U.S. DEPARTMENT OF THE INTERIOR
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GEOLOGIC INVESTIGATIONS SERIES I–2773

GEOLOGIC MAP OF THE HOGBACK MOUNTAIN QUADRANGLE, LEWIS AND CLARK AND MEAGHER COUNTIES, MONTANA

By
Mitchell W. Reynolds
2003

SCALE 1:24 000
CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Base from U.S. Geological Survey, 1962.
Polyconic projection. 1927 North American Datum.
10,000-foot grid based on Montana coordinate system, central zone.
1,000-meter Universal Transverse Mercator grid ticks, zone 12.

Geology mapped in August 1975,
July–August 1976, and August 1980.
Assisted in July 1976 by S.J. Ebling.
GIS data compilation by Sharon A. Smith, 1999.
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DESCRIPTION OF MAP UNITS

[Terminology for carbonate rocks from Folk (1962)]

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

Ql Landslide deposits (Holocene and Pleistocene)—Angular rock fragments, blocks, and soil that have moved downslope as a single unit in the northern part of the map area. Generally chaotic and unstratified fragments, locally weakly stratified; supports hummocky topography. Thickness as much as 60 m

Qog Old gravel (Holocene and Pleistocene)—Generally unconsolidated, stratified and unstratified gravel, sand, and some silt; deposited by streams; clasts rounded to subrounded; at elevations 15–75 m above recent stream channels. Thickness 5–65 m

QTg Older gravel (Pleistocene and Pliocene)—Unconsolidated to weakly consolidated, stratified gravel, sand, and some silt; deposited predominantly by streams, some as colluvium; clasts rounded to subrounded, subangular and angular adjacent to Soup Creek fault in secs. 32 and 33, T. 12 N., R. 1 W. In secs. 20 and 29, T. 13 N., R. 1 E. and sec. 22, T. 13 N., R. 1 W., contains subrounded and rounded pebbles and small cobbles of Phanerozoic rocks in silt or clayey-silt matrix. Locally contains sediment with tuffaceous matrix and possible tuff beds. Thickness as much as 18 m

OGb Basalt (Oligocene)—Interleaved andesitic basalt flows and thin sills; splits flaggy, local columnar jointing; one probable feeder dike mapped in NWcSEc sec. 36, T. 13 N., R. 1 W. Equivalent rocks in adjacent quadrangles to the south and east have radiometric ages of about 31 Ma (H.H. Mehnert, U.S. Geological Survey, written commun., 1985). Thickness as much as 85 m

Khd Hornblende diorite (Late Cretaceous)—Sills and irregularly shaped intrusive bodies of hornblende diorite; dark olive gray to olive black; weathers medium to light olive brown; fine to coarsely crystalline, equicrystalline; friable upon weathering. Biotite bearing; locally contains abundant epidote. In secs. 22–28, T. 13 N., R. 1 W., sills intrude strata of the Middle Cambrian Wolsey Shale (Ꞓw), Upper Mississippian Heath and Otter Formations of the Big Snowy Group (Mbu), and Pennsylvanian Quadrant Formation (Pℙpq) north and northeast of the Moors Mountain thrust fault klippen; such sills are not known southeast of the klippen. Sills generally 1–8 m thick, but one major sill is as thick as 155 m

Kk Kootenai Formation (Lower Cretaceous)—Siltstone and silty mudstone interbedded with lithic sandstone and limestone. Siltstone and mudstone are pale grayish red to grayish red, locally olive gray; split platy to shaly. Sandstone is pale grayish red and yellowish brown; sandstone units as thick as 18 m are fine to predominantly medium and coarse grained, split platy; abundant rounded black chert grains with quartz, feldspar, and light-colored lithic grains produce a salt-and-pepper appearance. Limestone is pale greenish-gray to light gray; limestone beds are laminated and very thin bedded; micritic and very finely crystalline; silty and sandy; locally contain small gastropods and possible algal filaments. Exposed formation thickness 275–335 m

Jme Morrison Formation and Ellis Group undivided (Jurassic)—Morrison Formation: siltstone, minor mudstone, and thin sandstone are greenish gray to grayish red; sandstone is grayish orange; discontinuous silty and clayey limestone beds contain sand grains, charophytes, and possible algal filaments. As mapped, locally includes grayish-black coaly siltstone bed, about 2–3 m thick, at top; might include beds of Early Cretaceous age at top. Thickness approximately 65 m. Disconformably overlies the Ellis Group.
In the map area, Ellis Group consists of the Swift Formation and Sawtooth Formation. Swift Formation: sandstone and siltstone and discontinuous very thin basal conglomerate; light olive gray to pale brownish gray, and medium and medium dark gray; splits platy and flaggy, locally shaly. Sawtooth Formation: calcareous sandstone and sandy limestone and lenticular calcareous pebble conglomerate containing oyster fossils at base; yellowish gray to grayish orange; weathers same; cross-laminated and laminated; splits flaggy. Ellis Group is approximately 134–168 m thick

PIPpq Phosphoria and Quadrant Formations, undivided (Permian and Pennsylvanian)—Phosphoria Formation (Permian): chert; light brownish gray and medium gray; locally contains microfossils; minor medium-brownish-gray dolomitic limestone containing chert nodules. Mostly removed by pre-Sawtooth Formation erosion; only discontinuous remnants less than 1 m thick preserved along Jme–PIPpq boundary within quadrangle; disconformably overlies Quadrant Formation.
Quadrant Formation (Pennsylvanian): sandstone and sandy dolomitic limestone; very light gray and light yellowish gray; weathers yellowish gray and pale grayish orange; quartz cement common; very thin and thin laminae and cross-laminae; splits platy and flaggy; supports ledges and locally low cliffs. Thickness 15–30 m

IPa Amsden Formation (Pennsylvanian)—Sandstone and interbedded silty mudstone; grayish red and light reddish brown; interbedded pinkish-gray limestone and sandstone at top; limestone-pebble conglomerate at base; rests unconformably on underlying rocks of the Big Snowy Group. Thickness 15–75 m

Big Snowy Group
Mbu Heath and Otter Formations, undivided (Upper Mississippian)—Upper part (Health Formation) consists of mudstone and silty mudstone with thin beds of sandy limestone and dolostone; mudstone is medium gray to predominantly medium dark gray and dark olive gray; limestone beds are yellowish gray, weather pale grayish orange, and contain crinoid columnals and brachiopod fragments. Lower part (Otter Formation) consists of silty mudstone and very thin limestone, dolostone, and sparse dolomitic sandstone beds; mudstone is pale greenish gray to olive gray; limestone, dolostone, and sandstone are light brownish gray to olive gray; laminated and very thin bedded; split shaly and flaggy. As shown in subsurface of the northeast corner of the quadrangle (cross section B–B'), includes the lower part of the Pennsylvanian Tyler Formation. Thickness is 230–335 m, locally including Late Cretaceous hornblende diorite sills (Khd)

Mbk Kibbey Formation (Upper Mississippian)—Siltstone, sandy siltstone, and limestone, with limestone and dolostone breccia at base; yellowish gray; pale-grayish-red and grayish-red calcareous siltstone interbeds; subangular pebbles and fragments of underlying Mississippian rocks in basal part; sandy limestone beds are locally stromatolitic. Thickens eastward in progressively lower thrust plates. Thickness 134–335 m

Mm Mission Canyon Limestone (Upper and Lower Mississippian)—Limestone; medium light to medium dark gray and light olive gray; weathers light gray, very light gray, and white; locally dolomitic; scattered nodular beds and isolated nodules of brownish-gray chert; limestone is generally recrystallized and fractured; coarsely crystalline; pressure solution surfaces common; columns and pods of dissolution collapse breccia present in upper one-third; thin bedded with local thin sets of cross-laminae; splits thick to massive; limestone pellets and fragments, oolites, and crinoid, brachiopod, and coral fossils and fossil fragments visible locally; thin bedded, local current cross-bedding; forms cliffs or rugged slopes. Thickness variable as a result of deformation and dissolution, 335–460 m

Ml Lodgepole Limestone (Lower Mississippian)—Limestone and interbedded silty limestone and highly calcareous siltstone; medium light to medium dark gray, light brownish gray to yellowish gray; weathers light gray, very light gray, and white, and moderate orange pink to pale yellowish orange in silty intervals; laminated and very thin bedded; fine- to medium-crystalline biosparite, oosparite, and intrasparite limestone; splits platy, shaly, and flaggy, with intervals of thick beds near center that split slabby; contains abundant fossils including brachiopods, crinoid fragments, bryozoa, corals, rare trilobite fragments, and trace fossils, including unidentified burrows, scattered Scalerotuba in lower part, and rare Zoophycus in upper part. Thickness variable as a result of deformation and dissolution, 305–350 m

MDt Three Forks Formation (Lower Mississippian and Upper Devonian)—Silty dolostone, calcareous siltstone and limestone, and mudstone; medium olive gray and olive gray; weathers pale grayish orange, grayish orange, and pale olive; contains intervals of medium-light-gray calcareous mudstone and olive-black to brownish-gray carbonaceous silty mudstone. Lower part contains limestone and calcareous siltstone; medium brownish gray; weathers yellowish gray, pale orange pink, and light brown. Local thin lenses of solution collapse limestone breccia at base. Limestone beds in upper part contain common brachiopods and crinoid columnals, some oncolites, and trace fossils, including Scalerotuba, Cosmorayphe, and unidentified smooth-walled small burrows. High total organic content in brownish- and grayish-black mudstone units. Splits shaly and flaggy, commonly covered by talus from overlying Lodgepole Limestone. Map unit includes Cottonwood Canyon Member of Lodgepole Limestone at top: carbonaceous mudstone; brownish black to grayish black; weathers pale yellowish brown and very pale orange. Thickness of map unit variable as a result of deformation, 18–37 m

Dj Jefferson Formation (Upper Devonian)—Dolostone; light and medium to medium dark brownish gray, locally medium gray; weathers medium brownish gray, pale yellowish brown, and yellowish gray; fine to medium crystalline; strong petroliferous fetid odor on fresh surface; local wavy cross-laminae, but generally structureless; thin beds of pelletoid limestone; rare very thin beds of dolomitic sandstone; contains lenses of brachiopod and trilobite(?) fragments and very thin intervals of stromatoporoid algae. Splits flaggy and blocky. Limestone at top is medium and medium dark gray; weathers very light gray and white; forms white ledges or low cliff at top of formation. Thickness variable as a result of deformation and dissolution, about 230 m

Dm Maywood Formation (Upper and Middle Devonian)—Dolostone; light gray, yellowish gray, and light brownish gray; weathers very pale orange and pale grayish orange; very thin intervals of dolomitic siltstone and sandy dolostone; laminated, wavy laminated, and thin bedded; a few laminae contain halite crystal casts; splits platy and flaggy. At base, discontinuous unit as thick as

6 m consists of thin beds and laminae of silty dolostone with siltstone partings and of very thin limestone and dolostone beds; grayish red and greenish gray; weathers yellowish gray and grayish red; lenticular beds contain pebbles reworked from underlying Upper Cambrian beds and probable fish(?) bone fragments. As mapped, locally includes some beds of the Upper Cambrian Pilgrim Formation. Total thickness 15–21 m

D€u Devonian and Cambrian rocks, undivided—Thin fault-bounded wedges of Devonian and Cambrian rocks, including the lower part of the Three Forks Formation (MDt), Jefferson Formation (Dj), and Cambrian Pilgrim Formation and Park Shale (€pp), Meagher Limestone(?) (€m), and Flathead Sandstone (€f) in fault contact with the Mississipian Mission Canyon Limestone (Mm) in S½ sec. 7, T. 12 N., R. 1 E. Continuity within wedges permits definitive identification of units, but discontinuous exposure and limited size of wedges does not permit showing faults at the map scale

€pp Pilgrim Formation and Park Shale, undivided (Upper and Middle Cambrian)—Pilgrim Formation (Upper Cambrian): pebbly limestone and silty limestone; light gray to light olive gray; weathers light gray, pale grayish orange, and grayish orange; beds 0.3–2 m thick. Interbedded silty claystone and claystone; light olive gray, olive gray; weather light olive, dusky yellow green and grayish green; very thinly laminated, split fissile and platy; intervals 0.1–5 m thick. Limestone is biopelsparite, with common to abundant trilobite fragments, pelmatozoan fragments, small chitinous brachiopods, oolites and pellets, and glauconite pellets in sparry calcite matrix. Flat pebbles of laminated micrite to silty biosparite limestone, 1–8 cm in largest dimension, are subrounded to rounded and are generally supported at high angles to bedding in silty, biopelsparite matrix. Gradational downward into Park Shale.
Park Shale (Middle Cambrian): silty claystone and claystone; sparse lenses, 4–25 cm thick, of pebbly biosparite limestone fill very thin channels; light olive gray and light olive; weathers olive gray and grayish green; fissile and platy.
Total thickness of mapped unit varies as a result of strong deformation in claystone and silty claystone intervals and lenticularity of pebbly limestone beds, 183–213 m

€m Meagher Limestone (Middle Cambrian)—Limestone; medium gray, medium dark gray, and medium brownish gray; weathers medium light gray; common grayish-orange, moderate-brown, and pale-grayish-red silty mottles, particularly in basal 30 m and top 50 m. Finely crystalline limestone with channel-fillings and beds of medium- to coarsely-crystalline fossiliferous oosparite and biopelsparite limestone. Discontinuous wavy laminae and beds 0.2–4 cm thick, with discontinuous silty limestone partings; weathers with knobby, locally reticular texture especially near the base and top of formation; forms steep slopes or low cliff. Contains locally abundant small trilobite fragments, some pelmatazoan(?) plates, and sparse chitinous brachiopod fragments. Generally folded disharmonically between mudstone and siltstone strata of the Park Shale above and Wolsey Shale below. Thickness about 75 m, but as much as 116 m likely as a result of deformation

Ꞓw Wolsey Shale (Middle Cambrian)—Silty mudstone and siltstone; light olive to light grayish green, locally olive black; weathers light olive gray, dusky yellow gray, and grayish red. Thin beds of pale-grayish-red silty sandstone are interbedded in olive-green siltstone in basal 5 m. Interval of medium-gray and medium-brownish-gray limestone, 3 m thick, is present about 60 m above base; weathers grayish red, brownish gray, and medium light gray; medium- to coarsely-crystalline sandy biosparite, with sparse to abundant pellets of glauconite; fossils are trilobite, brachiopod, and pelmatozoan(?) fragments. Limestone laminae and beds, 0.2–3 cm thick, are scattered throughout the unit. Top 30 m contains light-gray to light-greenish-gray limestone; weathers pale yellowish brown to grayish orange; trilobite biosparite; some greenish-gray siltstone chips on parting surfaces. Siltstone in lower one-third of unit contains scattered Cruziana and annelid(?) trace fossils. Strata split shaly and platy; limestone splits platy and flaggy. Apparent thickness varies as a result of local strong internal deformation, 150–245 m

Ꞓf Flathead Sandstone (Middle Cambrian)—Sandstone and pebbly sandstone; pinkish gray, yellowish gray, and very pale red; weathers pale reddish brown, yellowish gray, and light brownish gray; very thin siltstone beds at top; greenish gray and light olive gray; weathers greenish gray. Sandstone is fine to coarse grained, with locally abundant pebbles as large as 2 cm across. Grains and pebbles are quartz, quartzite, red and gray chert, and minor feldspar; grains generally well rounded, but shapes modified by pressure solution and quartz overgrowths; weakly to firmly indurated; common to abundant glauconite grains in uppermost 12 m; cross-laminae to very thin beds, herringbone cross-bedding near base and in top 15 m; thin sets of trough cross-laminae common; ripple lamine in upper part; splits flaggy and slabby, locally platy; forms resistant ledges and ridge. Thickness about 60–85 m

Zd Diorite sills (Upper Proterozoic)—Diorite; dark olive gray to predominantly olive black; medium and coarsely crystalline; very finely crystalline margins exposed locally; anorthosite, hornblende, biotite; some chlorite as an apparent alteration product of biotite. Weathers readily to friable state; discontinuous to very poor exposures in secs. 29 and 30, T. 12 N., R. 1 E., and locally in NE¼ sec. 25, T. 12 N., R. 1 W. Age determination on a similar but stratigraphically higher intrusive sill in the adjacent Canyon Ferry 7.5-minute quadrangle is 741.3±32.2 Ma (sample collected by M.W. Reynolds; K/Ar determination by H.H. Mehnert, U.S. Geological Survey, written commun., 1985). Estimated thickness 4.5–8 m

Belt Supergroup (Middle Proterozoic)

Yg Greyson Formation—In upper plate of Moors Mountain thrust fault, formation is siltite, argillitic siltite, argillite, and quartzite; olive gray, light greenish gray, and medium olive to medium dark gray; weathers greenish gray, pale olive, dusky yellow, and pale yellowish brown; in the klippen of the Moors Mountain thrust plate east of Hogback Mountain weathers generally olive gray, dark olive gray, and dark gray; even parallel, discontinuous wavy, and cross-laminae; contains very thin beds of silty fine-grained quartzite and, in lower and upper middle parts, thin concretionary lenses of dolomitic and calcareous siltite; splits shaly and platy.

In upper plate of Hogback Mountain thrust fault (shown by diagonal line pattern), formation is siltite and argillitic siltite containing scattered lenses of brownish-gray very fine quartzite; medium gray and predominantly medium dark gray to dark gray; weathers olive gray, dark greenish gray, and olive black; even parallel and discontinuous wavy parallel laminae; very thin sets of graded laminae; beds cut by thin quartz veins; local intense small- and intermediate-scale folding associated with thrusting; splits shaly and platy.

Partial exposed thickness as much as 1,130 m

Yn Newland Formation—Calcareous argillite and calcareous siltite; limestone and arkosic sandstone intervals in uppermost part. Argillite and siltite are medium gray and medium dark gray; weather pale grayish orange and grayish orange; very thinly even parallel laminated producing a varvelike appearance on weathered surface; local very thin low-angle inclined laminae. Limestone is medium light gray and medium gray; weathers light and medium light gray; aphanocrystalline and very finely crystalline, locally silty; sparry calcite replacement of some curved surfaces, and scattered to common coarse calcite fills fractures; beds locally highly contorted and cleaved adjacent to the Moors Mountain thrust fault; limestone intervals 0.5–5 m thick. Arkosic sandstone is grayish orange pink; weathers very pale orange and light brown; fine to medium grained, local coarse grains to granules; clasts of quartz, microcline feldspar, polycrystalline quartz, and rare laminated limestone; beds structureless to cross-laminated at low angles; local internal slump structures; beds 0.04–0.3 m thick. Lower exposed part of formation splits shaly and platy, and forms steep slopes; upper part splits shaly and, in limestone intervals, platy to slabby; forms ledges on steep slopes and ridge crest. Formation is structurally truncated from the lower part to the top as the Moors Mountain thrust fault ramps upward northwest from the south edge of the quadrangle to Checkerboard Gulch [center, west edge, and adjacent part of Nelson quadrangle (Reynolds and Hays, in press)]. The corresponding upward ramp in the Moors Mountain thrust fault klippen is present across secs. 17, 19, 29, 30, 31, and 32, T. 13 N., R. 1 E., and sec. 25, eastern part of sec. 35, and sec. 36, T. 13 N., R. 1 W. Exposed partial thickness as much as 1,675 m

GEOLOGIC SETTING

The Hogback Mountain quadrangle lies near the north end of the Big Belt Mountains in west-central Montana, about 40 km northeast of the capital city of Helena (fig. 1). The Big Belt Mountains rise as a north-northwest-trending range from the Smith River Valley on the east and the Helena and Townsend Valleys on the west. The Missouri River flows through a narrow canyon and valley incised through the northwestern part of the Big Belt Mountains. The mountains strike across two prominent west-northwest-trending physiographic and tectonic elements: the north end of the Helena Valley on the west, and the south margin of the Dry Range and Little Belt Mountains on the east (fig. 1).

The Hogback Mountain quadrangle, together with the adjacent Snedaker Basin and Nelson quadrangles (fig. 2), occupies a geologically significant position at the junction between the Big Belt Mountains and major cross-trending tectonic elements. The north edge of Helena Valley marks the southern edge of a principal tectonic zone, the Lewis and Clark line (fig. 1; Billingsley and Locke, 1939; Hobbs and others, 1965), which is recognized as a zone of recurrent major strike slip and vertical fault movement through geologic time (Reynolds, 1977, 1979; Harrison and Reynolds, 1976; Reynolds and Kleinkopf, 1977). Similarly, the south flank of the Little Belt Mountains and Dry Range was a zone of recurrent faulting from Middle Proterozoic to at least middle Miocene time. The zone is likely contiguous in the basement with the Lewis and Clark tectonic zone.

Rocks of the Hogback Mountain quadrangle are predominantly sedimentary strata that range in age from Middle Proterozoic (about 1,400 million years B.P.) to Recent. Pre-Tertiary (pre-66 million years B.P.) rocks are mostly marine in origin (see "Description of map units"). However, some strata such as parts of the Flathead Sandstone, Lower and lower Middle Devonian strata, and parts of the Mississippian Big Snowy Group, Pennsylvanian Amsden Formation, Jurassic strata, and Cretaceous Kootenai Formation, originated in nonmarine continental environments.

Tertiary and Quaternary deposits accumulated on alluvial plains and fans, or as talus and landslide deposits on the steep mountain slopes.

Igneous hornblende diorite (Khd) of Late Cretaceous age [estimated age approximately 73(?)–68(?) Ma] intrudes Cambrian and Mississippian rocks on the upper plate of the Hogback Mountain thrust fault northeast of Hogback Mountain (secs. 22–26, T. 13 N., R. 1 W.; geologic section A–A'). On the upper plate of the Moors Mountain thrust fault in the southeastern part of the quadrangle, thin diorite sills (Zd) intrude the Middle Proterozoic Newland Formation. Sills of similar composition and texture that intrude Middle Proterozoic rocks of the same plate in adjacent quadrangles are of Late Proterozoic age (741±32 Ma, H.H. Mehnert, U.S. Geological Survey, written commun., 1985; sampling by M.W. Reynolds).

In the east-central part of the Hogback Mountain quadrangle, andesitic basalt (OGb) was erupted as thin flows with intrusive sheets onto a surface eroded across all deformed older rocks. The lava flows, dated radiometrically at about 31 Ma (H.H. Mehnert, written commun., 1985), crop out mainly across the zone of intersection between the Big Belt Mountains and the west-trending tectonic front of the Little Belt Mountains and Dry Range (figs. 1 and 2), and suggest that deep-seated fracturing was active along the zone during middle Tertiary time.

The geologic structure of the Hogback Mountain quadrangle is highly complex. Three principal structural plates, each strongly deformed internally, are exposed at the surface (fig. 2). In ascending structural and chronological order the plates are the Avalanche Butte, Hogback Mountain, and Moors Mountain plates. Differential forces in a complex regional stress field included (1) deep-seated horizontal shear with compression that resulted in en echelon folds that trend northeast to east-northeast, nearly normal to the subsequent direction of thrust shortening; and (2) compression that produced north-northwest-oriented thrust faults and recumbent folds. Significant differences in the competence of units through the stratigraphic succession enhanced the structural complexity. Within the quadrangle, four stratigraphic intervals in particular served for detachment with strong internal deformation among thick, relatively competent stratigraphic units. The Middle Cambrian Wolsey Shale (Ꞓw) and the Upper and Middle

Cambrian Park Shale (Ꞓpp) served as detachment zones between which the Middle Cambrian Meagher Limestone folded disharmonically. Laminated rocks of the Lower Mississippian Lodgepole Limestone (Ml) deformed readily by fracture and flow to produce imbricate sheets within thrust plates or complexly folded and faulted wedges bounded by opposing faults. Laminated and thin-bedded terrigenous clastic strata and anhydrite in the Kibbey Formation [Upper Mississippian Big Snowy Group (Mbk)] served as a principal detachment zone separating folds and faulted folds in upper Paleozoic and Mesozoic rocks above from the underlying thick carbonate succession of the Lower and Upper Mississippian Mission Canyon Limestone (Mm). As a result of the stratigraphic inhomogeneities and complex tectonic stresses, some specific structures seem out of balance within the area of the Hogback Mountain quadrangle; however, across the broader region, fold and fault structures do balance.

The structurally lowest plate, called the Avalanche Butte plate (fig. 2; Reynolds and Hays, in press), is exposed from Beaver Creek and Diamond Gulch in the northwestern part of the quadrangle (secs. 29 and 32, T. 13 N., R. 1 W.) southeast across Trout Creek to Vigilante Gulch (sec. 29, T. 12 N., R. 1 E.). This lowest plate contains a complex sequence of recumbent1 anticlines and synclines that trend northwest. Thrust faults deform and duplicate the formations in folds of the plate (figs. 2 and 3; cross sections B–B', C–C', and D–D'). From Hogback Mountain to Middleman Mountain (secs. 2, 3, 11, 12, 13, 14, T. 12 N., R. 1 W.), the recumbent folds are broken by opposing west- and east-dipping faults, with the resulting geometry of a complex wedge zone (cross section B–B'). This wedge seems to have served as a buttress, around which, on the southeast, carbonate beds of the Lodgepole and Mission Canyon Limestones were folded in tight recumbent folds, attenuated, and broken by thrust faults into thin sheets (cross sections C–C' and D–D'). The structures in the plate are arched as a result of folding subsequent to the thrust faulting and folding within the plate. Folded and imbricated Paleozoic rocks of the Avalanche Butte plate are in stratigraphic continuity with broadly folded Upper Proterozoic rocks exposed east-southeast of Avalanche Butte up plunge from the Hogback Mountain quadrangle (fig. 2). The plate contains the lowest structural level of rocks that has been thrust over the southeast end of the frontal fold and fault belt and the continental autochthon (fig. 2).

The next higher and younger structural sequence, termed the Hogback Mountain thrust plate, is the intermediate level in the Big Belt Mountains structural complex, and is exposed across the northeast one-third of the quadrangle (fig. 2). The plate, bounded below by the Hogback Mountain thrust fault, is a faulted, detached recumbent fold in which previously developed folds are inverted1. Strata from the Middle Proterozoic Greyson Formation (Yg) to the Upper and Middle Mississippian Mission Canyon Limestone form the plate and are thrust over an overturned succession of Upper Mississippian to Lower Cretaceous (Kootenai Formation) strata in the northeast corner of the quadrangle. Folds that trend northeast to east-northeast (step 1 of fig. 3, folds A, B, and C) seem to be the oldest folds in the Hogback Mountain thrust plate and are refolded in an east-verging recumbent syncline whose axial trace strikes northwest (cross sections A–A', B–B', and D–D'; step 2 of fig. 3, fold D). The inverted Grouse Ridge syncline (cross section D–D'; step 3 of fig. 3, fold C) is the largest of the inverted folds in the recumbent syncline. The relatively linear trace of the Hogback Mountain fault across the plunging inverted folds in the upper plate is evidence that the thrust fault post-dates the earliest folding on the plate and most of the refolding in the recumbent syncline. The recumbent syncline with internal inverted folds seems to have developed as part of a structural ramp, for the Hogback Mountain fault cuts stratigraphically up section from the Middle Proterozoic Greyson Formation on the west to Mississippian rocks on the east as well as structurally upward across the lower limb of the easternmost syncline through the upper overturned limb. In SE¼ sec. 20, NW¼ 28, and NE¼ sec. 29, T. 13 N., R. 1 W., the Hogback Mountain fault surface is itself overturned to dip west on the overturned limb of the recumbent syncline. The relation suggests that the late stage of recumbent folding accompanied emplacement of the overlying Moors Mountain thrust plate (step 3 of fig. 3).

The Hogback Mountain thrust fault splays upward and eastward in a succession of thrust faults. The principal splay faults truncate the major recumbent syncline and form the boundary of a subjacent highly deformed wedge in very thin- and thin-bedded carbonate and silty carbonate, and calcareous siltstone strata of the Lodgepole Limestone (cross sections A–A' and B–B'). The next underlying fault displaces those Mississippian carbonate rocks and forms the principal detachment fault on which the succession of Upper Mississippian through Cretaceous rocks has been folded and thrust faulted in the frontal fold and fault belt independent of the underlying Upper and Middle Mississippian carbonate rocks and older strata of the autochthon (fig. 2). The detachment is at the base of the principal anhydrite-bearing interval of the Mississippian Kibbey Formation. Rocks above the detachment are folded disharmonically and broken by splays from the principal detachment fault. The latter rocks are exposed above the autochthon from about 13 km east to about 22 km northeast of the Hogback Mountain quadrangle (fig. 2; Reynolds, unpublished geologic maps of the Lingshire, Ellis Canyon, Lingshire Northeast, Lingshire Northwest, and BK Ranch 7.5-minute quadrangles, Montana).

The Moors Mountain thrust fault bounds the structurally highest and youngest Moors Mountain thrust plate exposed across the Hogback Mountain quadrangle. Along the fault, Middle Proterozoic rocks of the Newland (Yn) and Greyson (Yg) Formations have been transported over all deformed rocks of the Hogback Mountain and Avalanche Butte thrust plates (cross sections B–B', C–C', and D–D'; fig. 2). The Moors Mountain fault cuts downward east and north across both the Hogback Mountain and the Avalanche Butte plates. In the northeast one-third of the quadrangle, a broad klippen of the Moors Mountain fault rests structurally on inverted folds of the recumbently folded Hogback Mountain plate (cross section B–B' and fig. 2). The Moors Mountain fault ramps upward north across the quadrangle from low in the Middle Proterozoic Newland Formation (south edge of the quadrangle) into the upper middle part of the Greyson Formation (northwest corner of the quadrangle). Thus, the stratigraphic rise of the fault is about 3,350 m (11,000 ft) in a horizontal distance of about 11 km (7 mi). From this relation, the strike of steepest slope of the structural ramp seems to have been west across the center of the Hogback Mountain quadrangle. This position is spatially coincident with the projected traces of the Lewis and Clark tectonic zone and the tectonic zone bounding the south flank of the Dry Range and the Little Belt Mountains.

The structurally truncated contact of the Newland Formation with the Greyson Formation and the Moors Mountain fault surface (secs. 35 and 36, T. 13 N., R. 1 W.) marks a reference piercement point in the klippen. A matching piercement point on the Moors Mountain fault west of Hogback Mountain in the adjacent Nelson quadrangle (secs. 7 and 8, T. 12 N., R. 1 W; Reynolds and Hays, in press) establishes the original equivalence and continuity of rocks of the klippen with the main plate of the Moors Mountain fault. From the full extent of the klippen (fig. 2), the minimum horizontal structural transport of rocks of the Moors Mountain plate across the Hogback Mountain quadrangle is about 28 km (17.5 mi) in a northeast direction; however, the total transport may be as much as 65 km (40.6 mi).

The Moors Mountain fault was deformed by subsequent warping across the north-northwest trend of the current Hogback and Middleman Mountains (cross sections B–B' and C–C'). That warping might have been associated with middle and late Cenozoic high-angle normal faulting. During this episode of deformation, the Soup Creek fault (secs. 32 and 33, T. 12 N., R. 1 W.) developed with rocks on the western side dropped down toward Helena Valley, and the Hogback Mountain fault had recurrent movement down toward the east.

During 1981 and 1982, Getty Oil Company drilled a test hole, the No. 3-10 Federal, Hogback Mountain, to explore for oil from the west spur of Hogback Mountain (NE¼SW¼ sec. 3, T. 12 N., R. 1 W). Drilled to a total depth of 4,185 m (13,731 ft), the dry hole penetrated repeated sequences, each apparently in upright stratigraphic succession, of the Mission Canyon and Lodgepole Limestones, Devonian rocks, and Middle and Upper Cambrian strata. As a result of poor borehole conditions and a change to air drilling, rock sample recovery was limited to the top 2,609 m (8,560 ft). The sequence of units identified from geophysical logs and sample study is consistent with structure mapped in adjacent canyon exposures (upper part) and shown on cross section B–B'. The hole likely bottomed in the autochthonous sequence of Paleozoic and Middle Proterozoic rocks beneath the Avalanche Butte plate and wedge zone. Within the quadrangle area, extreme deformation of all units as well as elevated earth temperatures likely precluded the accumulation of economic amounts of petroleum (Reynolds and Close, 1984).

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1On this map, a recumbent fold is an overturned fold in which the axial surface is nearly horizontal or dips at a low angle. Overturned is applied herein to a fold in which one limb is overturned beyond the vertical, and inverted is used for a fold in which both limbs have been overturned beyond the vertical.

Contact—Dashed where approximately located; short dashed where inferred; dotted where concealed
Fault—Dashed where approximately located; short dashed where inferred; dotted where concealed
Normal fault—Short dashed where inferred; dotted where concealed. Bar and ball on downthrown side
Thrust fault—Showing dip of fault plane where known. Dashed where approximately located; short dashed where inferred; dotted where concealed; queried where location is inferred from indirect evidence. Sawteeth on upper plate. In cross sections, T, movement toward observer; A, movement away from observer; A with arrow, oblique movement away from observer; arrow shows relative direction of movement
Overturned thrust fault—Dashed where approximately located. Base of sawteeth on upper plate. In cross sections, arrow shows relative direction of displacement
Folds—Showing trace of axial surface, direction of dip of limbs, and direction of plunge of axis where known. Dashed were approximately located; short dashed where inferred; dotted where concealed
Anticline
Overturned anticline—Beds in one limb are overturned
Inverted anticline—Beds in both limbs of fold are overturned and dip toward the trace of the axial surface shown. Fold inverted on upper limb of northwest-trending recumbent fold (trace of recumbent fold not shown) that post-dates the now-inverted fold and predates or overlaps in time the development of the Hogback Mountain thrust fault
Syncline

Overturned syncline—Beds in one limb are overturned
Inverted syncline—Beds in both limbs are overturned and dip away from the trace of the axial surface shown. Fold inverted on upper limb of northwest-trending recumbent fold (trace of recumbent fold not shown) that post-dates the now-inverted fold and predates or overlaps in time the development of the Hogback Mountain thrust fault
Strike and dip of bedding—In areas of complex structure, ball on end of strike line shows top of beds determined from sedimentary features
Inclined
Overturned
Overturned greater than 180°
Horizontal
Vertical
Strike and dip of cleavage
Inclined
Minor quartz vein—Showing strike
Prospect
Dry oil well
Spring
Outcrop too small to show at map scale—Includes some float indicative of formation underlying slope veneered by forest soil

Figure 1. Generalized physiographic map of west-central Montana, showing location of the Hogback Mountain quadrangle (pink) in relation to regional tectonic features.

Figure 2. Tectonic map of the northern Big Belt Mountains, Montana, showing thrust sheets, tectonic units, and the distribution of Middle Proterozoic rocks, Phanerozoic rocks, and Oligocene basalt flows in relation to the Hogback Mountain quadrangle.

Figure 3. Suggested sequence of development of structure on the upper plate of the Hogback Mountain thrust fault in the northeastern part of the Hogback Mountain quadrangle and the western part of the adjacent Snedaker Basin quadrangle (fig. 2). The suggested steps merge in a continuum of deformation. Step 1. Northeast-trending anticlines (unlabeled) and synclines (A, B, and C) develop across a site west of their present location, possibly as en echelon folds during strike-slip faulting within the zone of the Lewis and Clark tectonic zone. Syncline C represents the Grouse Ridge syncline. Step 2. Folds developed in step 1 are folded recumbently along a northwest-trending axis as the Hogback Mountain thrust fault develops and advances east-northeast. The recumbent fold is D, and synclines A, B, and C become inverted in the upper limb of recumbent fold D. Step 3. Continued movement of the Hogback Mountain thrust, concurrent with (1) development of the overriding Moors Mountain thrust plate and (2) continued strike-slip movement in the basement along the Lewis and Clark tectonic zone, truncates the recumbent fold system and overfolds folds in the upper plate of the Hogback Mountain fault. The trace of the Hogback Mountain fault is deformed southeast in the area of the Snedaker Basin quadrangle (fig. 2). The inverted Grouse Ridge syncline (C) is overfolded.

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