GEOLOGIC MAP OF THE BOZEMAN 30' x 60' QUADRANGLE
SOUTHWESTERN MONTANA

Montana Bureau of Mines and Geology Open-File Report 648

2014

Compiled and mapped by

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GEOLOGIC SOURCE MAPS AND INDEX OF 7.5′ QUADRANGLES
BOZEMAN 30′ x 60′ QUADRANGLE

112° 111º

46°

Doherty Mtn 1, 5, 14, 15, 22, 23, 25, 30, 32, 40, 46, 48, 50, 51, 53, 55	Negro Hollow 10, 23, 25, 32, 36, 46, 50	Milligan Canyon 33, 46, 54	Three Forks 29, 37, 46	Logan 34, 37, 39, 43, 45, 55	Nixon Gulch 9, 12, 34, 39, 43, 45	Horseshoe Creek 9, 18, 43, 45	Flathead Pass 9, 18, 26, 45
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Pony 13, 31, 35, 38, 44, 46	Harrison 6, 17, 35, 44, 46	Willow Creek Reservoir 8, 21, 46, 48	Norris NE 8, 21, 45	Madison Plateau 12, 24, 37, 41, 45, 48, 52	Anceney 2, 9, 12, 24, 28, 45	Bozeman Hot Springs 9, 12, 24 28, 45	Bozeman 9, 11, 12, 24
Potosi Peak 13, 16, 38, 44, 54	Maltbys Mound 7, 16, 27, 38, 44, 55	Norris 8, 20, 48	Bear Trap Creek 2, 8, 20	Cherry Creek Canyon 2, 9, 28, 41	Ruby Mountain 2, 9, 24, 28, 41	Gallatin Gateway 2, 9, 24, 42, 48, 52	Wheeler Mountain 3, 9, 11, 24, 42, 47, 48, 52

45°30′

Numbers above correspond with reference list on next page.

GEOLOGIC MAP SOURCES
BOZEMAN 30′ x 60′ QUADRANGLE

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

Published, thesis, and dissertation maps

1. Alexander, R.G., Jr., 1951, pl. 1, scale 1:25,344.
2. Clabaugh, S.E., and Armstrong, F.C., 1950, pl. 11, scale 1:125,000.
3. Custer, S.G., 1995a, figs. 7-9.
4. Davis, W.E., Kinoshita, W.T., and Robinson, G.D., 1965.
5. Dixon, R.M., and Wolfgram, Diane, 1998, scale 1:24,000.
6. Elliott, W.S., 1998a, scale 1:24,000.
7. Elliott, W.S., 1998b, scale 1:24,000.
8. Feichtinger, S.H., 1970, pl. 1, scale 1:24,000.
9. Fix, P.F., 1940, pl. 21, scale 1:126,720.
10. Glaman, L.R.B., 1991, pl. 1, scale 1:12,000.
11. Glancy, P.A., 1964, pl. 1, scale 1:24,000.
12. Hackett, O.M., Visher, F.N., McMurtrey, R.G., and Steinhilber, W.L., 1960, pl. 2, scale 1:63,360.
13. Hall, R.D., and Heiney, J.S., 1983, fig. 2.
14. Harlan, S.S., and others, 2008b, fig. 2.
15. Hendrix, T.E., and Stellavato, N., 1976, fig. 10–1, scale 1:62,500.
16. Hess, D.F., 1967, pl. 3, scale 1:24,000.
17. Hoh, A.M., 1997.
18. Hughes, G.C., 1981, pl. 1, scale 1:63,000.
19. Kellogg, K.S., 1994, scale 1:24,000.
20. Kellogg, K.S., 1995, scale 1:24,000.
21. Kellogg, K.S., and Vuke, S.M., 1996, scale 1:24,000.
22. Kuenzi, W.D., 1966, scale 1:24,000.
23. Lofgren, D.L., 1985, pl. 1, scale 1:24,000.
24. Lonn, J.D., and English, A.R., 2002, scale 1:48,000.
25. Ludman, Alan, 1965, pl. 1, scale 1:6,000.
26. McMannis, W.J., 1955, pls. 1 and 2, scale 1:48,000.
27. Meyers, S.A., 1991, pl. 2, scale 1:6,000.
28. Mifflin, M.D., 1963, scale 1:31,680.
29. Mitchell, M.M., 1987, pl. 1, scale 1:24,000.
30. Moore, G.T., 1954, pl. 1, scale 1:6,000.
31. O’Neill, J.M., 1983, pl. 1, scale 1:50,000.
32. Richard, B.H., 1966, pls. 1-4, scale 1:24,000; pl. 5, scale 1:60,000; fig. 10, scale 1:31,680.
33. Robinson, G.D., 1963, pl. 1, scale 1:48,000.
34. Sayers, F.E., 1962, pl. 8, scale 1:33,000.
35. Schmidt, C.J., 1975, pl. 1, scale 1:24,000.
36. Schmidt, C.J., and O’Neill, J.M., 1982, fig. 17, scale 1:168,960.
37. Schneider, G.B., 1970, pl. 1, scale 1:24,000.
38. Smith, J.L., 1970, pl. 1, scale 1:48,000.
39. Spahn, R.A., Jr., 1967, pl. 1, scale 1:24,000.
40. Streeter, M.E., 1983, scale 1:24,000.
41. Tilley, C.W., 1976, pl. 1, scale 1:24,000.
42. Tysdal, R.G., 1966, pl. 1, scale 1:31,680.
43. Verrall, Peter, 1955, pl. 1, scale 1:24,000.
44. Vitaliano, C.J., and Cordua, W.S., 1979, scale 1:62,500.
45. Vuke, S.M., 2003, pl. 1, scale 1:50,000.
46. Vuke, S.M., 2006, pl. 1, scale 1:50,000.
47. Weber, W.M., 1965, pl. 1, scale 1:28,800.

Unpublished maps, excluding thesis and dissertation maps

48. Berg, R.B., Montana Bureau of Mines and Geology.
49. Cox, Bruce, Earthworks, Inc., for Golden Sunlight Mines, Inc.
50. Dresser, Hugh, Butte, MT, *A stereo picture guide to some of Montana’s thrust faults* (1996).
51. Hanneman, D., Whitehall GeoGroup, Inc., for Golden Sunlight Mines, Inc.
52. Lonn, J.D., Montana Bureau of Mines and Geology.
53. Nilsen, Tor, for Golden Sunlight Mines, Inc.
54. Schmidt, C.J., Western Michigan University
55. Vuke, S.M., Montana Bureau of Mines and Geology

Entire quadrangle

Vuke, S.M., Berg, R.B., Lonn, J.D., and Kellogg, K.S., 2002, scale 1:100,000.

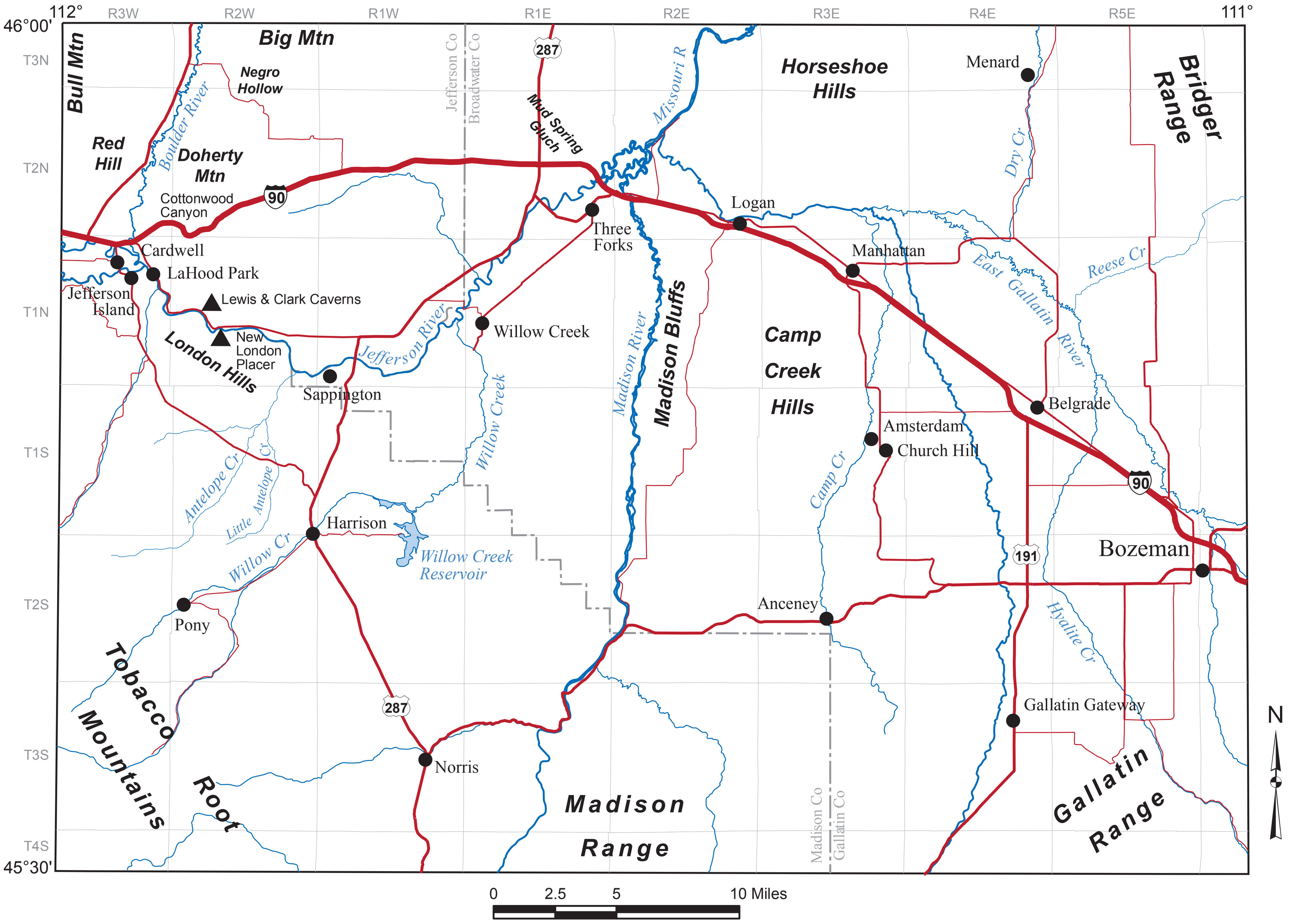

Figure 1. Location map for Bozeman 30' x 60' quadrangle.

DESCRIPTION OF MAP UNITS
BOZEMAN 30′ x 60′ QUADRANGLE

Qal **Alluvium (Holocene)**—Light gray to light brown gravel, sand, silt, and clay deposited in stream and river channels, on their floodplains, and on low terraces as much as about 6 m (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 small streams originating in Tertiary uplands are dominantly granule size and smaller, and may include rip-up clasts.

River alluvium:

Gallatin and East Gallatin Rivers: Rounded to well-rounded small boulders, cobbles, gravel, sand, silt, and clay, dominantly composed of Archean metamorphic rocks, and dark-colored volcanic rocks, with subordinate Paleozoic limestone, and Precambrian Belt rocks.

Madison River: Subrounded to rounded, gravel and sand with clasts rarely larger than cobble size (Robinson, 1963) dominantly composed of Archean metamorphic rocks, dark-colored igneous rocks, Paleozoic limestone, quartz, and chert.

Tributaries of Gallatin and East Gallatin River: Clast composition varies. Clasts of tributaries from the Tertiary of the Camp Creek Hills are derived primarily from the pebbles and cobbles of Tertiary fluvial deposits. Dry Creek and its tributaries contain clasts derived from the Maudlow Basin, Horseshoe Hills, Bridger Range, and local Tertiary and older Quaternary deposits. Estimated thickness of Holocene alluvium of Gallatin River is 15-25 m (50-80 ft) based on thicknesses in well logs where Qal rests directly on bedrock.

Jefferson River: Dominantly subrounded to rounded and fairly well sorted with clasts rarely larger than cobble size. Thickness probably less than 15 m (50 ft) in most areas.

Qc **Colluvium (Holocene)**—Unstratified, unconsolidated, poorly sorted, angular to subangular clasts derived from local sources. Thickness unknown, but maximum thickness is probably less than 10 m (33 ft).

Qls **Landslide deposit (Holocene)**—Unstratified, unsorted mixtures of sediment that moved downslope through mass wasting processes. Includes rotated or slumped blocks of bedrock and surficial sediment, earthflow deposits, and mudflow deposits. Color and lithology and grain size reflect that of parent rock and transported surficial material. Thickness probably less than 30 m (100 ft).

Qpa **Paludal deposit (Holocene)**—Sand, silt, and organic matter deposited in swamp, pond, or small lake environment. Thickness probably less than 10 m (33 ft).

Qdf **Debris-flow deposit (Holocene)**—Angular, subangular and subrounded clasts of poorly sorted, locally derived boulders and cobbles in a matrix of fine-grained sediment. Thickness probably about 15 m (50 ft) in thickest part.

Qe **Eolian deposit (Holocene and Pleistocene)**—Yellowish gray to very pale orange, silt and clay-size sediment with scattered grains and thin lenses of rounded fine-grained sand. Dominantly volcanic glass, quartz, and clay minerals with minor amounts of mica, feldspar, and calcite, also silt, and clay. Thinly mantles many more areas than shown on map. Thickness highly variable. Locally as much as 30 m (100 ft), but generally 1 m (3 ft) or less.

Qac **Alluvium and colluvium, undivided (Holocene and Pleistocene)**—Locally derived sediment on slopes. Color reflects that of parent material. Ranges from clay and silt to gravel, depending on source. Thickness generally less than 6 m (20 ft).

Qgr **Gravel deposit (Holocene and Pleistocene)**—Variable deposits of gravel, sand, silt, and clay 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 subrounded to rounded pebbles, cobbles, small boulders, and rare large boulders. Composition is dominantly orthoquartzite, vein quartz, quartz-rich gneiss, and dark volcanic rocks. North of the Jefferson River, most gravel deposits 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. Near the headwaters of the Missouri River, some of the deposits on pediment surfaces consist dominantly of angular limestone clasts. Thickness ranges from pediment veneer about 2.5 cm (1 inch) thick to valley fill as much as 120 m (400 ft) thick.

Qaf **Alluvial fan deposit (Holocene and Pleistocene)**—Deposit with preserved fan morphology at break in slope, composed of a heterogeneous mixture of subangular to moderately rounded coarse clasts as large as boulders, and fine-grained sediment (sand, silt, and clay) that is generally concentrated near fan margins. Clasts derived from adjacent uplands. Estimated thickness is about 30 m (100 ft) at thickest part.

Qab **Alluvium of braid plain (Holocene and/or Pleistocene)**—Rounded to well-rounded, dominantly cobble gravel with clasts as large as boulders, and sand, silt, and clay; mostly composed of Archean metamorphic rock fragments, and dark-colored volcanic rocks, with subordinate Paleozoic limestone and Proterozoic Belt rocks. Clast lithologies in general order of decreasing abundance include Precambrian metamorphic rocks, mafic volcanic rocks, dacite(?) porphyry, quartzite, sandstone, limestone, and chert. Two wells in this unit adjacent to the Gallatin River indicate thicknesses of Quaternary alluvium overlying Tertiary deposits of 9.5 m (31 ft) and 65 m (215 ft) (Hackett and others, 1960).

Qat **Alluvial terrace deposit (Holocene and/or Pleistocene)—**Subrounded and rounded pebbles, cobbles, and sand with some thin beds of clayey silt. Underlies distinct terraces adjacent to and at elevations higher than modern streams. Clast lithologies variable, but may include Precambrian metamorphic rock, igneous rock, quartzite, and sandstone. Thickness about 6 m (20 ft).

Qafh **Hyalite Alluvial Fan (Pleistocene)**—Deposit with distinct fan morphology composed of 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 11 km (7 mi) into the valley. Distribution of clast sizes varies. In general, coarse-grained sediment is dominant near the head of the fan and fine-grained sediment near the margins. Clasts are dominantly matrix supported and poorly sorted, although sediment deposited in distributary channels is moderately to well sorted and clast supported. Large clasts subrounded to rounded. May be as much as 60 m (200 ft) thick.

Qafo	**Alluvial-fan deposit, older than Qaf (Pleistocene)**—Light brown, gray, and locally reddish gray, angular and subangular, locally derived gravel in a coarse sand and granule matrix. Clast size ranges from pebble to small boulder. Fan morphology dissected. Maximum thickness probably about 45 m (150 ft).
Qabo	**Braid plain alluvium, older than Qab (Pleistocene)**—Rounded to well-rounded, dominantly cobble gravel with clasts as large as boulders, and sand, silt, and clay; mostly composed of clasts of Archean metamorphic rock, and dark-colored volcanic rock, with subordinate Paleozoic limestone and Proterozoic Belt rocks. Clast lithologies in general order of decreasing abundance include Precambrian metamorphic rocks, mafic volcanic rocks, dacite(?) porphyry, quartzite, sandstone, limestone, and chert. A well in this unit indicates a thickness of 9 m (30 ft) of alluvium overlying Tertiary deposits.
Qalo	**Alluvium, older than Qal (Pleistocene)**—Subrounded to rounded, fairly well sorted gravel with relatively few clasts larger than cobble size, and sand. Deposit covered by organic material, silt, and mud in some areas. Late Pleistocene bison and Holocene animal bones have been found in these deposits near Three Forks (Robinson, 1963). Thickness probably no more than 15 m (50 ft) in the Three Forks area (Robinson, 1963).
Qlso	**Landslide deposit, older than Qls (Pleistocene)**—Unstratified, unsorted mixtures of yellowish brown Tertiary sediment that moved downslope through mass wasting processes north and east of Bozeman. Offsets from landslide displacement apparent in roadcut exposures. Thickness probably less than 30 m (100 ft).
Qep	**Eolian and pediment deposits, undivided (Pleistocene)**—Yellowish gray, fine-grained tuffaceous sand and silt overlying pediment veneer of coarser sediment. Thickness generally less than 1 m (3 ft).
Qm	**Mantle (Pleistocene)**—Regolith and lag deposits with clasts as large as boulders derived from underlying Tertiary deposits and from Quaternary debris-flow deposits, subordinate water-transported deposits, and colluvium.
Qp	**Pediment deposit (Pleistocene)**—Sediment veneer that ranges from angular to rounded, dominantly pebble size or smaller clasts, to gravel on pediment surface.
Qg	**Glacial deposits, undivided (Pleistocene)**—Poorly sorted, angular to rounded, unconsolidated clasts of dominantly cobbles and boulders, but also pebbles, sand, silt, and clay. Large clasts are 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 45 m (150 ft).
Qgk	**Glacial kame deposit (Pleistocene)**—Moderately well sorted and stratified deposit in Tobacco Root Mountains associated with other glacial features.
Qgt	**Glacial till (Pleistocene)**—Unconsolidated, poorly sorted, angular to rounded clasts of dominantly cobbles and boulders, but also pebbles, sand, silt, and clay. Large clasts dominantly composed of Archean metamorphic rocks, and igneous rocks of the Tobacco Root Batholith. Includes some stratified outwash. Thickness less than 45 m (150 ft).

Qgo **Glacial outwash deposit (Pleistocene)**—Moderately to well sorted, subrounded to well rounded gravel immediately downslope from glacial till (Qgt deposits).

Qrg **Rock glacier deposit (Pleistocene)**—Angular rock debris cemented by interstitial ice.

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 35 m (115 ft).

QTafy **Alluvial fan deposit, younger than QTafo (Pleistocene and/or Pliocene)**—Overlies QTafo in Negro Hollow area. Light gray unconsolidated, angular to subangular, and subordinate subrounded gravel. Clasts are almost exclusively locally derived from Paleozoic limestone but also include locally derived chert and Quadrant Formation. Thickness probably less than 30 m (100 ft).

QTafo **Alluvial fan deposit, older than QTafy (Pleistocene and/or Pliocene)**—Underlies QTafy in Negro Hollow area. Light gray unconsolidated, angular to subangular, and subordinate subrounded gravel, and well cemented breccia, especially at the base. Basal breccia matrix is reddish brown in most places and patches of reddish brown matrix also occur locally, higher in the unit. Clasts are almost exclusively locally derived Paleozoic limestone but also include locally derived chert and Quadrant Formation. Includes slightly bentonitic, pinkish gray and very light gray, tuffaceous sandstone west of the southern part of Big Mountain. Thickness probably less than 30 m (100 ft).

QTat **Alluvial terrace deposit (Pleistocene and/or Pliocene)**—Angular clasts of Elkhorn Mountains Volcanics associated with a pebble gravel in a very limited linear distribution on the tops of low hills along a tributary of Spring Gulch in the northwestern part of the map. A Miocene Barstovian fossil was found in this unit (Robinson, 1963). Thickness about 1 m (4 ft).

QTep **Eolian, paleosol, and pediment deposits (Pleistocene and/or Pliocene)**—Dark brown, clayey silt and fine-grained eolian sand with sparsely distributed, matrix-supported pebbles and some cobbles that alternates with weakly developed paleosols. Pediment surface on deposit veneered with pebble-size and smaller clasts transported by sheetwash. Thickness probably less than 15 m (50 ft).

QTge **Gravel and eolian deposits, undivided (Pleistocene and/or Pliocene)**—Deposits in Jefferson Canyon with two distinct components – a gravel with mostly boulders, overlain by fine-grained sediment of probable eolian origin. At the New London placer, near Lewis and Clark Caverns, clast composition includes Archean metamorphic, Belt Supergroup quartzite, subangular and subrounded clasts of LaHood Formation conglomerate, individual quartzite clasts recycled from the LaHood Formation conglomerate, and Paleozoic limestone.

QTdf **Debris-flow deposit (Pleistocene and/or Pliocene)**—Angular, subangular, and subrounded clasts of poorly sorted, locally derived boulders and cobbles in a matrix of fine-grained sediment.

QTgr **Gravel deposits (Pleistocene and/or Pliocene, and patchy remnants of Miocene)**—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. An immature, matrix-supported breccia with angular to subangular granules, pebbles, and cobbles of Archean metamorphic rocks is below the gravel and included in the map unit. Combined thickness of both deposits is 6-12 m (20-40 ft). The deposit in the Tobacco Root Mountains contains matrix-supported, well-rounded pebbles, cobbles, and boulders up to 9 m (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 Gallatin Gateway have the same clast composition as pebbles and cobbles in the underlying Tertiary rocks, and may be local deposits related to faulting. In addition, several fossils indicate that there are patchy remnants of Miocene deposits (Robinson, 1963) that are included in this map unit west of the Madison River. Thickness about 9 m (30 ft).

Tertiary deposits of unknown age

Ts **Sediment or sedimentary rocks, undivided (Tertiary)**

Trs **Rhyolite sediment (Tertiary)**—Very light gray to white, well-bedded, well-indurated siltite, sandstone, and clast-supported sedimentary breccia composed almost entirely of rhyolite vitrophyre; clasts are angular and as much as 0.9 m (3 ft) long. Interlayered and locally intermixed with abundant white air-fall ash. Exposed thickness about 30 m (100 ft).

Trb **Red Bluff Formation (Tertiary)** (Kellogg, 1994):

Upper: White and light yellowish brown siltstone, sandstone, conglomerate, and subordinate, but conspicuous, brick red and maroon mudstone and siltstone; locally tuffaceous. Most clasts are Archean gneiss, and vein or pegmatite quartz, with some quartz monzonite and granodiorite from Tobacco Root Batholith. 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 are very large, some as much as 15 m (50 ft) wide. Type locality is within quadrangle in W½ sec. 13, T. 3 N ., R. 1 W.

Sixmile Creek Formation (younger than Hemingfordian unconformity)

Tscr **Reese Creek member (Miocene: Clarendonian and Hemphillian)**—Basal cobble or small boulder clast-supported conglomerate or gravel cemented by calcium carbonate, or unconsolidated with clasts coated by calcium carbonate overlain by orangish tan tuffaceous mudstone with lenses of fine-grained sandstone. Fine-grained upper part of unit best exposed near the mouth of Reese Creek. In most other areas, the poorly resistant, fine-grained part is poorly exposed. A vitric ash was sampled from near the mouth of Reese Creek that provided a K/Ar date of 8.9±0.4 Ma (youngest Clarendonian or oldest Hemphillian). The ash has an abrupt basal contact and climbing ripples at the top, and is 0.9-1.5 m (3-5 ft) thick (Hughes, 1980). The contact between this map unit and the underlying Madison Valley member is an angular unconformity in the northern Gallatin Valley.

Tsccb **Clarkston Basin member (Miocene)**—Brownish gray and brownish yellow breccia or unconsolidated deposit with clast-supported or matrix-supported, fine to coarse, angular clasts of dominantly Greyson, Newland, and Spokane Formation, and Paleozoic quartzite and limestone. Paleozoic clasts are as large as boulder size. Coarse- and fine-grained beds may alternate. Cementation may be variable producing irregular surfaces.

Tscmp **Madison Plateau member (Miocene: Clarendonian or Hemphillian)**—Sheet deposit of moderately well-sorted and well-rounded clast-supported cobble conglomerate or gravel; color reflects maroon, gray, and brown calcium-carbonate-coated cobbles of dominantly Belt quartzite duraclasts. Archean metamorphic clasts are found only at the base as pebble size or smaller. The clasts were likely reworked from underlying Madison Valley member pebble conglomerates that contain Archean clasts. May correlate with clast-supported cobble conglomerate in Reese Creek area at base of Reese Creek member, from which an ash bed yielded a K/Ar date of 8.9 ±0.4 Ma (Hughes, 1980; Lange and others, 1980). If so, the Madison Plateau member is likely youngest Clarendonian or oldest Hemphillian. West of the Madison River, unit appears to rest conformably on the Madison Valley member, but unconformably on the Dunbar Creek Member (Dunbar Creek Formation of Robinson, 1963) (Vuke and others, 2002). East of the Madison River, unit appears to rest conformably on the Madison Valley member and was involved in northeastward tilting and folding of underlying units with apparent conformity. Alternatively, unit may be younger than, and rest disconformably on the underlying Madison Valley member. Regardless, unit was deposited prior to northeastward tilting and folding of Tertiary strata. Thickness 6-10 m (20-30 ft).

Tsccc **Cottonwood Canyon member (Miocene)**—Brown conglomerate or gravel dominantly of rounded cobbles of Elkhorn Mountains Volcanics and Belt Supergroup quartzite, although almost exclusively derived from Elkhorn Mountains Volcanics west of the Boulder River. Conglomerate/gravel clasts include pebbles and small boulders in matrix of granules and coarse sand. Clasts are commonly stained with iron oxide. Conglomerate and gravel are in sheets and lenses interbedded with subordinate light gray, coarse-grained sandstone with conglomeratic stringers and floating granules, greenish brown or reddish brown, slightly bentonitic mudstone, tan siltstone, and micaceous, silty mudstone. Other than immediately west of the Negro Hollow uplift and east of Bull Mountain, unit contains abundant to occasional subrounded boulders of granitic rock with weathering rinds as much as ¼-inch thick. At one location south of the Negro Hollow uplift, extremely large boulders of granitic rock and Elkhorn Mountains Volcanics are present. Near Cottonwood Canyon this unit was called Ballard gravel by Aram (1979).

Near Cottonwood Canyon there appear to be two levels of deposits, both mapped as Cottonwood Canyon member. The upper deposit overlies a syncline in Cambrian units. It contains more clasts of intrusive rocks than the lower deposit, but similar to the lower deposit, does not contain Archean clasts. In the Cottonwood Canyon area, unit rests on LaHood Formation and Paleozoic rocks but does not contain clasts of either.

Barstovian fossils were found in the finer grained component of the unit between the Boulder River and the Negro Hollow uplift (Lofgren, 1985). Maximum exposed thickness as much as 100 m (330 ft).

Tsch **Harrison member (Miocene and/or Pliocene?)**—Grayish brown matrix-supported conglomerate or gravel with subrounded, texturally poorly sorted and disorganized clasts, ranging from pebbles to large boulders in iron oxide-stained matrix of granule and smaller size clasts. Clast composition dominantly Archean metamorphic rocks (mostly gneiss and schist) with subordinate quartzite, granitic rock including pegmatite, and Paleozoic limestone. Locally well-cemented, but generally unconsolidated. Linear distribution of unit extends along Antelope and Little Antelope Creeks to Sappington. Appears cut into older Tertiary units and in places rests on Archean and Paleozoic rocks. Linear geometry and presence of granitic boulders are similar to the Red Bluff Formation near Norris, Montana, about ten miles to the southeast (Kellogg, 1994 and 1995). Maximum thickness as much as 60 m (200 ft).

Tscmv Madison Valley member (Miocene: Clarendonian and Barstovian)

Madison Bluffs, Madison Plateau, and Camp Creek Hills area. Pinkish tan or tan, tuffaceous silt or siltstone and marl interbedded with crossbedded, texturally immature, coarse-grained sandstone that contains lenses of pebble conglomerate or local cobble conglomerate ranging from matrix- to clast-supported, and from cemented to unconsolidated. Conglomerate clasts are dominantly Archean gneiss and extrusive volcanic rocks, with subordinate Belt rocks, and occasional Paleozoic limestone clasts. Sandstone has large root casts locally, and marl beds are typically full of small root casts. Several vitric ash beds are present throughout the unit. Opalized wood fragments are abundant in many conglomerate lenses. Conglomerate also contains relatively abundant disarticulated bones, bone fragments, and occasional teeth. Numerous articulated Barstovian fossils have been collected and studied from the fine-grained parts of this unit (Tabrum and Nichols, 2001; Douglass, 1899, 1901, 1903, 1907a, 1907b, 1908, 1909a, 1909b; Frick, 1937; Dorr, 1956; Sutton, 1977; Sutton and Korth, 1995; Evander, 1996), including the Anceney beds of Dorr (1956).

The contact between this unit and the underlying Dunbar Creek Member of the Renova Formation is sharp and locally appears unconformable as noted by Hackett and others (1960). In the northernmost part of the Madison Bluffs, the contact appears to be an angular unconformity. A relatively resistant bed at the base of the Madison Valley formation cuts down to nearly the level of the Climbing Arrow Member. In the southernmost part of the Madison Bluffs, calcic paleosols occur at the contact between the Madison Valley member and the underlying Dunbar Creek Member of the Renova Formation. Thickness 60 m (200 ft) throughout most of the Madison Bluffs area, but thickens to 90 m (300 ft) in the southern bluffs.

Dry Creek area. Grayish orange, crossbedded sandstone and pebble conglomerate interbedded with brownish orange tuffaceous siltstone and marl. Sandstone beds contain large lenses of dominantly pebble conglomerate with occasional cobble-size clasts or local cobble conglomerate. Conglomerates vary from matrix supported to clast supported. Unlike the clast composition in the Madison Bluffs and Camp Creek Hills areas, the clasts in the Menard area are dominantly Paleozoic limestone and Mesozoic sandstone, with subordinate andesitic volcanic rock and minor metamorphic rocks. Hughes (1980) interpreted the volcanic rock source as the Maudlow Basin where Livingston Group rocks are exposed. Near the Bridger Range, the clasts are dominantly Proterozoic LaHood Formation arkose, Paleozoic limestone, and quartz. Thickness near Menard about 30 m (100 ft). It is not known if the Madison Valley member thickens dramatically to the east, or if it has been down-faulted from the Bridger Range to Dry Creek. It is at a much higher elevation close to the Bridger Range than at Dry Creek.

Some of the coarse-grained beds of the Madison Valley member are shown on the map with a dotted pattern. In general, these are medium to coarse grained, fairly laterally persistent sandstone beds with numerous lenses of conglomerate and conglomeratic sandstone. Hughes (1981) describes these conglomeratic sandstones as “blanket-like” deposits in the Dry Creek area.

In local areas south of Manhattan and in the southeastern part of the map area, some of the conglomerate lenses contain dominantly cobble- rather than the more typical pebble-size clasts of other areas. These cobble conglomerates serve as caprocks with overlying fine-grained sediment stripped away. The cobble conglomerates have been interpreted as alluvial terrace deposits (Hackett and others, 1960) and pediment gravels (Mifflin, 1963), but were traced into the Madison Valley member in several places. They are shown as coarse-grained beds of the Madison Valley member. Gravel pits are numerous in the coarse-grained beds of the Madison Valley member.

Tscpb **Parrot Bench member (Middle Miocene: Barstovian)**—Brown conglomerate and gravel dominantly of subrounded to rounded cobbles of Elkhorn Mountains Volcanics and Belt Supergroup quartzite. Conglomerate/gravel clasts range from pebbles to small boulders in matrix of granules and coarse sand. Clasts are commonly stained with iron oxide. Resembles Cottonwood Canyon member which is also Barstovian, but has been included as part of the Parrot Bench map unit to the west (Vuke and others, 2004). Middle to Late Miocene Barstovian and Hemphillian fossils have been found in the Parrot Bench member immediately to the west of the map area on Parrot Bench (Kuenzi, 1966), but only the lower, probably Barstovian, part of the member is exposed in the map area.

Renova Formation (older than Hemingfordian unconformity)

Trnh **Negro Hollow member (Early Miocene**: **Arikareean)**—(Description modified from Lofgren, 1985). Dominantly poorly sorted, unconsolidated to moderately well cemented matrix-supported pebble conglomerate with granitic clasts dominant, and subordinate clasts of Elkhorn Mountains Volcanics, in a tuffaceous silt matrix. Conglomerate locally crossbedded. Lenses of clast-supported conglomerate generally at top of beds. Matrix-supported conglomerate grades laterally into, or is interbedded with, tabular beds of thinly laminated vitric silt and ash. Late Arikareean age determined from fossils (Lofgren, 1985). East of North Boulder River tuffaceous silt is dominant, and conglomerate is subordinate. Thickness about 275 m (900 ft).

Trdc **Dunbar Creek Member (Eocene and Oligocene: Arikareean, Whitneyan, Orellan, and Chadronian)**—The type section for the Dunbar Creek is within quadrangle in E½ sec. 7, T. 1 S., R. 2 E. (Robinson, 1963). Name derived from Dunbar Creek, a now obsolete name for a tributary of Mud Creek in the Three Forks area north of I-90.

Madison Bluffs and Camp Creek Hills. White to very light gray and light tan, tuffaceous planar-bedded siltstone and fine-grained sandstone with numerous tiny root casts, glassy ash beds, light gray tuffaceous limestone beds, and an interval of white diatomite beds near the top that extends the length of the Madison Bluffs. Distinguished from Madison Valley member by color, diatomite marker beds, and lack of significant conglomerate lenses. An $^{40}Ar/^{39}Ar$ date from the Dunbar Creek Formation in the Madison Bluffs on a single crystal feldspar yielded a range of 15-23 Ma with a weighted mean ~21.5 Ma, making it likely Arikareean North American Land Mammal age (upper Oligocene or lower Miocene). Hackett and others (1960) correlated the Dunbar Creek Member (their unit 1) in the Madison Bluffs and Camp Creek Hills with deposits near Menard in the Dry Creek area. Ostracode, gastropod, and fish fossils have been reported from the Dunbar Creek Formation in the Madison Bluffs (Blake, 1959; Dorr, 1956; Schneider, 1970). Thickness of unit about 45m (150 ft) in central Madison Bluffs, but may be thicker in the southern part of the Madison Bluffs where it is obscured by slope alluvium and colluvium. In the northernmost bluffs, it thins abruptly to about (15 m) 50 ft.

Calcic paleosols as described by Hanneman and others (1994) occur near road level in the area of Madison Buffalo Jump State Park (D. Hanneman, oral communication, 2002). They also occur where this unit is exposed in the northernmost and southernmost parts of the bluffs. Maximum exposed thickness about 45 m (150 ft).

Dry Creek area. White to very light gray and light tan, tuffaceous siltstone, fine-grained sandstone and mudstone, tuffaceous marl and limestone, and ash. Ostracode and gastropod fossils have been reported from this unit in the Dry Creek area (Hughes, 1980; Hackett and others, 1960; Verrall, 1955), and Klemme (1949) reported mammal fragments in this unit in the Dry Creek area. An ash in the Dry Creek area yielded a K/Ar date of 30.6±1.2 Ma (Whitneyan, Oligocene) (Hughes, 1980; Lange and others, 1980).

Willow Creek Reservoir area. Interbedded white, light gray, and light tan, very fine grained locally vuggy limestone and sandy limestone, white to light brown, tuffaceous, micaceous, calcareous siltstone and sandstone, and massive white ash. Contains silicified stems 1 cm in diameter with visible internal structure, and tubular root casts. Exposed thickness about 60 m (200 ft). Called Norwegian Creek beds by Feichtinger (1970).

Three Forks area. Very light gray to grayish yellow, thick-bedded, tuffaceous silt and siltstone with subordinate sand, sandstone, conglomerate, and rare bentonitic clay and very light gray limestone. North of the Jefferson River, unit includes many tongues of poorly sorted, poorly rounded carbonate-rich gravel not present south of the Jefferson River. The tuffaceous rocks and sediment are dominantly composed of fine volcanic ash. An Arikareean fossil, *Diceratherium armatum* Marsh, was found in a sandstone bed four miles south of Three Forks (Wood, 1933) in the lower Dunbar Creek Member. Also, an Arikareean beaver was described from the bluffs on the west side of the Madison River "about nine or ten miles south of Three Forks" (Douglass, 1901) in the Dunbar Creek Member. North of the Jefferson River the Dunbar Creek Member contains Chadronian (Eocene) fossils (Tabrum and others, 2001). North of the Jefferson River the contact between the Climbing Arrow and Dunbar Creek Members is conformable, and south of the Jefferson River, the contact is disconformable. Thickness as much as 90 m (300 ft) in the southeastern part of the map area.

Trca **Climbing Arrow Member (Eocene: Uintan, Duchesnean, Chadronian)**—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 NE¼ NE¼ NE¼ sec. 11, T. 2 N., R.1 W. (Lange and others, 1980). Type section is within quadrangle in W½ sec. 12, T. 1 N., R. 1 E. (Robinson, 1963). Thickness not less than 230 m (750 ft), but may be considerably more than 300 m (1,000 ft) (Robinson, 1963).

Trmc **Milligan Creek Member (Eocene)**—(Robinson, 1963): Light gray, fine-grained, tuffaceous, argillaceous limestone, marlstone, and calcareous mudstone units that interfinger with sandstone and conglomerate with rounded to subrounded clasts that are dominantly quartz and volcanic rock. Type section is within quadrangle in E½ sec. 11, NW¼ sec. 12, and SW¼ sec. 1, T. 1 N., R. 1 W.

Trrh **Red Hill member (Eocene: early Chadronian)**—Dominantly moderate red, reddish orange, and reddish brown kaolinitic 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, and red immature granitic sandstone. Unit typically weathers to red soil. Several vertebrate fossils found in member on Bull Mountain are early Chadronian (A. Tabrum, personal communication *in* Rothfuss, 2007). Member present on southern Bull Mountain and southern Doherty Mountain, and in Milligan Canyon and possibly Timber Canyon. Includes Sphinx conglomerate of Robinson (1963). Deposited in alluvial fan environments proximal to basin-margin uplifts (Rothfuss, 2007). Thickness variable; locally more than 90 m (300 ft) thick (Robinson, 1963).

Igneous rock

Tan **Andesite (Eocene)**—Medium gray, dominantly andesite porphyry, but also includes porphyritic latite, and latite porphyry. Many small phenocrysts of feldspar and mafic minerals are only slightly larger than the groundmass (Robinson, 1963). Exposed thickness as much as 110 m (360 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 260 m (850 ft).

Tav **Absaroka Volcanics (Eocene)**—Light brown-weathering, dark gray to black, basic, slightly porphyritic andesite with plagioclase, augite, and hypersthene phenocrysts in individual flows interlayered with stratified flow breccias. Exposed thickness 260 m (850 ft).

Tba **Basalt (Eocene?)**—(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 200 m (650 ft). Olivine basalt near Three Forks mostly compact but vesicular in some places. Homogeneous flow bands and minor flow breccia.

TKa **Andesite (Eocene or Late Cretaceous)**—(Dixon and Wolfgram, 1998): Porphyritic basaltic andesite on Bull Mountain, blocky to massive, 40-50 percent plagioclase phenocrysts that average 5 mm to 1 cm (0.2-2 in.) within a deep red to gray matrix. Silicified and argillic along contact with Mission Canyon Formation.

TKl **Latite (Eocene or Late Cretaceous)—***Three Forks area* (Robinson, 1963): Medium gray to medium dark gray latite that weathers to steely purplish tones similar to the Elkhorn Mountains Volcanics. Latite has sparse and small phenocrysts of feldspar and pyroxene in a dense, nonvesicular holocrystalline matrix.

TKda **Dacite (Eocene or Upper Cretaceous)**—(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 75 m (250 ft).

TKfi **Felsic intrusive rocks, undivided (Eocene or Late Cretaceous)**—*Red Mountain area* (Kellogg, 1995): Gray, pinkish gray, and purple porphyritic rhyolite or dacite with an aphanitic, cherty matrix. Plagioclase phenocrysts as long as 8 mm, but typically 3 mm. In most places flow banded. A columnar-jointed sill as thick as 25 m (82 ft) intruded the contact or lower part of the Flathead Formation southeast of Red Mountain.

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 0.5 m (1.5 ft) thick. Exposed thickness as much as 75 m (250 ft).

Ki **Intrusive rocks, undivided**

Kem **Elkhorn Mountains Volcanics (Late 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 that are rounded and as much as 50 cm (20 inches) wide in a coarse-grained sand matrix. Rests unconformably on units as old as the Lodgepole Limestone. As much as 2,750 m (9,000 ft) thick (Alexander, 1955).

Kan **Andesite (Late Cretaceous)**—Rocks with variable generally andesitic composition.

Kdia **Diabase (Late Cretaceous)**—*Horseshoe Hills* (Sayers, 1962): Highly altered, porphyritic augite diabase.

Kg **Granite (Late Cretaceous)**—*Tobacco Root Batholith* (Smith, 1970): Equigranular and fine- to medium-grained. Generally finer grained than other batholith rock types. Potassium feldspar megacrysts generally rare and relatively small, but occasionally as large as 3.0 cm. Plagioclase generally in euhedral crystals; quartz and potassium feldspars almost invariably anhedral. Potassium feldspars are poikilitic and include all other mineral types. Biotite, magnetite, apatite, sphene, and zircon accessory minerals.

Kgd **Granodiorite (Late Cretaceous)**—*Tobacco Root Batholith* (Smith, 1970): Dominantly fine-grained and equigranular to subordinate coarse-grained porphyries. Hornblende and biotite are visible megascopically. Potassium feldspar phenocrysts are typically smaller and less numerous than hornblende and biotite phenocrysts.

Khd **Hornblende diorite (Late Cretaceous)**—*Tobacco Root Batholith* (Smith, 1970): Hypidiomorphic granular to panidiomorphic fine- to medium-grained; 12-28% hornblende, 3-8%, quartz with accessory minerals biotite, pyroxene, sphene, magnetite, zircon, apatite, allanite, and rutile. (Kellogg, 1994): Dark gray, fine- to coarse-grained, equigranular to inequigranular, well indurated hornblende diorite and hornblende monzodiorite.

Khto **Hornblende tonolite (Late Cretaceous)**—*Tobacco Root Batholith* (Smith, 1970): Medium-grained and equigranular to porphyritic tonolite with 5-13% hornblende. Elongated ferromagnesian minerals emphasize flow structures. Potassium feldspars are poikilitic and quartz occurs as intergrowths with these and plagioclase. Granitoid texture is common and subhedral-euhedral crystals are completely interlocking. Quartz is interstitial and feldspars are zoned.

Kto **Tonalite (Late Cretaceous)**—*Tobacco Root Batholith* (Smith, 1970): Medium-grained and equigranular to porphyritic with pink potassium feldspar megacrysts in about 1/3 of the exposures. Platy elongated ferromagnesian minerals emphasize flow structures. Potassium feldspars are poikilitic and quartz occurs as intergrowths with ferromagnesian minerals and plagioclase. Granitoid texture is common and subhedral-euhedral crystals are completely interlocking. Quartz is interstitial and feldspars are zoned.

Kqm **Quartz monzonite or monzogranite (Late Cretaceous)**—*10N Pluton* (Robinson, 1963): Pink, pale grayish brown or moderate brown weathering, dominantly quartz monzonite and monzogranite, but also includes monzonite porphyry, diorite porphyry, and quartz latite porphyry. Strongly lineated. Exposed thickness 75 m (250 ft). *Tobacco Root Batholith* (Smith, 1970): Medium-grained (1.2-2.0 mm) ranging from equigranular to coarse porphyritic with 5 cm (2 in.) long potassium feldspar megacrysts. Most quartz monzonite at least slightly porphyritic.

Ksk **Skarn (Late Cretaceous**)—Contact metamorphosed Paleozoic carbonate rocks adjacent to the 10N Pluton north of Three Forks. Includes isolated, small igneous intrusive bodies (Michael Garverich, oral communication, 2012).

Kmod **Monzonite and diorite (Late Cretaceous)**—(Robinson, 1963): Porphyritic monzonitic and dioritic rocks of the 10N Pluton north of Three Forks

Kse **Sedan Formation (Upper Cretaceous)**—(Skipp and others, 1999):

Mudstone member: Greenish gray and brownish gray volcaniclastic mudstone, siltstone, sandstone, and minor interbedded conglomerate and altered vitric tuff.

Middle sandstone member: Olive green and dark greenish gray, volcaniclastic sandstone, conglomerate, mudflow conglomerate, and minor siltstone and mudstone.

Ash-flow tuff member: Pale yellowish green, light greenish gray, grayish red, and pale yellowish brown, welded to non-welded tuff and ash-flow tuff conglomerate, interbedded with volcaniclastic conglomerate, sandstone, mudstone, and porcellanite.

Lower sandstone member: Dark olive gray, greenish gray, and yellowish gray, volcaniclastic sandstone, siltstone, mudstone, altered crystal vitric tuff, minor hornblende dacite, and minor lignitic coal.

Equivalent to Miner Creek and Cokedale Formations of the Livingston Group (Berg and others, 2000).

Thickness of formation in map area about 915 m (3,000 ft).

Ket **Eagle and Telegraph Creek Formations, undivided**

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 75 m (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 75 m (250 ft).

Kcot **Cody through Thermopolis formations, undivided**

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 150 m (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 170 m (550 ft).

Kbl **Blackleaf Formation (Upper and Lower Cretaceous)**—*Jefferson Canyon area* (McLane, 1971).

Upper: Gray, soft, ripple-marked, lithic sandstone and dark gray shale with marine fossils.

Basal: Brownish gray, very fine grained, crossbedded, resistant, quartz sandstone with quartz overgrowths. Exposed thickness of formation in Jefferson Canyon less than 30 m (100 ft).

Kmdt **Muddy Sandstone and Thermopolis Shale, undivided**

Muddy Sandstone: Interbedded micaceous, planar bedded or crossbedded sandstone and subordinate dark gray to black, fissile shale or mudstone.

Thermopolis Shale

Upper: 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 sandstone with quartz overgrowths, crossbedded 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 90-105 m (300-350 ft).

Kt **Thermopolis Formation (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 sandstone with quartz overgrowths, crossbedded 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. Thickness about 90-105 m (300-350 ft).

Kk **Kootenai Formation**

Upper: Light gray gastropod coquina or gastropod-rich limestone that may also contain charophyte and ostracode fossils. The gastropod limestone is not present in the Bridger Range (McMannis, 1952).

Middle: Variegated shale and mudstone, dominated by red, orange, and purple with subordinate light and medium gray colors, interbedded with light gray "salt-and-pepper" limonitic or non-limonitic, fine- to coarse-grained, poorly to well-sorted, massive or crossbedded, chert-rich, locally conglomeratic sandstone.

Basal: Light brown to yellowish gray "salt-and-pepper" conglomeratic, cross-bedded, chert-rich sandstone or conglomerate. Thickness about 120 m (400 ft).

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

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 105 m (350 ft).

Je **Ellis Group (Jurassic)**

Jsw **Swift Formation**—Grayish orange, calcareous, limonitic or glauconitic, crossbedded, coarse-grained, fossiliferous, quartz sandstone. Thickness about 20 m (65 ft).

Rierdon Limestone—Light gray, oölitic, fossiliferous limestone, and calcareous shale. Quartz and chert sand grains are interspersed throughout some of the limestone beds. Locally, quartz and chert clasts are granule or small pebble size. Thickness about 15 m (50 ft).

Sawtooth Formation

<u>Upper</u>: Yellowish brown, fossiliferous mudstone; thin-bedded fossiliferous carbonaceous siltstone and dolomite; and light gray, thin-bedded, fossiliferous limestone.

<u>Lower</u>: 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. Thickness 0-25 m (0-80 ft).

TRd **Dinwoody Formation (Triassic)**—Reddish brown to dark brown, fossiliferous, silty limestone with abundant *Lingula* brachiopods. Thickness 30-40 m (100-130 ft) (Elliott, 1998a).

PIPMps **Phosphoria, Quadrant, and Snowcrest Range Group, undivided (Permian, Pennsylvanian, and Mississippian)**

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

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 30-60 m (100-200 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 15 m (50 ft) (McMannis, 1952) to 150 m (500 ft) (Robinson, 1963).

IPMsr **Snowcrest Range Group, undivided (Pennsylvanian and Mississippian)**

Conover Ranch Formation (Pennsylvanian and Mississippian)—Red, blackish red, and pale red, irregularly bedded calcareous mudstone, siltstone, and sandstone, and gray dolomitic limestone. Not present locally in Three Forks area. Thickness 0-25 m (0-80 ft).

Lombard Limestone (Mississippian)—Dark gray, reddish gray, or black, fossiliferous shale, shaly limestone, and cherty limestone. 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 0-130 m (0-425 ft).

Kibbey Formation (Mississippian)—Thin-bedded to massive, calcareous red, pink, and pale yellowish orange orthoquartzite, yellowish brown, silty, laminated to flaggy, finely crystalline limestone with interbeds of yellowish brown, highly calcareous siltstone, and thin interlaminae of dark gray chert. 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 0-38 m (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 ranging from 115 m (375 ft) in the Gallatin Range (Tysdal, 1966) to 130 m (430 ft) in the Bridger Range (McMannis, 1952) to 460 m (1,510 ft) in the Three Forks area (Robinson, 1963).

Ml **Lodgepole Limestone (Mississippian)**—Dark gray, thin-bedded, microcrystalline limestone, with yellowish brown and grayish orange thin partings and interbeds of calcareous mudstone. Basal Cottonwood Canyon Member black shale present in northwestern part of map area. Thickness ranges from 60-260 m (200-855 ft).

MDt **Three Forks Formation (Mississippian and Devonian)**—Sappington Member: 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 15-30 m (50-100 ft) (Sandberg, 1965).

Trident Member: 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. 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 the map area within the Three Forks type section (Sloss and Laird, 1947) north of the Gallatin River at Logan. Thickness ranges from 25-45 m (80-150 ft).

DЄjms **Jefferson, Maywood, and Snowy Range Formations, undivided**

Dj **Jefferson Formation (Devonian)**—Birdbear Member: Light brownish gray to medium gray, very finely crystalline to microcrystalline, sucrosic, partly pseudo-brecciated dolomite. Type section of member (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 25 m (80 ft).

Lower member: Dark yellowish brown, brownish gray, medium dark gray, and light olive gray, finely crystalline, fetid dolomite, and calcitic dolomite. Thickness ranges from 145 to 200 m (475-655 ft).

DЄmr **Maywood and Red Lion Formations, undivided**

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 sucrosic 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 27 m (90 ft).

Red Lion Formation (Cambrian) (Western part of map area only, lateral equivalent of Snowy Range Formation)—Light pinkish gray, greenish gray, and light gray, sucrosic dolomite; grayish orange dolomite with silicified wavy shale partings; local flat pebble dolomite conglomerate. Thickness as much as 18 m (60 ft) in western part of map area.

D€msr **Maywood and Snowy Range Formations, undivided**

€sr **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 1.22-7.62 m (4-25 ft) biostromal columnar limestone composed of calcareous fossil algae at the base of the member (McMannis, 1952). In the Horseshoe Hills, the biostromal columnar limestone is at the base up to the middle of the member, but is missing east of Nixon Gulch and northeast of Trident (Verrall, 1955). Thickness as much as 62 m (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 2-23 m (6-76 ft) (Tysdal, 1966; McMannis, 1952) in eastern part of map area.

€pi **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 60 m (200 ft) (eastern part of map area) to as much as 137 m (450 ft) (western part of map area).

€pm **Park and Meagher Formations, undivided**

€p **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 12-106 m (40-350 ft).

€m **Meagher Limestone (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 90-167 m (300-550 ft).

Ꞓw **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 a greenish brown, carbonaceous, silty limestone in middle of unit. May be interbedded with thin quartzite 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 12 m (40 ft) in the Gallatin Range (Tysdal, 1966) to as much as 120 m (400 ft) (western part of map).

Ꞓf **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. 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 12-45 m (40-150 ft).

Yg **Greyson Formation (Mesoproterozoic)**—Greenish gray and yellowish brown siltite and fine-grained quartzite with subordinate limestone (Robinson, 1967). Exposed thickness 200 m (650 ft).

Yn **Newland Formation (Mesoproterozoic)**—Gray and yellowish brown, calcareous siltite, limestone, and fine-grained quartzite (Robinson, 1967). Exposed thickness 150 m (490 ft).

Yla **LaHood Formation, undivided (Mesoproterozoic)**—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 3.6 m (12 ft) wide in local areas, but size decreases dramatically in lobate patterns that fan northward. Clasts are angular to subround.

Shale facies (Greyson Shale of Alexander, 1955): Black, brown, or purple, fissile, to non-fissile, 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).

LaHood Formation facies descriptions that follow were taken from an unpublished report by Tor Nilsen for the Golden Sunlight Mines, Inc.

Ylaf **LaHood Formation, alluvial-fan and fan-delta facies**

The best observed exposures are in the Huller Spring area and vicinity of Lewis and Clark Caverns.

Debris-flow component: Reddish to purplish weathering, massively bedded sandstone that lacks internal current-formed sedimentary structures. Displays reverse grading, matrix-supported angular clasts, poor sorting of both matrix and clasts, and isotropic fabrics.

Stratified component: Grayish-weathering, planar-bedded and low-angle crossbedded sandstone with local shale drapes and interbeds, moderately to well sorted, subangular to rounded clasts and rip-up clasts of shale; local channel-form geometries, and finingupward cycles at several localities. Shale interbeds characteristically weather to brown and olive brown and locally exhibit mudcracks, wave ripples, and parallel lamination. At Huller Spring, large angular blocks of migmatite, and angular to rounded clasts of quartzofeldspathic gneiss characterize the basal part of the facies. Overlying deposits consist chiefly of massive, pebbly, arkosic sandstone, interbedded with crossbedded and planar bedded pebbly arkosic sandstone, and minor amounts of argillite.

Facies fines to north, and has larger component of stratified beds with better rounded and sorted clasts than to the south. Unit locally represents fan-delta deposits into small lakes.

Ylsh **LaHood Formation, shelf facies**

Crops out south of Jefferson River along western border of map.
Massive to parallel bedded, pebbly sandstone; stratigraphically between submarine-canyon and alluvial fan facies.

Ylsl **LaHood Formation, slope facies**

Crops out in the Cave Fault area.
Characterized by abundant synsedimentary slumps. Consists dominantly of mudstone with thin siltstone turbidites and graded non-turbidite intra-flow deposits. Highly tectonized because of the lack of competent beds and appears to consist mostly of sheared and deformed argillite.

Ylsc **LaHood Formation, submarine-canyon facies**

Crops out in Lewis and Clark Caverns State Park area, where it appears to have cut directly into the alluvial fan/fan-delta facies.
Boulder to pebble conglomerate and conglomeratic sandstone that is poorly stratified and highly channelized. Canyons relatively small–less than 2 km (6,560 ft) wide–and are cut into shallow marine units, so exposures are principally of the upper parts of the canyons.

Ylis **LaHood Formation, inner submarine-fan facies**

Crops out in LaHood Canyon and in the Cave Fault area.
Channel axis component: Boulder to pebble conglomerate and pebbly sandstone with thin shale interbeds.
Channel-margin component: Argillite with thin interbeds of turbidite siltstone and very fine grained sandstone.

Ylms **LaHood Formation, middle submarine-fan facies**

Crops out east of the Golden Sunlight Mine, in LaHood Canyon, and in the Cave Fault area.
Characteristic repetitive fining- and thinning-upward sequences with channelized bases and interbedded, thin-bedded overbank turbidites. Overbank turbidites consist of thin, but coarse-grained, laterally discontinuous deposits with abundant small-scale slump folds that generally indicate directions of slumping away from channel axes. Locally contains large boulders of marble and limestone in LaHood Canyon and Cave fault areas. Apron-like fan geometries along the steep Proterozoic Willow Creek fault promoted transport of boulders into the middle-fan channels.

Ylos **LaHood Formation, outer submarine-fan facies**

Crops out east of the Golden Sunlight Mine, north and east of Cardwell, and in LaHood Canyon.

Typically well exposed because of the abundant resistant sandstone beds that make up stacked, thickening and coarsening-upward sequences. Characteristic Bouma sequences and abundant sole markings. Fan-fringe deposits commonly contain thinner and finer-grained beds organized into thinner coarsening-upward sequences with lower sandstone-to-shale ratios than central parts of fans. Individual beds are typically planar, well-graded, and separated by shale intervals. Slurried beds, in which the Bouma B division contains shale rip-up clasts that are locally very large, are common in many sections and can be mistaken for slump folds.

Ylbp **LaHood Formation, basin-plain facies**

Crops out south and east of the Golden Sunlight Mine.

Generally poorly exposed because consists mostly of argillite with thinly interbedded, laterally continuous and planar-bedded, distal turbidites. Abundant sole markings on relatively thick beds of sandstone. Generally has a lower sandstone-to-shale ratio, thinner beds of turbidite sandstone, and lacks thickening- and coarsening-upward sequences compared to the outer fan facies. Facies generally has lower sandstone-to-shale ratio and thinner and finer-grained beds of sandstone to the north.

The following two units are found in Precambrian basement rock in the map area. Although important, they could not be shown well at the map scale.

Diabase (Neoproterozoic)—Numerous dikes that cut across Archean rocks, but do not extend into younger rocks. (Schmidt and Garihan, 1986b).

Pegmatite and quartz veins (Late Cretaceous, and Paleoproterozoic)—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.

Xsp **Spuhler Metamorphic Series (Paleoproterozoic)**—Light gray to reddish brown, purplish brown, or deep golden brown anthophyllite-gedrite gneiss and subordinate schist. Weathers to dark brown or blackish brown.

Xg **Granite (Paleoproterozoic?)**—Possibly Cretaceous.

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

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

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

XAqa **Quartzite and amphibolite (Paleoproterozoic and Archean?)**—Interlayered white quartzite and amphibolite.

XAqfg Quartzofeldspathic gneiss (Paleoproterozoic and Archean?)—(Vitaliano and Cordua, 1979): 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.

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

CITED REFERENCES AND BIBLIOGRAPHY

Achauer, C.W., 1959, Stratigraphy and microfossils of the Sappington Formation in southwestern Montana, *in* Hammond, C.R. and Trapp, H., Jr., eds., Sawtooth-Disturbed Belt area: Billings Geological Society 10th Annual Field Conference Guidebook, p. 41–49.

Alexander, R.G., Jr., 1951, The geology of the Whitehall area, Montana: Princeton, N.J., Princeton University, Ph.D. dissertation, 150 p.

Alexander, R.G., Jr., 1955, The geology of the Whitehall area, Montana: Yellowstone-Bighorn Research Association Contribution 195, 111 p.

Andretta, D.B., and Alsup, S.A., 1960, Geology and Cenozoic history of the Norris-Elk Creek area, southwest Montana, *in* Campau, D.E., and Anisgard, H.W., eds., West Yellowstone—earthquake area: Billings Geological Society 11th Annual Field Conference Guidebook, p. 185–190.

Angeloni, L.M., 1988, The role of water in the formation of granulite and amphibolite facies rocks, Tobacco Root Mountains, Montana: Missoula, University of Montana, M.S. thesis, 51 p.

Aram, R.B., 1979, Cenozoic geomorphic history relating to Lewis and Clark Caverns, Montana: Bozeman, Montana State University, M.S. thesis, 150 p.

Aram, R.B., 1981, Geologic history of Lewis and Clark Caverns, Montana, *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society Field Conference and Symposium Guidebook, p. 285–300.

Archibald, F.W., 1940, The geology of the Limespur-Sappington area: Butte, Montana School of Mines*, B.S. thesis, 14 p.

Axelrod, R.B., 1984, Tertiary sedimentary facies, depositional environments, and structure, Jefferson Basin, southwest Montana: Missoula, University of Montana, M.S. thesis, 64 p.

Ballard, J.K., 1939, Geology report on field trip near Whitehall, Montana: Butte, Montana School of Mines*, B.S. thesis, 25 p.

Barnes, J., 1954, Structural analysis of the northern end of the Tobacco Root Mountains, Madison County, Montana: Bloomington, Indiana University, Ph.D. dissertation, 194 p.

Basu, Abhijit, Molinaroli, Emanuela, and Andersson, Steen, 1998, Diversity of physical and chemical properties of detrital zircons and garnets in Cenozoic sediments of southwestern Montana: The Mountain Geologist, v. 35, no. 1, p. 23–29.

Bean, C.L., 1981, A geochemical study of the North Doherty intrusive complex, Jefferson County, Montana: Bloomington, Indiana University, M.S. thesis, 134 p.

Berg, A.B., 1959, Geology of the northwestern corner of the Tobacco Root Mountains, Madison County, Montana: St. Paul, University of Minnesota, M.S. thesis, 75 p.

Berg, R.B., Lopez, D.A., and Lonn, J.D., 2000, Geologic map of the Livingston 30′x 60′ quadrangle, south-central Montana: Montana Bureau of Mines and Geology Open-File Report MBMG 406, 1:100,000 scale [adjacent to this map].

Berry, G.W., 1943, Stratigraphy and structure at Three Forks, Montana: Geological Society of America, v. 54, p. 1–30.

Blake, O.D., 1959, Big Snowy stratigraphy in the area adjacent to the Rocky Mountain front [Montana], *in* Hammond, C.R., and Trapp, H., Jr., eds., Sawtooth-Disturbed Belt area: Billings Geological Society 10th Annual Field Conference Guidebook, p. 64–68.

Blake, O.D., Hanson, A.M., and Hackett, O.M., 1953, Field Trip no. 1, Stratigraphy and structure in the Three Forks area, *in* Blake, O.M., ed., Guidebook of field excursions: Geological Society of America, Rocky Mountain section, 6th Annual Conference Guidebook, p. 19–30.

Bole, G.R., 1962, The geology of part of the Manhattan quadrangle, Gallatin County, Montana: Berkeley, University of California, M.A. thesis, 82 p.

Bonnet, A.T., 1979, Lithostratigraphy and depositional setting of the limestone-rich interval of the LaHood Formation (Belt Supergroup), southwestern Montana: Bozeman, Montana State University, M.S. thesis, 87 p.

Boyce, R., 1975, Depositional systems in the LaHood Formation, Belt Supergroup, Precambrian, southwest Montana: Austin, University of Texas, Ph.D. dissertation, 247 p.

Boyd, W.D., 1968, Simulation via time-partitioned linear programming: a ground and surface water allocation model for the Gallatin Valley of Montana: Bozeman, Montana State University, M.S. thesis, 217 p.

Brady, J.B., 2004, General geology and tectonic setting of the Tobacco Root Mountains, *in* Brady, J.B., Burger, H.R., Cheney, J.T., and Harms, T.A., eds., Precambrian geology of the Tobacco Root Mountains, Montana: Geological Society of America Special Paper 377, p. 1-14.

Brady, J.B., Mohlman, H. K., Harris, Caroline, Carmichael, S.K., Jacob, L.J., and Chaparro, W.R., 2004, General geology and geochemistry of metamorphosed Proterozoic mafic dikes and sills, Tobacco Root Mountains, Montana, *in* Brady, J.B., Burger, H.R., Cheney, J.T., and Harms, T.A., eds., Precambrian geology of the Tobacco Root Mountains, Montana: Geological Society of America Special Paper 377, p. 89-129.

Brady, J.B., Kovaric, D.N., Cheney, J.T., Jacob, L.J., and King, J.T., 2004, ^{40}Ar/^{39}Ar ages of metamorphic rocks from the Tobacco Root Mountains region, Montana, *in* Brady, J.B., Burger, H.R., Cheney, J.T., and Harms, T.A., eds., Precambrian geology of the Tobacco Root Mountains, Montana: Geological Society of America Special Paper 377, p. 131-149.

Brodowy, J.M., Lageson, D.R., Ryan, C., and Snyder, B., 1991, Structure and neotectonics of the eastern Three Forks Basin, northern Intermountain seismic belt, southwest Montana: Geological Society of America Abstracts with Programs, v. 23, no. 5, p. A233–A234.

Brunsvold, L.D., 1989, A seismic reflection study of the Jefferson Basin, southwest Montana: Butte, Montana College of Mineral Science and Technology*, M.S. thesis, 45 p.

Brustkern, R.L., 1977, The impact of land use change on the groundwater resources of the Bozeman, Montana area: Montana State University Joint Water Resources Center Report 88, 35 p.

Burger, H.R., and eleven others, 2004, Geology and geochemistry of the Spuhler Peak Metamorphic Suite, *in* Brady, J.B., Burger, H.R., Cheney, J.T., and Harms, T.A., eds., Precambrian geology of the Tobacco Root Mountains, Montana: Geological Society of America Special Paper 377, p. 47-70.

Burger, H. R., III, and Thompson, M.D., 1970, Fracture analysis of the Carmichael Peak Anticline, Madison County, Montana: Geological Society of America Bulletin, v. 81, p. 1821–1836.

Burfeind, W.J., 1967, A gravity investigation of the Tobacco Root Mountains, Jefferson basin, Boulder Batholith, and adjacent areas of southwestern Montana: Bloomington, Indiana University, Ph.D. dissertation, 146 p.

Burton, B.R., Lageson, D.R., Schmidt, C.J., Ballard, D.W., and Warne, J.R., 1993, Large-magnitude shortening of the Lombard thrust system, Helena salient, Montana fold and thrust belt: implications for emplacement of the Boulder Batholith and reconstruction of the Belt Basin, *in* Berg, R.B., ed., Belt Symposium III: Montana Bureau of Mines and Geology Special Publication 112, p. 229–243.

Capozza, F.C., 1967, The geology of the Bone Basin and Perry Canyon intrusions, Madison County, Montana: Bloomington, Indiana University, M.A. thesis, 48 p.

Carl, J.D., 1970, Block faulting and development of drainage, northern Madison Mountains, Montana: Geological Society of America Bulletin, v. 81, p. 2287–2298.

Chadwick, R.A., 1981, Geologic Road Log—Livingston to Three Forks, *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society Field Conference and Symposium Guidebook, p. 380–387.

Chadwick, R.A., 1969, The northern Gallatin Range, Montana: northwestern part of the Absaroka-Gallatin volcanic field: University of Wyoming Contributions to Geology, v. 8, p. 150–166.

Chadwick, Tom, compiler, 1996, Geology of the Whitehall district, Jefferson County, Montana, plate 2, 1:12,000 scale, *in* Taylor, E.K., 1997, Formation of ferricretes from acid rock drainage at Golden Sunlight Mine, Jefferson County, Montana: Butte, Montana Tech of The University of Montana, M.S. thesis, 179 p., 2 plates.

Chase, R.B., Schmidt, C.J., and Genovese, P.W., 1993, Influence of Precambrian rock compositions and fabrics on the development of Rocky Mountain foreland folds, *in* Schmidt, C.J., Chase, R.B., and Erslev, E.A., eds., Laramide basement deformation in the Rocky Mountain foreland of the western United States: Geological Society of America Special Paper 280, p. 45-72.

Cheney, J.T., Webb, A.A.G., Coath, C.D., and McKeegan, K.D., 2004, *In situ* ion microprobe ^{207}Pb/^{206}Pb dating of monazite from Precambrian metamorphic suites, Tobacco Root Mountains, Montana, *in* Brady, J.B., Burger, H.R., Cheney, J.T., and Harms, T.A., eds., Precambrian geology of the Tobacco Root Mountains, Montana: Geological Society of America Special Paper 377, p. 151-179.

Christiansen, J.H., 1970, Gravity, magnetic, and electrical resistivity investigation of selected fault and stratigraphic contacts in southern Jefferson County and northern Madison County, Montana: Bloomington, Indiana University, M.A. thesis, 63 p.

Clabaugh, S.E., 1952, Corundum deposits of Montana: U.S. Geological Survey Bulletin 983, 100 p.

Clabaugh, S.E., and Armstrong, F.C., 1950, Corundum deposits of Gallatin and Madison Counties, Montana: U.S. Geological Survey Bulletin 969-B, p. 29–53.

Cooley, J.T., 1993, Fluvial systems of the upper Jurassic Morrison Formation, northern Beartooth and Gallatin Ranges, southwest Montana: Bozeman, Montana State University, M.S. thesis, 55 p.

Condit, D.D., 1919, Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah, *in* White, David, and Ashley, G.H., eds., Contributions to economic geology: U.S. Geological Survey Bulletin 711, p. 15–40 [includes information for Bozeman 30′x 60′ quadrangle.]

Cordua, W.J., 1973, Precambrian geology of the southern Tobacco Root Mountains, Madison County, Montana: Bloomington, Indiana University, Ph.D. dissertation, 147 p.

Craiglow, C.J., 1986, Tectonic significance of the Pass fault, central Bridger Range, southwest Montana: Bozeman, Montana State University, M.S. thesis, 37 p.

Cressman, E.R., 1955, Physical stratigraphy of the Phosphoria Formation in part of southwestern Montana: U.S. Geological Survey Bulletin 1027-A, p. 1–31.

Cressman, E.R., and Swanson, R.W., 1960, Permian rocks in the Madison, Gravelly, and Centennial Ranges, Montana: *in* Campau, D.E., and Anisgard, H.W., eds, West Yellowstone—Earthquake area: Billings Geological Society 11th Annual Field Conference Guidebook, p. 226–232.

Cressman, E.R., 1964, Stratigraphy and petrology of the Permian rocks of southwestern Montana: U.S. Geological Survey Professional Paper 313-C, p. 275–569.

Congdon, C., 1935, The general geology of the Cardwell Mining District: Butte, Montana School of Mines*, B.S. thesis, 11 p.

Cowen, M.T., 1958, The petrography of volcanic rocks of the Jefferson Island quadrangle, Montana: Bloomington, Indiana University, M.A. thesis, 57 p.

Cummings, M.L., and McCulloch, W.R., 1992, Geochemistry and origin of amphibolite and ultrmafic rocks, Branham Lakes area, Tobacco Root Mountains, southwestern Montana, *in* Bartholomew, M.J., Hyndman, D.W., Mogk, D.W., and Mason, Robert, eds., Basement Tectonics 8–Characterization and comparison of ancient and Mesozoic continental margins: Proceedings of the Eighth International conference on basement tectonics held in Butte, Montana, USA, August 1988, Dordrecht/Boston/London, Kluwer Academic Publishers, p. 323-340.

Custer, S.G., 1995a, A walking tour of the geology of the southeastern Gallatin Valley, *in* Self-Guided Field Trips Near Bozeman: 47th Annual Meeting Rocky Mountain Section of the Geological Society of America, Guidebook, p. 1–10.

Custer, S.G., 1995b, Paleozoic and Mesozoic stratigraphy of the Bridger Range, *in* Self-Guided Field Trips Near Bozeman: 47th Annual Meeting Rocky Mountain Section of the Geological Society of America, Guidebook, p. 35–48.

Davis, W.E., Kinoshita, W.T., and Smedes, H.W., 1963, Bouguer gravity, aeromagnetic and generalized geologic map of the western part of the Three Forks Basin, Jefferson, Broadwater, Madison, and Gallatin Counties, Montana: U.S. Geological Survey Geophysical Investigation Map GP-498, scale 1:62,500.

Davis, W.E., Kinoshita, W.T., and Robinson, G.D., 1965, Bouguer gravity, aeromagnetic, and generalized geologic map of the eastern part of the Three Forks Basin, Broadwater, Madison, and Gallatin Counties, Montana: U.S. Geological Survey Geophysical Investigations Map GP-497, scale 1:62,500.

DeWitt, Ed, Foord, E.E., Zartman, R.E., Pearson, R.C., and Foster, Fess, 1996, Chronology of Late Cretaceous igneous and hydrothermal events at the Golden Sunlight gold-silver breccia pipe, southwestern Montana: U.S. Geological Survey Bulletin 2155, 48 p.

Dixon, R.M. and Wolfgram, Diane, 1998, Bedrock geology of the Elkhorn Mountains Volcanics in the southern Bull Mountain area, Jefferson County, Montana: Montana Bureau of Mines and Geology Open-File Report MBMG 374, scale 1:24,000.

Donohue, D.A., 1989, Paleochannel aquifer potential at Montana State University—a test of hypotheses: Bozeman, Montana State University, M.S. thesis, 94 p.

Dorobek, S.L., and Smith, T.M., 1989, Cyclic sedimentation and dolomitization history of the Devonian Jefferson Formation, southwestern Montana: *in* French, D.E. and Grabb, R.F., eds., Geologic Resources of Montana: Montana Geological Society Field Conference Guidebook: Montana Centennial Edition, p. 31–46.

Dorf, Erling, and Lochman, Christina, 1940, Upper Cambrian formations in southern Montana: Geological Society of America Bulletin, v. 51, p. 541–556.

Dorr, J.A., 1954, *Hypsoparia bozemanensis*, a new genus and species of leptarctine mustelid from the late Miocene Madison Valley Formation of Montana: Annals of Carnegie Museum, v. 33, p. 179–184.

Dorr, J.A., 1956, Anceney local mammal fauna, latest Miocene, Madison Valley Formation, Montana: Journal of Paleontology, v. 30, p. 62–74.

Douglass, Earl, 1899, The Neocene lake beds of western Montana and descriptions of some new vertebrates from the Loup Fork: Missoula, University of Montana, M.S. thesis, 27 p.

Douglass, Earl, 1901, Fossil Mammalia of the White River beds of Montana: American Philosophical Society Transactions, v. 21, p. 227–279.

Douglass, Earl, 1903, New vertebrates from the Montana Tertiary: Annals of Carnegie Museum, v. 2, p. 145–199.

Douglass, Earl, 1907a, *Merycochoerus* and a new genus of Merycoidodonts with some notes on other Agriochoeridae: Annals of Carnegie Museum, v. 4, p. 84–98.

Douglass, Earl, 1907b, New Merycoidodonts from the Miocene of Montana: Bulletin of the American Museum of Natural History, v. 23, p. 202–222.

Douglass, Earl, 1908, Rhinoceroses from the Oligocene and Miocene deposits of North Dakota and Montana: Annals of Carnegie Museum, v. 4, p. 256–266.

Douglass, Earl, 1909a, A description of a new species of *Procamelus* from the upper Miocene of Montana with notes upon *Procamelus madisonius* Douglass: Annals of Carnegie Museum, v. 5, p. 159–165.

Douglass, Earl, 1909b, *Dromomeryx,* a new genus of American ruminants: Annals of Carnegie Museum, v. 5, p. 457–479.

Dresser, H.W., 1996, A stereo picture guide to some of Montana's thrust faults: Montana Bureau of Mines and Geology Open-File Report, 76 p.

Dresser, H.W., 1996, Faults, fans, and pediments of southwestern Montana: A stereo picture guide, 57 p., *in press* as Montana Bureau of Mines and Geology Open-File Report

Dull, Kathleen, 1994, A gravity study of the North Boulder Basin in southwestern Montana: Bloomington, Indiana University, M.S. thesis, 145 p.

Dyman, T.S., Tysdal, R.G., Porter, K.W., and Thompson, G.A., 1996, Measured sections and correlations of mid-Cretaceous rocks near the Lombard Thrust of the Helena Salient in southwestern Montana: U.S. Geological Survey Open-File Report 95-841, 6 p.

Eckerty, D.G., 1968, The geology of the Elkhorn Mountains Volcanics in southern Jefferson and northern Madison Counties, Montana: Bloomington, Indiana University, M.S. thesis, 180 p.

Elliott, W.S., 1998a, Geologic map of the Harrison 7.5-minute quadrangle, Madison County, Montana: Montana Bureau of Mines and Geology Open File Report MBMG 375, Part 1, scale 1:24,000.

Elliott, W.S., 1998b, Geologic map of the Maltbys Mound 7.5-minute quadrangle, Madison, County, Montana: Montana Bureau of Mines and Geology Open-File Report MBMG 375, Part 2, scale 1:24,000.

Elliott, W.S., 1998c, Tectono-stratigraphic control of Quaternary and Tertiary sediments and structure along the northeast flank of the Tobacco Root Mountains, Madison County, Montana: Bloomington, Indiana University, M.S. thesis, 113 p.

Evander, R.L., 1996, Horses (*Mammalia, Equidae*) from the Barstovian (Miocene) Anceney Local Fauna, Montana: Paludicola, v. 2, p. 248–257.

Feichtinger, S.H., 1970, Geology of a portion of the Norris quadrangle, Madison and Gallatin Counties, Montana: Bozeman, Montana State University, M.S. thesis, 89 p.

Fields, R.W., and Petkewick, R.M., 1967, Tertiary stratigraphy and geologic history of the upper Jefferson, Ruby, lower Beaverhead, and lower Big Hole Valleys, *in* Centennial Basin of southwestern Montana: Billings Geological Society 18th Annual Field Conference Guidebook, p. 71–78.

Fields, R.W., Tabrum, A.R., Rasmussen, D.L., and Nichols, R., 1985, Cenozoic rocks of the intermontane basins of western Montana and eastern Idaho: A summary, *in* Flores, R.M., and Kaplan, S.S., eds., Cenozoic Paleogeography of West-Central United States: Rocky Mountain Paleogeography Symposium 3, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 9–36.

Fix, P.F., 1940, Structure of Gallatin Valley, Montana: Boulder, University of Colorado, Ph.D. dissertation, 68 p.

Frick, C., 1937, Horned ruminants of North America: Bulletin of the American Museum of Natural History, v. 69, no. 1, p. 669.

Foster, Fess, 1991, Geology and general overview of the Golden Sunlight Mine, Jefferson County, Montana, *in* Mineral Deposits of Montana: The Association of Exploration Geochemists, 15th International Geochemical Exploration, Symposium, Field Trip Guidebook, p. 26–36.

Foster, Fess and Chadwick, Tom, 1999, Some observations regarding formation, correlations, and regional paleogeography of the southern Helena Embayment, *in* Berg, R.B., ed., Belt Symposium III Abstracts, 1993: Montana Bureau of Mines and Geology Open-File Report MBMG 381, p. 20–22.

Foster, Fess, and Chadwick, Tom, 1990, Relationship of the Golden Sunlight Mine to the Great Falls Tectonic Zone, *in* Moye, F.J., ed., Geology and ore deposits of the Trans-Challis Fault System/Great Falls Tectonic Zone: Tobacco Root Geological Society, 15th Annual Field Conference Guidebook, p. 77–81.

Foster, Fess, Chadwick, Tom, and Nilsen, T.H., 1999, Paleodepositional setting and synsedimentary mineralization in Belt Supergroup rocks of the Whitehall, Montana area, *in* Berg, R. B., ed., Belt Symposium III Abstracts, 1993: Montana Bureau of Mines and Geology Open-File Report MBMG 381, p. 23–25.

Foster, Fess, Cox, Bruce, and Chadwick, Tom, 1993, Field Trip—Economic, environmental and "socioeconomic" geology of the Whitehall Valley, southwestern Montana, *in* Childs, J.F., and Lageson, D.R., eds., Economic and Regional Geology of the Tobacco Root-Boulder Batholith region, Montana: Tobacco Root Geological Society, 18th Annual Field Conference, Northwest Geology, v. 22, p. 79–102.

Foster, Fess, and Smith, T., 1995, A summary of the geology and environmental programs at the Golden Sunlight Mine, Whitehall, Montana, *in* Mogk, D.W., ed., Field Guide to Geologic Excursions in southwest Montana: Geological Society of America, Rocky Mountain Section, Northwest Geology, v. 24, p. 77–83.

Fountain, D.M., and Desmarais, N.R., 1980, The Wabowden Terrane of Manitoba and the Pre-Belt basement of southwestern Montana: a comparison: Montana Bureau of Mines and Geology Special Publication 82, p. 35–46.

Fryxell, J.C., and Smith, D.L., 1986, Paleotectonic implications of arkose beds in Park Shale (Middle Cambrian), Bridger Range, south-central Montana, *in* Peterson, J.A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir, v. 41, p. 159–171.

Gardner, L.S., 1959, Revision of Big Snowy Group in central Montana: American Association of Petroleum Geologists Bulletin, v. 43, p. 329–349.

Garihan, J.M., Schmidt, C.J., Young, S.Y., and William, M.A., 1983, Geology and recurrent movement history of the Bismark-Spanish Peaks-Gardiner fault system, southwest Montana, *in* J.D. Lowell, ed., Rocky Mountain Foreland Basins and Uplifts: Rocky Mountain Association of Geologists, p. 295–314.

Gary, S.D., 1980, Quaternary geology and geophysics of the upper Madison Valley, Madison County, Montana: Missoula, University of Montana, M.S. thesis, 61 p.

Gehman, C., 1997, Interpretation of a Tertiary-fill basin in southwestern Montana through the use of geophysical techniques, *in* Proceedings: Tenth Keck Research Symposium in Geology, The College of Wooster, Wooster, Ohio, p. 298–301.

Gillmeister, N.M., 1971, Petrology of Precambrian rocks in the central Tobacco Root Mountains, Madison County, Montana: Cambridge, Massachusetts, Harvard University, Ph.D. dissertation, 201 p.

Gillmeister, N.M., 1972, Cherry Creek-Pony Group relationship in the central Tobacco Root Mountains, Madison County, Montana: Northwest Geology, v. 1, p. 21–24.

Glaman, L.R.B., 1991, The geology of Negro Hollow, Jefferson County, Montana: Butte, Montana College of Mineral Science and Technology*, M.S. thesis, 69 p.

Glancy, P.A., 1964, Cenozoic geology of the southeastern part of the Gallatin Valley, Montana: Bozeman, Montana State University, M.S. thesis, 66 p.

Graham, S.A., and Suttner, L.J., 1974, Occurrence of Cambrian islands in southwest Montana: The Mountain Geologist, v. 11, no. 2, p. 71–84.

Grant, R.E., 1965, Faunas and stratigraphy of the Snowy Range Formation in southwestern Montana and northwestern Wyoming: Geological Society of America Memoir 96, 171 p.

Griffith, E.F., 1982, Environmental geology of the southwest margin of the Gallatin Valley, Gallatin County, Montana: Bozeman, Montana State University, M.S. thesis, 106 p.

Guthrie, G.A., 1984, Stratigraphy and depositional environment of the Upper Mississippian Big Snowy Group in the Bridger Range, southwest Montana: Bozeman, Montana State University, M.S. thesis, 105 p.

Gutschick, R.C., Suttner, L.J., and Switek, M.J., 1962, Biostratigraphy of transitional Devonian-Mississippian Sappington Formation of southwest Montana, *in* Devonian System of Montana: Billings Geological Society 13th Annual Field Conference, p. 79–89.

Hackett, O.M., Visher, F.N., McMurtrey, R.G., and Steinhilber, W.L., 1960, Geology and ground-water resources of the Gallatin Valley, Gallatin County, Montana: U.S. Geological Survey Water-Supply Paper 1482, 28 p.

Hall, R.D., and Heiney, J.S., 1983, Glacial and postglacial physical stratigraphy and chronology, North Willow Creek and Cataract Creek drainage basins, eastern Tobacco Root Range, southwestern Montana, U.S.A.: Arctic and Alpine Research, v. 15, p. 19–52.

Hall, R.D., and Michaud, D., 1988, The use of hornblende etching, clast weathering, and soils to date alpine glacial and periglacial deposits: A study from southwestern Montana: Geological Society of America Bulletin, v. 100, p. 458–467.

Hallock, A.R., 1955, The geology of a portion of the Horseshoe Hills: Butte, Montana School of Mines*, M.S. thesis, 69 p.

Hamilton, T.S., 1974, The petrology of the North Doherty mafic sill, Jefferson County, Montana: Bloomington, Indiana University, M.A. thesis, 117 p.

Hanley, T.B., 1976, Stratigraphy and structure of the central fault block, northwestern Tobacco Root Mountains, Madison County, Montana, *in* Lankston, M.M., ed., Tobacco Root Geological Society, Field Conference Guidebook: Montana Bureau of Mines and Geology Special Publication 73, p. 7–14.

Hanley, T.B., 1975, Structure and petrology of northwestern Tobacco Root Mountains, Madison County, Montana: Bloomington, Indiana University, Ph.D. dissertation, 206 p.

Hanneman, D.L., and Wideman, C.J., 1991, Sequence stratigraphy of Cenozoic continental rocks, southwestern Montana: Geological Society of America Bulletin, v. 103, p. 1335–1345.

Hanneman, D.L., Wideman, C.J., and Halvorson, James, 1994, Calcic paleosols: their use in subsurface stratigraphy: American Association of Petroleum Geologists Bulletin, v. 78, p. 1360-1371.

Hanson, A.M., 1952, Cambrian stratigraphy in southwestern Montana: Montana Bureau of Mines and Geology Memoir 33, 46 p.

Harlan, S.S., Geissman, J.W., and Snee, L.W., 2008a, Paleomagnetism of Proterozoic mafic dikes from the Tobacco Root Mountains, southwest Montana: Precambrian Research, v. 163, Issue 3-4, p. 239-264.

Harlan, S.S., Geissman, J.W., Whisner, S.C., and Schmidt, C.J., 2008b, Paleomagnetism and geochronology of sills of the Doherty Mountain area, southwestern Montana: Implications for the timing of fold and thrust belt deformation and vertical-axis rotations along the southern margin of the Helena Salient: Geological Society of America Bulletin, v. 120, p. 1091-1104.

Harlan, S.S., Snee, L.W., and Geissman, J.W., 1990, Paleomagnetic and $^{40}Ar/^{39}Ar$ results from mafic dikes and basement rocks, southwest Montana: EOS, Transactions of the American Geophysical Union, v. 71, p. 1297.

Harms, T.A., Burger, H.R., Blednick, D.G., Cooper, J.M., King, J.T., Owen, D.R., Lowell, Josh, Sincock, M.J., Kranenburg, S.R., Pufall, Ann, and Picornell, C.M., 2004, *in* Brady, J.B., Burger, H.R., Cheney, J.T., and Harms, T.A., eds., Precambrian geology of the Tobacco Root Mountains, Montana: Geological Society of America Special Paper 377, p. 203-226.

Harms, T.A., Brady, J.B., Burger, H.R., and Cheney, J.T., 2004, Advances in the geology of the Tobacco Root Mountains, Montana, and their implications for the history of the northern Wyoming province, *in* Brady, J.B., Burger, H.R., Cheney, J.T., and Harms, T.A., eds., Precambrian Geology of the Tobacco Root Mountains, Montana: Geological Society of America Special Paper 377, p. 227–243.

Harrison, J.E., Griggs, A.B., and Wells, J.D., 1974, Tectonic features of the Precambrian Belt Basin and their influence on post-Belt structures: U.S. Geological Survey Professional Paper 866, 15 p.

Hawley, David, Bonnet-Nicolaysen, Adrienne, and Coppinger, Walter, 1982, Stratigraphy, depositional environments, and paleotectonics of the LaHood Formation, *in* Smith, D.L., ed., Field Trip Guidebook, Rocky Mountain Section, Geological Society of America, 35th Annual meeting, 20 p.

Hawley, David, and Schmidt, C.J., 1976, Some aspects of the LaHood Formation and structure in the Jefferson Canyon area, *in* Lankston, M.M., ed., Tobacco Root Geological Society, Field Conference Guidebook: Montana Bureau of Mines and Geology Special Publication 73, p. 151–165.

Hay, J.E., 1997, An investigation of groundwater recharge along the western flank of the southern Bridger Range: Bozeman, Montana State University, M.S. thesis, 129 p.

Haynes, W.P., 1916, The Lombard overthrust and related geological features: Journal of Geology, v. 24, p. 269–290.

Hendrix, T.E., and Stellavato, Nick, 1976, Pervasive deformation of the Meagher oölitic limestone, North Boulder Valley, Montana, *in* Lankston, M.M., ed., Tobacco Root Geological Society, Field Conference Guidebook: Montana Bureau of Mines and Geology Special Publication 73, p. 131–139.

Hess, D.F., 1967, Geology of pre-Beltian rocks in the central and southern Tobacco Root Mountains, with reference to superposed effects of the Laramide-age Tobacco Root Batholith: Bloomington, Indiana University Ph.D. dissertation, 333 p.

Hess, D.F., 1976, Road log and field guide—geology of Norris-McAllister area, *in* Lankston, M.M., ed., Tobacco Root Geological Society, Field Conference Guidebook: Montana Bureau of Mines and Geology Special Publication 73, p. 131–90.

Hewitt, C., and Olson, H.D., 1951, Geology of a postulated volcanic vent northeast of Whitehall, Montana: Butte, Montana School of Mines*, B.S. thesis, 22 p.

Hill, C.L., 2001a, Late Pliocene and Pleistocene geology and paleontology in the Three Rivers Basin, Montana, *in* Nichols, R., ed., Cenozoic vertebrate paleontology and geology of southwestern Montana and adjacent areas, *in* Hill, C.L., ed., Mesozoic and Cenozoic paleontology in the western plains and Rocky Mountains: Society of Vertebrate Paleontology 61st annual field trip guidebook, Museum of the Rockies Occasional Paper no. 3, p. 113–125.

Hill, C.L., 2001b, Pleistocene mammals of Montana and their geologic context, *in* Nichols, R., ed., Cenozoic vertebrate paleontology and geology of southwestern Montana and adjacent areas, *in* Hill, C.L., ed., Mesozoic and Cenozoic paleontology in the western plains and Rocky Mountains: Society of Vertebrate Paleontology 61st annual field trip guidebook, Museum of the Rockies Occasional Paper no. 3, p. 127–144.

Hill, T.P., Werner, M.A., and Horton, M.J., 1967, Chemical composition of sedimentary rocks in Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Wyoming: U.S. Geological Survey Professional Paper 561, 241 p. [includes data from Bozeman 30′ x 60′ quadrangle].

Hoh, A.M., 1997, Gravity survey of a Cenozoic basin in Madison County, Montana, *in* Proceedings: Tenth Keck Research Symposium in Geology: The College of Wooster, Wooster, Ohio, p. 306–309.

Holland, F.D., Jr., 1952, Stratigraphic details of Lower Mississippian rocks of northeastern Utah and southwestern Montana: American Association of Petroleum Geologists Bulletin, v. 36, no. 9, p. 1697–1734.

Hughes, G.C., 1980, Tertiary stratigraphy and depositional history of the Dry Creek Valley, Gallatin County, Montana: Bozeman, Montana State University, M.S. thesis, 147 p.

Hughes, G.C., 1981, Tertiary stratigraphy and depositional history of the Cry [sic] Creek Valley, Montana, *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society, Field Conference and Symposium Guidebook, p. 111–119.

Immega, I.P., and Klein, C., Jr., 1975, Mineralogy and petrology of some metamorphic Precambrian iron-formations in southwestern Montana: American Mineralogist, v. 61, p. 1117–1144.

Jacobs, A.M., 1969, Pleistocene proto-cirque hollows in the Cataract Creek Valley, Tobacco Root Mountains, Montana: Indiana University, Ph.D. dissertation, 95 p.

James, H.L., and Hedge, C.E., 1980, Age of the basement rocks of southwest Montana: Geological Society of America Bulletin, v. 91, p. 11–15.

James, W.C., 1977, Origin of nonmarine-marine transitional strata at the top of the Kootenai Formation, southwestern Montana: Bloomington, Indiana University, Ph.D. dissertation, 433 p.

Johns, W.M., Straw, T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30’ west longitude: Montana Bureau of Mines and Geology Open-File Report MBMG 91, 79 p., 2 pls.

Johns, W.M., 1961, Geology and ore deposits of the southern Tidal Wave mining district, Madison County, Montana: Montana Bureau of Mines and Geology Bulletin 24, 53 p.

Johns, W.M., 1951, Description and geology of the Milligan Canyon area and the South Boulder section: Butte, Montana School of Mines*, B.S. thesis, 22 p.

Johns, W.M., Berg R.B., and Dresser, H.W., 1981, Road Log—Three Forks to Twin Bridges via U.S. Highways 10 and 287 and State Highway 287, *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society, Field Conference and Symposium Guidebook, p. 388–391.

Johnson, K.E., Brady, J.B., MacFarlane, W.A., Thomas, R.B., Poulsen, C.J., Sincock, M.J., 2004, *in* Brady, J.B., Burger, H.R., Cheney, J.T., and Harms, T.A., eds., Precambrian geology of the Tobacco Root Mountains, Montana: Geological Society of America Special Paper 377, p.71-87.

Jones, N.A., 1949, The Livingston Formation of the South Boulder area: Butte, Montana School of Mines*, B.S. thesis, 16 p.

Kavanagh, J., 1965, A study of selected igneous bodies of the Norris-Red Bluff area, Madison County, Montana: Bozeman, Montana State University, M.S. thesis, 60 p.

Kellogg, K.S., 1994, Geologic map of the Norris quadrangle, Madison County, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-1738, scale 1:24,000.

Kellogg, K.S., 1995, Geologic map of the Beartrap Creek quadrangle, Madison County, Montana: U.S. Geological Survey Geologic Quadrangle Map-1757, scale 1:24,000.

Kellogg, K.S., Schmidt, C.J., and Young, S.W., 1995, Basement and cover-rock deformation during Laramide contraction in the northern Madison Range (Montana) and its influence on Cenozoic basin formation: American Association of Petroleum Geologists Bulletin, v. 79, no. 8, p. 1117–1137.

Kellogg, K.S., and Vuke, S.M., 1996, Geologic map of the Willow Creek Reservoir and Norris NE quadrangles, Gallatin and Madison Counties, Montana: U.S. Geological Survey Open-File Report 96-012, scale 1:24,000.

Kellogg, K.S., and Williams, V.S., 2000, Geologic map of the Ennis 30′ x 60′ quadrangle, Madison and Gallatin Counties, Montana, and Park County, Wyoming: U.S. Geological Survey Geologic Investigations Map I-2690, scale 1:100,000.

Kendall, T.K., Miller, D.R., and Woodward, L.A., 1993, Field Trip—Mineral Hill Mining District Road Log, *in* Childs, J.F., and Lageson, D.R., eds., Economic and Regional Geology of the Tobacco Root-Boulder Batholith region, Montana: Tobacco Root Geological Society, 18th Annual Field Conference, Northwest Geology, v. 22, p. 119–129.

Kinley, T.M., 1987, The occurrence and timing of gold mineralization at the Red Pine mine, western Tobacco Root Mountains, southwestern Montana: Bozeman, Montana State University, M.S. thesis, 129 p.

Kittel, D.F., 1950, Basic sills in Cottonwood Creek Canyon, Jefferson County, Montana: Butte, Montana School of Mines*, B.S. thesis, 21 p.

Klemme, H.D., 1949, The geology of Sixteen Mile Creek area, Montana: Princeton, N.J., Princeton University, Ph.D. dissertation, 197 p.

Klepper, M.R., Weeks, R.Z., and Ruppel, E.T., 1957, Geology of the southern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geological Survey Professional Paper 292, 82 p.

Koehler, S.W., 1976, Petrology of the diabase dikes of the Tobacco Root Mountains, Montana, *in* Lankston, M.M., ed., Tobacco Root Geological Society, Field Conference Guidebook: Montana Bureau of Mines and Geology Special Publication 73, p. 27–35.

Kolodziejski, K.D., 1997, Gravity and seismic refraction survey of the contact between Cenozoic deposits and Archean bedrock in the Willow Creek watershed, Madison County, Montana, *in* Proceedings: Tenth Keck Research Symposium in Geology Proceedings, p. 310–313.

Kozak, S.J., 1961, Structural geology of the Cherry Creek basin area, Madison County, Montana: Iowa City, Iowa University, Ph.D. dissertation, 136 p.

Krogh, T.E., Kamo, S.L., Hanley, T.B., Hess, D.F., Dahl, P.S., and Johnson, R.E., 2011, Geochronology and geochemistry of Precambrian gneisses, metabasites, and pegmatite from the Tobacco Root Mountains, northwestern Wyoming craton, Montana: Canadian Journal of Earth Sciences, v. 48, p. 161–185.

Krothe, N.C., and Bergeron, M.P., 1981, The relationship between fracture traces and joints in a Tertiary basin, southwest Montana: Ground Water, v. 19, no. 2, p. 138–143.

Kulik, D.M., and Schmidt, C.J., 1988, Region of overlap and styles of interaction of Cordilleran Thrust Belt and Rocky Mountain Foreland, *in* Schmidt, C.J., and Perry, W.J., Interaction of the Rocky Mountain Foreland and the Cordilleran Thrust Belt: Geological Society of America Memoir 171, p. 75–98.

Kuenzi, W.D., 1966, Tertiary stratigraphy in the Jefferson River Basin, Montana: Missoula, University of Montana, Ph.D. dissertation, 293 p.

Kuenzi, W.D., and Fields, R.W., 1971, Tertiary stratigraphy, structure, and geologic history, Jefferson Basin, Montana: Geological Society of America Bulletin, v. 82, p. 3373–3394.

Kuenzi, W.D., and Richard, B.H., 1969, Middle Tertiary unconformity, North Boulder and Jefferson Basins, southwest Montana: Geological Society of America Bulletin, v. 80, p. 315.

Lageson, D.R., 1992, Structural analysis of the Horseshoe Hills transverse fold-thrust zone, Gallatin County, Montana: a preliminary report, *in* Elliott, J.E., ed., Guidebook for the Red Lodge-Beartooth Mountains-Stillwater Area: Tobacco Root Geological Society 17th Annual Field Conference Guidebook, Northwest Geology, v. 20/21, p. 117–124.

Lageson, D.R., 1989, Reactivation of a Proterozoic continental margin, Bridger Range, southwestern Montana, *in* French, D.E., and Grabb, R.F., eds., Geological Resources of Montana, volume I: Montana Geological Society Field Conference Guidebook, Centennial Edition, p. 279–298.

Lageson, D.R., and Montagne, J., 1981, Geologic road log—Dillon to Three Forks, Montana, *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society Field Conference and Symposium Guidebook, p. 399–406.

Lageson, D.R., Schmidt, C.J., Dresser, H.W., Welker, M., Berg, R.B., and James, H.L., 1983, Road Log—Helena to Bozeman via MacDonald Pass, Garrison, Deer Lodge, Butte, Homestake Pass, Jefferson Canyon, and Three Forks, *in* Smith, D.L., ed., Guidebook of the Fold and Thrust Belt, west-central Montana: Montana Bureau of Mines and Geology Special Publication 86, p. 33–82.

Lamberton, H.M., III, 1948, Structure and stratigraphy near Whitehall, Montana: Princeton, N.J., Princeton University, B.S. thesis, 83 p.

Lange, I.M., Fields, R.W., Fountain, D.M., Moore, J.N., Qamar, A.I., Silverman, A.J., Thompson, G.R., Chadwick, R.A., Custer, S.G., and Smith, D.L., 1980, National uranium resource evaluation, Bozeman quadrangle, Montana: prepared for U.S. Department of Energy, Grand Junction, CO, 87 p.

Lewis, S.E., 1988, Field guide to mesoscopic features in the LaHood Formation, Jefferson River Canyon area, southwestern Montana, *in* Lewis, S.E., and Berg, R.B., eds., Precambrian and Mesozoic Plate Margins: Montana, Idaho, and Wyoming: Montana Bureau of Mines and Geology Special Publication 96, p. 155-158.

Lillegraven, J.A., and Tabrum, A.R., 1983, A new species of *Centetodon* (Mammalia, Insectivora, Geolabididae) from southwestern Montana and its biogeographical implications: Contributions to Geology, University of Wyoming, v. 22, no. 1, p. 57–73.

Lillis, H.E., 1942, Geologic field mapping eight miles north of Three Forks, Montana: Butte, Montana School of Mines*, B.S. thesis, 14 p.

Lindquist, A., 1966, Structure and mineralization of the Whitehall mining district, Jefferson County, Montana: Butte, Montana College of Mineral Science and Technology*, M.S. thesis, 104 p.

Lofgren, D.L., 1985, Tertiary vertebrate paleontology, stratigraphy, and structure, North Boulder River Basin, Jefferson County, Montana: Missoula, University of Montana, M.S. thesis, 113 p.

Lonn, J.D., 1993, Phanerozoic mineralization in the Tobacco Root Mountains, Madison County, Montana: a review, *in* Childs, J.F., and Lageson, D.R., eds., Economic and Regional Geology of the Tobacco Root-Boulder Batholith region, Montana: 18th Annual Field Conference, Tobacco Root Geological Society, Northwest Geology, v. 22, p. 5–7.

Lonn, J.D., and English, A.R., 2002, Preliminary geologic map of the eastern part of the Gallatin Valley, Montana: Montana Bureau of Mines and Geology Open-File Report 457, scale 1:48,000.

Lowell, Josh, 1994, Pieces of the puzzle: a metamorphic and deformational history of the Spuhler Peak Formation, Tobacco Root Mountains, Montana: Colorado Springs, Colorado College, 100 p.

Ludman, Alan, 1965, Geology of the Doherty igneous complex, Jefferson County, Montana: Bloomington, Indiana University, M.A. thesis, 48 p.

Marvin, R.F., 1952, Description and geologic history of selected areas in the vicinity of Gallatin Canyon, Gallatin County, Montana: Butte, Montana School of Mines*, M.S. thesis, 68 p.

Maughan, E.K., and Roberts, A.E., 1967, Big Snowy and Amsden Groups and the Mississippian-Pennsylvanian boundary in Montana: U.S. Geological Survey Professional Paper 554-B, 27 p.

May, K.A., 1985, Archean geology of a part of the northern Gallatin Range, southwest Montana: Bozeman, Montana State University, M.S. thesis, 91 p.

McBride, B.D., Schmidt, C.J., Guthrie, G.E., and Sheedlo, M.K., 1992, Multiple reactivation of a collisional boundary: An example from southwestern Montana, *in* Bartholomew, M.J., Hyndman, D.W., Mogk, D.W., and Mason, Robert, eds., Basement Tectonics 8–Characterization and comparison of ancient and Mesozoic continental margins: Proceedings of the Eighth International conference on basement tectonics held in Butte, Montana, USA, August 1988, Dordrecht/ Boston/ London, Kluwer Academic Publishers, p. 341-357.

McLane, M.J., 1971, Phanerozoic detrital rocks at the north end of the Tobacco Root Mountains, southwestern Montana: a vertical profile: Bloomington, Indiana University, Ph.D. dissertation, 253 p.

McMannis, W.J., 1952, Geology of the Bridger Range: Princeton, N.J., Princeton University, Ph.D. dissertation, 172 p.

McMannis, W.J., 1955, Geology of the Bridger Range, Montana: Geological Society of America Bulletin, v. 66, p. 1385–1430.

McMannis, W.J., 1960, Exit geologic road log: Ennis to Bozeman, *in* Campau, D.E. and Anisgard, H.W., eds, West Yellowstone—Earthquake area: Billings Geological Society 11th Annual Field Conference Guidebook, p. 312–313.

McMannis, W.J., 1962, Devonian stratigraphy between Three Forks, Montana and Yellowstone Park, *in* Billings Geological Society Guidebook, 13th Annual field Conference, p. 4–12.

McMannis, W.J., 1963, LaHood Formation—a coarse facies of the Belt Series in southwestern Montana: Geological Society of America Bulletin, v. 74, p. 407–436.

McMannis, W.J., 1965, Résumé of depositional and structural history of western Montana: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 1802–1823.

McNamee, R.C., 1938, Study and correlation of Belt and Cambrian arkoses near Limespur, Montana: Butte, Montana School of Mines*, B.S. thesis, 14 p.

McThenia, A.W., Jr., 1960, Geology of the Madison River Canyon area north of Ennis, Montana, *in* Campau, D.E., and Anisgard, H.W., eds., West Yellowstone—earthquake area: Billings Geological Society, 11th Annual Field Conference Guidebook, p. 155–164.

Meyers, J.H., 1980, Tidal-flat carbonates of the Maywood Formation (Frasnian) and the Cambrian-Devonian unconformity, southwestern Montana, *in* Fouch, T.D., and Magathan, E.R., eds., Paleozoic Paleogeography of the west-central United States, Rocky Mountain Paleogeography Symposium 1: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 39–54.

Meyers, J.H., 1981, Carbonate sedimentation in the Ellis Group (Jurassic) on the southern flank of Belt Island, southwestern Montana: *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society, Field Conference and Symposium Guidebook, p. 83–91.

Meyers, S.A., 1991, Structural analysis of the Upper Hot Springs Mining District, Madison County, Montana: Moscow, University of Idaho, 153 p.

Mifflin, M.D., 1963, Geology of a part of the southern margin of the Gallatin Valley, southwestern Montana: Bozeman, Montana State University, M.S. thesis, 111 p.

Miller, E.W.B., 1987, Laramide basement deformation in the northern Gallatin Range and southern Bridger Range, southwest Montana: Bozeman, Montana State University, M.S. thesis, 78 p.

Miller, E.W., and Lageson, D.R., 1993, Influence of basement foliation attitude on geometry of Laramide basement deformation, southern Bridger Range and northern Gallatin Range, Montana, *in* Schmidt, C.J., Chase, R.B., and Erslev, E.A., eds., Laramide basement deformation in the Rocky Mountain foreland of the western United States: Geological Society of America Special Paper 280, p. 73–88.

Mitchell, M.M., 1987, Geometric and mesofabric analysis of the Hossfeldt Anticline-Eustis Syncline and the Lombard thrust zone near Three Forks, southwestern Montana: Knoxville, University of Tennessee, M.S. thesis, 160 p.

Mitchell, M.M., and Woodward, N.B., 1988, Kink detachment fold in the southwest Montana Fold and Thrust Belt: Geology, v. 16, p. 162–165.

Mogk, D.W., Burger, H.R., Mueller, P.A., D'Arcy, Kimberly, Heatherington, A.L., Wooden, J.L., Abeyta, R.L., Martin, Jennifer, and Jacob, L.J., 2004, Geochemistry of quartzofeldspathic gneisses and metamorphic mafic rocks of the Indian Creek and Pony-Middle Mountain Metamorphic Suites, Tobacco Root Mountains, Montana, *in* Brady, J.B., Burger, H.R., Cheney, J.T., and Harms, T.A., eds., Precambrian geology of the Tobacco Root Mountains, Montana: Geological Society of America Special Paper 377, p. 15-46.

Mogk, D.W., and Henry, D.J., 1988, Metamorphic petrology of the northern Archean Wyoming province, southwestern Montana: evidence for Archean collisional tectonics, *in* Ernst, W.G., ed., Metamorphism and crustal evolution of the western United States (Rubey Volume VII): Englewood Cliffs, New Jersey, Prentice Hall, p. 362–382.

Montagne, J.M., and Chadwick, R.A., 1976, Road log from Bozeman to Specimen Creek via Gallatin Canyon and U.S. 191, *in* Lankston, M.M., ed., Tobacco Root Geological Society, Field Conference Guidebook: Montana Bureau of Mines and Geology Special Publication 73, p. 38–52.

de la Montagne, J.M., 1960, Geomorphic problems in the Madison Valley, Madison County, Montana: An introduction and synthesis, *in* Campau, D.E., and Anisgard, H.W., West Yellowstone—Earthquake area: Billings Geological Society 11th Annual Field Conference Guidebook, p. 165–169.

de la Montagne, J.M, and six others, 1960, Preliminary geomorphic map of the Madison Valley, Montana (showing Recent tectonic features), *in* Campau, D.E., and Anisgard, H.W., West Yellowstone—Earthquake area: Billings Geological Society, 11th Annual Field Conference Guidebook, Plate 1.

Moore, B.K., 1984, Controls on ground-water availability and quality in the Bridger Canyon area: Bozeman, Montana State University, M.S. thesis, 187 p.

Moore, G.T., 1954, Intrusions in the Middle Cambrian formations, Cottonwood Canyon, Jefferson County, Montana: Bloomington, Indiana University, M.A. thesis, 45 p.

Morgan, W.T., and Hall, R.D., 1982, Pediments in the North Boulder River Basin, southwestern Montana: American Quaternary Association program and Abstracts, University of Washington, Seattle, p. 143.

Moritz, C.A., 1951, Triassic and Jurassic stratigraphy of southwestern Montana: American Association of Petroleum Geologists Bulletin, v. 35, p. 1781–1814.

Mueller, P.A., Burger, H.R., Wooden, J.L., Heatherington, A.L., Mogk, D.W., and D'Arcy, Kimberly, 2004, Age and evolution of the Precambrian crust of the Tobacco Root Mountains, Montana, *in* Brady, J.B., Burger, H.R., Cheney, J.T., and Harms, T.A., eds., Precambrian geology of the Tobacco Root Mountains, Montana: Geological Society of America Special Paper 377, p. 181-202.

Mueller, P.A., Heatherington, A.L., D'Arcy, K.A., Wooden, J.L., and Nutman, A.P., 1996, Contrasts between Sm-Nd whole-rock and U-Pb zircon systematics in the Tobacco Root Batholith, Montana: implications for the determination of crustal age provinces: Tectonophysics, v. 265, p. 169–179.

Neibaur, H., 1940, A geological report on an area five miles southeast of Renova, Montana, and on an area seven miles south of Jefferson Island, Montana: Butte, Montana School of Mines*, M.S. thesis, 25 p.

Nelson, W.L., 1962, A seismic study of North Boulder Valley and other selected areas, Jefferson and Madison Counties, Montana: Bloomington, Indiana University, M.S. thesis, 32 p.

Nichols, Ralph, Tabrum, A.R., and Hill, C.L., 2001, Introduction: Cenozoic mammals, southwest Montana, *in* Nichols, R., ed., Cenozoic vertebrate paleontology and geology of southwestern Montana and adjacent areas, *in* Hill, C.L., ed., Mesozoic and Cenozoic paleontology in the western plains and Rocky Mountains: Society of Vertebrate Paleontology 61st annual field trip guidebook, Museum of the Rockies Occasional Paper no. 3, p. 79–81.

Nichols, T.L., 1989, Resistivity and seismic refraction exploration for ground water near Bozeman, Gallatin County, Montana: Butte, Montana College of Mineral Science and Technology*, M.S. thesis, 104 p.

O'Neill, J.M., 1993, The Great Falls tectonic zone, Montana-Idaho: an Early Proterozoic collisional orogen beneath and south of the Belt Basin, *in* Berg, R.B., ed., Belt Symposium III: Montana Bureau of Mines and Geology Special Publication 112, p. 222–228.

O'Neill, J.M., 1983, Geologic map of the Middle Mountain-Tobacco Root Roadless Area, Madison County, Montana: U.S. Geological Survey Map MF-1590-A, scale 1:50,000.

O'Neill, J.M., and Cather, E.E., 1984, Middle Mountain-Tobacco Root Roadless Area, Montana, *in* Marsh, S.P., Kropschot, S.J., and Dickinson, R.J., Wilderness mineral potential, assessment of mineral-resource potential in U.S. Forest Service lands studied 1964-1984, v. 2, p. 721–723.

O'Neill, J.M., Schmidt, C.J., and Genovese, P.W., 1990, Dillon cutoff—basement-involved tectonic link between the Disturbed Belt of west-central Montana and the Overthrust Belt of extreme southwestern Montana: Geology, v. 18, p. 1107–1110.

Orr, J.B., 1958, The Tertiary of western Montana, *in* 8th Annual Field Conference Guidebook: Society of Vertebrate Paleontology, p. 25–33.

Qamar, Anthony, and Hawley, Bronson, 1979, Seismic activity near the Three Forks Basin, Montana: Bulletin of the Seismological Society of America, v. 69, no. 6, p. 1917–1929.

Paine, M.H., 1970, A reconnaissance study of the gastropod limestone (Lower Cretaceous) in southwest Montana: Bloomington, Indiana University, M.A. thesis, 124 p.

Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 356–406.

Parker, J.S., 1961, A preliminary seismic investigation of Tertiary basin fill in the Jefferson Island quadrangle, Montana: Bloomington, Indiana University, M.S. thesis, 35 p.

Paull, R.A., Paull, R.K., and Kraemer, B.R., 1989, Depositional environments of Lower Triassic rocks in southwestern Montana and adjacent parts of Wyoming and Idaho: *in* French, D.E., and Grabb, R.F., eds., Geologic Resources of Montana: Montana Geological Society, Field Conference Guidebook: Montana Centennial Edition, p. 69–90.

Peale, A.C., 1896, Three Forks Folio, no. 24: U.S. Geological Survey Atlas.

Peale, A.C., and Merrill, G.P, 1893, The Paleozoic section in the vicinity of Three Forks, Montana: U.S. Geological Survey Bulletin 110, 56 p.

Perry, E.S., 1950, Highlights of geology between Three Forks and Whitehall: Billings Geological Society, 1st Annual Field Conference Guidebook, p. 56–59.

Peterson, J.A., 1972, Permian sedimentary facies, southwestern Montana, *in* Lynn, J., Balster, C., and Warne, J., eds., Crazy Mountains Basin: Montana Geological Society, 21st Annual Field Conference Guidebook, p. 69–74.

Petricca, A.M., 1985, Sedimentology and diagenesis of the interbedded carbonate and siliciclastic rocks of the Big Snowy, Amsden, and Quadrant Formations, Tobacco Root Mountains region, southwestern Montana: Bloomington, Indiana University, M.S. thesis, 160 p.

Peugh, S.K., 1997, Gravity and seismic refraction survey of Cenozoic deposits in the Willow Creek watershed and the region surrounding Harrison, southwest Montana, *in* Proceedings: Tenth Keck Research Symposium in Geology, Colorado Springs, The Colorado College, p. 318–321.

Porter, E.W., and Ripley, E.M., 1985, Petrologic and stable isotope study of the gold-bearing breccia pipe at the Golden Sunlight deposit, Montana: Economic Geology, v. 80, p. 1689–1706.

Precht, W.F., and Shepard, W.W., 1989, Waulsortian carbonate buildups of Mississippian age from Montana and relations to rifting, *in* French, D.E., and Grabb, R.F., eds., Geologic Resources of Montana: Montana Geological Society Field Conference Guidebook: Centennial Edition, p. 65–68.

Rambosek, A.F., 1946, Geology and ore deposits of the Golden Sunlight mine and vicinity: Butte, Montana School of Mines*, M.S. thesis, 28 p.

Reid, R.R., 1957, Bedrock geology of the north end of the Tobacco Root Mountains, Madison County, Montana: Montana Bureau of Mines and Geology Memoir 36, 68 p.

Reid, R.R. 1963, Metamorphic rocks of the northern Tobacco Root Mountains, Madison County, Montana: Geological Society of America Bulletin, v. 74, p. 293–306.

Reid, S.K., and Dorobek, S.L., 1989, Application of sequence stratigraphy in the Mississippian Mission Canyon Formation and stratigraphic equivalents, southwestern Montana and east-central Idaho, *in* French, D.E., and Grabb, R.F., eds., Geologic Resources of Montana: Montana Geological Society Field Conference Guidebook: Centennial Edition, p. 47–53.

Reiter, F.H., 1962, The geology of a portion of the Manhattan quadrangle, the Horseshoe Hills area, Gallatin County, Montana: Ann Arbor, University of Michigan, M.S. thesis, 46 p.

Reshkin, M., 1963, Geomorphic history of the Jefferson Basin, Jefferson, Madison, Silver Bow Counties, Montana: Bloomington, Indiana University, Ph.D. dissertation, 146 p.

Reyner, M.L., 1947, Geology of the Tidal Wave district, Madison County, Montana: Butte, Montana School of Mines*, M.S. thesis, 27 p.

Richard, B.H., 1966, Geologic history of the intermontane basins of the Jefferson Island quadrangle, Montana: Bloomington, Indiana University, Ph.D. dissertation, 121 p.

Robinson, G.D., 1960, Middle Tertiary unconformity in southwestern Montana: U.S. Geological Survey Professional Paper 400-B, Article 101, p. B227–B228.

Robinson, G.D, 1961, Origin and development of the Three Forks basin, Montana: Geological Society of America Bulletin, v. 72, p. 1003–1014.

Robinson, G.D., 1963, Geology of the Three Forks quadrangle, Montana: U.S. Geological Survey Professional Paper 370, 143 p.

Robinson, G.D., 1967, Geologic map of the Toston quadrangle, southwestern Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-486, scale 1:24,000.

Robinson, G.D., Klepper, G.C., and Obradovich, J.D., 1968, Overlapping plutonism, volcanism, and tectonism in the Boulder Batholith region, western Montana, *in* Coats, R.R., Hay, R.L., and Anderson, C.A., eds., Studies in volcanology: Geological Society of America Memoir 116 p. 557–576.

Robinson, G.D., and Marvin, R.F., 1967, Upper Cretaceous volcanic glass from western Montana: Geological Society of America Bulletin, v. 78, p. 601–608.

Root, F., 1965, Structure, petrology and mineralogy of pre-Beltian metamorphic rocks of the Pony-Sappington area, Madison County, Montana: Bloomington, Indiana University, Ph.D. dissertation, 230 p.

Rothfuss, J.L., 2007, Alluvial facies of the Eocene Red Hill map unit of the Renova Formation in context of Cenozoic paleotopography and extensional tectonism in southwestern Montana: Allegeny, Pennsylvania, Allegheny College, Senior Comprehensive Project, 74 p.

Rothfuss, J.L., 2012, Application of detrital zircon provenance in paleogeographic reconstruction of an intermontane basin system, Paleogene Renova Formation, southwest Montana: Geological Society of America Special Paper 487, p. 63-95.

Roy, W.R., 1980, Glacial geology of the South Boulder Valley, Tobacco Root Range, Montana: Bloomington, Indiana University, M.S. thesis, 163 p.

Roy, W.R., and Hall, R.D., 1981, Glacial geology of the South Boulder Valley, Tobacco Root Range, Montana: *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society Field Conference and Symposium Guidebook, p. 125–132.

Ruppel, E.T., 1982, Cenozoic block uplifts in southwest Montana and east-central Idaho: U.S. Geological Survey Professional Paper 1224, 24 p.

Ruppel, E.T., 1993, Cenozoic tectonic evolution of southwest Montana and east-central Idaho: Montana Bureau of Mines and Geology Memoir 65, 62 p.

Ruleman, C.A., III, 2002, Quaternary tectonic activity within the northern arm of the Yellowstone tectonic parabola and associated seismic hazards, southwest Montana: Bozeman, Montana State University, M.S. thesis, 158 p.

Rutland, Carolyn, 1985, Geochemistry of the Elkhorn Mountains Volcanics, southwestern Montana: East Lansing, Michigan State University, Ph.D. dissertation, 96 p.

Sagar, Joe, and Childs, John, 1993, Field Trip—Maltbys Mound, *in* Childs, J.F., and Lageson, D.R., eds., Economic and Regional Geology of the Tobacco Root-Boulder Batholith region, Montana: Tobacco Root Geological Society, 18th Annual Field Conference: Northwest Geology, v. 22, p. 103–116.

Sahinen, U.M., 1939, Geology and ore deposits of the Rochester and adjacent mining districts, Madison County, Montana: Montana Bureau of Mines and Geology Memoir 19, 53 p.

Salt, K.J., 1987, Archean geology of the Spanish Peaks area, southwestern Montana: Bozeman, Montana State University, M.S. thesis, 81 p.

Samuelson, K.J., and Schmidt, C.J., 1981, Structural geology of the western Tobacco Root Mountains, southwestern Montana, *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society, Field Conference and Symposium Guidebook, p. 191–199.

Sandberg, C.A., 1962, Stratigraphic section of type Three Forks and Jefferson Formations at Logan, Montana, *in* Billings Geological Society Guidebook, 13th Annual Field Conference, p. 47–50.

Sandberg, C.A., 1965, Nomenclature and correlation of lithologic subdivisions of the Jefferson and Three Forks Formations of southern Montana and northern Wyoming: U.S. Geological Survey Bulletin 199, p. N1–N18.

Sandberg, C.A., and McMannis, W.J., 1964, Occurrence and paleogeographic significance of the Maywood Formation of Late Devonian age in the Gallatin Range, southwestern Montana: U.S. Geological Survey Professional Paper 501-C, p. C50–C54.

Sando, W.J., 1990, HUM Lithosome: An example of regional stratigraphic synthesis in the Mississippian of the Western Interior of the United States: U.S. Geological Survey Bulletin 1881, p. E1–E17.

Sando, W.J, and Dutro, J.T., Jr., 1960, Stratigraphy and coral zonation of the Madison Group and Brazer Dolomite in northeastern Utah, western Wyoming, and southwestern Montana, *in* Wyoming Geological Association 15th Annual Field Conference Guidebook, p. 117–126.

Sando, W.J., Sandberg, C.A., and Perry, W.J., Jr., 1985, Revision of Mississippian stratigraphy, northern Tendoy Mountains, southwest Montana, *in* Sando, W.J., ed., Mississippian and Pennsylvanian Stratigraphy in southwest Montana and adjacent Idaho: U.S. Geological Survey Bulletin 1656, p. A1–A5.

Saterdal, A., 1945, Vermiculite, occurrence, character, and concentration of minerals from the Pony District, Madison County, Montana: Butte, Montana School of Mines*, B.S. thesis, 5 p.

Sayers, F.E., 1962, The geology of a portion of the Manhattan quadrangle, the Horseshoe Hills area, Gallatin County, Montana: Santa Barbara, University of California, M.S. thesis, 61 p.

Schmidt, C.J., 1975, An analysis of folding and faulting in the northern Tobacco Root Mountains, southwest Montana: Bloomington, Indiana University, Ph.D. dissertation, 480 p.

Schmidt, C.J., 1976, Structural development of the Lewis and Clark Caverns State Park area, southwest Montana, *in* Lankston, M.M., ed., Tobacco Root Geological Society, Field Conference Guidebook: Montana Bureau of Mines and Geology Special Publication 73, p. 141–150.

Schmidt, C.J., 1979, Discussion of origin of west-directed thrusts on the east flank of the Negro Hollow syncline, Jefferson County, Montana, *in* Suttner, L.J., ed., Near surface batholiths, related volcanism, tectonism, sedimentation, and mineral deposition: Geological Society of America, Granite II Penrose Conference Guidebook, p. 84–91.

Schmidt, C.J., 1988, Comment and reply on "Kink detachment fold in the southwest Montana fold and thrust belt": Geology, v. 16, p. 1052–1055.

Schmidt, C.J., Aram, Richard, and Hawley, David, 1987, The Jefferson River Canyon area, southwestern Montana, *in* Beus, S., ed.: Geological Society of America, Centennial Field Guide-Rocky Mountain Section, p. 63–68.

Schmidt, C.J., Evans, J.P., and Douglas, B., 1991, Pull apart origin for the Tobacco Root Batholith, southwestern Montana: Geological Society of America, Abstracts with Programs, Rocky Mountain Section, v. 23, no. 4, p. 90.

Schmidt, C.J., and Garihan, J.M., 1983, Role of recurrent movement of northwest-trending basement faults in the tectonic evolution of southwestern Montana, *in* Lowell, J., ed., Rocky Mountain foreland basins and uplifts: Rocky Mountain Association of Geologists, p. 271–294.

Schmidt, C.J., and Garihan, J.M., 1986a, Middle Proterozoic and Laramide tectonic activity along the southern margin of the Belt Basin, *in* Roberts, S.M., ed., Belt Supergroup—A guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 217–235.

Schmidt, C.J., and Garihan, J.M., 1986b, Role of recurrent movement of northwest-trending basement faults in the tectonic evolution of southwestern Montana, *in* Alderich, M.J., and Laughlin, R., eds.: Proceedings of the 6th International Conference on Basement Tectonics, p. 1–15.

Schmidt, C.J., and Geiger, Beth, 1985, Nature of deformation in foreland anticlines and impinging thrust belt: Tobacco Root and southern Highland Mountains, Montana: Tobacco Root Geological Society, 10th Annual Field Conference Guidebook, p. 41–65.

Schmidt, C.J., Genovese, P.W., and Chase, R.B., 1993, Role of basement fabric and cover-rock lithology on the geometry and kinematics of twelve folds in the Rocky Mountain foreland, *in* Schmidt, C.J., Chase, R.B., and Erslev, E.A., eds., Laramide basement deformation in the Rocky Mountain foreland of the western United States: Geological Society of America Special Paper 280, p. 1-44.

Schmidt, C.J., Genovese, P.W., and Foster, Fess, 1989, Road Log—Structure and economic geology along the transverse thrust zone of southwestern Montana, *in* French, D.E., and Grabb, R.F., eds., Geologic Resources of Montana: Montana Geological Society Field Conference Guidebook: Centennial Edition, p. 482–501.

Schmidt, C.J., and Hendrix, T.E., 1981, Tectonic controls for thrust Belt and Rocky Mountain foreland structures in the northern Tobacco Root Mountains–Jefferson Canyon area, southwestern Montana, *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society, Field Conference and Symposium Guidebook, p. 167–180.

Schmidt, C.J., James, C., and Shearer, J., 1981, Estimate of displacement in major zone of tear-thrusting in the Fold and Thrust Belt, southwest Montana: American Association of Petroleum Geologists Bulletin, v. 65, p. 986–987.

Schmidt, C.J., and O'Neill, J.M., 1982, Structural evolution of the Southwest Montana Transverse Zone, *in* Powers, R.B., ed., Geologic studies of the Cordilleran Thrust Belt: Rocky Mountain Association of Geologists field guidebook, v. 1, p. 193–218.

Schmidt, C.J., O'Neill, J.M., and Brandon, W.C., 1988, Influence of Rocky Mountain foreland uplifts on the development of the frontal fold and thrust belt, southwestern Montana, *in* Schmidt, C.J., and Perry, W.J., Jr., eds., Interaction of the Rocky Mountain foreland and the Cordilleran thrust belt: Geological Society of America Memoir 171, p. 171–201.

Schmidt, C.J., Smedes, H.W., and O'Neill, J.M., 1990, Syncompressional emplacement of the Boulder and Tobacco Root Batholiths (Montana–USA) by pull-apart along old fault zones: Geological Journal, v. 25, p. 305–318.

Schmitt, J.G., 1988, Sedimentation and tectonic setting of the middle Proterozoic LaHood Formation, Belt Supergroup, southwestern Montana, *in* Lewis, S.E., and Berg, R.B., eds., Precambrian and Mesozoic Plate Margins: Montana, Idaho, and Wyoming: Montana Bureau of Mines and Geology Special Publication 96, p. 89–96.

Schmitt, J.G., Haley, J.C., Lageson, D.R., Horton, B.K., Azevedo, P.A., 1995, Sedimentology and tectonics of the Bannack-McKnight Canyon-Red Butte area, southwest Montana: new perspectives on the Beaverhead Group and Sevier Orogenic Belt, [includes road logs—Bozeman to Three Forks, and Three Forks to Whitehall], *in* Mogk, D.W., ed., Field Guide to Geologic Excursions in southwest Montana: Northwest Geology, v. 24, p. 245–313.

Schneider, G.B., 1970, Cenozoic geology of the Madison Bluffs area, Gallatin County, Montana: Bozeman, Montana State University, M.S. thesis, 56 p.

Scholten, R., and Hait, M.H., Jr., 1962, Devonian System from shelf edge to geosyncline, southwestern Montana-central Idaho, *in* Montana Geological Society 13th Annual Field Conference Guidebook, p. 13–22.

Schwartz, R.K., 1972, Stratigraphic and petrographic analysis of the Lower Cretaceous Blackleaf Formation, southwestern Montana: Bloomington, Indiana University, Ph.D. dissertation, 268 p.

Schwartz, R.K., 1982, Broken Early Cretaceous foreland basin in southwestern Montana: sedimentation related to tectonism, *in* Blake, R., ed., Geologic Studies of the Cordilleran Thrust Belt: Rocky Mountain Association of Geologists, Field Guidebook v. 1, p. 159–183.

Schwartz, R.K., and DeCelles, P.G., 1988, Cordilleran foreland basin evolution in response to interactive Cretaceous thrusting and foreland portioning, southwestern Montana, *in* Schmidt, C.J., and Perry, W.J., Jr., eds., Interaction of the Rocky Mountain Foreland the Cordilleran Thrust Belt: Geological Society of America Memoir 171, p. 489-513.

Schwartz, T.M., and Schwartz, R.K., 2013, Paleogene postcompressional intermontane basin evolution along the frontal Cordilleran fold-and-thrust belt of southwestern Montana: Geological Society of America Bulletin, v. 125, no. 5-6, p. 961-984.

Skeels, D.C., 1939, Structural geology of the Trail Creek-Canyon Mountain area, Montana: Journal of Geology, v. 47, p. 816–840.

Skipp, Betty, Lageson, D.R., and McMannis, W.J., 1999, Geologic map of the Sedan quadrangle, Gallatin and Park Counties, Montana: U.S. Geological Survey Geologic Investigation Map I-2634, version 2.0, scale 1:48,000 [adjacent to Bozeman 30′ x 60′ quadrangle].

Skipp, Betty, and Peterson, A.D., 1965, Geologic map of the Maudlow quadrangle, southwestern Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-452, scale 1:24,000 [adjacent to Bozeman 30′ x 60′ quadrangle].

Sloss, L.L., and Hamblin, R.H., 1942, Stratigraphy and insoluble residues of the Madison Group (Mississippian) of Montana: American Association of Petroleum Geologists, v. 26, p. 305–335.

Sloss, L.L., and Laird, W.M., 1947, Devonian System in central and northwestern Montana: American Association of Petroleum Geologists Bulletin, v. 31, no. 8, p. 1404–1430.

Sloss, L.L., and Moritz, C.A., 1951, Paleozoic stratigraphy of southwestern Montana: American Association of Petroleum Geologists Bulletin, v. 35, p. 2135–2169.

Smedes, H.W., 1966, Geology and igneous petrology of the northern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geological Survey Professional Paper 510, 116 p.

Smith, D.L., Welker, Molly, and students, 1995, Driving tour of the geology of the southeastern Gallatin Valley, Bridger Range, and western margin of the Crazy Mountains Basin, *in* Self-guided field trips near Bozeman, Montana: Geological Society of America-Rocky Mountain Section, 47th Annual Meeting Guidebook, p. 12–34.

Smith, J.L., 1970, Petrology, mineralogy, and chemistry of the Tobacco Root Batholith, Madison County, Montana: Bloomington, Indiana University, Ph.D. dissertation, 198 p.

Spahn, R.A., Jr. 1967, Geology of the southwestern Horseshoe Hills area, Gallatin County, Montana: Bozeman, Montana State University, 95 p.

Spry, P.G., Paredes, M.M., Foster, Fess, Truckle, Jack, and Chadwick, Tom, 1996, A genetic link between gold-silver telluride and porphyry molybdenum mineralization at the Golden Sunlight deposit, Whitehall, Montana: Fluid inclusion and stable isotope studies: Economic Geology, v. 91, p. 507–526.

Spry, P.G., Foster, Fess, and Chadwick, T.H., 1997, The mineralogy of the Golden Sunlight gold-silver telluride deposit, Montana, USA: Mineralogy and Petrology, v. 59, p 143–164.

Sonderegger, J.L., and Ohguchi, T., 1988, Irrigation related arsenic contamination of a thin, alluvial aquifer, Madison River Valley, Montana, U.S.A.: Springer Verlag, Environmental Geology and Water Science, v. 11, no. 2, p. 153–161.

Sterne, E.J., 1990, Using surface geology of folded thrusts to explore hidden, subsurface thrust packages; three examples from the Montana thrust belt: American Association of Petroleum Geologists Bulletin, v. 74, p. 1346.

Stickney, M.C., 1997, Seismic source zones in southwest Montana: Montana Bureau of Mines and Geology Open-File Report MBMG 366, 51 p.

Stickney, M.C., 1993, Seismicity of the Tobacco Root Mountains and surrounding region, Montana, *in* Childs, J.F. and Lageson, D.R., eds., Economic and Regional Geology of the Tobacco Root-Boulder Batholith region, Montana: Tobacco Root Geological Society, 18th Annual Field Conference, Northwest Geology, v. 22, p. 49–54.

Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602–1625.

Stickney, M.C., and Lageson, D.R., 1999, The Nov. 6, 1997 M 3.7 Belgrade, MT earthquake: Unusual aspects and their implications to regional seismicity: Geological Society of America Abstracts with Programs, v. 31, no. 4, p. A-57.

Streeter, M.E., 1983, The geology of the southern Bull Mountain area, Jefferson County, Montana: Kalamazoo, Western Michigan University, M.S. thesis, 88 p.

Suttner, L.J., 1968a, Clay minerals in the Upper Jurassic-Lower Cretaceous Morrison and Kootenai Formations, southwestern Montana: Earth Science Bulletin, v. 1, p. 1–14.

Suttner, L.J., 1968b, Stratigraphic and petrographic analysis of Upper Jurassic-Lower Cretaceous Morrison and Kootenai Formations, southwest Montana: American Association of Petroleum Geologists Bulletin, v. 53, p. 1391–1410.

Suttner, L.J., Schwartz, R.K., and James, W.C., 1981, Late Mesozoic to Early Cenozoic foreland sedimentation in southwest Montana, *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society, Field Conference and Symposium Guidebook, p. 93–103.

Sutton, J.F., 1977, Mammals of the Anceney local fauna (Late Miocene) of Montana: Lubbock, Texas Tech University, Ph.D. dissertation, 241 p.

Sutton, J.F., and Korth, W.W., 1995, Rodents (Mammalia) from the Barstovian (Miocene) Anceney local fauna, Montana: Annals Carnegie Museum 64, p. 267–314.

Tabrum, A.R., and Nichols, Ralph, 2001, Tertiary paleontology of southwest Montana and adjacent Idaho, *in* Nichols, R., ed., Cenozoic vertebrate paleontology and geology of southwestern Montana and adjacent areas, *in* Hill, C.L., ed., Mesozoic and Cenozoic paleontology in the western plains and Rocky Mountains: Society of Vertebrate Paleontology 61st annual field trip guidebook, Museum of the Rockies Occasional Paper no. 3, p. 88–112.

Talpt, Arthur, 1938, The Jefferson Canyon gypsum deposit: Butte, Montana School of Mines*, B.S. thesis, 22 p.

Tansley, W., Schafer, P.A., and Hart, L.H., 1933, A geological reconnaissance of the Tobacco Root Mountains, Madison County, Montana: Montana Bureau of Mines and Geology Memoir 9, 57 p.

Tendall, B.A., 1978, Mineralogy and petrology of Precambrian ultramafic bodies from the Tobacco Root Mountains, Madison County, Montana: Bloomington, Indiana University, M.S. thesis, 126 p.

Thomas, R.C., 1995, Cambrian mass extinction (“biomere”) boundaries: a summary of thirty years of research, *in* Mogk, D.W., ed., Field guide to geologic excursions in southwest Montana: Rocky Mountain section, Geological Society of America Meeting, Northwest Geology, v. 24, p. 67–75.

Thomas, W.A., 2011, Cambrian-Devonian stratigraphy along the southwest Montana transverse zone and tectonic history of the Willow Creek fault system: Montana Bureau of Mines and Geology Geologic Map 55, 40 p., 1 sheet.

Thomas, W.A., Allen, J.L., Mars, J.C., McDowell, R.J., Azevedo, P.A., Buck, B.J., Corner, H.J., and Dodd, J.R., 1996, Willow Creek basement fault zone beneath the southwest Montana transverse zone: dormant during Cambrian-Devonian time: Mountain Geologist, v. 33, no. 4, p. 115–124.

Thomas, W.A., 1990, Controls on locations of transverse zones in thrust belts: Eclogae Geologicae Helvetiae, v. 83, p. 727–744.

Thompson, G.R., Fields, R.W., and Alt, David, 1982, Land-based evidence for Tertiary climatic variations: northern Rockies: Geology, v. 10, p. 413–447.

Thompson, G.R., Fields, R.W., and Alt, David, 1981, Tertiary paleoclimates, sedimentation patterns, and uranium distribution in southwestern Montana: *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society, Field Conference and Symposium Guidebook, p. 105–109.

Tilley, C.W., 1976, Geology of the Spanish Creek area, Madison and Gallatin Counties, Montana: Bozeman, Montana State University M.S. thesis, 111 p.

Tuck, L.K., Dutton, D.M., and Nimick, D.A., 1997, Hydrologic and water-quality data related to the occurrence of arsenic for areas along the Madison and Upper Missouri Rivers, southwestern and west-central Montana: U.S. Geological Survey Open-File Report 97-203, 124 p.

Tysdal, R.G., 1966, Geology of a part of the north end of the Gallatin Range, Gallatin County, Montana: Bozeman, Montana State University, M.S. thesis, 92 p.

Tysdal, R.G., 1986, Thrust faults and back thrusts in the Madison Range of southwestern Montana foreland: American Association of Petroleum Geologists Bulletin, v. 70, p. 360–376.

Tysdal, R.G., and Simons, F.S., 1985, Geologic map of the Madison roadless area, Gallatin and Madison Counties, Montana: U.S. Geological Survey Miscellaneous Map MF-1605-B, scale 1:96,000.

Verrall, Peter, 1955, Geology of the Horseshoe Hills area, Montana: Princeton, N.J., Princeton University, Ph.D. dissertation, 371 p.

Vice, D.H., 1982, A review of the thermal infrared imagery for the Jefferson River Survey, southwestern Montana: Montana Bureau of Mines and Geology Open-File Report 98, 69 p.

Vitaliano, C.J., and Cordua, W.S., 1979, Geologic map of the southern Tobacco Root Mountains, Madison County, Montana: Geological Society of America Map and Chart Series MC-31, scale 1:62,500.

Vitaliano, C.J., Kish, S.A., and Towell, D.G., 1976, K-Ar dates and Sr isotopic values for rocks of the Tobacco Root Batholith, southwestern Montana: Isochron/West, no. 28, p.13–15.

Vuke, S.M., 2003, Geologic map of western and northern Gallatin Valley, southwestern Montana: Montana Bureau of Mines and Geology Open-File Report 481, scale 1:100,000.

Vuke, S.M., 2006, Geologic map of the Cenozoic deposits of the lower Jefferson Valley, southwestern Montana: Montana Bureau of Mines and Geology Open-File Report 537, 41 p., 1 sheet, scale 1:50,000, 1:50,000.

Vuke, S.M., Lonn, J.D., Berg, R.B., Kellogg, K.S., 2002, Preliminary geologic map of the Bozeman 30′ x 60′ quadrangle, southwestern Montana: Montana Bureau of Mines and Geology: Open-File Report 469, 39 p., 1 sheet, scale 1:100,000.

Vuke, S.M., Coppinger, W.W., and Cox, B.E., 2004, Geologic map of Cenozoic deposits in the Upper Jefferson Valley, southwestern Montana: Montana Bureau of Mines and Geology Open-File Report 505, 35 p., scale 1:50,000.

Wagner, S.L., 1963, Effect of Laramide folding on previously folded Precambrian metamorphic rocks, Madison County, Montana: Bloomington, Indiana University, M.S. thesis, 27 p.

Wantland, D., 1951, Seismic investigations in connection with U.S. Geological Survey groundwater studies in the Gallatin River Valley, Montana: U.S. Bureau of Reclamation Geology Report no. G-115, 8 p.

Wardlaw, B.R., and Pecora, W.C., 1985, New Mississippian-Pennsylvanian stratigraphic units in southwest Montana and adjacent Idaho: U.S. Geological Society Bulletin 1656, p. B1–9**.**

Warne, J.R., Sterne, E.J., and Thompson, G.G., 1997, Road Log—From Livingston to Helena via Bridger Range, Lombard Thrust, Jefferson Canyon, Devils Fence Anticline, and Gates of the Mountains marina, *in* Sterne, E.J. and Warne, J.R., eds., Thrust Systems of the Helena Salient-Montana Thrust Belt: Montana Geological Society and Tobacco Root Geological Society Joint Field Conference Guidebook p. 13–35.

Weber, W.M., 1965, General geology and geomorphology of the Middle Creek area, Gallatin County, Montana: Bozeman, Montana State University, M.S. thesis, 86 p.

Werkema, M., Hendrix, T.E., and Schmidt, C.J., 1981, Analysis of the Sappington fault in the "J" structure, Jefferson County, Montana, *in* Tucker, T.E., ed., Southwest Montana: Montana Geological Society, Field Conference and Symposium Guidebook, p. 93–103.

Werner, A.V., 1994, Sedimentology of alpine debris-flow and talus deposits in Sacajawea Cirque, Bridger Range, Montana: Bozeman, Montana State University, M.S. thesis, 92 p.

Wilson, A.B., and Elliott, J.E., 1977, Geologic map of the western and northern parts of the Gallatin National Forest, south-central Montana: U.S. Geological Survey Geologic Investigation Map I-2584, scale 1:126,270.

Wilson, D.A., 1962, A seismic and gravity investigation of the North Boulder River and Jefferson River Valleys, Madison and Jefferson Counties, Montana: Bloomington, Indiana University, M.S. thesis, 43 p.

Wilson, M.C., and Davis, L.B., 1994, Late Quaternary stratigraphy, paleontology, and archaeology of the Sheep Rock Spring Site (24JF292), Jefferson County, Montana: Current Research in the Pleistocene, v. 11, p. 100–102.

Wilson, T.L., 1948, Karst Kamp asbestos deposits, Gallatin County, Montana: Butte, Montana School of Mines*, B.S. thesis, 17 p.

Winston, Don, 1986, Middle Proterozoic tectonics of the Belt Basin, western Montana and northern Idaho, *in* Roberts, S.M., ed, Belt Supergroup: a guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 245–257.

Wood, H.E., Jr., 1933, A fossil rhinoceros (*Diceratherium armatum*) from Gallatin County, Montana: U.S. National Museum Proceedings, v. 82, p. 1–4.

Wooden, J.L., Vitaliano, C.J., Koehler, S.W., and Ragland, P.C., 1978, The Late Precambrian mafic dikes of the southern Tobacco Root Mountains, Montana: Geochemistry, Rb-Sr geochronology, and relationship to Belt tectonics: Canadian Journal of Earth Sciences, v. 15, p. 467–473.

Woodward, L.A., 1983, Structural geology of the Helena salient: a synopsis, *in* Smith, D.L., Guidebook of the Fold and Thrust Belt, west-central Montana: Montana Bureau of Mines and Geology Special Publication 86, p. 83-87.

Woodward, L.A., Miller, D.R., and Kendall, T.K., 1993, Geology and ore deposits of the Mineral Hill Mining District, Madison County, Montana, *in* Childs, J.F., and Lageson, D.R., eds., Economic and Regional Geology of the Tobacco Root-Boulder Batholith region, Montana: Tobacco Root Geological Society, 18th Annual Field Conference, Northwest Geology, v. 22, p. 9–17.

Young, S.W., 1985, Structural history of the Jordan Creek area, northern Madison Range, Madison County, Montana: Austin, University of Texas, M.S. thesis, 112 p.

Zen, E-an, 1977, Fault connections in southwestern Montana: U.S. Geological Survey Professional Paper 1050, p. 66–67.

Zietz, Isidore, 1960, Configuration of the 10N pluton, Three Forks, Montana: U.S. Geological Survey Professional Paper 400-B, p. B229–230.

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