatite. Sequences of one to six flows rest on surfaces of low relief eroded across older rocks in north-central part of quadrangle; radiometric ages range from 30.09±0.13 to 32.84±0.23 Ma (L.W. Snee and D.P. Miggins, U.S. Geological Survey, written communs., 2001, 2002). Thickness as much as 150 m

OGbp **Basalt in plug or volcanic neck (Oligocene)**—Trachybasalt; very dark gray to black, locally reddish orange; microcrystalline, generally equicrystalline; local phenocrysts of olivine; commonly highly fractured; where exposed in relief as a result of erosion, shows vertical columnar jointing in cylindrical intrusive bodies; map unit includes volcanic necks consisting of andesitic basalt breccia in matrix of basaltic tuff and basalt (secs. 35 and 36, T. 13 N., R. 2 E.)

OGr **Rhyolite flows and shallow intrusive bodies (Oligocene)**—Light gray, moderate reddish brown, to pinkish gray; flow banded, locally spherulitic, lithophysal, and (or) vesicular; locally perlitic; grades locally into breccia with matrix of rhyolite; phenocrysts of quartz, smoky quartz, sanidine, and rare biotite and plagioclase feldspar in flow-banded layers; contains rare lithic fragments of quartz monzonite and Upper Cretaceous andesite; occurs as flows and small intrusive bodies in southwest corner of quadrangle. Exposures as thick as 60 m

Eor **Rhyolite (Eocene)**—Very light gray and yellowish-gray to pale-red, aphanocrystalline to microcrystalline rhyolite with scattered to common phenocrysts of quartz and some sanidine; flow banding locally evident; in adjacent White Sulphur Springs 30' x 60' quadrangle, $^{40}Ar/^{39}Ar$ age of rhyolite is 48.69 Ma (L.W. Snee and D.P. Miggins, U.S. Geological Survey, written commun., 2002)

Eobqm **Biotite quartz monzonite (Eocene)**—Medium to coarsely crystalline, equigranular quartz monzonite with common books and flakes of biotite; rare to locally common hornblende, and scattered pyroxene; alkali and sodic feldspars in nearly equal abundance; rock becomes finer crystalline and porphyritic in intrusive tongues into adjacent Paleozoic rocks; unit forms main body of Devils Footstool laccolith in northeastern part of quadrangle

Eobhqm **Biotite hornblende quartz monzonite (Eocene)**—Medium to coarsely crystalline, equigranular quartz monzonite with common to abundant books and flakes of biotite and hornblende in matrix of sodic and alkali feldspar in nearly equal abundance; common to scattered quartz crystals; forms main body of Woods Mountain laccolith in northeast corner of quadrangle; 43.8 Ma (L.W. Snee and D.P. Miggins, U.S. Geological Survey, written commun., 2002)

Eobd **Biotite dacite (Eocene)**—Medium-gray to medium-light-gray dacite: phenocrysts of biotite in very finely crystalline to aphanocrystalline groundmass of plagioclase feldspar, minute biotite, and minor hornblende; might be a distal phase of unit Eobhd that crops out nearby; occurs as thin sills near Smith River (secs. 12, 13, and 25, T. 12 N., R. 4 E.), in Dry Fork drainage (secs. 19, 20, 29, and 30, T. 11 N., R. 6 E.), and in Tenderfoot Creek drainage (secs. 16 and 21, T. 14 N., R. 4 E. and sec. 25, T. 14 N., R. 5 E.)

Eobhd **Biotite hornblende dacite (Eocene)**—Medium-gray to medium-light-gray dacite: phenocrysts of biotite and hornblende in very finely crystalline to aphanocrystalline groundmass of plagioclase feldspar, minute biotite, and some hornblende. Intruded along faults and fractures parallel to bedding in central eastern part of quadrangle and as sills adjacent to Tenderfoot Creek fault zone and along Smith River in northeastern part of quadrangle

Eoql **Quartz latite (Eocene)**—Porphyritic with finely crystalline to microcrystalline quartz latite: phenocrysts of biotite and scattered hornblende and pyroxene, in microcrystalline matrix of sodic and scattered alkali feldspar and rare quartz; distinguished from unit Eobqd by microcrystalline matrix and evident alkali feldspar in rock

Eobqd **Biotite quartz diorite (Eocene)**—Finely crystalline and porphyritic biotite quartz diorite; biotite and some hornblende phenocrysts in matrix of sodic feldspar with rare possible alkali feldspar and rare quartz

TKd **Garnet peridotite in diatreme (Tertiary or Upper Cretaceous)**—Breccia containing xenoliths of upper mantle and lower crustal rocks, host rock, and blocks of overlying sedimentary rock in alkali basalt matrix in nearly vertical pipe; xenocrysts and phenocrysts of olivine, clinopyroxene and spinel, peridotite, two-pyroxene granulite, and pyroxenite; rounded xenocrysts of olivine and chrome diopside; foundered slabs as much as about 9 m across of strata from the Blackleaf and Kootenai Formations and Upper Cretaceous rhyodacite welded tuff; diatreme exposed on south side of Ming Bar in sec. 13, T. 13 N., R. 3 W.

Kau **Adel Mountain Volcanics, undivided (Upper Cretaceous)**—Dark-gray, greenish-black, and dark-brownish-gray trachybasalt and trachyandesite breccia, abundant latite dikes and sills, and small intrusive bodies of quartz latite, latite, monzonite, and nepheline syenite; fragments in breccia are commonly porphyritic with phenocrysts of augite and andesine feldspar; locally contains feldspathoid minerals; crudely bedded locally, but generally breccias are massive; numerous dikes intrude breccia and extend southeast from principal exposures of unit into silty claystone of adjacent Lower Cretaceous marine strata; unit includes intrusive bodies in Tyrell and Wooden Shoe Creeks and small intrusive bodies in breccia south of Middle Creek Lake; $^{40}Ar/^{39}Ar$ radiometric ages establish the accumulation and emplacement of the rocks between approximately 73 and 76 Ma (Harlan and others, 2005)

Kad **Dacite**—Scattered dikes and small intrusive bodies of porphyritic dacite to latite composition, intruding main mass of Adel Mountain Volcanics and adjacent Lower Cretaceous strata

Kaql **Quartz latite**—Porphyritic to equigranular quartz latite; phenocrysts of biotite, some hornblende, and scattered, partially resorbed quartz; very finely to finely crystalline groundmass of sodic feldspar, hornblende, minor alkali feldspar, and scattered pyroxene. Present south of Middle Creek Lake in sec. 36, T. 14 N., R. 1 W.

Kal **Latite**—Porphyritic to equigranular hornblende biotite latite: phenocrysts of hornblende and some biotite in very finely to finely crystalline groundmass of sodic feldspar, hornblende, minor alkali feldspar, and scattered pyroxene; locally becomes more coarsely crystalline, grading into nepheline syenite and monzonite; comprises intrusive bodies in Middle Creek drainage

Kr **Rhyodacite flows or shallow intrusive bodies (Late Cretaceous)**—Aphanocrystalline calcic-rhyodacite: light olive gray, light brownish gray, and pale yellowish brown; abundant crystals of labradorite; local zones of amygdules; occurs as flows or intrusive sheets, nearly concordant with adjacent strata; present in northwest corner of quadrangle

Kbg **Biotite granite (Late Cretaceous)**—Medium crystalline biotite granite: pinkish gray and yellowish gray; orthoclase and microcline with minor calcium feldspar; common books and flakes of biotite; common interstitial quartz crystals; common to abundant nodules of tourmaline, and tourmaline along fractures. Intrudes Butte Quartz Monzonite (Kbqm) in southwest corner of quadrangle

Kqm **Quartz monzonite (Late Cretaceous)**—Quartz monzonite: finely to medium crystalline with coarsely crystalline phenocrysts; light gray to yellowish gray and pinkish gray; groundmass of alkali feldspar and rare quartz, with phenocrysts of alkali feldspar, biotite, hornblende, and aegirine augite; outer part of Boulder Baldy pluton has common fluorite as an accessory mineral. Boulder Baldy pluton was emplaced between 69 and 74 Ma (Snee and others, 2002)

Kbqm **Butte Quartz Monzonite (Late Cretaceous)**—Quartz monzonite: coarsely crystalline, locally medium crystalline and porphyritic; light gray, medium gray, and light pinkish gray; homogeneous with rare, faint, planar internal structure; euhedral to subhedral plagioclase crystals partly enclosed by alkali feldspar crystals and quartz. Alkali feldspar occurs as large euhedral to subhedral poikilitic twinned phenocrysts; quartz occurs as irregular crystals and intercrystalline masses and in graphic intergrowths with alkali feldspar; biotite occurs as euhedral books and as small isolated flakes; scattered hornblende crystals with irregular-shaped margins; rare pyroxene; accessory minerals include magnetite, ilmenite, sphene, zircon, and apatite; intruded by some aplite and pegmatite dikes; locally abundant zenoliths of diorite, welded tuff, and scattered other crystalline rocks; comprises Boulder batholith and is exposed in southwest corner of quadrangle. Youngest part of Boulder batholith crystallized between 68 and 78 Ma (du Bray and Snee, 2002, p. 9)

Kmd **Monzodiorite (Late Cretaceous)**—Quartz monzodiorite: medium crystalline and porphyritic; very light olive gray, very light gray, and yellowish gray; phenocrysts of perthitic alkali feldspar in matrix of intercrystalline quartz, plagioclase feldspar, hornblende, and rare biotite; contains apatite, zircon, and titanite; mapped as central zone of Boulder Baldy pluton in Big Belt Mountains at south edge of quadrangle and in Little Butte area in southwest corner of quadrangle

Kmo **Monzonite (Late Cretaceous)**—Medium to coarsely crystalline with finely crystalline margins; locally porphyritic with alkali phenocrysts as large as 3 cm; alkali and plagioclase feldspar in nearly equal proportions, with scattered to common quartz; common biotite; scattered hornblende and epidote after hornblende; medium and medium light gray, locally light gray and pinkish gray; rock grades locally into quartz monzonite southward in plutons of Spokane Hills; also present in sec. 16, T. 10 N., R. 5 E.

Kgd **Biotite granodiorite (Late Cretaceous)**—Granodiorite: medium to finely crystalline hypidiomorphic; medium gray and medium light gray to light olive gray; augite, biotite, hornblende, and hypersthene with intercrystalline labradorite feldspar, minor quartz and alkali feldspar; intruded by Butte Quartz Monzonite (Kbqm) in southwest corner of quadrangle

Kda **Dacite (Late Cretaceous)**—Porphyritic biotite dacite: medium gray and medium light gray; pale grayish red to grayish red where weathered or altered; phenocrysts of plagioclase feldspar, some as large as 8 mm across; zoned and twinned, commonly with resorbed rims; biotite phenocrysts 1–2 mm across; rare quartz crystals strongly resorbed; matrix is aphanocrystalline to very finely crystalline intergrowth of plagioclase feldspar and mafic minerals; rock forms Bilk Mountain pluton (north side of White Gulch in Big Belt Mountains), and is present between Camas Creek and Ayers Gulch, in lower reach of Thompson Gulch, and near Little Birch Creek in southeastern part of quadrangle

Kla **Latite (Late Cretaceous)**—Microcrystalline to porphyritic latite; light to medium gray, locally dark gray to grayish black; intergrown crystals of sodic feldspar, some alkali feldspar with hornblende and biotite; scattered pyroxene; locally contains uncommon quartz crystals; forms sills, dikes, and small irregular-shaped intrusive bodies

Ki **Basaltic and andesitic sills, dikes, and irregular-shaped bodies related to the Elkhorn Mountains Volcanics (Late Cretaceous)**—Aphanocrystalline to finely crystalline andesitic basalt and locally some rhyodacite; grades locally into syenodiorite and diorite porphyry. Some bodies have small phenocrysts of labradorite or augite, or both; hornblende in others. Mapped on east flank of Elkhorn Mountains in southwest corner of map area

Kt **Trachybasalt and syenogabbro (Late Cretaceous)**—Gray-dappled rocks that contain many small phenocrysts of labradorite and augite, and a few phenocrysts of alkali feldspar and olivine in zeolite-bearing, aphanitic to finely crystalline matrix; in semi-concordant sheets; present in northwest corner of quadrangle; might be related to the Adel Mountain Volcanics

Kqd **Quartz diorite (Late Cretaceous)**—Medium to finely crystalline, locally porphyritic quartz diorite; intergrown sodic feldspar and quartz, with scattered alkali feldspar; phenocrysts of biotite and chloritized hornblende; associated with hornfelsed Mesoproterozoic strata and might be an early intrusive phase of Boulder Baldy pluton; crops out from Big Birch Creek to Thompson Gulch in southeast corner of quadrangle

Kd **Diorite (Late Cretaceous)**—Medium to finely crystalline diorite, locally with feldspar and hornblende phenocrysts; andesine feldspar, hornblende, biotite, and uncommon pyroxene; medium dark gray, dark gray, and grayish black; occurs in sills in northwest corner of map area, and as a small intrusive body on northwest side of Confederate Gulch in central southern part of quadrangle

Kbd **Biotite diorite (Late Cretaceous)**—Finely to medium crystalline, with books and flakes of biotite and common hornblende; sodic feldspar and locally rare alkalic(?) feldspar; finer crystalline facies grades into dacite with appearance of some quartz; mapped west of Camas Creek

Khd **Hornblende diorite (Late Cretaceous)**—Sills and irregular-shaped intrusive bodies of hornblende diorite: dark olive gray to olive black, weathers medium to light olive brown; finely to coarsely crystalline, equicrystalline; friable upon weathering; biotite bearing; locally contains abundant epidote. Sills are concentrated in upper plate of Moors Mountain thrust fault and in Upper Mississippian and Pennsylvanian strata of disturbed belt with which sills are folded and faulted; a sill of hornblende diorite intrudes Eldorado thrust fault on west flank of Beartooth Mountain about 4.5 km west of northwest corner of quadrangle; within Canyon Ferry Dam quadrangle, Paleozoic strata containing hornblende diorite sills are both faulted against and overlain or intruded by the Adel Mountain Volcanics. Hornblende diorite sills are generally 1–8 m thick, but one major sill is as thick as 65 m

Kp **Pyroxenite (Late Cretaceous?)**—Medium to finely crystalline pyroxenite; very dark gray, dark greenish gray, to greenish black; intergrown crystals of clinopyroxene and brown hornblende with olivine and minor biotite; rare interstitial anorthite; abundant magnetite; exposed as two small bodies in sec. 17, T. 10 N., R. 5 E.; age uncertain; might be related to emplacement of Neoproterozoic diorite sill exposed about 5 km to the southeast

Kog **Olivine gabbro (Late Cretaceous)**—Coarsely crystalline olivine gabbro: dark gray to dark greenish gray; olivine, hypersthene, augite, hornblende, and biotite with interstitial orthoclase feldspar; present in sec. 9, T. 9 N., R. 3 W.

Ktm **Two Medicine Formation, undivided (Upper Cretaceous)**—Interbedded sandstone, siltstone, and mudstone; local conglomerate beds and, near base, thin coaly siltstone; some beds have large component of volcanic detritus and altered shards; medium light to medium gray, grayish green, pale brown to moderate brown; tongues of dark-gray volcanic wacke southwestward across northwest corner of quadrangle. Total exposed thickness about 600 m

Ktf **Volcanic member**—Thick sheets of medium-brown and dark-grayish-red rhyodacite welded ash-flow tuff; a few extrusive bodies of calcic rhyodacite and quartz latite and related tuff breccia; only lower part exposed. Thickness more than 375 m

Elkhorn Mountains Volcanics (Upper Cretaceous)

Keva **Ash-flow tuff member**—Fragments of pumice and rock fragments in a matrix of largely devitrified glass shards; ash flows range from nonwelded to densely welded and flow laminated; contains phenocrysts of feldspar, quartz, hornblende, pyroxene, biotite, and magnetite; locally includes lenses of volcanic megabreccia with large clasts of laminated welded tuff in densely welded tuff; interbedded with lenses of mudflow breccia and conglomerate within the middle member of the Elkhorn Mountains Volcanics (Smedes, 1966, p. 25–26). Thickness from about 500 to 1,100 m

Kevm **Middle member**—Interbedded andesitic, rhyodacitic, and basaltic pyroclastic rocks, lahar deposits, volcanic breccia, and a few andesite flows; interfingers with the ash-flow member (Keva), becoming subordinate to ash-flow tuffs southwest of quadrangle. Thickness about 500–1,300 m

Kevl **Lower member**—Interbedded andesitic and basaltic flows and flow breccia, and andesitic, rhyodacitic, and basaltic pyroclastic rocks; unit contains pebble and cobble conglomerate, lapilli tuff, andesitic sandstone, and siltstone; some very thin lenses of ash-flow tuff. Total thickness about 665 m

Ks **Slim Sam Formation (Upper Cretaceous)**—Medium-gray to medium-light- and medium-greenish-gray volcaniclastic and volcanic rocks; massive epiclastic tuff beds composed of fine-grained volcanic rock and grains of quartz, mica, hornblende, and opaque minerals in matrix of altered chlorite and sericite; some interbedded volcanic sandstone, porcellanite, mudstone, and volcanic pebble conglomerate; sedimentary beds display low- to high-angle crossbedding in strata that fill channels. [Formation mapped as restricted by Tysdal (2000).] Thickness ranges from about 125 to 240 m

Ket **Eagle Sandstone and Telegraph Creek Formation, undivided (Upper Cretaceous)**—Mapped on flanks of Elkhorn Mountains in southwest corner of quadrangle.

Eagle Sandstone: feldspathic quartz arenite containing chert grains and some lithic clasts and hornblende grains; fine to medium grained, silty in some beds; uppermost fine-grained sandstone contains mudstone that displays root casts; sandstone is likely of back-beach and delta-plain origin. Thickness about 25–30 m

Telegraph Creek Formation: interbedded claystone and siltstone grading upward into silty sandstone and siltstone. Sandstone is yellowish gray and light greenish gray, very fine grained to fine grained, poorly to moderately sorted; calcareous; contains trace fossils of offshore and shoreface environments. Mudstone is medium dark and dark gray, grades upward into medium and medium light gray. Unit is gradational into the overlying Eagle Sandstone. Estimated thickness about 160 m

Kvt **Virgelle Sandstone and Telegraph Creek Formation, undivided (Upper Cretaceous)**—Sandstone in upper one-third (Virgelle Sandstone). Interbedded mudstone, clayey siltstone, and very thin sandstone in lower two-thirds. Mapped in northwest corner of quadrangle. Thickness about 140 m

Kvi **Intrusive igneous rocks, undivided (Late Cretaceous)**—Rhyolite and rhyodacite and minor dacite in dikes and sills and small irregular-shaped bodies; likely intruded at shallow depths; related to the Two Medicine Formation

Ktc **Telegraph Creek Formation (Upper Cretaceous)**—Interbedded mudstone, clayey siltstone, and sandstone; amount of sandstone increases upward; dark gray and medium dark gray. Sandstone is medium and light gray; weathers yellowish gray and pale grayish orange; ripple cross laminated to low-angle planar cross laminae with numerous burrows on parting surfaces. Mudstone and siltstone are very thinly laminated and laminated; display mudcracks and ripple marks with small cylindrical burrows on some parting surfaces; splits platy; contains scattered scaphites, baculites, and pelecypods. Thickness about 100 m

Kmu **Marias River Formation, undivided (Upper Cretaceous)**—Interbedded siltstone, clayey siltstone, and bentonite in upper part (Kevin Member); silty claystone, very thin siltstone, clayey siltstone, very thin sandstone beds, and some bentonite in lower part (Fertig, Cone, and Floweree Members). Strongly disrupted by faulting. Present in northwest corner of quadrangle. Thickness about 165–225 m

Kmk **Kevin Member**—Siltstone, clayey siltstone, and bentonite; medium dark gray and mainly dark gray to black. Siltstone is olive gray to light olive gray and medium light gray; bentonite is yellowish gray, as thick as 0.3 m. Member contains one bed of conglomerate comprised of well-rounded pebbles of black and dark-gray chert. Member is thinly laminated to very thin bedded, and splits shaly and platy. Thickness about 90–120 m

Kml **Lower part, undivided**—Fertig, Cone, and Floweree Members, undivided. Upper part is alternating dark-gray siltstone and silty claystone and ledge-forming, medium-gray and medium-olive-gray sandstone (Fertig Member). Lower part is dark-gray silty claystone, siltstone, and claystone; splits shaly and papery; contains several beds of bentonite as thick as 9 cm, which weathers pale grayish orange (Cone and Floweree Members). Unit mapped in northwest corner of quadrangle. Thickness 75–105 m

Kb **Blackleaf Formation, undivided (Upper and Lower Cretaceous)**—Structurally interleaved parts of the Vaughn, Taft Hill, and Flood Members, described below, but mainly strata of the lower two members. Thin tuff beds in siltstone suggest structural slices of the Vaughn Member, and rare occurrences of pelecypods in interlaminated mudstone and very thin sandstone document presence of the Taft Hill Member; interleaved units are intruded by common, locally numerous dikes and sills of the Adel Mountain Volcanics, and are commonly covered by veneers of detritus derived from the volcanic rocks. Mapped mainly north of Middle Creek in northwestern part of quadrangle. Thickness about 150–275 m

Kbv **Vaughn Member (Upper and Lower Cretaceous)**—Interbedded tuffaceous sandstone, siltstone, and tuffaceous mudstone, and thin bentonite beds and laminae; lenticular pebble conglomerate, and lenses of carbonaceous siltstone; greenish gray, light olive green, and pale yellowish green, locally dark green; laminated to very thin bedded; characteristic high content of volcanic ash, locally as much as about 15 percent; some vitric volcanic detritus; pebbles in conglomerate are abundant black chert, white and pink quartzite, and green argillite; local carbonaceous plant debris. Present in northwestern part of quadrangle. Thickness 90–125 m

Kbt **Taft Hill Member (Lower Cretaceous)**—Mudstone and silty claystone with very thin interbedded calcareous sandstone; dark gray to olive gray; calcareous; sandstone near top is pale greenish gray; discoidal, calcareous sandstone concretions; contains sparse glauconite; mudstone is papery, fissile; sandstone contains local fossil pelecypods. Present in northwestern part of quadrangle. Thickness varies from about 45 to 75 m because of deformation on thrust sheets

Kbf **Flood Member (Lower Cretaceous)**—Sandstone at base and glauconitic fine-grained sandstone about 24 m above base; pale grayish orange to pale olive gray; weathers grayish orange; very thin bedded; bioturbated, uneven wavy beds. Interbedded silty mudstone, mudstone, and siltstone; medium dark gray, olive gray, medium olive gray, and dark gray; fissile. Sandstone contains common marine trace fossils, carbonaceous debris, and rare fragments of pelecypods. Member is present on thrust plates in northwestern part of quadrangle. Thickness about 15–75 m

Kc **Colorado Group, undivided (Upper and Lower Cretaceous)**—Interbedded sandstone, mudstone, and siltstone; local lenses of pebble conglomerate. Sandstone is medium dark gray, medium light gray, and medium olive gray to pale greenish gray; medium to fine grained, locally siliceous with clay matrix; grains of quartz, chert, some biotite, and abundant sodic feldspar; splits flaggy to blocky. Mudstone and siltstone are medium olive gray, greenish gray, and medium to dark gray; some beds are tuffaceous, bentonitic, or porcellanous; laminated; split papery and platy; local plant debris and rare brackish-water pelecypods in upper part. Mapped on flanks of Elkhorn Mountains in southwest corner of quadrangle. Thickness about 460 m

Kck **Colorado Group (Upper and Lower Cretaceous) and Kootenai Formation (Lower Cretaceous), undivided**—Highly metamorphosed rocks of the Colorado Group and Kootenai Formation adjacent to granodiorite and Butte Quartz Monzonite intrusive rocks in southwest corner of quadrangle

Kk **Kootenai Formation (Lower Cretaceous)**—Siltstone and silty mudstone with interbedded lithic sandstone and limestone. Siltstone and mudstone are pale grayish red to grayish red, locally olive gray; sandstone is pale grayish red and yellowish brown; limestone is pale greenish gray to light gray. Siltstone and mudstone split platy to shaly. Sandstone units as thick as 18 m are fine grained to predominantly medium and coarse grained; split platy; abundant rounded black chert grains with quartz, feldspar, and light-colored lithic grains produce a salt-and-pepper appearance. Thin limestone beds in lower part are laminated and very thin bedded, micritic, and very finely crystalline; silty and sandy; locally contain small gastropods and possible algal filaments. In north-central part of quadrangle, formation has granule to small pebble conglomerate at base; clasts are gray to black chert, red siliceous argillite, and some alkali feldspar; polycrystalline quartz, white quartz, and scattered to rare biotite of metamorphic origin; conglomerate seems to rest unconformably on the Morrison Formation. Thickness 215–335 m

KJme **Morrison Formation (Lower Cretaceous and Upper Jurassic) and Ellis Group (Upper and Middle Jurassic), undivided**—Morrison Formation: greenish-gray to grayish-red siltstone and minor mudstone; thin grayish-orange sandstone; discontinuous silty and clayey limestone beds contain sand grains, charatophytes, and possible algal filaments. As mapped, locally includes grayish-black coaly siltstone and low-grade coal interval, about 2–4 m thick, at top. Disconformity at base. About 65 m thick.

Ellis Group consists of the Swift Formation at the top and the Sawtooth Formation at the base. Swift Formation: sandstone and siltstone and discontinuous very thin basal conglomerate; light olive gray to pale brownish gray and medium and medium dark gray; splits platy and flaggy, locally shaly. Sawtooth Formation: calcareous sandstone and sandy limestone and lenticular calcareous pebble conglomerate containing oyster fossils at base; yellowish gray to grayish orange; weathers same; cross laminated and laminated; splits flaggy. Sawtooth Formation absent by erosion beneath the Swift Formation northeast and east of Indian Creek and Trout Creek in the Big Belt Mountains; northeast of erosional truncation, the Swift Formation contains lenticular pebble and cobble conglomerate at base, and conglomerate containing boulders, as large as 32 cm across, at base in secs. 31 and 32, T. 14 N., R. 2 E. and secs. 5 and 6, T. 13 N., R. 2 E. Pebbles and cobbles are black and dark-gray chert, medium-gray siliceous siltite, polycrystalline quartz, and minor quartz. The Ellis Group is approximately 30–75 m thick in west and thins rapidly northeast and east to locally about 8 m

KJm **Morrison Formation (Lower Cretaceous and Upper Jurassic)**—Greenish-gray and pale-red to grayish-red siltstone and minor mudstone, and thin grayish-orange sandstone; discontinuous silty and clayey limestone beds contain sand grains, charatophytes, and possible algal filaments; laminated and very thin bedded. Sandstone is very fine and fine grained, silty, and calcareous. As mapped, includes grayish-black coaly siltstone and low-grade coal, about 2–5 m thick, at top. Coal is best developed in Ts. 13 and 14 N., R. 1 W. to R. 2 E. In western part of quadrangle, unit has unconformity at top, but seems to intertongue north-northeast with basal sandstone beds of the Kootenai Formation. Palynomorphs from grayish-black siltstone laminae near top of mapped unit are Early Cretaceous in age (Robert Tschudy, U.S. Geological Survey, oral commun., 1977; and Robert Cushman, Loma Linda University, written commun., 1999). Structurally attenuated beds, including pale-red and greenish-gray silty sandstone, silty mudstone, and carbonaceous shale at mouth of White Gulch (sec. 19, T. 10 N., R. 2 E.), are assigned to the Morrison Formation. About 48–65 m thick

Je **Ellis Group, undivided (Upper and Middle Jurassic)**—As mapped, comprised of the Swift Formation at top and local lenses of the Sawtooth Formation at base. Group mapped separate from the Morrison Formation at north edge of quadrangle in secs. 2, 3, and 4, T. 14 N., R. 2 E.

Swift Formation: sandstone and siltstone and discontinuous very thin basal conglomerate; light olive gray to pale brownish gray and medium and medium dark gray; splits platy and flaggy, locally shaly. About 6–15 m thick. Unconformably overlies the Sawtooth Formation.

Sawtooth Formation: calcareous sandstone and sandy limestone and lenticular calcareous pebble conglomerate containing oyster fossils at base 0–2 m thick; yellowish gray to grayish orange; weathers same; cross laminated and laminated; splits flaggy. About 0–4 m thick

PIPpq **Phosphoria (Permian) and Quadrant (Pennsylvanian) Formations, undivided**—Phosphoria Formation: light-brownish-gray and medium-gray chert, locally containing microfossils; medium-brownish-gray dolomitic limestone containing chert nodules; locally contains lenses of phosphate northwest of Montana City, at southwest edge of quadrangle. Generally the Phosphoria Formation has been removed by pre-Sawtooth Formation erosion (Jurassic and Triassic); only discontinuous remnants preserved in northwestern part of quadrangle. Thickness 0–20 m.

Quadrant Formation: sandstone and sandy dolomitic limestone; very light gray and light yellowish gray; weathers yellowish gray and pale grayish orange; common quartz cement; very thin and thin laminae and cross laminae; splits platy and flaggy; forms ledges and local low cliffs. About 105 m thick in southwestern and west-central parts of quadrangle, but thins north by pre-Sawtooth Formation (Jurassic and Triassic) erosion to a wedge edge in northwest corner, and thins east to about 4 m in central part of quadrangle

IPq **Quadrant Formation (Pennsylvanian)**—Sandstone and sandy dolomitic limestone; very light gray and light yellowish gray; weathers yellowish gray and pale grayish orange; quartz cement common; very thin and thin laminae and cross laminae; splits platy and flaggy; supports ledges and local low cliffs. Mapped as a discrete unit in southwestern part of quadrangle and from northern part of Big Belt Mountains east where the Phosphoria Formation is absent by erosion. About 105 m thick in southwestern and west-central parts of quadrangle, but thins north by pre-Middle Jurassic erosion to a wedge edge in northwest corner, and thins east to about 4–5 m in central part of quadrangle

IPa **Amsden Formation (Pennsylvanian)**—Sandstone and interbedded silty mudstone; grayish red and light reddish brown; interbedded pinkish-gray limestone and sandstone at top; limestone-pebble conglomerate at base; rests unconformably on underlying rocks of the Tyler Formation or Big Snowy Group. Thickness 15–105 m

IPal **Limestone succession at top**—Limestone, sandy limestone, and dolostone; very light gray to light yellowish gray, locally very pale pinkish gray; laminated and very thinly laminated; splits platy and flaggy; forms steep slopes or cliffs; some algal lamination in thin limestone beds; contains crinoid fragments and brachiopods. Thickness as much as about 75 m

IPar **Red-bed succession at base**—Interbedded siltstone, silty sandstone, very thin sandstone, discontinuous limestone, and pebble conglomerate form red-bed sequence at base of Amsden Formation: pale red, reddish brown, and yellowish gray to white; pebbles of aphanocrystalline limestone, finely crystalline fossiliferous limestone, and medium-gray shale; rests unconformably on underlying units, truncating the Tyler Formation and upper part of the Heath Formation. Thickness approximately 4–18 m

IPMab **Amsden Formation (Pennsylvanian) and Big Snowy Group (Upper Mississippian), undivided**

Mt **Tyler Formation, undivided (Upper Mississippian)**—Mudstone, thin siltstone, thin, locally basal conglomerate, and sandstone. Mudstone: dark gray to black, locally olive black; sparse to no evident organic matter; contains thin stringers of very fine grained silty sandstone and sandstone. Conglomerate: pebbles of silty limestone, discoidal clasts of medium-gray shale, quartz, and fragments of fine-grained sandstone; ferruginous; grades upward into sparkling white quartz arenite. Thin beds of silica-cemented quartz arenite, locally highly ferruginous, higher in formation; coarse-grained lithic arenite in lower part mapped as unit Mts. Clay-rich mudstone of main part of formation fails readily on slopes to form debris flows and large landslides. Present mainly in north-central part of quadrangle; formation is truncated by pre-Amsden (Pennsylvanian) erosion from Antelope Creek (secs. 16 and 17, T. 12 N., R. 2 E.) northwest into sec. 1, T. 13 N., R. 1 E., where the erosional edge is truncated on a thrust fault that transports Pennsylvanian rocks over a lower plate of Cretaceous strata. The Tyler Formation is not known farther west in Montana. Thickness about 0–180 m

Mtu **Upper part**—Mudstone, clayey mudstone, and thin beds of siltstone; medium dark gray and dark gray, locally black; clayey; scattered thin beds of medium-gray siltstone and siliceous siltstone, locally with laminae of very fine sand; splits fissile, shaly; fails readily on slopes to form debris flows; commonly intruded by one or more thin diorite and biotite diorite sills of Late Cretaceous age. Thickness about 90–105 m

Mts **Sandstone and conglomeratic sandstone in lower part**—Sandstone: pale grayish gray, light brownish gray, and very light gray to white; fine to predominantly medium grained, with lenses of coarse grains and granule pebbles; some thin interbedded siltstone beds and mudstone partings; quartz, chert, feldspar, and lithic grains; local silica cement produces sparkling character, and locally ferruginous with limonite and hematite grains that produce reddish-orange stain; forms ledge or resistant outcrops that support broad dip slopes. Thickness about 18–25 m

Mb **Big Snowy Group, undivided (Upper Mississippian)**—Shown only in cross sections *A–A'* and *B–B'*

Mho **Heath and Otter Formations, undivided**—In upper part, mudstone and silty mudstone with thin beds of sandy limestone and dolostone. Mudstone is medium gray to predominantly medium dark gray and dark olive gray; organic rich. Limestone beds are very light gray and yellowish gray; weather yellowish gray and pale grayish orange; limestone beds contain crinoid columnals and brachiopod fragments. In middle part, silty mudstone and very thin limestone, dolostone, and sparse dolomitic sandstone beds; limestone, dolostone, and sandstone are light brownish gray to olive gray; laminated and very thin bedded. In lower part, predominantly mudstone with interbedded thin limestone and dolostone. Mudstone is light green, pale greenish gray, and grayish green to olive gray; splits shaly and flaggy; limestone and dolostone are very light gray and pale yellowish gray; weather yellowish gray and pale grayish orange; locally oolitic and contain concentrically banded algal colonies. Total thickness about 230–335 m but thinned by shearing in secs. 8 and 17, T. 12 N., R. 2 E.

Mh **Heath Formation**—Mudstone and silty mudstone with thin beds of limestone, dolostone, and minor sandy limestone. Mudstone is medium gray to predominantly medium dark gray and dark olive gray; organic rich; contains local flattened assemblages of thin brachiopod shells in black mudstone. Limestone beds are yellowish gray; weather pale grayish orange; contain crinoid columnals and brachiopod fragments. The Heath Formation locally rests unconformably on the Kibbey Formation (secs. 22–24, T. 13 N., R. 1 W.). Some thin diabase sills of Late Cretaceous age and basalt dikes of Oligocene age locally intrude mudstone intervals. Estimated thickness 40–120 m; locally thickened by imbrication on faults

Mo **Otter Formation**—Mudstone, claystone, silty mudstone, limestone, and minor dolostone. Mudstone: light green, grayish green, light bluish green, violet, and black; very thinly laminated; splits papery and shaly. Limestone: light gray to yellowish gray; laminated; locally, algal laminations with abundant laterally linked oval fossil algal colonies. Thickness of formation, about 0–85 m, varies as a result of folding, imbrication by faulting, and apparent local truncation by pre-Heath Formation erosion

Mk **Kibbey Formation**—Siltstone, sandy siltstone and limestone, and gypsum; limestone, sandy limestone, and local dolostone breccia at base; yellowish gray, pale grayish red, and grayish red; subangular pebbles and fragments of underlying Mississippian rocks in basal part; sandy limestone beds are locally stromatolitic; siltstone in lower part is reddish brown and moderate reddish brown; sandy siltstone at top of formation is pale grayish yellow to pale grayish orange, weathers pale to moderate reddish orange; locally cliff forming; upper siltstone beds overlie interval of bedded gypsum that is commonly highly distorted by flow and serves as the detachment interval for faults at the southeast terminus of the Montana disturbed belt. Formation is unconformable on the underlying Mission Canyon Limestone. Thickness about 65–105 m, but formation is locally strongly deformed and locally thinned by shearing so that thickness is variable across short distances

Mmu **Madison Group, undivided (Upper and Lower Mississippian)**—Undivided Mission Canyon Limestone and Lodgepole Limestone. Mapped in southwest corner of quadrangle, where metamorphism resulting from emplacement of Boulder batholith and related intrusive bodies has recrystallized the limestone to obscure distinctions between formations

Mm **Mission Canyon Limestone (Upper and Lower Mississippian)**—Limestone; medium light to medium dark gray and light olive gray; weathers light gray, very light gray, and white; locally dolomitic; scattered nodular beds and isolated nodules of brownish-gray chert; limestone is generally recrystallized and fractured; coarsely crystalline; pressure solution surfaces common; columns and pods of dissolution collapse breccia present in upper one-third; thin bedded with local thin sets of cross laminae; splits thick to massive; limestone pellets and fragments, crinoid, brachiopod, and coral fossils and fossil fragments, and oolites visible locally; thin bedded, local current crossbedding; forms cliffs or rugged slopes. Thickness variable as a result of deformation and dissolution; generally about 480–510 m thick in the west; thins east to 250–375 m

Ml **Lodgepole Limestone (Lower Mississippian)**—Limestone and interbedded silty limestone and highly calcareous siltstone; medium light to medium dark gray and light brownish gray to yellowish gray; weathers light gray, very light gray, and white, and moderate orange pink to pale yellowish orange in silty intervals; laminated and very thin bedded; finely to medium crystalline biosparite, oosparite, and intrasparite limestone; splits platy, shaly, and flaggy, with intervals of thick beds near center that split slabby; contains abundant fossils including brachiopods, crinoid fragments, bryozoa, corals, rare trilobite fragments, and trace fossils, including unidentified burrows, scattered *Scalerotuba* in lower part, and rare *Zoophycus* in upper half. Thickness variable as a result of deformation and dissolution, 225–280 m

MDt **Three Forks Formation (Lower Mississippian and Upper Devonian)**—Includes the Cottonwood Canyon Member of the Lodgepole Limestone at top: carbonaceous mudstone; brownish black to grayish black; weathers pale yellowish brown and very pale orange.

Three Forks Formation: silty dolostone, calcareous siltstone and limestone, and mudstone; medium olive gray and olive gray; weathers pale grayish orange, grayish orange, and pale olive; contains intervals of medium-light-gray calcareous mudstone and olive-black to brownish-gray carbonaceous silty mudstone. In lower part, limestone and calcareous siltstone are medium brownish gray; weather yellowish gray, pale orange pink, and light brown. Local thin lenses of solution collapse limestone breccia at base. Limestone beds in upper part contain common brachiopods and crinoid columnals, some oncolites, and trace fossils, including *Scalerotuba*, *Cosmorayphe*, and unidentified smooth-walled small burrows. High total organic content in brownish- and grayish-black mudstone units in western part of Big Belt Mountains. Splits shaly and flaggy; commonly covered by talus from overlying formation. Thickness locally variable as a result of deformation, 18–37 m; about 95 m thick in southwestern part of quadrangle

Du **Upper and Middle Devonian rocks, undivided**—Lower part of the Three Forks Formation, and the Jefferson and Maywood Formations, undivided. Mapped at southeast edge of map area in secs. 7, 8, and 17, T. 10 N., R. 6 E., and in northeast corner of map area in secs. 2–4 and 9–11, T. 14 N., R. 5 E.

D€u **Upper and Middle Devonian and Upper and Middle Cambrian rocks, undivided**—Thin fault-bounded wedges of Devonian and Cambrian rocks, including the lower part of the Three Forks Formation (MDt), the Jefferson Formation (Dj), the Cambrian Pilgrim Formation and Park Shale, undivided (€pp), the Meagher Limestone (€m), and the Flathead Sandstone (€f), in fault contact with the Mississippian Mission Canyon Limestone (Mm) in sec. 7, T. 12 N., R. 1 E. Continuity within the wedges permits definitive identification of units, but discontinuous exposure and limited size of wedges does not permit showing faults at map scale

Dj **Jefferson Formation (Upper Devonian)**—Dolostone; light and medium to medium dark brownish gray, locally medium gray; weathers medium brownish gray, pale yellowish brown, and yellowish gray; finely to medium crystalline; strong petroliferous fetid odor on fresh surface; local wavy cross laminae, but commonly structureless; thin beds of pelletoid limestone; rare very thin beds of dolomitic sandstone; contains lenses of brachiopod and trilobite(?) fragments and very thin intervals of stromatoporoid algae; splits flaggy and blocky. Limestone at top in Big Belt Mountains is medium and medium dark gray; weathers very light gray and white; locally forms white ledges or low cliff at top of formation. Adjacent to major faults along south flank of Dry Range and east of Smith River in sec. 30, T. 11 N., R. 5 E., formation contains abundant dark-yellowish-orange, moderate-brown, and light-brown jasperoid and manganese. Thickness variable as a result of deformation and dissolution, about 130–200 m

D€m **Maywood Formation (Upper and Middle Devonian) and local Upper Cambrian beds**—Dolostone; light gray, yellowish gray, and light brownish gray; weathers very pale orange and pale grayish orange; very thin intervals of dolomitic siltstone and sandy dolostone; laminated, wavy laminated, and thin bedded; a few laminae contain halite crystal casts; splits platy and flaggy. At base, includes discontinuous unit as thick as 6 m that consists of thin beds and laminae of silty dolostone with siltstone partings and very thin limestone and dolostone beds; grayish red and greenish gray; weathers yellowish gray and grayish red; lenticular beds contain pebbles reworked from underlying Upper Cambrian beds and probable fish(?) bone fragments. As mapped, includes some mudstone and disrupted limestone beds of Late Cambrian age. Thickness 5–21 m

€pp **Pilgrim Formation (Upper Cambrian) and Park Shale (Upper and Middle Cambrian), undivided**—Pilgrim Formation forms upper part: pebbly limestone and silty limestone; interbedded silty claystone and claystone, 0.1–5 m thick, and pebbly limestone and limestone beds, 0.3–2 m thick.

Park Shale forms lower part: silty mudstone and claystone; sparse very thin channels filled with pebbly biosparite limestone; light olive gray and light olive; weathers olive gray and grayish green; fissile and platy; fails readily on slopes to produce landslides and debris flows.

Total thickness of mapped unit, 183–190 m, varies as a result of strong deformation in claystone and silty claystone intervals and lenticularity of pebbly limestone beds

€pi **Pilgrim Formation (Upper Cambrian)**—Pebbly limestone and silty limestone; light gray to light olive gray; weathers light gray, pale grayish orange, and grayish orange; beds 0.3–2 m thick. Interbedded silty claystone and claystone; light olive gray and olive gray; weathers light olive, dusky yellow green, and grayish green; very thinly laminated; split fissile and platy; intervals 0.1–5 m thick. Limestone is biopelsparite, with common to abundant trilobite fragments, pelmatozoan fragments, small chitinous brachiopods, oolites, and carbonate and glauconite pellets in sparry calcite. Flat pebbles of laminated micrite to silty biosparite limestone, 1–11 cm in largest dimension, are subrounded to rounded and generally supported at high angles to bedding in siltstone or silty biopelsparite matrix. Thickness about 25–50 m across much of quadrangle; locally as thick as 150 m in western part

Ꞓp **Park Shale (Upper and Middle Cambrian)**—Silty mudstone and siltstone; light olive gray and light olive; weathers greenish gray; fissile and platy; contains sparse lenses, 4–25 cm thick, of biosparite limestone in thin channels and rare channels filled with glauconite and quartz sandstone; clay-rich mudstone of main part of formation fails readily on slopes to form debris flows and large landslides; hornfelsed black and brittle adjacent to plutons. Thickness 35–60 m

Ꞓh **Hasmark Formation (Upper and Middle Cambrian)**—Upper part is predominantly dolostone; uniformly medium gray; weathers medium light and light gray; crystals of dolomite are locally enlarged and the color altered to very light gray by metamorphism adjacent to plutons on southwest edge of quadrangle. Lower part is medium and medium light gray with irregular mottles of dark-gray dolostone and very light gray to white mottles in dark-gray dolostone; very thin and thin bedded, irregular, uneven bedding within the mottles. Thickness about 125–135 m

Ꞓm **Meagher Limestone (Middle Cambrian)**—Limestone; medium gray, medium dark gray, and medium brownish gray; weathers medium light gray; common grayish-orange, moderate-brown, and pale-grayish-red silty mottles, particularly in basal 30 m and in top 50 m. Finely crystalline limestone with channels and beds of medium-crystalline to coarsely crystalline biosparite and biopelsparite limestone. Discontinuous wavy laminae and beds, 0.2–4 cm thick, with discontinuous silty limestone partings; weathers with knobby, locally reticular texture especially at base and top of formation; forms steep slopes or low cliff. Contains locally abundant small trilobite fragments, some pelmatozoan(?) plates, and sparse chitinous brachiopod fragments. Generally folded disharmonically between mudstone and siltstone strata of the Park Shale above and the Wolsey Formation beneath. Thickness about 40 m, but as much as 90 m, likely as a result of deformation; thins east across quadrangle to about 3 m in Tenderfoot Creek drainage

Ꞓw **Wolsey Formation (Middle Cambrian)**—Silty mudstone and siltstone; light olive to light grayish green, locally olive black; weathers light olive gray, dusky yellow gray, and grayish red. Thin beds of pale-grayish-red silty sandstone are interbedded in olive-green siltstone in basal 5 m. Interval of medium-gray and medium-brownish-gray limestone, 3 m thick, present about 60 m above base in northwestern part of quadrangle; weathers grayish red, brownish gray, and medium light gray; medium-crystalline to coarsely crystalline sandy biosparite, with sparse to abundant pellets of glauconite; fossils are trilobite, brachiopod, and pelmatozoan(?) fragments. Limestone laminae and beds, 0.2–3 cm thick, are scattered throughout siltstone. Top 30 m contains light-gray to light-greenish-gray limestone; weathers pale yellowish brown to grayish orange; trilobite biosparite; some greenish-gray siltstone chips on parting surfaces. Siltstone in lower one-third contains scattered *Cruziana* and annelid(?) trace fossils. Strata split shaly and platy; limestone splits platy and flaggy. Apparent thickness, 125–245 m, varies as a result of local strong internal deformation

Ꞓf **Flathead Sandstone (Middle Cambrian)**—Sandstone and pebbly sandstone, with very thin siltstone beds at top; pinkish gray, yellowish gray, and very pale red; weathers pale reddish brown, yellowish gray, and light brownish gray. Siltstone interbeds at top are greenish gray and light olive gray; weather greenish gray. Sandstone is fine to coarse grained, with locally abundant pebbles as large as 3 cm across. Grains and pebbles are quartz, quartzite, red and gray chert, siliceous siltite, and minor feldspar; grains generally well rounded, but shapes modified by pressure solution and quartz overgrowths; weakly to firmly indurated; glauconite grains present in uppermost 5 m and increase in abundance toward the top. From Dry Range to east edge of quadrangle, formation contains lenses and very thin to thin beds of conglomerate that consists of fine to coarse pebbles and some local cobbles of white and pink polycrystalline quartz, pale-red chert, red siliceous siltite, and quartzite in matrix of silica-cemented quartz arenite. Between sec. 24, T. 12 N., R. 4 E. and adjacent sec. 19, T. 12 N., R. 5 E. and east edge of quadrangle, some thin lenticular conglomerate beds that fill apparent channels also contain well-rounded cobbles and boulders, as much as 35 cm across, which consist of quartzite and quartz-cemented quartz-granule-pebble conglomerate derived from the Neihart Quartzite. Formation displays cross laminae to very thin beds and herringbone crossbedding near base and in top 15 m; thin sets of trough cross laminae are common; ripple laminae in upper part; splits flaggy and slabby, locally platy; forms resistant ledges and ridge. Trace fossils, including *Scolithus*?, *Thallasinoides*, and other annelid(?) burrows, are scattered to locally abundant in uppermost 10–20 m, and rare in lower part of formation. Adjacent to exhumed islands of Paleoproterozoic granite gneiss (Xgg), formation displays high-angle cross stratification oriented radially away from the islands. Formation generally thickens across east-central part of quadrangle. Thickness about 20–105 m

Zd **Diorite (Neoproterozoic)**—Diorite; dark olive gray to predominantly olive black; medium and coarsely crystalline; very finely crystalline margins exposed locally; anorthosite, hornblende, and biotite; some chlorite as an apparent alteration product of biotite. Weathers readily to friable state; discontinuous to very poor exposures in secs. 29 and 30, T. 12 N., R. 1 E., and locally in NE¼ sec. 25, T. 12 N., R. 1 W. Occurs in linear bodies approximately parallel to trend of Belt Mountains, and as sills folded with the Newland Formation (Yn) in southeast corner of quadrangle. Sills range in age from 741.3±32.2 to 826±41 Ma (Reynolds, 2003; Marvin and Dobson, 1979, p. 20). Estimated thickness 4–18 m, locally 30–35 m

Belt Supergroup (Mesoproterozoic)

Yh **Helena Formation**—Dolomitic limestone and limestone with partings of dolomitic siltite; medium gray to medium dark gray; weathers grayish orange and pale grayish orange to yellowish gray; common to abundant molartooth structure; scattered small vertically stacked, laterally linked stromatolite colonies; formation splits platy parallel to abundant fractures. On west side of Big Belt Mountains, formation is truncated northwest of sec. 31, T. 11 N., R. 1 W. and south of sec. 16, T. 9 N., R. 2 E. by Neoproterozoic–pre-Middle Cambrian erosion. In that remnant, formation is 0–150 m thick; in southwest corner of quadrangle, the Helena is as thick as about 1,225 m

Ye **Empire Formation**—Argillite and siltite with very thin beds of quartzite and sandy limestone; pale grayish green and pale olive gray; weathers grayish green and greenish gray; some thin intervals near base weather pale red and pale reddish brown; laminated and very thin bedded argillite and siltite; splits shaly and platy; metamorphosed to hornfels with some skarn at margins of plutons in Spokane Hills. Quartzites are very light gray to white; weather same; fine to medium grained; very thin bedded, ripple cross laminated, and planar small-scale cross laminae; calcareous, local silica cement; common dissolution porosity in sandstones. Limestone beds, 4–20 cm thick, are silty and contain fine sand. Formation grades downward into the Spokane Formation (Ys) and upward into the Helena Formation (Yh). On west flank of Big Belt Mountains, formation is truncated by Neoproterozoic–pre-Middle Cambrian erosion northwest and northeast of sec. 27, T. 11 N., R. 1 W., and southeast and east of sec. 16, T. 9 N., R. 2 E. Thickness in this remnant of formation is 0–325 m; in Spokane Hills, exposed thickness is about 240 m

Ys **Spokane Formation**—Siltite and argillite; pale red and moderate reddish brown, and very thin greenish-gray intervals in basal 20 m; weathers moderate reddish brown, grayish red, and dusky red; laminated and very thin bedded; cross laminated, locally ripple cross laminated; predominantly silt and clay on parting surfaces. Locally common ripup clasts and fluid-escape structures; scattered lenticular beds of fine-grained quartz arenite and calcareous quartz arenite as thick as 14 cm; scattered beds of sandy limestone and rare stromatolitic limestone, 20–35 cm thick, interbedded with greenish-gray siltite in basal 45 m. Formation is truncated along a west-northwest-trending line in successively higher fault blocks from Smith River near Cottonwood Creek, to Wagner Gulch, and to

Big Log Gulch as a result of Neoproterozoic–pre-Middle Cambrian erosion. Thickness 0–1,480 m

Yg **Greyson Formation**—Siltite, argillitic siltite, feldspathic quartzite, and minor argillite.

Upper part, as thick as 480 m, is composed of interbedded siltite, feldspathic quartzite, calcareous feldspathic quartzite, and local sandy limestone. Siltite is medium olive gray, greenish gray, and medium dark gray; weathers greenish gray, pale olive, olive gray, dusky yellow, and pale yellowish brown; fine even parallel laminae, discontinuous wavy laminae, and ripple cross laminae. Feldspathic quartzite intervals, as thick as 4 m, grade in uppermost part into calcareous feldspathic quartzite and sandy limestone interbedded with greenish-gray to light-brownish-gray siltite; feldspathic quartzite is light pinkish gray, yellowish gray, and light gray; weathers light gray to pale yellowish orange; fine to medium grained; low-angle planar crossbedding, local herringbone crossbedding in very thin sets, and even parallel laminae; load structures in quartzite bed at base of upper part.

Middle part, as thick as 870 m, is predominantly very dark gray, dark olive gray, and dark brownish gray siltite with very dark gray argillite partings; scattered very thin coarse siltite and rare very fine grained quartzite beds; siltite is locally dolomitic with local oval dolomitic concretions; wavy parallel laminae; some very thin ripple cross laminae; splits platy and shaly; locally exhibits well-developed pencil cleavage.

Lower part, about 200 m thick, contains interbedded siltite and feldspathic quartzite. Siltite is dark gray, olive black, and dark olive gray; weathers medium gray, medium olive gray, medium dark gray, and very dark gray. Quartzite intervals are 0.2–0.5 m thick; brownish gray to medium gray; weather pale yellowish brown and light brownish gray; fine to medium grained, locally coarse grained with scattered pebbles and locally abundant argillite chips; predominantly quartz with common feldspar grains; local well-developed secondary solution porosity; even parallel laminae and cross laminae in low-angle sets; interbedded with dark-olive-black to dark-olive-gray siltite.

Formation generally forms smooth dark-gray or olive-gray slopes with steeper ledge-lined slopes in lowest and uppermost parts. Upper part of formation is truncated on progressively higher structural blocks by Neoproterozoic–Middle Cambrian erosion northeast and north of a west-northwest-trending line from SW¼ sec. 14, T. 11 N., R. 4 E., through SE¼ sec. 35, T. 12 N., R. 2. E., to NE¼ sec. 3, T. 12 N., R. 2 W. As thick as about 1,550 m

Ygh **Greyson Formation, lower plate of Moors Mountain thrust fault and upper plate of Hogback Mountain thrust fault**—Medium-gray and medium-dark-gray to dark-gray siltite and argillitic siltite; scattered lenses of brownish-gray, very fine grained quartzite; weathers olive gray, dark greenish gray, and olive black; even parallel and discontinuous wavy parallel laminae; very thin sets of graded laminae; splits shaly and platy. Unit bounded above and below by thrust faults and is shown in west-central part of map area in Big Belt Mountains to distinguish strata of the same formation superposed on different thrust sheets

Yn **Newland Formation**—Calcareous argillite and calcareous siltite; limestone and arkosic sandstone intervals in uppermost part. Argillite and siltite are medium gray and medium dark gray; weather pale grayish orange and grayish orange; very thinly even parallel laminated producing a varvelike appearance on weathered surface; local very thin low-angle inclined laminae. Limestone is medium light gray and medium gray; weathers light and medium light gray; aphanocrystalline and very finely crystalline, locally silty; sparry calcite replacement locally forms some curved surfaces and reticulate patterns in limestone; scattered to common coarse calcite fills fractures; beds locally highly contorted and cleaved adjacent to Moors Mountain thrust fault; limestone intervals 0.5–5 m thick. Arkosic sandstone is grayish orange pink; weathers very pale orange and light brown; fine to medium grained, local coarse grains to granules; clasts of quartz, microcline feldspar, polycrystalline quartz, and rare laminated limestone; beds structureless to cross laminated at low angles; local internal slump structures; beds 0.04–0.3 m thick.

Lower exposed part of formation splits shaly and platy, and forms steep slopes; upper part splits shaly and, in limestone intervals, platy to slabby; forms ledges on steep slopes and ridge crest. Formation is generally metamorphosed to hornfels from core of Boulder Baldy pluton radially outward about 3–6.5 km. From center of east edge of quadrangle to secs. 29 and 30, T. 12 N., R. 4 E., formation is truncated structurally from its lower to upper part, and only top of formation is present above a thrust fault in northeast corner of T. 11 N., R. 3 E. Also, formation is structurally truncated from its lower part to the top in upper plate of Moors Mountain thrust fault from Magpie Gulch west-northwest to Checkerboard Gulch (secs. 7 and 8, T. 12 N., R. 1 W.). Corresponding truncated edge of formation is exposed in klippen of Moors Mountain thrust plate across secs. 17, 19, 29, 30, 31, and 32, T. 13 N., R. 1 E., and sec. 25, eastern part of sec. 35, and sec. 36, T. 13 N., R. 1 W. Formation is not known in Montana northwest or north of structurally truncated wedge edge in Checkerboard Gulch. Thickness ranges from 0 to about 2,400 m

Ynei **Neihart Quartzite**—Fine-grained, well-sorted quartzite; very light gray to white; weathers same; well-rounded grains predominantly of quartz and minor orthoclase feldspar, in matrix of silica; grains and matrix exhibit weak to moderate pressure solution; highly fractured; occurs in two thin wedges caught between faults bounding Protoproterozoic granite gneiss (Xgg) on the north and Mesoproterozoic Newland Formation (Yn) on the south in secs. 30 and 31, T. 12 N., R. 6 E.; occurs also as xenoliths too small to show at map scale in quartz monzonite of Boulder Baldy pluton in secs. 2 and 11, T. 9 N., R. 3 E.

Xgg **Granite gneiss (Paleoproterozoic)**—Light-pinkish-gray and pinkish-gray to medium-light-gray granite gneiss; coarsely crystalline; weak to locally moderate foliation defined by alignment of biotite and some hornblende in coarsely crystalline quartz, alkali feldspar, minor sodic feldspar, local muscovite, and rare garnet. From east edge of quadrangle west to Smith River, unit encloses increasingly abundant bodies of biotite gneiss (Xbg) a few meters to as much as 250 m long and 150 m wide; granite gneiss underlies the continental autochthon of northeast quarter of quadrangle and plunges west under Phanerozoic rocks of Dry Range and of Montana disturbed belt in north-central part of quadrangle

Xbg **Biotite gneiss (Paleoproterozoic)**—Dark-gray and medium-dark-gray biotite gneiss; grades into biotite schist; biotite with intercrystalline sodic feldspar and some hornblende; bodies of biotite gneiss are intruded by, and surrounded by, granite gneiss (Xgg); biotite gneiss is within metamorphic crystalline core of continental autochthon of northeastern part of quadrangle

Xhd **Hornblende diorite (Paleoproterozoic)**—Inclusions of fine- to medium-crystalline metamorphosed hornblende diorite in coarsely crystalline granite gneiss (Xgg); dark gray; weathers predominantly very dark gray and black; metamorphic intergrowths of hornblende and sodic feldspar

Xsy **Syenite (Paleoproterozoic)**—Coarsely crystalline sodic feldspar with gneissic texture as rare xenolithic wedges in granite gneiss (Xgg), east of Smith River in northeastern part of quadrangle

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