GEOLOGIC MAP OF THE MUSSELSHELL 30' x 60' QUADRANGLE

CENTRAL MONTANA

by

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Montana Bureau of Mines and Geology
Open File Report MBMG 386

1999

Revised:
2/2005: New Text: unit descriptions
12/2005: Text revisions; minor map revisions

This report has had preliminary reviews for conformity with Montana Bureau of Mines and Geology's technical and editorial standards.

Partial support has been provided by the STATEMAP component of the National Cooperative Geologic Mapping Program of the U.S. Geological Survey under Contract Number 98-HQ-AG2080.

GEOLOGIC SUMMARY

The Musselshell quadrangle is located in central Montana in an area of rolling plains and high, deeply dissected benches bounded on the west by the Little Snowy Mountains. The Musselshell River crosses the quadrangle's southeast corner. Areas of complex geologic structure involve Paleozoic and Mesozoic sedimentary rocks that are commonly intruded by alkalic dikes and sills. Gravel-covered benches obscure bedrock in some areas, but elsewhere deep incision by the Musselshell River drainage has exposed excellent stratigraphic sections and has revealed structural features.

Geologic Structure

In the Musselshell quadrangle, northwest- and northeast-trending structural grains intersect, reflecting the tectonic patterns described by Thomas (1974). Compressional events along each of these trends have formed small and large fold structures and numerous associated faults. Intersecting folds are observed in the northwest map area where the formerly mapped Flat Willow Syncline (Dobbin and Erdmann, 1955), near its culmination west of Durfee Creek Dome, is intersected by a small, northeast-trending anticline along the South Fork of Flatwillow Creek. The Flat Willow Syncline also appears to be intersected by the northwest plunge of Devils Basin Anticline in the west-central map area. Thus, although Dobbin and Erdmann's (1955) structure contour map, drawn on top of the Fall River Sandstone, suggests a continuous synclinal feature for the Flat Willow Syncline, surface mapping of the Fall River Sandstone through Mowry Formation indicates that these formations dip continuously southwest from the north side of Flatwillow Creek into the unnamed, tightly folded syncline along the north side of Durfee Creek Dome. The syncline paralleling Durfee Creek Dome is tentatively interpreted to extend southward and then to swing east to join the Willow Creek Syncline along the south side of Devils Basin Anticline. An additional effect of compressional stress along intersecting structural grains is the parallel northwest trend but reversed asymmetry of Durfee Creek Dome and Devils Basin Anticline.

The northwest-trending Devils Basin Anticline in the center of the map area exposes Lower Cretaceous Kootenai Formation red beds and sandstones. Oil is produced from the Pennsylvanian-Mississippian Tyler and Heath Formations. Upper Cretaceous beds on the anticline's northeast end and Paleocene beds on its steeply dipping south flank are still largely covered by gravel deposits but poorly resistant Cretaceous shales lower in the section are extensively exposed around the structure's southeast end. The steep south limb of the anticline is cut by both northeast- and northwest-trending faults as beds dip into the Willow Creek Syncline. The trend of Devils Basin Anticline continues east to Big Wall Dome that exposes the Niobrara Formation in its center. Oil is produced from the Alaska Bench and Tyler Formations at a depth of approximately 3,000 feet. East and north of the Devils Basin-Big Wall structures, Upper Cretaceous beds occur in broad northwest- and northeast-trending folds that are locally faulted.

Across the northern third of the map area, a complex series of northeast-trending faults occurs within a northwest-trending zone first mapped in detail by Johnson and Smith (1964). These authors provided enough detailed stratigraphy in the marine shale section of the lower

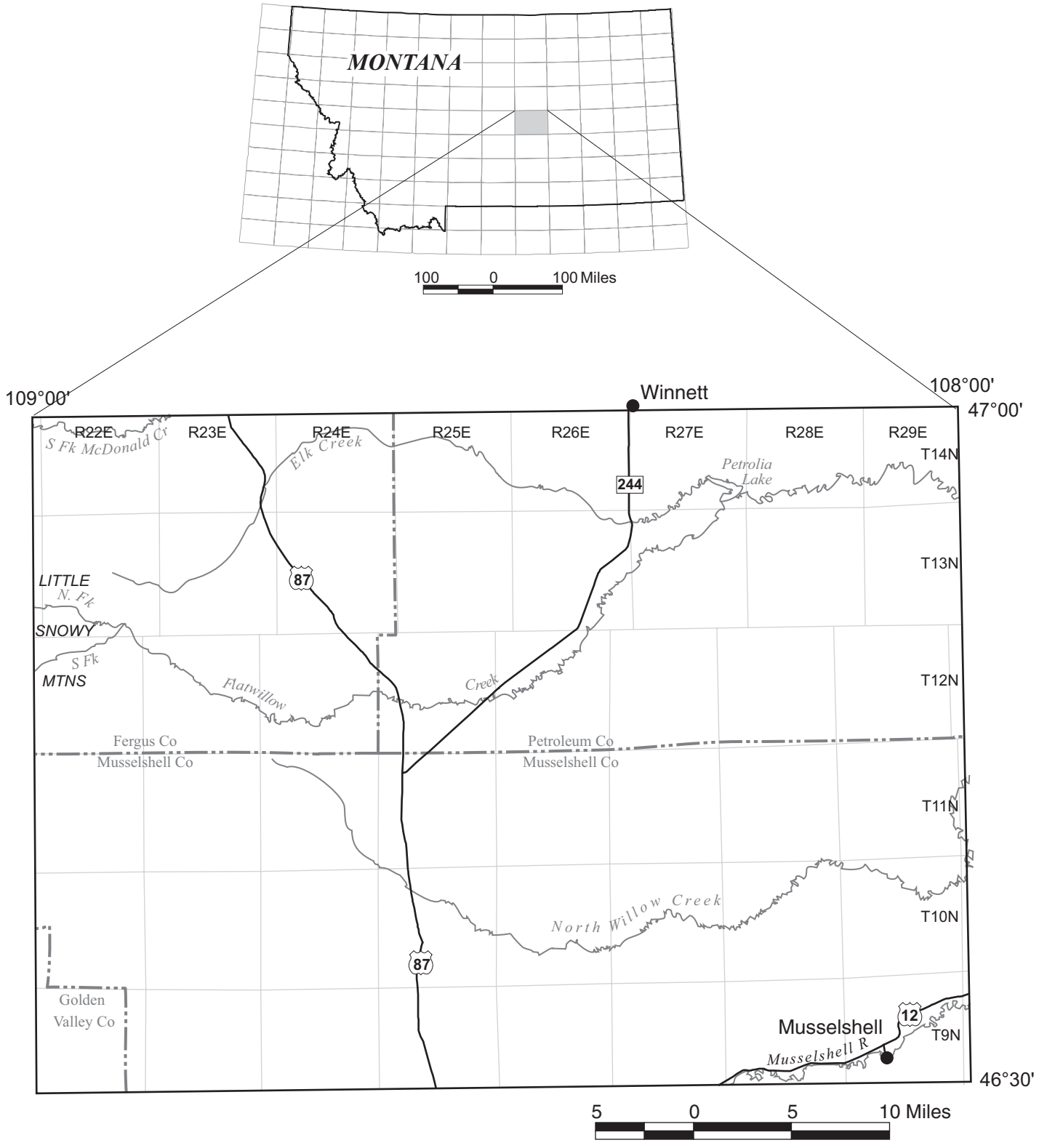


Figure 1. Location of Musselshell 30'x60' quadrangle, central Montana.

Upper Cretaceous (earlier mapped as a single unit, the Colorado Shale) to permit recognition of this fault system within these shales. They also mapped the fault system eastward in younger Cretaceous beds. The present map shows additional faults in this area. The west-east-trending axis of the Flat Willow Anticline is mapped within this fault zone by Johnson and Smith (1964). This fault zone is a wrench fault system within which the en echelon normal faults are the shallow expression of wrenching at depth. This zone parallels several other wrench fault systems in central Montana including the zone along the crest of the Cat Creek Anticline north of this map area and the Lake Basin and Nye-Bowler fault zones to the south of the area (Johnson and Smith, 1964; Thomas, 1974).

Stratigraphy

The stratigraphic section (Figure 2) is dominated by Cretaceous rocks; a complete section is exposed including Lower Cretaceous Kootenai Formation red beds, the regionally thick section of Lower and lower Upper Cretaceous marine shales, the Upper Cretaceous Eagle Sandstone and Judith River Formation clastic wedges with intervening marine shales, and the culminating nonmarine beds of the Lance Formation. In the marine shale section below the Eagle Sandstone, the Mowry Shale is a key unit because of the resistance of its basal sandstone and overlying siliceous mudstones. Similarly, the Mosby Sandstone, upper member of the Belle Fourche Shale, provides a resistant marker bed within the shale sequence in the central map area. However, the Mosby pinches out under the gravel deposits somewhere between sec. 22, T.11 N., R. 24 E. (south flank of Devils Basin Anticline) and sec. 21, T. 11 N., R. 23 E., marking a southwestern depositional edge for this marine sandstone.

New Mapping

New mapping includes several newly recognized stratigraphic and structural details:

1. The Upper Cretaceous Lance Formation has been identified in the area based on lithology and on correlation with earlier mapping to the east (Foster and others, 1990). This formation is a lateral equivalent of the Hell Creek Formation that is occasionally seen in limited outcrop in the map area. The two formations differ primarily with respect to occurrence of dark-colored smectitic shales and mudstone that characterize the Hell Creek but are generally absent within the Lance. Overall, Lance colors are lighter and sandstones are coarser grained than in the Hell Creek. In this quadrangle, extensive erosional scour by fluvial channel processes that dominate Lance deposition frequently cut out the underlying Fox Hills marine shoreface beds. Thus, although limited exposures of both Fox Hills Sandstone and Hell Creek Formation can be observed in the field, they cannot be mapped at the present scale and are incorporated into the Lance Formation.

2. The approximately 1900-ft interval previously mapped as the Colorado Shale is now subdivided into seven formations: Fall River Formation, Thermopolis Formation, Mowry Shale, Belle Fourche Shale (including two members), Greenhorn Formation, Carlile Formation, and Niobrara Formation, in ascending order. This interval is underlain by Kootenai Formation red beds and overlain by Telegraph Creek Formation marine shale and overlying shoreface sandstones of the Eagle Sandstone.

3. A pre-Rierdon, Middle Jurassic erosional event, possibly of regional extent, is recognized in the uppermost Piper Formation (Jp) below the overlying Rierdon Formation (Jr). (A) Near the northwest map border, a locally occurring yellow weathering, calcareous, conglomeratic, medium-grained channel sandstone is considered part of the upper Piper shoreface sandstone unit that is widely distributed in the region. This channel scours into yellow, calcareous middle Piper mudstone that looks like Rierdon but lacks the Rierdon's diagnostic *Gryphea sp.* fossils. Conglomeratic clasts include fragments of Piper mudstone. The channel is overlain by typical yellow, calcareous, *Gryphea*-bearing Rierdon mudstone. (B) In the same northwest map area, the Piper Formation (Jp) is absent in an eastward direction possibly removed by this pre-Rierdon event. (C) Along the crest of Spindletop Dome in sections 26 and 36, T. 13 N., R. 23 E., Rierdon beds lie on or nearly on Alaska Bench Formation (&ab) limestone. An enigmatic 1- to 3-ft, yellow, calcareous mudstone separates the two and contains rounded chert nodules clearly derived from the underlying Alaska Bench. This yellow mudstone could be Rierdon Formation, and is so mapped. Alternatively, it could be a remnant of middle Piper Formation mudstone that has been scoured by the upper Piper erosional event with which the channel described in (A) is associated.

4. Also in the northwest map area, the Rierdon Formation thickness goes to zero within a mile or two, in a southward and (?)eastward direction. This loss of section may reflect a post-Rierdon-pre-Swift erosional event. Rierdon was not recognized on Button Butte Dome where Swift (Jsw) appears to rest directly on Alaska Bench (&ab).

5. Beds of the Pennsylvanian Alaska Bench (&ab) and Pennsylvanian-Mississippian Tyler Formation (&Mt) have been mapped separately for the first time in this area. Following Porter and others (1996), we have continued to place the Pennsylvanian-Mississippian boundary within upper beds of the Tyler Formation based on Dutro and others (1984, p. 423), Wardlaw (1985), and on personal conversation with Bruce Wardlaw, U.S. Geological Survey conodont specialist (1977).

6. On the northwest flank of Button Butte Dome, in the northwest quadrant of the map area, limestone beds cropping out in three ravines were earlier mapped as Heath Formation (Gardner, 1950) overlain by Alaska Bench limestone. More recently, the Heath Formation has been redefined, and the overlying Tyler Formation has been established although disagreement about these formations continues. On the present map, these beds have been assigned more generally to the Big Snowy Group that includes the Heath; upper and lower contacts were not exposed. However, these evenly bedded limestones bear strong resemblance to the Bear Gulch Limestone, middle member of the Tyler Formation within the Amsden Group, a unit that was not recognized in 1950. In either case, some amount of missing Tyler section is implied and the outcrops warrant further study.

7. Durfee Creek Dome is a highly asymmetric, northwest-trending fold with a steeply dipping to overturned north limb. In the dome's interior, gypsum beds of the lower Kibbey Formation (Mk) are the deepest beds exposed that also have good lateral exposure within the dome (underlying Madison Group limestone occurs in a few limited outcrops). Standing on these gypsum beds on the north limb and looking south, the gypsum beds are approximately 30 ft higher on the roll-over of the south limb. Dip

relations on the steep to overturned north limb do not seem to require a thrust-fault interpretation, although a fault may well be present at depth. Instead, south-dipping, overturned beds on the north limb rotate abruptly through a synclinal axis and flatten out across the syncline's very broad north limb.

8. On earlier maps, beginning with Dobbin and Erdmann (1955), the Flat Willow Syncline is projected from the north side of Devils Basin Anticline northwest to a termination northwest of Durfee Creek Dome. On the Musselshell quadrangle map, this synclinal trend is intersected by a small, northeast-trending, Kootenai-cored anticline northwest of Durfee Creek Dome that is being breached by the South Fork of Flatwillow Creek. Thus, on this quadrangle map the Flat Willow Syncline is shown as terminating against the plunge of Devils Basin Anticline (sec. 30, T. 12 N., R. 24 E.), and the structural low west of the South Fork of Flatwillow Creek is informally renamed Flat Willow basin.

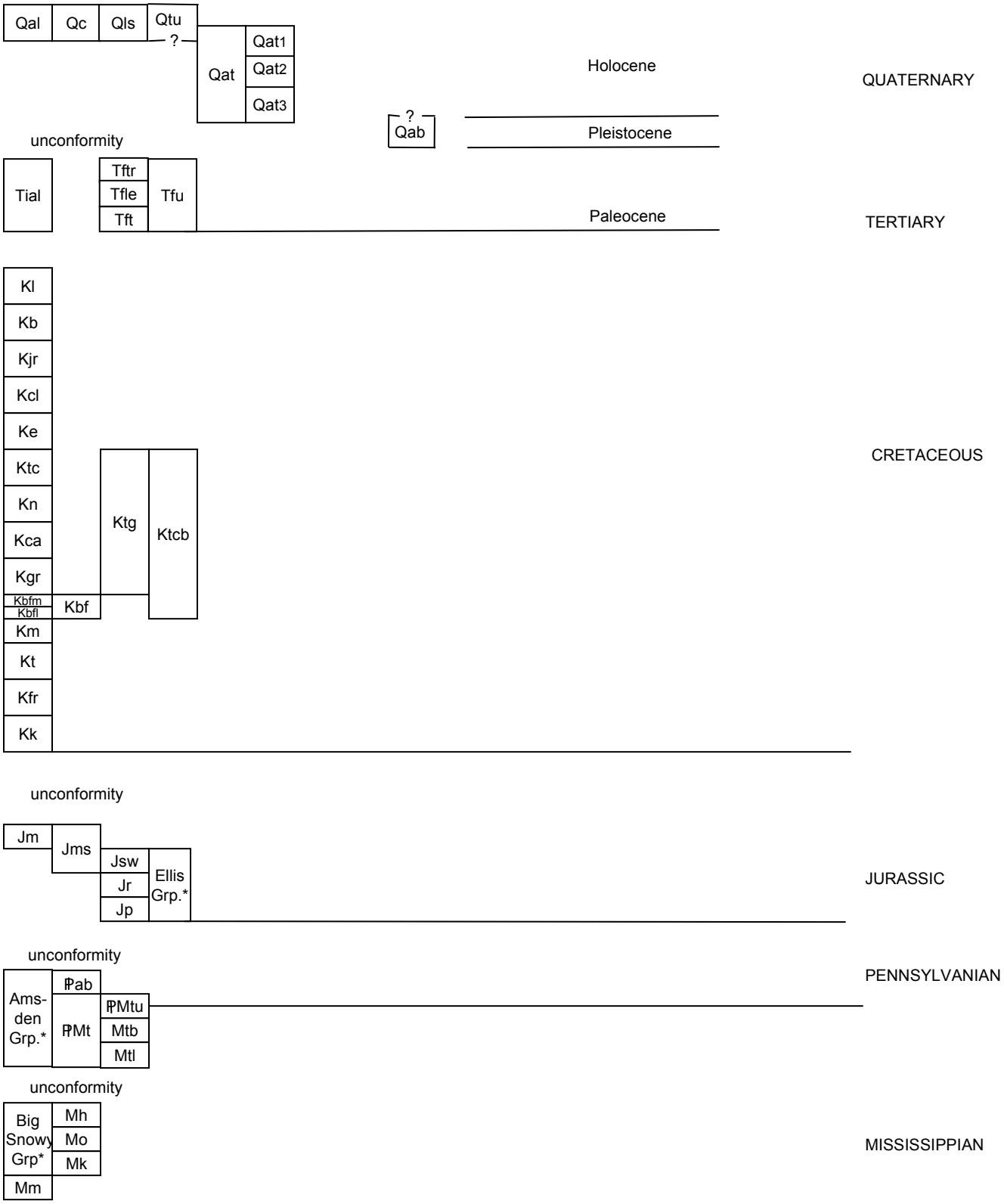
Gravel Deposits (Qab)

Gravel deposits are extensive across the map area and have not been studied in detail by us or other workers. Presently they are considered Quaternary (?Pleistocene) in age based on the tentative conclusion drawn for the gravel deposits in the northwest-adjacent Lewistown quadrangle (Porter and Wilde, 1993b, revised 1999). This conclusion was based, in turn, on data of Lindsey (1982) who found 100,000 B.P. travertine fragments in a high-elevation gravel on North Moccasin Mountain. The gravels could be, in part, Tertiary in age.

These gravel deposits are here described as alluvium of dissected braid plains. The deposits appear to be coalesced alluvial braid plain sediments that accumulated on the flanks of mountain ranges during a time of higher rates of erosion/sedimentation and are now being dissected and redistributed by modern stream processes. They occur at several levels and are locally cemented. These are not pediment gravels, except where they locally form a thin veneer on an exposed pediment surface. They may include gravels now lying on terraces as modern streams incise and redistribute the earlier braid plain sediments. More sedimentologic, provenance, and stratigraphic study is needed for these gravel deposits.

Sources of Previous Geologic Mapping in the Quadrangle

This report combines the previous mapping of Reeves (1927), Gardner (1950, 1959), and Johnson and Smith (1964) within the map area (Figure 3) and provides extensive new mapping of both the Pennsylvanian-Mississippian and the Cretaceous sections. Mapped units have been integrated with recent geologic mapping completed by MBMG in adjacent 1:100,000-scale quadrangles (north-adjacent Winnett quadrangle: Porter and Wilde, 1993a, revised 1999; west-adjacent Big Snowy Mountains quadrangle: Porter and others, 1996; south-adjacent Roundup quadrangle: Wilde and Porter, 2000; east-adjacent Melstone quadrangle: Vuke and Wilde, 2004).



* = Not a map unit

Figure 2. Correlation chart of map units for Musselshell 30’ x 60’ quadrangle map.

DESCRIPTION OF MAP UNITS

Quaternary Deposits

Qal FLOOD PLAIN AND CHANNEL ALLUVIUM (HOLOCENE) – Tan and gray-tan gravel, sand, silt, and clay deposited in channels and on flood plains of modern streams. Thickness not measured.

Qc COLLUVIUM DEPOSITS (HOLOCENE) – Tan, yellow-tan, and cream-colored, nonstratified deposits of sheet-wash and minor slumps on slopes adjacent to active streams and on deeply weathered shales. Thickness not measured.

Qls LANDSLIDE DEPOSITS (HOLOCENE) – Large-scale rotated slide blocks and incoherent mass-wasting developed in the Heath and lower Tyler Formations along Bear Gulch Creek in northwest part of map. Other, smaller landslides also mapped, primarily in the Claggett Shale.

Qtu TUFA (HOLOCENE) – Light-grayish-white amorphous deposit precipitated from waters sourcing from a now inactive spring located in Durfee Gap on Durfee Creek Dome approximately at the contact of the Heath and Tyler Formations. Deposit locally occurs as a crusted surface on bedrock short distances away from the spring. Deposit also found for a short distance outside the gap, resting on Mowry Shale. Deposit locally shows a box-like or fenestral structure. Where more massive and dense it might better be termed travertine.

Qat ALLUVIAL TERRACE DEPOSITS, UNDIVIDED (HOLOCENE) – Described by Johnson and Smith (1964). Composed predominantly of gravel and sand, commonly with a cap of silt and clay. Gravel size generally less than 2 inches in diameter; deposits generally poorly sorted. Along the Flat Willow drainage, clast composition is predominantly limestone with lesser amounts of sandstone, ironstone, chert, and igneous rock types all probably derived largely from the Big Snowy and Judith Mountains to the west and northwest, respectively. Johnson and Smith (1964) report occurrence of glacial boulders scattered on higher terrace levels. Thickness varies from a thin veneer to 10 feet or more. In the map area, deposits mapped by Johnson and Smith (1964) as terrace gravel levels 4 through 8 are mapped by us as alluvial braid plain deposits (Qab). At these levels, calcium-carbonate cementing of gravels occurs locally.

Qat1 ALLUVIAL TERRACE, YOUNGEST (LOWEST) - Mapped by Johnson and Smith (1964).

Qat2 ALLUVIAL TERRACE, SECOND YOUNGEST - Mapped by Johnson and Smith (1964).

Qat3 ALLUVIAL TERRACE, THIRD YOUNGEST (HIGHEST) - Mapped by Johnson and Smith (1964).

Qab ALLUVIUM OF BRAID PLAIN DEPOSITS (QUATERNARY) – Light-gray to yellowish-white and gray-brown weathering deposits of uncemented to locally cemented cobbles in pebble, sand, and clay matrix. Cobbles predominantly light-gray, rounded clasts of Madison Group limestone, commonly with powdery white calcareous coatings. Cemented intervals 1-5 feet thick with iron-rich calcareous matrix commonly weathering reddish to yellow-orange or rusty brown. Unit includes several levels of thick gravels apparently deposited in broad, coalescing alluvial fans formed on slopes of adjacent mountain ranges and now being incised by modern streams and largely removed. Unit extensively preserved along flanks of Devils Basin Anticline in the central map area. Age of unit is unknown but considered to be early Quaternary based on conclusions of Lindsay (1982) for similar gravels flanking the Moccasin Mountains. Unit may be Tertiary in age. Unit equivalent to Qab unit mapped on northwest-adjacent Lewistown quadrangle (Porter and Wilde, 1993b; revised 1999) and to part of Qpg unit mapped on north-adjacent Winnett quadrangle (Porter and Wilde, 1993a, revised 1999). Thickness not measured, but probably from less than 1 foot to 40 feet based on descriptions of Johnson and Smith (1964).

Tertiary Rocks

Tial INTRUSIVE ROCKS, ALKALIC, UNDIVIDED – Medium-brown, green-brown, to yellow-brown, brick red, and orange weathering; ultramafic, porphyritic, and commonly containing small and large (1/2 to 18 inches in diameter) angular, slightly metamorphosed blocks of sedimentary bedrock, generally shale. Intrusions commonly deeply weathered, poorly to moderately resistant, and form crumbly, coarse rubble. They occur as low, slightly resistant dikes forming streaks across the ground, as irregular dike ridges with relief of 5-10 feet or more, and as sills in the Elk Creek drainage just north of this map area (sec. 5 and 6, T. 14 N., R. 25 E.). Strike orientation of dikes is north 55° to 70° east. Intrusions are commonly associated with, and often lateral extensions of, northeast-trending faults, particularly along the highly fault-segmented Flat Willow Anticline. For detailed discussion of composition and emplacement history of these igneous intrusions, refer to: Harlan and others (1991), Hearn (1989), Johnson and Smith (1964), Kohrt (1991); Marvin and others (1980), Ross (1926), and Scambos (1991).

Tfu FORT UNION FORMATION, UNDIVIDED (PALEOCENE)

Tftr TONGUE RIVER MEMBER -- Yellowish-gray to light-gray fine- to medium-grained, trough cross-bedded, planar-bedded or massive appearing sandstone interbedded with lesser amounts of brownish-gray carbonaceous shale and yellowish-gray siltstone, and coal beds. Thicker sandstone units form ledges and rim rocks in the southern part of the map area and unit floors the Willow Creek Syncline. Unit generally supports good growths of pines. Thickness not measured in map area; Vuke and Wilde (2004) report an erosion-thinned section of 60 feet in east-adjacent Melstone quadrangle.

Tfle LEBO MEMBER – Medium- to dark-gray and olive-gray shale that is commonly smectitic or carbonaceous, interbedded with silty shale, thin, yellowish-gray

sandstone and siltstone, and thin, lenticular coal beds. Typically forms gently rolling, grass-covered slopes where dips are low. Thickness not measured in map area; Vuke and Wilde (2004) report a thickness of 150 feet in Melstone quadrangle.

Tft TULLOCK MEMBER -- Yellowish-gray, fine- to medium-grained, trough cross-bedded, planar-bedded or massive appearing sandstone. Interbedded with lesser amounts of brownish-gray, greenish-gray claystone, or dark-gray carbonaceous shale. Sandstone beds are thinner, more tabular and more laterally persistent than those in the underlying Lance Formation. Often supports growths of shrubs and small pines. Thickness not measured in map area; Vuke and Wilde (2004) report a thickness of about 265 feet in Melstone quadrangle.

Mesozoic Rocks

Kl LANCE FORMATION (UPPER CRETACEOUS) -- Tan to light-brownish-gray, cliff- and ledge-forming, fine-grained, thick-bedded to massive, commonly cross- stratified sandstone interbedded with medium-gray to olive-gray, fissile shale, tan to greenish-gray clays and a few thin coal lenses. Sandstone beds support pine growth locally. The basal sandstones are channel deposits from 20 feet to more than 100 feet thick; locally, these basal channel sandstones have eroded into the underlying Bearpaw Shale. This formation is stratigraphically equivalent to the interval containing the Fox Hills and the Hell Creek Formations as mapped farther east (Vuke and Wilde, 2004). Locally and of limited extent, typical Fox Hills Formation and Hell Creek Formation lithologies are observed between the channel sandstone deposits of the Lance, but these formations were not mapped at the scale of the present report. Sandstone beds are thicker and more lenticular than those in the overlying Tullock Member of the Fort Union Formation. Total formation thickness is from 400 feet to 450 feet.

Kb BEARPAW SHALE (UPPER CRETACEOUS) -- Medium-gray to brown-gray weathering, fissile, nonresistant, marine shale; thin, greenish-white or yellow-white bentonite layers common throughout; uppermost and lowermost beds silty and sandy; large ovoid reddish-purple weathering concretions common especially in lower part; gray weathering, calcareous concretions more common in upper part; both concretion types commonly very fossiliferous. Thicknesses of 1,318 feet (Cobban, 1953) and 1,100 feet (Vuke and Wilde, 2004) have been reported.

Kjr JUDITH RIVER FORMATION (UPPER CRETACEOUS) -- Composed of three distinct intervals. Lower unit: yellow-gray weathering, very fine- or fine-grained, quartzose, massive to poorly bedded, locally cross-stratified, burrowed to bioturbated sandstone. Trace fossils include locally abundant *Ophiomorpha*. Uppermost beds light-brown, ferruginous, forming resistant ledge or cap. Middle unit: green-gray weathering, fine-grained sandstones, siltstones, mudstones, and brownish carbonaceous shale; numerous conspicuous rusty-brown to purple-black weathering ironstone concretions. Upper unit: composed of basal yellow-gray to yellow-brown weathering, fine-grained, quartzose sandstone overlain by sequence of interbedded sandstone, mudstone, and carbonaceous shale with common small ferruginous concretions. Middle and upper units

of formation typically weather to badlands. Middle and upper units apparently become less well defined to the east: Vuke and Wilde (2004) report only two distinct intervals in the Melstone quadrangle. Thickness not measured in quadrangle area; reported thicknesses include: 273 feet measured by Cobban (1953) east of Mosby, MT; 215-275 feet reported by Vuke and Wilde (2004) in the Melstone quadrangle.

Kcl CLAGGETT SHALE (UPPER CRETACEOUS) -- Dark-gray or gray-brown fresh surfaces commonly weathering to brown; blocky to fissile, commonly sandy. Characteristic orange-brown weathering, smooth, ovoid, calcareous concretions in upper middle part are as much as 3 feet in diameter, commonly highly fractured with yellow calcite vein filling, and weather into mounds of small, sharp-edged orange-brown fragments. Numerous gray-white bentonite layers 1 to 5 inches thick in lower part of formation are equivalent to the Ardmore Bentonite (Gill and Cobban, 1973). Black chert pebbles occasionally observed locally in lower few feet are presumed to be reworked by burrowing organisms into lower Claggett beds from underlying chert-pebble-bearing beds of uppermost Eagle Formation. Brown weathered color often distinguishes this unit from Bearpaw Shale where stratigraphic position is uncertain. Formation is commonly bare to sparsely vegetated. Thickness not measured in quadrangle area; 430 feet measured by Cobban (1953, p. 98) east of Mosby, MT; 350-400 feet reported by Vuke and Wilde (2004) in the Melstone quadrangle.

Ke EAGLE SANDSTONE (UPPER CRETACEOUS) -- Composed of three distinct units. Lower unit (Virgelle Member of some authors): white to yellow-gray weathering, concretionary, fine- and medium-grained, friable to moderately hard, cherty sandstone, generally massive and burrowed to locally cross-stratified, and commonly forms prominent cliff. Middle unit: poorly exposed, thin sandstones and gray-green shale with thin lignite seams. Upper unit: yellow-tan weathering, light-gray, fine-grained, cherty sandstone, commonly cross-stratified, massive, locally cliff-forming where dips are steep, but often nonresistant and poorly exposed where dips are low. A coarse chert-pebble conglomerate commonly occurs in upper few beds and on upper surface; black chert pebbles in soils often indicate presence of unit. Thickness not measured in quadrangle area; 288 feet reported by Johnson and Smith (1964) for east part of Sand Springs quadrangle; 200 feet reported by Vuke and Wilde (2004) for the Melstone quadrangle.

Ktc TELEGRAPH CREEK FORMATION (UPPER CRETACEOUS) -- Medium- to light-gray weathering, noncalcareous, sandy shale. Lower part contains characteristic thin beds of small, dark-red ironstone concretions weathering to angular chips. Upper part becomes silty to sandy, with characteristic bands of calcareous, tan to chocolate-brown weathering, dark-gray siltstone concretions. Upper contact with overlying Eagle Sandstone is transitional and generally placed at base of lowest cliff-forming sandstone; lower contact with Niobrara Formation shales is generally obscure beneath soils and is approximately located throughout map area except where lumped with other units in areas of steep dip or structurally thinned section. Thickness of about 164 feet given by Johnson and Smith (1964) for outcrops near Winnett, MT on north-adjacent Winnett quadrangle.

Ktg TELEGRAPH CREEK THROUGH GREENHORN FORMATION, UNDIVIDED (UPPER CRETACEOUS)

Ktcb TELEGRAPH CREEK FORMATION THROUGH BELLE FOURCHE FORMATION, UNDIVIDED (UPPER CRETACEOUS)

Kn NIOBRARA FORMATION (UPPER CRETACEOUS) -- Dark- to medium-olive-gray, fissile shale. Lower part weathers medium-gray and contains numerous thin, orange weathering bentonite beds sometimes forming banded look. Upper part strongly calcareous, commonly weathers lighter-gray, and is stratigraphically equivalent to “First White Specks Zone” of Canadian and U.S. subsurface. Gray and light-gray, calcareous, commonly slightly septarian concretions common in upper beds of lower part. Sage Hen concretionary limestone bed described by Johnson and Smith (1964) as base of unit in Cat Creek Anticline area not present in this quadrangle. See Porter and Wilde (1993a; revised 1999) for more complete formation description where formation better exposed. Thickness not measured in quadrangle; 300-400 feet reported in Johnson and Smith (1964) for Cat Creek-Mosby area.

Kca CARLILE SHALE (UPPER CRETACEOUS) -- Formation poorly to very poorly exposed in quadrangle but can be mapped based on occasional recognition of characteristic zones of concretions that are described in detail for the Winnett quadrangle (Porter and Wilde, 1993a; revised 1999). Shale is generally dark-gray to medium-gray weathering. Lower part contains characteristic horizons of abundant oval, dark red, ironstone concretions that weather to small, angular, chippy fragments forming red, rubbley patches in blue-gray fissile shale. Middle part contains characteristic zone of large, sandy, dull-orange weathering concretions, commonly highly fractured and containing cone-in-cone structures. Upper part contains common whitish-gray weathering concretions, generally not septarian. Thickness not measured in quadrangle; approximately 300 feet reported in Johnson and Smith (1964) for Cat Creek-Mosby area.

Kgr GREENHORN FORMATION (UPPER CRETACEOUS) -- Medium- to light-gray, calcareous shale, nonresistant and weathering to characteristic cream-colored, calcareous soil. Unit equivalent to “Second White Specks Zone” of U.S. and Canadian subsurface. A laterally persistent bed of light-gray weathering septarian limestone concretions occurs at top of formation. Forms whitish patchy soil above Mosby Sandstone on northeast flank of Devils Basin Anticline. Approximate thickness 25-30 feet.

Kbf BELLE FOURCHE FORMATION (UPPER CRETACEOUS)

Kbfm MOSBY SANDSTONE MEMBER -- Brown weathering, light-gray, very fine grained to fine-grained, salt-and-pepper sandstone, commonly fossiliferous, locally calcareous. Occurs in thin, commonly trough cross-stratified beds with interbeds of dark-gray shale; transitional from underlying lower Belle Fourche shales. Unit forms two closely spaced sandstone ledges of variable resistivity; upper ledge more laterally continuous; lower ledge predominantly concretionary and locally contains pockets of abundant turritellid gastropods and several pelecypod forms. Ledges each about 5 feet thick separated by about 10 feet of

dark-gray shale. Where exposures are good, upper sandstone ledge is overlain by 3-5 feet dark-gray fissile, noncalcareous shale below base of overlying calcareous Greenhorn Formation. Best exposures are on northeast flank of Devils Basin Anticline where the ammonite *Dunveganoceras albertense* was collected in the uppermost bed. Mosby Sandstone pinches out stratigraphically between Devils Basin Anticline and Durfee Creek Dome, reflecting its southwest depositional edge away from its source to the north (Rice, 1984). Total thickness about 25-30 feet.

Kbfl LOWER SHALE MEMBER, INFORMAL -- Dark-gray, noncalcareous shale, poorly exposed in map area. The following lithologies observed as described for Winnett quadrangle area (Porter and Wilde, 1993a, revised 1999), from base to top: characteristic dark-purple-black ironstone concretions and associated bentonites in lower part; gray, coarse- to medium-grained, chert-pebbly sandstone about 6 feet thick frequently observed about 100 feet above base of member; prominent orange weathering, large, calcareous, sandy, commonly fractured concretions in upper part. Thickness not measured in map area; 303 feet reported by Johnson and Smith (1964) for Winnett quadrangle.

Km MOWRY FORMATION (UPPER CRETACEOUS) -- Contains two distinct lithologies -- an upper, resistant, gray weathering sandstone interval and an underlying gray siltstone and shale. Sandstones: The laterally persistent, ridge-forming sandstone is light-brown-gray weathering, gray, chert-bearing, commonly glauconitic, fine- to medium-grained, and locally coarse-grained with chert pebbles in upper beds. Beds are planar to cross-stratified in thin to thick beds with thin, dark-gray, clayey shale interbeds, and locally iron-stained. The sandstone generally forms a laterally continuous ridge with 1 or 2 less resistant sandstone ledges below; these lower sandstones generally mud-rich, burrowed to bioturbated, and blocky weathering. Siltstone and claystone: light-silvery-blue to white weathering, dark-gray and olive-gray, thin-bedded to laminated siltstone and fissile shale with common powdery yellow jarosite on bedding planes. This formation commonly forms the only resistant unit above the Fall River/Kootenai beds and below the Eagle Sandstone, and thus is a critical mapping horizon. Thickness not measured in quadrangle; approximate thickness 150 feet.

Kt THERMOPOLIS SHALE (LOWER CRETACEOUS) -- Comprised of dark-gray to black weathering shale, tan-gray weathering sandy shale, olive-tan weathering laminated very fine-grained sandstone, and dark gray-brown weathering, quartzose, medium-grained sandstone; numerous thin, white bentonite beds throughout. Generally poorly resistant and poorly exposed, occupying grass-covered interval between overlying Mowry Shale and underlying Fall River Sandstone; sandstone-bearing middle part may form low subparallel scarps or ledges. Three informal members recognized but not mapped separately; see Wilde and Porter (2001) for full descriptions of these members. Total formation thickness about 650 feet.

Kfr FALL RIVER SANDSTONE (LOWER CRETACEOUS) -- Tan-brown weathering, light-gray-tan or buff-tan, predominantly fine-grained quartzose sandstone, commonly brown-speckled on fresh surfaces. Equivalent to First Cat Creek Sandstone of subsurface. Cross-stratified and ripple-laminated in thin to thick beds with numerous very thin, dark

shale partings. Interbedded dark, clayey to sandy shale that is laminated to burrowed to bioturbated. Invertebrate tracks and trails on bedding plane surfaces. Thickness not measured in map area; 70 feet reported by Johnson and Smith (1964).

Kk KOOTENAI FORMATION (LOWER CRETACEOUS) -- Fine- to coarse-grained, chert-bearing, feldspathic, commonly cross-stratified sandstone, and dark- to medium-red, gray-green and minor buff-colored silty, blocky weathering shale and mudstone. Thick basal sandstone (Third Cat Creek Sandstone of subsurface), as much as 100 feet thick, is gray, medium- and coarse-grained, conglomeratic, chert-bearing, cross-stratified. Middle part of formation dominated by varicolored mudstones, predominantly red and yellow-tan; thin, gray-white nodular limestone beds occur locally. Upper part of formation interbedded red mudstones and yellow and brown, thin-bedded, fine-grained, quartzose sandstones with minor chert and feldspar (Second Cat Creek Sandstone of subsurface). Approximate formation thickness 400-550 feet (Gardner, 1950).

Jm MORRISON FORMATION (UPPER JURASSIC) -- Variegated mudstones, thin, gray limestones, and orange-brown sandstones. Four discrete intervals recognized, from base to top: (1) red and green mudstones capped by orange-brown weathering, slabby, very fine- to fine-grained quartzose sandstone; about 15 feet thick; (2) light-gray weathering interval of shale and thin, highly fractured limestone beds and lenses; about 20 feet thick; (3) dull-red and green variegated mudstone interval with two prominent cross-stratified, quartzose sandstones in upper part; both sandstones orange-brown weathering and resistant at top but light-yellow-white and rusty-speckled below; sandstones separated by mudstone and minor sandstone lenses; both sandstones have clay-pebble conglomerate in basal part; interval about 25 feet thick; (4) medium-gray carbonaceous shale and siltstone, and minor quartzose sandstone lenses commonly bearing coaly fragments; from 15 to 30 feet thick. Total formation thickness variable but estimated as 60 to 80 feet.

Jms MORRISON FORMATION AND SWIFT SANDSTONE, UNDIVIDED (UPPER AND MIDDLE JURASSIC)

ELLIS GROUP (MIDDLE JURASSIC)

Jsw SWIFT SANDSTONE -- Brown weathering, gray, fine- to coarse-grained, glauconitic and calcareous sandstone; cross-stratified and ripple-laminated with numerous clay partings; interbedded with thin-bedded to lenticular mudstones. Basal few feet of sandstone commonly coarse-grained and conglomeratic, containing chert pebbles, mudstone clasts, and abundant broken shell material, particularly of oysters. Sandstone commonly forms resistant ridge or ledge. Locally, a lower interval, as much as 30 feet thick, is present and here assigned to the Swift. It is composed of tannish sandy shale with occasional worn belemnites that contrast with the well formed belemnites present in typical Rierdon shales. This lower Swift interval recognized on Button Butte and probably along road south from Beckett, both in northwest area of map. Locally, the Swift rests conformably on the Rierdon Formation or unconformably on the Alaska Bench Formation. Thickness of 74 feet reported by Gardner (1950).

Jr RIERDON FORMATION -- Pale-yellow weathering, gray-brown, highly calcareous shale and thin-bedded, light-gray weathering limestones; locally very fossiliferous, dominated by oysters, *Gryphea* sp. brachiopods, and, locally, belemnites; whole and fragmented fossils litter some exposures. Formation mostly poorly exposed, forming soft soils. Rierdon apparently absent around east flank of Little Snowy Mountains from south of Durfee Creek Dome northward almost to South Mc Donald Creek and also on Button Butte; in these areas the Swift Formation appears correspondingly thicker by the presence of the lower shale interval. Two small exposures of a yellow weathering calcareous shale soil on Spindletop Dome are thought to be Rierdon. Thickness of 0-80 feet reported by Gardner (1950).

Jp PIPER FORMATION -- Poorly exposed, deeply weathered, dull-red and yellow-tan mudstones forming soils. Formation thin; lithologies present may correlate with lower beds of much thicker Piper section west and north of this map area. Formation present only in northwest corner of map area south of Beckett, where it may be conformable with underlying Alaska Bench Formation. South of Beckett area, Piper is absent, and Rierdon rests on Alaska Bench Formation. Thickness not measured in quadrangle.

Paleozoic Rocks

AMSDEN GROUP (PENNSYLVANIAN AND MISSISSIPPIAN)

NOTE: The Pennsylvanian-Mississippian boundary is within the upper Tyler Formation in the Big Snowy Mountains area (Dutro and others, 1984, p. 423; Wardlaw (1985); Wardlaw, Bruce, written comm., 1997).

IPab ALASKA BENCH FORMATION (PENNSYLVANIAN) -- White to light-lavender and pink weathering, light-gray, well-bedded, micritic limestone, locally dolomitic, commonly red-stained; beds dense and brittle; interbedded with red and maroon mudstones. Nodules and stringers of brown weathering gray chert in lower beds at Durfee Creek Dome. Upper beds on Button Butte weather yellowish and contain well bedded limestone, light-gray chert beds, locally a quartzose sandstone, and locally a brecciated limestone bed at the very top. These upper lithologies at Button Butte may possibly be an erosional remnant of the Devils Pocket Formation of Maughan and Roberts (1967). Formation forms flank of Little Snowy Mountains and Button Butte dome in northwest area of map. Estimated thickness 250-300 feet (from Gardner, 1950).

IPMt TYLER FORMATION, UNDIVIDED (PENNSYLVANIAN AND MISSISSIPPIAN) -- Yellow-gray, quartzose, fine- and medium-grained, thin- to thick-bedded sandstones, commonly red- or brown-stained, and interbedded with red, gray, and black mudstones and shale. Lower and upper informal members very similar and only mapped separately here where the laterally restricted but easily recognized Bear Gulch Limestone Member is present as a middle member. Where the Bear Gulch Limestone is absent, the Tyler is mapped as a single unit.

IPMtu TYLER, UPPER MEMBER, INFORMAL (PENNSYLVANIAN AND MISSISSIPPIAN) -- Dominantly mudstones and shale with lesser amounts of sandstone. Mudstone and shale mostly red with minor amounts of dark-gray shale. Sandstones commonly red-stained, white to yellowish-gray, fine- to medium-grained, quartzose, cross-stratified, moderately cemented. Basal beds locally conglomeratic at contact with underlying Bear Gulch Limestone that is source of clasts. Equivalent to Cameron Creek Member of Maughan and Roberts (1967); these authors report thicknesses of 222 and 83 feet at reference sections west of this map area.

Mtb BEAR GULCH LIMESTONE (UPPER MISSISSIPPIAN) -- Alternating finely laminated, evenly bedded, micritic, silty limestone beds and calcareous siltstones and claystones. Limestones resistant, medium-gray, weathering to light-gray and tannish-gray; siltstone-claystone beds slightly darker-gray and form nonresistant, recessive intervals between limestone beds. Regularity of stratification is characteristic. Locally, unit contains abundant fish and invertebrate fossils of a Late Mississippian restricted marine environment (Lund and others, 1993). Exposed along and adjacent to Atherton Creek just south of South Fork McDonald Creek in northwest corner of map area.

Mtl TYLER, LOWER MEMBER, INFORMAL (MISSISSIPPIAN) -- Red-stained white to yellowish-gray, quartzose, well-sorted, fine- to medium-grained, cross-stratified, commonly calcareous sandstone with lesser amount of interbedded gray mudstone, some dark-gray fissile shale, and minor amount of reddish shale and mudstone. Sandstone commonly massive-appearing and may form low cliffs; usually only moderately cemented; locally friable and weathering to rounded surfaces. Conglomeratic at base; clasts are Heath limestone. Equivalent to Stonehouse Canyon Member of Maughan and Roberts (1967). Thickness highly variable in the region owing to deposition of lower Tyler on erosional surface of underlying Heath Formation. Maughan and Roberts (1967) report 288 and 101 feet at reference sections west of this map area.

Mbs BIG SNOWY GROUP (MISSISSIPPIAN). Mapped as undivided Big Snowy Group in small ravines on Button Butte Dome. See discussion on page 4, item 6.

Mh HEATH FORMATION -- Dark-gray, light-gray, and sometimes white weathering, black, petroliferous limestone and interbedded black, fissile shale. Minor gypsiferous beds occur locally. Shales locally silty and commonly calcareous. Thickness of formation highly variable owing to pre-Jurassic erosion. Maughan and Roberts (1967) report thicknesses of 76 feet and 322 feet at two reference sections in Little Snowy Mountains west of map area.

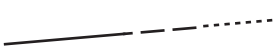
Mo OTTER FORMATION -- Tan, gray-green, and some vivid green, blocky,

commonly calcareous shales, and thin-bedded, light-gray to white, brittle, micritic limestones; limestones locally oolitic and/or fossiliferous to coquinoid with brachiopods and crinoid columnals. Exposed only on Durfee Creek Dome in this map area. Thickness of formation highly variable owing to pre-Jurassic erosion; 290 and 374 feet measured by Maughan and Roberts (1967) at two reference sections in Little Snowy Mountains west of map area.

Mk KIBBEY FORMATION -- Deep-red, calcareous mudstones and siltstones, and red-stained, white to gray, fine-grained, well-sorted, quartzose sandstone. Exposed only on Durfee Creek Dome in this map area. A thick gypsum interval at the base, in contact with underlying Madison Group beds, is included in the Kibbey following Maughan and Roberts (1967) who include evaporites within the Kibbey; alternatively, the gypsum might be an erosional remnant of the Charles Formation of the Madison Group. Thickness variable; 190 and 220 feet measured by Maughan and Roberts (1967) at two reference sections in Little Snowy Mountains west of map area.

Mm MADISON GROUP (MISSISSIPPIAN) -- Light-gray weathering, medium-gray, massive limestone exposed in two small outcrops in core of Durfee Creek Dome in northwest map area. Unit is probably Mission Canyon Formation.

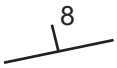
GEOLOGIC MAP SYMBOLS



Contact; dashed where approximately located, dotted where concealed.

Synclinal fold showing trace of axial plane; dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge where known.

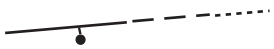
Anticlinal fold showing trace of axial plane; dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge where known.



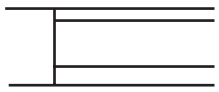
Strike and dip of bedding; degrees of dip indicated.

Horizontal bedding.

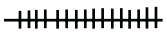
Strike and dip of overturned bedding; degrees of dip indicated.



Fault; dashed, where approximately located, dotted where concealed. Ball and bar on downthrown side.



Indicates a change in map units shown, based on combining units in areas of (1) steep dip, and/or (2) inadequate outcrop for assuming approximate contact locations.



Igneous dike or plug

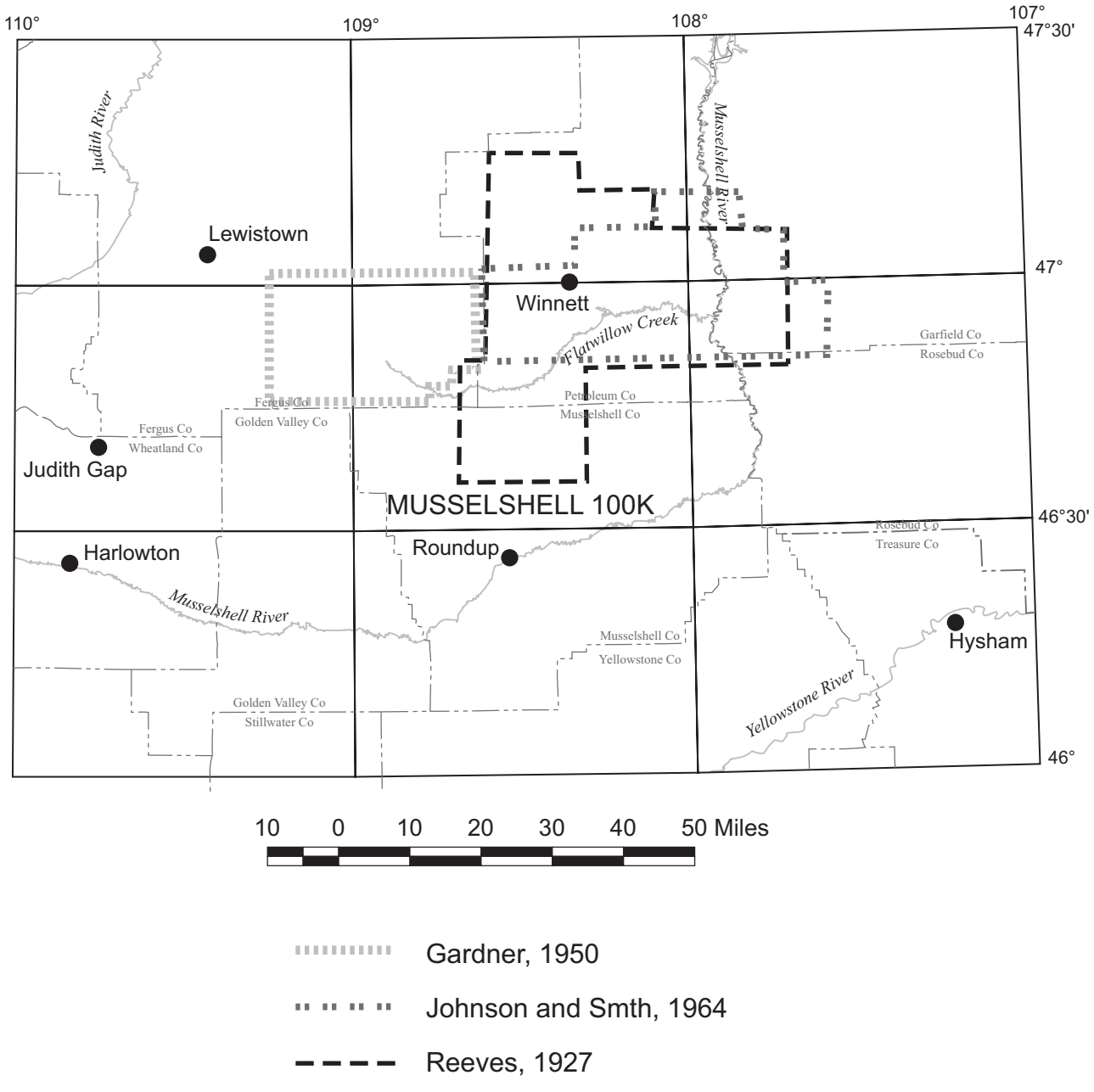


Figure 3. Index map of sources of previous geologic mapping in and adjacent to the Musselshell quadrangle. See references for complete citations.

SOURCES OF PREVIOUS GEOLOGIC MAPPING

Musselshell 30' x 60' Quadrangle

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