PRELIMINARY GEOLOGIC MAP OF THE BOZEMAN 30' x 60' QUADRANGLE

SOUTHWESTERN MONTANA

Compiled and mapped by
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Minor revisions: 1/03
Text revised and plate removed: 6/03
References added, Plate 2 removed: superseded by Geologic Map of Western and Northern Gallatin Valley (Vuke, 2003). Page 2 text changed to reflect this.

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PRELIMINARY GEOLOGIC MAP OF THE BOZEMAN 30' x 60' QUADRANGLE

This geologic map of the Bozeman 30'x 60' quadrangle is released with the intention that it will be followed by a revised version that incorporates new mapping of the Cenozoic deposits, including Geologic Map of Northern and Western Gallatin Valley, Southwestern Montana (Vuke, 2003). Ash samples have been collected for $^{40}Ar/^{39}Ar$ dates from Tertiary beds in the Madison bluffs and Storey Hills areas, and the results will also be included in a future version of the enclosed map.

The senior author has made tentative structural interpretations on the enclosed map that are based on map patterns but with only minimal subsurface data. These interpretations were not shown on the earlier blueline version of Plate 1 (MBMG Open file report 334). Faults shown as concealed or inferred are speculative. It is clear from surface mapping, however, that many faults, especially those that strike northwest-southeast, have had multiple episodes of reactivation that may include reversal of vertical movement and strike-slip movement. Only the last episode of movement or the net movement is indicated on the map.

Cross sections and discussion are not provided with this map, but they will be included with the future revised version. The map user is referred to the extensive bibliography provided with the map for more information at this time.

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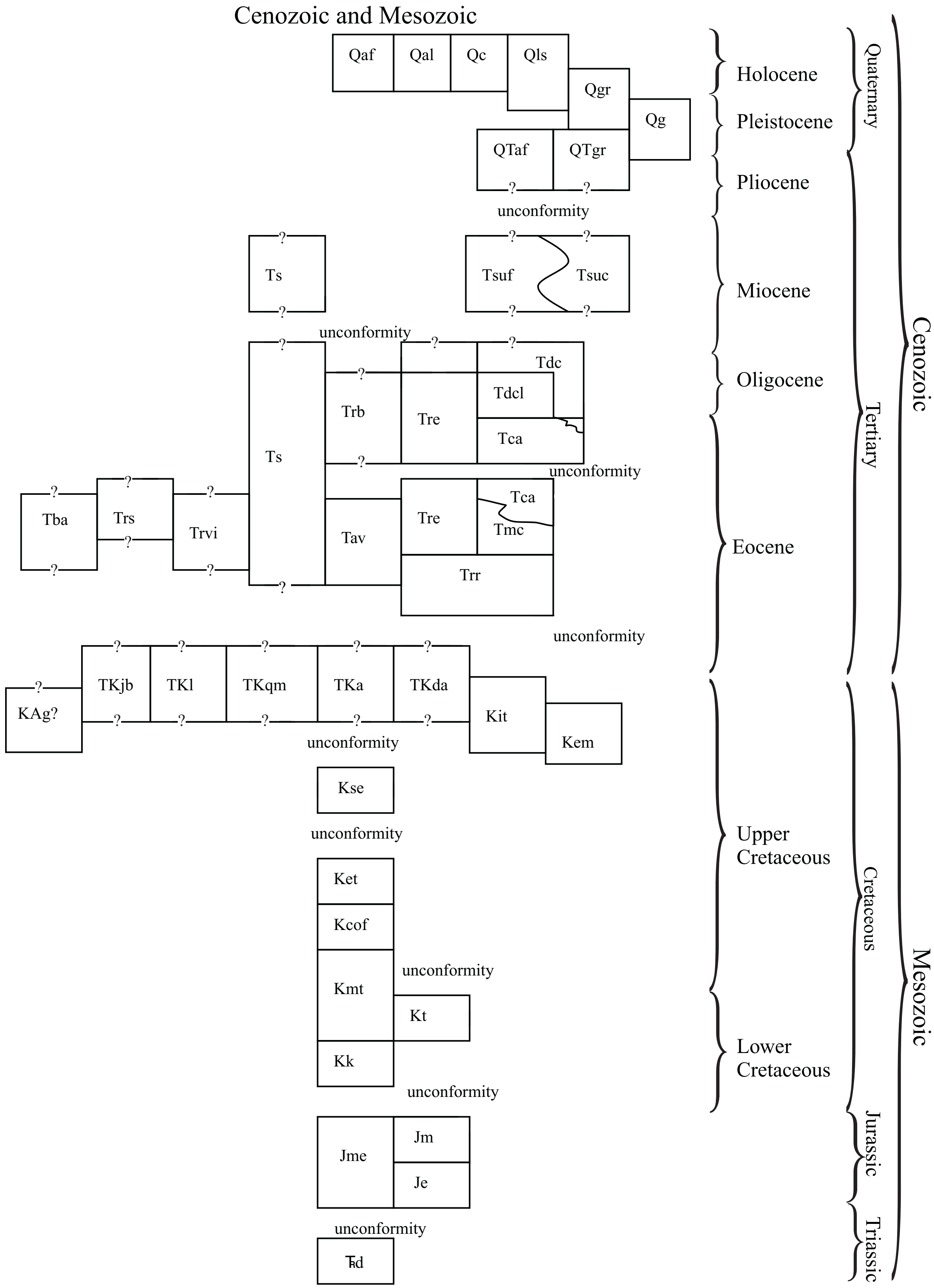
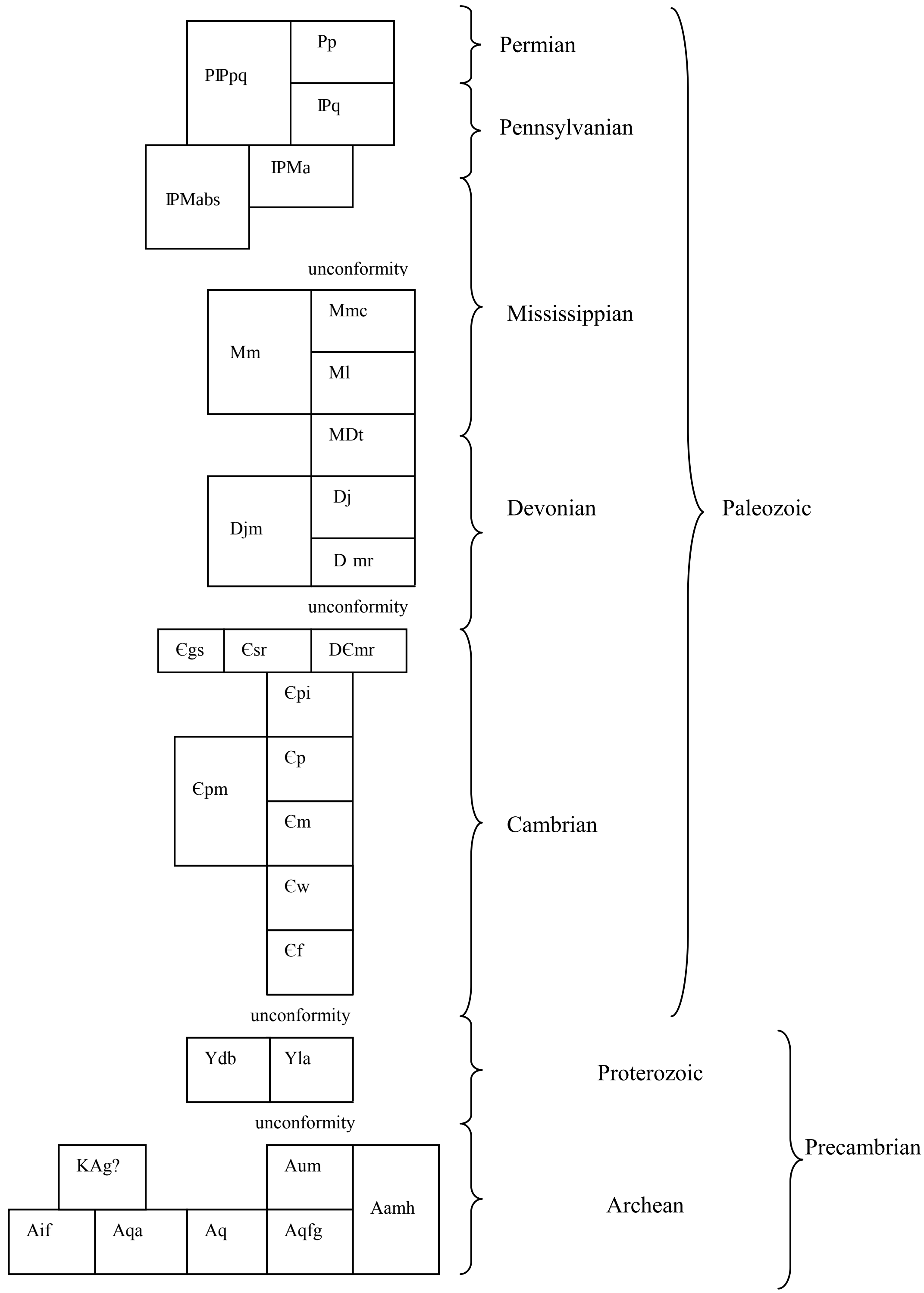
CORRELATION DIAGRAM
BOZEMAN 30’ x 60’ QUADRANGLE



CORRELATION DIAGRAM (continued)
BOZEMAN 30' x 60' QUADRANGLE

Paleozoic and Precambrian



GEOLOGIC MAP SOURCES AND INDEX OF 7.5’ QUADRANGLES
BOZEMAN 30’ x 60’ QUADRANGLE

112° (west) to 111° (east); 46° (top) to 45°30’ (bottom)

Doherty Mountain 1, 12, 18, 20, 24, 26, 39, 41, 43	Negro Hollow 9, 18, 20, 26, 30, 40, 43	Milligan Canyon 27, 43	Three Forks 23, 27	Logan 28, 31, 32, 35	Nixon Gulch 8, 11, 28, 32, 35	Horseshoe Creek 8, 14, 35, 43	Flathead Pass 8, 14, 21, 38
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Potosi Peak 36, 43	Maltbys Mound 6, 36, 43	Norris 7, 15, 36	Bear Trap Creek 2, 7, 16	Cherry Creek Canyon 2, 22, 8, 33	Ruby Mountain 2, 8, 19, 22, 33	Gallatin Gateway 2, 8, 19, 34, 38, 42	Wheeler Mountain 3, 8, 10, 19, 34, 37, 38, 42

Numbers above correspond with reference list on next page.

GEOLOGIC MAP SOURCES AND INDEX OF 7.5’ QUADRANGLES
BOZEMAN 30’ x 60’ QUADRANGLE

Numbers below correspond with index of map sources on next page.

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Entire quadrangle

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DESCRIPTION OF MAP UNITS
BOZEMAN 30' x 60' QUADRANGLE

Note: Thicknesses are given in feet because original field maps were on 7.5' quadrangles with contour intervals in feet. To convert feet to meters (the contour interval unit on this map), multiply feet x 0.3048.

Qal **Alluvium (Holocene)**—Light gray to light brown gravel, sand, silt, and clay deposited in stream and river channels, on floodplains, and on low terraces as much as about 20 ft above modern streams and rivers. Moderately sorted to well sorted. Larger clasts subangular to well rounded. Composition varies, but includes clasts of Archean metamorphic rocks, Precambrian orthoquartzite, Paleozoic limestone and quartzite, vein quartz, and volcanic rocks. Clasts of some smaller streams originating in Tertiary uplands are dominantly granule size and smaller and may include rip-up clasts. Thickness variable, but may be as much as 50 ft in channels of Jefferson, Madison, and Gallatin Rivers.

Loess (Holocene and Pleistocene) (Not mapped)—Tan, calcareous silt, clay, and sand that mantles many areas. Thickness as much as 4 ft on hilltops, thinner on slopes.

Qc **Colluvium (Holocene and Pleistocene)**—Light grayish-brown deposits on gentle slopes in the Tobacco Root Mountains. Mostly sand, silt, and clay with many fewer cobbles and pebbles. Thickness unknown, but maximum thickness is probably less than 30 ft.

Qat **Alluvial terrace deposit (Holocene and Pleistocene)**

Qaf **Alluvial fan deposit (Holocene and Pleistocene)**—Light gray to light brown gravel, sand, silt, and clay deposited where Hyalite Creek crosses an abrupt change in slope gradient (where the fault-bounded northern Gallatin Range meets the Bozeman valley) extending for about 7 miles into the valley, and similarly from 1 to 5 miles into the Gallatin Valley from the front of the Bridger Range. Distribution of clast sizes varies. In general, coarser sediment is dominant near the head of the fan and finer sediment near the margins. Clasts are dominantly matrix supported, and dominantly poorly sorted, although sediment deposited in distributary channels is moderately to well sorted and clast-supported. Larger clasts subrounded to rounded. May be as much as 200 ft thick.

Qls **Landslide deposit (Holocene and Pleistocene)**—Mass-wasting deposit that consists of stable to unstable, unsorted mixtures of clay- to boulder-size sediment at the north end of the Gallatin Range. Includes rotated or slumped blocks of bedrock and surficial sediment, earthflow deposits, and mudflow deposits. Color and lithology reflect that of parent rocks and transported surficial materials. Thickness probably less than 100 ft.

Qgr **Gravel deposits, undivided (Holocene and/or Pleistocene)**—Various deposits of gravel, sand, and silt that include alluvium, pediment veneer, colluvium, outwash, and fan deposits. Clast composition, rounding, and sorting vary depending on deposit location and type. The most extensive deposits are in the Gallatin Valley and include dissected blankets of sub-rounded to rounded pebbles, cobbles, small boulders, and rare larger boulders. Composition is dominantly orthoquartzite, vein quartz, quartz-rich gneiss, and dark volcanic rocks. Thickness ranges from pediment veneer about one inch thick to valley fill as much as 400 ft thick. North of the Jefferson River, most are fan and alluvial deposits that overlie pediment surfaces. Clast composition reflects local sources and clasts range from angular to rounded depending on the type of deposit. In the area of the headwaters of the Missouri River, some of the deposits on pediment surfaces consist dominantly of angular limestone clasts.

South of the Jefferson River many gravel deposits are dominantly well-rounded pebbles and cobbles of quartzite, well-cemented sandstone, volcanic and metamorphic rocks. These gravels range from a veneer to deposits over 100 ft thick. Some of the gravel deposits south of the Jefferson River are thin sheet deposits of subangular to angular, locally derived clasts.

In the Cottonwood Canyon area and eastward for ten miles (apparent on either side of Interstate 90), map unit also includes the "Ballard gravels" (Aram, 1979). Clast size is dominantly cobble to coarse sand, but includes boulders. Clast composition is dominantly Elkhorn Mountains Volcanics and orthoquartzite with some angular clasts of Renova Formation (Aram, 1979, 1981). *[Removed from map following 2002 field work; Ballard gravels are Tertiary deposits.]*

Qab **Alluvial braid plain deposit (Holocene? and Pleistocene)**—Well-rounded, well-sorted bouldery gravel and sand with some thin beds of clayey silt. Underlies the plain that extends from Bozeman Hot Springs to north of Belgrade. Clast lithologies in order of abundance are: Precambrian metamorphic rocks, mafic volcanic rocks, dacite (?) porphyry, sandstone, quartzite, limestone, and chert. As much as 800 ft thick (Hackett and others, 1960).

Qat **Alluvial terrace deposit (Pleistocene)**—Well-rounded, well-sorted, bouldery gravel and sand with some thin beds of clayey silt. Underlies terrace 10-25 ft above modern stream deposits. Clast composition similar to Qab. About 20 ft thick.

Qafo **Older alluvial fan deposit (Pleistocene**)—Poorly to well-sorted, rounded to sub-angular gravel sand, and silt with minor amounts of clay. Surfaces have distinct fan shape. Clasts locally derived and in general, grain size decreases and degree or sorting increases with distance from mountain fronts. Generally less than 100 ft thick.

Qg **Glacial deposits, undivided (Pleistocene)**—Poorly sorted, angular to rounded, unconsolidated clasts of dominantly cobbles and boulders, but also pebbles, sand, silt, and clay. Larger clasts of dominantly Archean metamorphic rocks, and igneous rocks of the Tobacco Root Batholith. Includes unstratified till and stratified outwash, and thin cirque lake deposits that probably include some Holocene sediment. Thickness of deposits less than 150 ft.

QTgr **Gravel deposits (Pleistocene, and/or Pliocene)**—Well-rounded, moderately well-sorted, clast-supported, calcite-cemented to unconsolidated cobble and pebble gravel with some small boulders, on either side of the Madison River. Sand and granule matrix. Clast composition dominantly gray and purple orthoquartzite of Belt Supergroup, with much less abundant gray Archean gneiss, white vein quartz, igneous clasts, and Paleozoic orthoquartzite. A white calcrete as much as 1 ft thick is present below the deposit in many places. Thickness of deposits 30–50 ft. Other deposits near Willow Creek, in the Tobacco Root Mountains in the southwestern part of the quadrangle, and just west of Four Corners and Gallatin Gateway may be unrelated to those described above. Near Willow Creek, gravel consists of angular to rounded matrix-supported cobbles, most of which are white quartz, schist, and amphibolite. Some of the clasts have caliche rinds. Matrix is sand and silt. Include basal immature, matrix-supported breccia with angular to subangular granules, pebbles, and cobbles of Archean metamorphic rocks. Combined thickness of both deposits is 20 to 40 ft. The deposit in the Tobacco Root Mountains contains matrix-supported, well-rounded pebbles, cobbles, and boulders up to 30 ft thick in a sandy matrix. Clast composition includes Archean metamorphic rocks, granodiorite of the Tobacco Root Batholith, and well cemented sandstone. Deposits west of Four Corners and Gallatin Gateway have the same clast composition as pebbles and cobbles in the underlying Tertiary rocks. Thickness of map unit about 30 ft. *[Deposits west of Four Corners and Gallatin Gateway were removed from map following 2002 field work. They are cobble conglomerate lenses within a Miocene unit. QTgr near Willow Creek and Qgr near Harrison are also this Miocene unit.]*

QTaf **Alluvial fan deposit (Pleistocene and/or Pliocene)**—Deposit similar to Qaf, but underlies Qaf, and is separated from it by a pediment surface. Thickness as much as 120 ft.

QTdf **Debris flow deposit (Pleistocene and/or Pliocene)**—Mostly poorly stratified, poorly sorted, pebbly sand, but includes some subangular, bouldery gravel with huge boulders up to 6 ft in diameter.

Clasts composed of locally derived Precambrian metamorphic rocks and Paleozoic limestone. At least 200 ft. thick.

Ts **Sediment or sedimentary rock, undivided (Tertiary)**—Includes units that could not be assigned to established Tertiary stratigraphy at this time.
Diamicton in Cherry Creek area: Subangular to subrounded clasts of Archean gneiss and Paleozoic rocks as large as 6.5 ft long. Thickness of unit greater than 160 ft.
Conglomerate west of Willow Creek Reservoir: Subangular to angular clasts of Archean gneiss and subrounded cobbles of vein quartz, Archean gneiss and amphibolite. Many clasts have caliche rinds, underlain by conglomerate with subangular to angular clasts of Archean rocks, mostly pebble size, but with some cobbles. Thickness 70 ft.
Tuffaceous siltstone and sandstone between tributaries of Burnt Creek west of Norris: Dominantly light-brown, locally tuffaceous siltstone and fine-grained sandstone with pebbly beds and lenses. Pebbles dominantly quartz and subordinately Archean gneiss. Thickness 40 ft.

Upper Tertiary

Upper Tertiary sediment or sedimentary rocks, undivided (Miocene and Pliocene?)—An informal allostratigraphic unit bounded at its base by the early-Tertiary (Hemmingfordian) unconformity and at its top by an unconformity separating it from overlying surficial deposits. (An allostratigraphic unit is a mappable stratiform body of sedimentary rock that is defined and identified on the basis of its bounding discontinuities [North American Stratigraphic Code, 1983, p. 865-867]). Unit is in the stratigraphic position of the Sixmile Creek Formation (Robinson, 1963) as redefined by Kuenzi and Fields (1971). Note that the original type Sixmile Creek Formation of Robinson (1963, 1967), lies both below and above the middle Tertiary unconformity (Fields, and others, 1985). Unit is also in the stratigraphic position of the Madison Valley formation (informal) (Douglass, 1907). Thickness about 900 ft.

Tsuf **Dominantly fine-grained facies (Miocene)**—Grayish-pink to grayish-orange clayey, tuffaceous siltstone with grayish-brown to light gray conglomeratic sandstone beds and numerous lenses and some beds of dominantly pebble conglomerate or gravel that may be either matrix- or clast-supported. Siltstones typically have numerous calcareous rootlet traces, and zones of root casts are present locally. Conglomerate or gravel typically includes clasts derived from Archean and dark extrusive and intrusive volcanic rocks, characteristically including reddish brown scoria as well as chert, quartzite, and rare limestone. An exception is the Dry Creek area where clasts are almost exclusively Paleozoic limestone and Precambrian LaHood arkose. Locally, conglomerate or gravel clasts are dominantly cobble and and small boulder size. In the Madison bluffs area bone fragments and pieces of opalized wood are common. Fossils found in lenses of pebble congomerate or gravel in the basal and middle parts of the unit were identified as a Barstovian *Merychippus* jaw bone and teeth by Alan R. Tabrum (Carnegie Museum of Natural History, Pittsburgh, 2002), and Ralph Nichols (Museum of the Rockies, Bozeman, 2002). Glassy ash beds are present locally in the siltstone. Thickness about 300 ft.

Tsuc **Dominantly coarse-grained facies (Miocene and Pliocene?)**—Brown to gray conglomerate.
North Boulder River area (Lofgren, 1985): Clast composition west of the North Boulder River is of Elkhorn Mountains Volcanics, and east of the river is of Paleozoic carbonate rocks with some intrusive rocks. Matrix-supported conglomerates are poorly sorted, laterally continuous, with angular to subrounded pebbles, cobbles, and boulders. Clast-supported conglomerates are tabular to lensoid, moderately sorted, and contain subangular to subrounded pebbles, cobbles, and rare boulders. Other conglomerates are dominated by pebbles, granules, and sand. Clasts typically have caliche rinds.

Clasts are typically caliche-coated. Placement of basal contact with the Renova Formation was inferred in the northwestern part of the quadrangle following fossil identification of Lofgren (1985), and includes only that part of the Tertiary above the early-Tertiary (Hemmingfordian) unconformity.
Bozeman area (Glancy, 1964): Conglomerate, sandstone, siltstone, and nearly pure volcanic ash beds. Clast composition of conglomerate mainly andesite, diorite, gabbro, and granodiorite porphyries, porphyritic granodiorite, basalt, and andesite with sporadic Archean gneiss,

sandstone, and limestone. In some areas there is also a component of angular Livingston Group sandstone. Thickness about 1,200 ft.

Dry Creek, Reese Creek area (Hughes, 1980): Coarse sandstone and conglomerate interbedded with subordinate amounts of fine-grained mudstone, tuffaceous marl, and vitric ash. Conglomerate clast composition is dominantly Paleozoic limestone and Precambrian LaHood arkose. A K/Ar date of 8.9±0.4 (late Miocene) was obtained from and ash in this unit in NE1/4, NE ¼, NE1/4 sec. 6, T1N, R5E (Hughes, 1980, Lang and others, 1980). Exposed thickness about 500 ft., maximum thickness not known in this area.

Lower Tertiary

Tdc **Dunbar Creek Formation (Eocene and Oligocene)**—Dominantly grayish-yellow, yellowish-white, and light gray, tuffaceous siltstone and fine-grained sandstone, with isolated coarse-grained sandstone and conglomerate beds and lenses; and calcareous, tuffaceous paleosol beds. Conglomerate beds with subangular to subrounded granule- and pebble-size clasts that include: Paleozoic limestone; red clasts that may be derived from Proterozoic Belt rocks; coarse sand- and granule-size glassy quartz grains; and rarely, isolated pebble- to small cobble-size clasts of scoria and silicified wood. Conglomerates are dominantly matrix-supported. Many coarse-grained sandstones are poorly sorted and superficially resemble granitic rocks by their clast composition and distribution. Some sandstones also contain many red grains that may be derived from Proterozoic Belt rocks. A K-Ar date of 30.6±1.2 (Oligocene) was obtained from the Dunbar Creek Formation (Renova Formation) in the Dry Creek Valley (Hughes, 1980). Type section is within quadrangle in E1/2 sec. 7, T1S, R2E (Robinson, 1963). Thickness 800–1000 ft (Robinson, 1963).

Tdcl **Lower Dunbar Creek Formation? (Eocene? or Oligocene?)**—Yellowish-white, light gray to gray, light brown silty or sandy tuffaceous limestone interbedded with calcareous siltstone, fine-grained sandstone, and air-fall ash beds. Some beds contain root casts. Tentatively correlated with tuffaceous, calcareous paleosol beds in the lower Dunbar Creek Formation south of Three Forks. Called “Norwegian Creek carbonate unit” by Feichtinger (1970). Thickness at least 150 ft.

Tca **Climbing Arrow Formation (Eocene)**—Pale olive, light olive brown, and reddish-brown, bentonitic, sandy clay and claystone that displays “popcorn” weathering; yellowish-gray, coarse-grained, argillaceous sand and sandstone; and white, tuffaceous siltstone and fine-grained sandstone composed almost entirely of volcanic glass. Throughout, coarse sand grains are typically subangular to subrounded, and composed of quartz, feldspar, and biotite. A K/Ar date of 50.4±1 (Eocene) was obtained from an ash in the NE1/4, NE1/4, NE1/4 sec. 11, T2N, R1W (Lang and others, 1980). The discrepancy between this date and Chadronian vertebrate fossils found in this unit suggests that there may be an unconformity within the unit (D. Hanneman, personal communication, 2002).Type section is within quadrangle in W1/2 sec.12, T1N, R1E (Robinson, 1963). Thickness not less than 750 ft, but may be considerably more than 1000 ft (Robinson, 1963).

Tmc **Milligan Creek Formation (Eocene)**—Light gray, fine-grained, tuffaceous, argillaceous limestone, marlstone, and calcareous mudstone that interfinger with sandstone and conglomerate with rounded to subrounded clasts dominantly of quartz and volcanic rock. Type section is within quadrangle in E1/2 sec. 11, NW1/4 sec. 12, and SW1/4 sec. 1, T1N, R1W (Robinson, 1963).

Trb **Red Bluff Formation (Eocene?)**—Upper: White and light yellowish-brown siltstone, sandstone, conglomerate, and subordinate, but conspicuous, brick-red and maroon mudstone and siltstone; locally tuffaceous. Most clasts Archean gneiss, and vein or pegmatite quartz, with some quartz monzonite and granodiorite from Tobacco Root Batholith (map unit Kit). Locally, highly silicified. Lower: Subrounded to well-rounded, matrix supported, bouldery diamictite. Clast composition dominantly quartz monzonite or granodiorite of the Tobacco Root Batholith with matrix of immature decomposed quartz monzonite or granodiorite. Boulders very large, some as large as 50 ft wide. Type locality is within quadrangle in W1/2 sec.13, T3N, R1W (Kellogg, 1994).

Tre **Renova Formation (Eocene and Oligocene)**

Dunbar Creek Member (Eocene? and Oligocene)—Grayish-orange, immature and submature vitric siltstone, tuffaceous, montmorillonitic mudstone, immature to submature very fine-grained to granular sandstone, very coarse-grained arkose, and conglomerate. Thickness about 1000 ft (Kuenzi and Fields, 1971).

Climbing Arrow Member (Eocene)—Pale olive-gray, tuffaceous, montmorillonitic mudstone, immature vitric siltstone (Kuenzi and Fields, 1971), and fine-grained, submature to immature arkosic sandstone or granule conglomerate that superficially resembles a granitic rock, contains both biotite and a light-colored mica (muscovite or phlogopite?), and weathers to gruss-like, unconsolidated sediment. Thickness at least 175 ft (Kuenzi and Fields, 1971).

Bone Basin Member (Eocene)—Light yellowish-gray, pale olive-gray, pale olive, and nearly white alternating micritic and oölitic limestone, montmorillonitic mudstone, vitric siltstone, vitric arenite, arkose, and minor conglomerate. Type section in quadrangle in sec. 33, T1N, R4W and sec. 28, T1N, R4W (Kuenzi and Fields, 1971). Thickness as much as 3,500 ft (Kuenzi and Fields, 1971).

Trr **Red Hill member (Eocene)** (informal)—Dominantly moderate-red and reddish-orange mudstone with thin beds and lenses of pale olive-gray or moderate red, very coarse-grained, immature sandstone with clasts that include limestone, shiny black chert, clear and rose quartz, and red mudstone rip-up clasts; granule, pebble, and conglomerate lenses of similar composition in red mudstone matrix; and limestone breccia with red mudstone matrix. Unit typically weathers to red soil. Includes Conrow Creek conglomerate of Lofgren (1985) and Sphinx conglomerate of Robinson (1963).

Tav **Absaroka Volcanics (Eocene)**—Light-brown-weathering, dark-gray to black, basic, slightly porphyritic andesite that contains plagioclase, augite, and hypersthene phenocrysts in superimposed individual flows interlayered with stratified flow breccias. Exposed thickness 850 ft.

Trvi **Rhyolite vitrophyre (Eocene)**—White, pink, and gray, flow-banded, sparsely porphyritic rhyolite of dominantly brown cloudy glass and subordinate sanidine with sparse phenocrysts of altered biotite. Extensively brecciated near margin. Exposed thickness 850 ft.

Trs **Rhyolite vitrophyre sediment (Eocene)**—Very light gray to white, well-bedded, well-indurated siltite, sandstone, and clast-supported sedimentary breccia composed almost entirely of rhyolite vitrophyre; clasts angular and as much as 3 ft long. Interlayered and locally intermixed with abundant white air-fall ash. Exposed thickness about 100 ft.

Tba **Basalt (Eocene?)**—(from Robinson, 1963) Black, very dark gray, and grayish-brown, fine-grained intergranular basalt and basalt breccia flows along Cherry Creek fault. Commonly vesicular or flow banded. Vesicles in many places encrusted by yellow, fine-grained zeolite. Exposed thickness as much as 650 ft. Olivine basalt near Three Forks mostly compact but vesicular in some places. Homogeneous flow bands and minor flow breccia.

TKjb **Jasperoid breccia (Eocene or Upper Cretaceous)**—Yellow, tan, and reddish-brown, banded jasperoid that is almost entirely brecciated, and consists of angular clasts as much as 1 1/2 ft thick. Exposed thickness as much as 250 ft.

TKl **Latite (Eocene or Upper Cretaceous)**—Medium-gray to medium-dark-gray with sparse and small phenocrysts of feldspar and pyroxene in a dense nonvesicular holocrystalline matrix (Robinson, 1963). Many latite sills not mapped. Exposed thickness as much as 300 ft.

TKqm **Quartz monzonite (Eocene or Upper Cretaceous)**—(from Robinson, 1963) Pink, pale grayish-brown- or moderate-brown-weathering, dominantly quartz monzonite, but also includes monzonite porphyry, diorite porphyry, and quartz latite porphyry. Exposed thickness 250 ft.

TKa **Andesite (Eocene or Upper Cretaceous)**—(from Robinson, 1963) Medium-gray, dominantly andesite porphyry, but also includes porphyritic latite, and latite porphyry. Many small phenocrysts of both feldspar and mafic minerals only slightly larger than the groundmass. Exposed thickness as much as 360 ft.

TKda **Dacite (Eocene or Upper Cretaceous)**—(from Robinson, 1963) Medium-light-gray with local yellowish-brown or yellowish-green splotches from oxidation of iron-bearing minerals; uniformly fine-grained. Dominantly dacite, but includes some quartz latite. Exposed thickness as much as 250 ft.

Intrusive rock, undivided (Eocene or Upper Cretaceous) (Not mapped)—Intrusive rock of various compositions including, but not limited to, pyroxenite, latite, rhyolite, andesite, trachyandesite, diorite, monzonite, granodiorite, granitic aplite, basalt, and lamprophyre in small stocks, plugs, dikes, and thin sills.

KAg **Granite (Late Cretaceous or Archean)**

Pegmatite and quartz veins (Late Cretaceous, and Early Proterozoic to Archean) (Not mapped)—White to pink, coarse-grained to very coarse-grained, massive and foliated dikes and sills composed mostly of potassium feldspar, quartz, plagioclase, muscovite, and rarely, biotite. In some places grades into quartz veins that are white, massive quartz in lenticular, generally discordant veins and irregular pods. Very widespread in areas of Archean rocks.

Kit **Intrusive rock of the Tobacco Root Batholith (Upper Cretaceous)**—Gray, coarse-grained, inequigranular to porphyritic, massive, hornblende-biotite granodiorite, quartz monzonite, monzogranite, and monzodiorite. Exposed thickness as much as 1,300 ft.

Kem **Elkhorn Mountains Volcanics (Upper Cretaceous)**—Dominantly dark gray, grayish-black, greenish-black, light gray, and very dusky reddish-purple andesite porphyry, tuff, conglomerate, breccia, and minor flows; and subordinate basalt. Andesite porphyry displays variable texture and resistance. Conglomerates contain clasts up to boulder size that are rounded and as much as 20 inches in diameter in a coarse-grained sand matrix. Rests unconformably on units as old as the Lodgepole Limestone. As much as 9,000 ft thick (Alexander, 1955).

Kse **Sedan Formation (Upper Cretaceous)**—(from Skipp and others, 1999) Mudstone member (informal): Greenish-gray and brownish-gray volcaniclastic mudstone, siltstone, sandstone, and minor interbedded conglomerate and altered vitric tuff.
Middle sandstone member (informal): Olive-green and dark greenish-gray, volcaniclastic sandstone, conglomerate, mudflow conglomerate, and minor siltstone and mudstone.
Ash-flow tuff member (informal): Pale yellowish-green, light greenish-gray, grayish-red, and pale yellowish-brown, welded to nonwelded tuff and ash-flow tuff conglomerate, interbedded with volcaniclastic conglomerate, sandstone, mudstone, and porcellanite.
Lower sandstone member (informal): Dark olive-gray, greenish-gray, and yellowish-gray, volcaniclastic sandstone, siltstone, mudstone, altered crystal vitric tuff, minor hornblende dacite, and minor lignitic coal. Formation equivalent to Miner Creek and Cokedale Formations of the Livingston Group (Berg and others, 2000). Thickness of formation in map area about 3000 ft.

Ket **Eagle Sandstone and Telegraph Creek Formation, undivided (Upper Cretaceous)**
Eagle Sandstone—Grayish-orange to light olive-gray, arkosic, cross-bedded fine- to medium-grained, thin-bedded sandstone interbedded with siltstone. Contains carbonaceous siltstone, carbonaceous shale, and thin coal beds at base and top. Thickness about 250 ft.
Telegraph Creek Formation—Light olive-gray to pale yellowish-brown, thin-bedded to massive, very fine-grained calcareous, arkosic sandstone and siltstone, interbedded with silty mudstone. Thickness about 250 ft.

Kcof **Cody Shale and Frontier Formation, undivided (Upper Cretaceous)**

Cody Shale—Dark gray to brown mudstone interbedded with siltstone and very fine grained sandstone. Greenish-gray, thin-bedded, glauconitic, fine-grained sandstone in middle of formation. Thickness about 500 ft.

Frontier Formation—Light brownish-gray, fine- to coarse-grained thick-bedded to massive sandstone with subordinate siltstone. Dark gray to black, thin, chert-pebble conglomerate in some localities generally at bases of thick sandstone beds (Dyman, and others, 1996; McMannis, 1952). Thickness about 550 ft.

Kmt **Mowry and Thermopolis Shale, undivided**

Mowry Shale (Upper and Lower Cretaceous)—Dark gray to olive-green, siliceous and nonsiliceous mudstone with thin interbeds of siltstone, and fine-grained sandstone. Thickness about 350 ft.

Kt **Thermopolis Shale (Lower Cretaceous)**—Upper: Dark-gray to black, fissile shale to mudstone, that contains thin interbeds of micaceous, planar- or cross-bedded, lithic sandstone.
Middle: Medium-gray, fissile, micaceous, clayey shale with a few thin interbeds of siltstone (Dyman, and others, 1996).
Basal: Yellowish-gray- to pale-olive-weathering, light gray, fine- to medium-grained with quartz overgrowths, cross-bedded or ripple marked, clean, well-sorted quartz sandstone that may have interspersed limonite specks. Unconformably overlain by Elkhorn Mountains Volcanics in western part of map area. Thickness about 300–350 ft.

Kk **Kootenai Formation (Lower Cretaceous)**—Upper: Light gray gastropod coquina or gastropod-rich limestone that may also contain charophytes and ostrocods. The gastropod limestone is not present in the Bridger Range (McMannis, 195\2).
Middle: Dominantly red, orange, and purple variegated shale and mudstone with subordinate light and medium gray shale and mudstone, interbedded with light-gray "salt-and-pepper" limonitic or nonlimonitic, fine- to coarse-grained, poorly to well-sorted, massive or cross-bedded, chert-rich, locally conglomeratic sandstone.
Basal: Light brown to yellowish-gray "salt-and-pepper" conglomeratic, cross-bedded, chert-rich sandstone or conglomerate. Thickness about 400 ft.

Jm **Morrison Formation (Jurassic)**—Green, red, and gray variegated mudstone, shale, and siltstone with thin, interbedded yellowish-brown to grayish-orange, very fine-grained sandstone and siltstone beds, and thin, gray limestone beds. Carbonaceous shale or coal at the top in some areas of the northern part of the quadrangle. Thickness about 350 ft.

Je Ellis Group (Jurassic)

Swift Sandstone—Grayish-orange, calcareous, limonitic or glauconitic, cross-bedded, coarse-grained, fossiliferous, quartz sandstone. Thickness about 60 ft.

Rierdon Limestone—Light-gray, oölitic, fossiliferous limestone, and calcareous shale. Quartz and chert sand grains are interspersed throughout some of the limestone beds, and locally the quartz and chert clasts are granule or small pebble size. Thickness about 50 ft.

Sawtooth Formation—Upper: Yellowish-brown, fossiliferous mudstone; thin-bedded fossiliferous carbonaceous siltstone and dolomite; and light-gray, thin-bedded, fossiliferous limestone.
Lower: Gray to dark brown conglomeratic quartz and chert sandstone of variable thickness, with subangular to subrounded chert and light gray limestone pebbles. Formation not present in western part of map area. Thickness 0 to 80 ft.

Jme **Morrison Formation and Ellis Group, undivided**

Ꞇd **Dinwoody Formation (Triassic)**—Reddish-brown to dark brown, fossiliferous, silty limestone with abundant *Lingula* brachiopods. Sparcely present in map area; mapped only in Harrison 7.5-minute quadrangle (Elliott, 1998a) Thickness 0 to130 ft.

Pp **Phosphoria Formation (Permian)**—Brown, to greenish-brown, laminated or thin- to thick-bedded chert, yellow to yellowish-orange sandstone and siltstone, greenish-gray, medium- to coarse-grained, oölitic, phosphatic sandstone, and yellowish-gray dolomitic limestone. May also include conglomerate with well rounded chert pebbles or cobbles. Thickness ranges from 100 to 200 ft.

IPq **Quadrant Formation (Pennsylvanian**)—Light gray, pinkish-gray, and yellowish-gray, medium- to thick-bedded, medium- to fine-grained, well-sorted, quartz sandstone with rounded clasts, cemented by quartz overgrowths. Very light gray, medium to thick dolomite beds may be present in the lowermost and uppermost parts, interbedded with quartz sandstone. Thickness variable, ranging from 50 ft (McMannis, 1952) to 500 ft (Robinson, 1963).

PIPpq **Phosphoria and Quadrant Formations, undivided (Permian and Pennsylvanian)**

IPMa **Amsden Formation (Pennsylvanian and Mississippian)**—Red, blackish-red, and pale red, irregularly bedded mudstone, siltstone, and sandstone, and gray dolomitic limestone (Lombard Limestone of Blake, 1959). May include equivalents of the Snowcrest Group of Wardlaw and Pecora (1985), Big Snowy Group of Gardner (1959), and/or Amsden Group of Maughan and Roberts (1967). Thickness 120 ft (Glaman, 1991) to 650 ft (Robinson, 1963).

IPMabs **Amsden and Big Snowy Formations, undivided (Pennsylvanian and Mississippian)**

Big Snowy Formation—*Bridger Range* (McMannis, 1952): Upper: Dark gray to black, fossiliferous shale, shaly limestone, and cherty limestone. Middle: Red, pink, and pale yellowish-orange sandstone, sandy siltstone, sandy dolomite, and subordinate red siltstone. Lower: Red and pink, dolomitic silststone, and red to purple hackly shale with subordinate thin, light gray or very pale orange dolomite, or dolomite-clast breccia. *Eustis Syncline, western Horseshoe Hills* (Verrall, 1955): Upper (Heath Fm. equivalent): Dark gray to reddish-gray fissile, blocky shale and dark brownish-gray, thin-bedded to massive, calcareous orthoquartzite. Thickness 89 ft. Middle (Otter Fm. equivalent): Yellowish-brown, silty, laminated to flaggy, finely crystalline limestone with interbeds of yellowish-brown, highly calcareous siltstone, and thin interlaminae of dark gray chert. Thickness 19 ft. Lower (Kibbey Fm. equivalent): Medium gray to yellowish-orange fissile to hackly shale. Lower part has numerous thin interbeds of medium to dark gray, impure, calcareous, hard, quartzitic sandstone with grayish-orange shale beneath each bed. Thickness 125 ft.

Mm **Madison Group, undivided (Mississippian)**
Mmc **Mission Canyon Limestone (Mississippian)**—Gray, microcrystalline, thick-bedded locally fossiliferous limestone with abundant gray, black, olive-black, and pale yellowish-brown, lentil-shaped or elongate chert nodules. Solution breccia and paleo-karst features are apparent in some areas. Variable thickness ranges from 430 ft (McMannis, 1952) to 1500 ft (Robinson, 1963).

Ml **Lodgepole Limestone (Mississippian)—**Dark-gray, thin-bedded, fossiliferous, microcrystalline limestone, with yellowish-brown and grayish orange, thin partings and interbeds of calcareous mudstone. Thickness ranges from 200 to 855 ft.

MDt **Three Forks Formation (Mississippian and Devonian)—** Sappington Member (from Sandberg, 1965): Yellowish-orange and yellowish-gray thin- to thick-bedded, flaggy siltstone and fine-grained sandstone. May contain U-shaped trace fossils. Type section is in map area near Logan (Holland, 1952), and type locality is in the map area in Milligan Canyon near Sappington (Berry, 1943). Thickness 57–100 ft.

Trident Member (from Sandsberg, 1965): Greenish-gray, light olive-gray, and yellowish-gray calcareous to slightly calcareous fossiliferous clay shale, with yellowish-gray, dark yellowish-orange, and medium gray dolomitic limestone, silty dolomite, and calcitic dolomite at the base and a massive bed of fossiliferous argillaceous limestone at the top. Type section is in map area about five miles northwest of Logan (Sandberg, 1965).

Logan Gulch Member: Yellowish-gray and grayish-red, argillaceous limestone or shale breccia that may be partly interbedded with dolomitic shale, dolomitic siltstone, and silty dolomite; yellowish-gray, thin-bedded, contorted limestone; and red mudstone. Type section (Sandberg,

1962) is in map area within the Three Forks type section (Sloss and Laird, 1947) north of the Gallatin River at Logan. Thickness ranges from 90 to 150 ft.

Dj **Jefferson Formation (Devonian)—**Birdbear Member: Light brownish-gray to medium gray, very finely crystalline to microcrystalline, sucrosic, partly pseudobrecciated dolomite. Type section (Sandberg, 1965) is in map area within the type section of the Jefferson Formation (Sloss and Laird, 1947) on the north side of the Gallatin River near Logan. Thickness about 80 ft.
Lower member (informal): Dark yellowish-brown, brownish-gray, medium-dark gray, and light olive-gray, finely crystalline, fetid dolomite, and calcitic dolomite. Thickness ranges from 470 to 665 ft.

Djm **Jefferson and Maywood Formations, undivided**
Jefferson Formation (Devonian) (see above)
Maywood Formation (Devonian)—Grayish-red, thin- to medium-bedded, aphanitic to very finely crystalline, dense to friable and shaly dolomite. Locally contains a bright pale yellow saccharoidal limestone bed in the upper part. Grayish-red to yellowish-orange calcareous siltstone at base in some places. Not present in the northern Gallatin Range (Tysdal, 1966). Thickness as much as 90 ft.

Єgs **Grove Creek and Snowy Range Formations (Cambrian)—**(southwestern part of map area only)
Grove Creek Formation: Light pinkish-gray, greenish-gray, and light gray, sucrosic dolomite; grayish-orange dolomite with silicified wavy shale partings; local flat-pebble dolomite conglomerate.
Snowy Range Formation: Green shale and gray limestone that is partly a flat-pebble conglomerate; bed of columnar fractured limestone locally present in lower part of Snowy Range Formation.

DЄmr **Maywood and Red Lion Formations, undivided (Devonian and Cambrian)**—
Maywood Formation (Devonian) (See above)

Єsr **Snowy Range Formation (Cambrian)** (Eastern part of map area only, lateral equivalent of Red Lion Formation)—Sage Pebble Conglomerate Member: Medium light gray to light olive-gray, thin- to medium-bedded, flat-pebble limestone conglomerate with subangular to subrounded clasts; and very finely crystalline to aphanitic, dense limestone with minor interbeds and interlaminae of greenish to red fissile shale and subordinate light grayish-red, irregular-bedded or laminated siltstone, banded or mottled with yellowish-orange. In the Bridger Range there is a persistent 4 to 25 ft biostromal columnar limestone composed of calcareous fossil algae at the base of the member (McMannis, 1952). In the Horseshoe Hills, it is at the base up to the middle of the member, but missing east of Nixon Gulch and northeast of Trident. (Verrall, 1955). Thickness as much as 204 ft in the Bridger Range (McMannis, 1952). Flat pebble conglomerate is not present in the Gallatin Range, but a limestone member is present in the stratigraphic position of the Sage Pebble Conglomerate Member that also has a biostromal columnar limestone at its base (Tysdal, 1966).
Dry Creek Member: Light olive-gray, grayish-green, or bluish-gray, fissile shale with interbedded pale orange to yellowish-brown, calcareous, fine-grained sandstone and siltstone beds that commonly have scour bases. Thickness is irregular, ranging from 6 ft (Tysdal, 1966) to 76 ft (McMannis, 1952) in eastern part of map area.

Єpi **Pilgrim Limestone (Cambrian)**—Light gray or bluish-gray limestone or dolomite, typically with yellowish-orange mottles. May be sandy or sucrosic; may contain intraformational flat-pebble conglomerate, or lenses of dark gray limestone or dolomite that are glauconitic, oölitic, and/or fossiliferous; weathers hackly. Thickness ranges from 200 ft (eastern map area) to as much as 450 ft (western map area).

Єp **Park Shale (Cambrian)**—Grayish-green and pale purple, fissile shale and silty shale. May contain a thin limestone bed or limestone flat-pebble conglomerate at the top, and thin interbeds of grayish-red-purple, coarsely crystalline, ferruginous limestone. Thickness ranges from 150 to 350 ft.

Єm **Meagher Formation (Cambrian)**—Light gray or bluish-gray limestone, dolomite, or dolomitic limestone, with yellowish-orange or moderate orange-pink mottles; weathers hackly. Dominantly thick-bedded, but thin-bedded in part, with siltstone partings. In the eastern part of the map area, may contain interbeds of greenish-gray, micaceous, fissile shale. May contain oölitic beds with some oncolites and intraformational conglomerate. Thickness ranges from 300 to 550 ft.

Єpm **Park and Meagher Formations, undivided (Cambrian)**—See above.

Єw **Wolsey Shale (Cambrian)**—Dominantly grayish-green, but also grayish-purple and grayish-red-purple, micaceous, fissile, wavy-bedded shale with trace fossils on many bedding surfaces. In western part of map area includes Silver Hill Member in middle of formation, a greenish-brown, carbonaceous, silty limestone unit. May be interbedded with thin orthoquartzite beds at base. May contain trilobite casts and molds. In some areas plutonic rocks take the place of the Wolsey Shale (Robinson, 1963). Thickness ranges from 150 ft (eastern map area) to as much as 400 ft (western map area).

Єf **Flathead Formation (Cambrian)**—Very light gray, pinkish-gray, or light brownish-gray quartzose sandstone or orthoquartzite, and well-cemented granule to pebble conglomerate. May be massive or crossbedded and contain subordinate grayish-green, grayish-purple or grayish-red-purple, micaceous, fissile shale beds. In some areas in the central part of the map area, the Flathead Formation is missing by nondeposition. Basal unconformity places the Flathead on Archean rocks south of the Willow Creek fault, and on Proterozoic rocks north of the fault. Where present, thickness ranges from 40 ft (Gallatin Range; Tysdal, 1966) to 150 ft.

Ydb **Diabase (Proterozoic)—**Includes igneous bodies northwest of Pony and numerous unmapped dikes that cut across Archean rocks, but do not extend into younger rocks (Schmidt and Garihan, 1986b).

Yla **LaHood lithosome (Proterozoic)**—Map unit includes the LaHood Formation, and units that have been called Newland Limestone and Greyson Shale following Alexander (l955), all of which are part of the Belt Supergroup. The shale and limestone intertongue with LaHood lithologies and are genetically related (Foster and Chadwick, 1999; Foster and others, 1999), but cannot be correlated spatially or temporally with the type Newland or Greyson in the map area (Foster and Chadwick, 1999; Hawley, and others, 1982; Bonnet, 1979). For this reason, the LaHood is mapped as a lithosome (Sando, 1990) that includes the LaHood Formation as redefined by McMannis (1963), and the fine-grained and carbonate facies it intertongues with. The names *Newland* and *Greyson* are not used on this map. (Correlation of the LaHood with the Newland and Greyson may be demonstrable just north of the map area from the northern Bridger Range into the Big Belt Mountains [McMannis, 1963, Fig. 8]).

LaHood Formation facies: Dark gray, dark brownish-green, and locally reddish-brown, arkosic boulder to granule conglomerate, arkose, arkosic siltite, arkosic argillite, and some impure carbonate beds. Clasts composed primarily of various Archean metamorphic, and igneous rocks; matrix light, olive gray mudstone. Type section in map area near LaHood Park (Alexander, 1955; McMannis, 1963). Clast size as much as 12 ft wide in local areas, but size decreases dramatically in lobate patterns that fan outward from the south. Clasts are angular to subround.
Shale facies (Greyson Shale of Alexander, 1955): Black, brown, or purple, fissile, to nonfissile, carbonaceous or silty shale, interbedded with gray siltite and argillite, coarse- to fine-grained arkose, and thin carbonate beds.
Carbonate facies (Newland Limestone of Alexander, 1955): Dark gray to light gray, thin-bedded to laminated limestone, and olive-gray dolomite; locally contains algal structures (Verrall, 1955).

Aqfg **Quartzofeldspathic gneiss**—Includes plagioclase-microcline-quartz biotite (“granitic”) gneiss, plagioclase-quartz-biotite (“tonalitic”) gneiss, banded biotite gneiss, aluminous gneiss and schist, gedrite gneiss, and garnet gneiss.
Plagioclase-microcline-quartz-biotite gneiss: Light-gray to light-pinkish gray, medium-grained, weakly to moderately foliated gneiss ranging from granodiorite to syenogranite.
Plagioclase-quartz-biotite gneiss: Gray, medium-grained, inequigranular, weakly to moderately foliated, tonalitic gneiss. Includes some trondhjemitic and granodioritic gneiss.

Banded biotite gneiss: White, light gray, dark gray, and black, medium-grained, well-foliated, inequigranular, tonalitic to quartz-monzonitic gneiss, commonly migmatitic.
Aluminous schist and gneiss: Gray to dark brownish-gray, medium-grained, inequigranular, generally well foliated, commonly micaceous gneiss and schist containing aluminosilicate minerals.
Gedrite gneiss: Brown to grayish brown, moderately well-foliated, medium-grained, gedrite gneiss. Generally occurs in small lenses and concordant layers in other Archean rocks.
Garnet gneiss: Highly garnetiferous assemblage of various colors that includes biotite-garnet schist, sillimanite-garnet schist, garnetiferous quartzite, quartzite, garnetiferous quartzofeldspathic gneiss, corundum gneiss, gedrite schist, cummingtonite schist, and garnetiferous amphibolite (Vitaliano and Cordua, 1979).

Aamh **Amphibolite and hornblende gneiss (Archean)**—Gray to black, medium-grained, hypidiomorphic, equigranular, moderately foliated to well-foliated hornblende-plagioclase gneiss and amphibolite.

Aum **Ultramafic rock (Archean)**—Includes mafic to intermediate gneiss, hornblende-plagioclase gneiss, amphibolite, granulite, and intrusive metabasite.

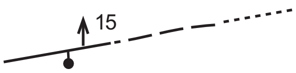
Aqa **Quartzite and amphibolite (Archean)**—Interlayered white quartzite and amphibolite.

Aq **Quartzite (Archean)**—White, gray, and brown, medium- to coarse-grained, inequigranular, moderately foliated to massive quartzite.

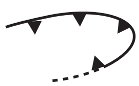
Aif **Banded iron formation (Archean)**—Dark reddish-brown to orange-brown, massive to layered quartz-hematite rock locally containing abundant quartz veins; limonitic, especially along fractures.

MAP SYMBOLS
BOZEMAN 30’ x 60’ QUADRANGLE

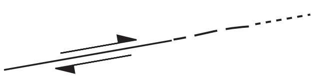
Contact between geologic units—Dashed where approximately located; dotted where concealed.



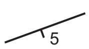
Fault, high-angle normal or reverse—Long-dashed where approximately located, short-dashed where inferred, dotted where concealed. Ball and bar on downthrown side. Arrow indicates direction of fault plane dip where known; number indicates angle of fault plane dip in degrees where measured. Many high angle faults have had episodes of reactivation and reversal of movement. Only the last movement or net movement is indicated.



Fault, thrust—Sawteeth on upper plate; dotted where concealed.



Fault, strike-slip or oblique slip—Long-dashed where approximately located, short-dashed where inferred, dotted where concealed. Arrows indicate relative lateral movement. Most faults with this symbol are oblique slip with both dextral and reverse movement (Schmidt, 1971).



Strike and dip of bedding—Number indicates angle of dip in degrees.

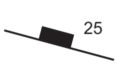
Vertical beds.

Overturned beds—Number indicates angle of dip in degrees.

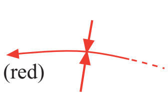
Horizontal beds.

Strike and dip of foliation—Number indicates angle of dip in degrees.

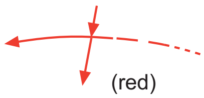
Vertical foliation



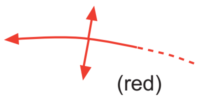
Strike and dip of joint plane—Number indicates angle of dip in degrees.



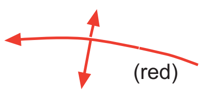
Syncline—Showing trace of axial plane and direction of plunge; dotted where concealed. Plunge arrow omitted where not plunging or plunge direction unknown. Synform in Archean rocks where top of beds is unknown.



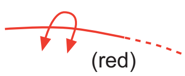
Synclinal bend—Showing trace of axial plane and direction of plunge where known. Dashed where inferred; dotted where concealed; short arrow on more steeply dipping limb.



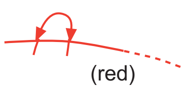
Anticline—Showing trace of axial plane and direction of plunge; dotted where concealed. Plunge arrow omitted where not plunging or plunge direction unknown. Antiform in Archean rocks where top of beds is unknown.



Asymmetric anticline—Showing trace of axial plane and direction of plunge. Short arrow on more steeply dipping limb.

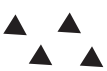


Overturned anticline—Showing trace of axial plane. Dotted where concealed.

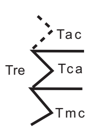


Overturned syncline—Showing trace of axial plane. Dotted where concealed.

Shear zone



Zone of tectonic brecciation



Symbol change—From area where two or more units are combined, to area where they are mapped individually or fewer units are combined. Dotted where concealed.

CITED REFERENCES AND BIBLIOGRAPHY
BOZEMAN 30'x 60' QUADRANGLE

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