GEOLOGIC MAP OF THE LEWISTOWN 30' x 60' QUADRANGLE

CENTRAL MONTANA

by

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GEOLOGIC SUMMARY

The Lewistown quadrangle is located in the center of Montana and includes the Judith Mountains and the Moccasin Mountains. These large Tertiary intrusive centers are cored by a variety of alkalic porphyritic rocks in faulted domal structures that also expose Paleozoic and Mesozoic rocks. Smaller domes in the area, some newly mapped in this report, expose only Paleozoic and Mesozoic rocks but may be cored by intrusives at depth. A thick Cretaceous section forms the outer flanks of these domes and underlies the extensive Quaternary gravel deposits that cover a large part of the map area (figure 1).

This report combines the work of Goddard (1988) in the Judith Mountains, Lindsey (1982) in the Moccasin Mountains, Vine (1956) in the Stanford-Hobson area, and Gardner (1959) in the Lewistown area (figure 2) with new mapping, principally of Cretaceous units. Because all these earlier maps were at scales larger than the 1:100,000 scale of the present map, modifications of previous maps have been made, principally the combining of rock units into mappable units at the 1:100,000 scale and the elimination of numerous small mapped outcrop areas. These modifications apply largely to Goddard's (1988) map of the Judith Mountains. Mapped units have been integrated with recent work completed by MBMG in adjacent 1:100,000-scale quadrangles (east-adjacent Winnett quadrangle: Porter and Wilde, 1993, revised 1999; west-adjacent Belt quadrangle: Vuke *et al.*, 1995; south-adjacent Big Snowy Mountains quadrangle: Porter *et al.*, 1996).

An objective of the new mapping, principally of the Cretaceous section below the base of the Eagle Sandstone in the eastern part of the map, is to subdivide the interval previously mapped as the Colorado Shale. The Colorado Shale is an approximately 1,900-foot-thick Lower and lower Upper Cretaceous sequence of widespread distribution in central Montana. The Lewistown area lies in a transitional position with respect to appropriate use of Black Hills or western Montana stratigraphic terminology in this part of the Cretaceous section. This map continues the application of Black Hills terminology westward from the east-adjacent Winnett quadrangle (Porter and Wilde, 1993; revised 1999), but changes to western Montana terminology, the Marias River Formation, west of the Judith Mountains.

Cretaceous Stratigraphic Nomenclature

Stratigraphic terminology for the Cretaceous section is slightly different in each of the four source maps mentioned above, but has been unified on the present map. Following the work of Cobban (1951, 1953) and Johnson and Smith (1964), Porter and Wilde (1993; revised 1999) retained the Black Hills terminology for the Cretaceous section above the Kootenai Formation and below the Telegraph Creek Formation in the east-adjacent Winnett quadrangle. This interval was previously mapped as a single formation, the Colorado Shale, in most of central Montana. However, the new mapping divides this shale into seven formations — Fall River Formation, Thermopolis Formation, Mowry Shale, Belle Fourche Shale, Greenhorn Formation, Carlile Formation, and Niobrara Formation, in ascending order — all with close lithologic similarity to the same formations in the Black Hills region. This eastern terminology is retained in the Lewistown quadrangle as far west as the east flank of the Judith Mountains. From the east flank of the Judith Mountains to the western edge of the map, the term Marias River Formation (Kmr) is applied to rocks above the Mowry Shale and below the Telegraph Creek Formation, as first described by Cobban *et al.* (1976) in west-central Montana and as

subsequently mapped by Vuke *et al.* (1995) in the west-adjacent Belt quadrangle. Marias River member lithologies (not mapped in the Lewistown quadrangle, but mapped by Vuke *et al.,* 1995) closely correspond to their Black Hills stratigraphic equivalents, reflecting the remarkably consistent depositional conditions within the Western Interior sedimentary basin during this interval of Cretaceous time. Thus, the change to western Montana terminology is somewhat arbitrarily established in the Lewistown area of central Montana.

Throughout the central and western map area, from the west flank of the Judith Mountains, the Telegraph Creek and Marias River formations are mapped as a single unit (Ktcm), following Vine (1956). In the northwest map area, the upper member (Kevin Member; Niobrara Formation stratigraphic equivalent) of the Marias River crops out in numerous drainages but is not mapped. In the same northwest map area, the mapped Eagle Sandstone contains some upper Telegraph Creek transitional beds and is not yet fully integrated with the west-adjacent Belt quadrangle.

The Mowry Shale is a key unit in the Cretaceous section in this area because of its relative resistance and distinctive bluish-white weathering, fish-scale-bearing, siltstone lithology within the thick marine shale section below the Eagle Sandstone. The Mowry was mapped also by Lindsey (1982; as Kcm, the middle Colorado Shale) in the Moccasin Mountains. In the Judith Mountains, Goddard (1988) included the Mowry with his Kcu (upper Colorado Shale) unit, but the formation is clearly recognizable and mappable on the flanks of the Judith Mountains. South of South Moccasin Mountain, along Beaver and Cottonwood creeks, the Mowry Shale is newly recognized in the map area, and delineates a broad syncline between the Moccasin Mountains and the Big Snowy Mountains, largely masked by thick alluvial braid plain deposits.

Structure

Subdivision of the earlier mapped Colorado Shale into its seven component formations has permitted delineation of several newly mapped domes and folds within the Lewistown quadrangle. The domes are presumed to be cored by plutons and extend the known area of intrusive bodies associated with the Judith Mountains. The folds extend southeast and east and are continuous with folds mapped earlier by Porter and Wilde (1993; revised 1999).

In addition to the five domal structures mapped by Gardner (1959) southeast of Lewistown, four new domes have been mapped north of Highway 200 in this report (Parr Creek, Chippewa Creek, Maiden Creek, and Brickyard Creek domes). They lie in a broad synclinal reentrant on the southeast flank of the Judith Mountains. Three are mapped in Cretaceous units, the fourth has Mississippian rocks exposed in its center. Brickyard Creek Dome, mapped in shales of the Greenhorn Formation and Belle Fourche Shale, is the western end of a long, shallow anticline extending eastward into the Winnett 30' x 60' quadrangle (Porter and Wilde, 1993; revised 1999); it is largely masked by thin, unmapped gravels and breached by Brickyard Creek.

Maiden Creek Dome, with Kootenai red beds exposed in its center, bifurcates a syncline that is the western extension of a syncline in the western Winnett 30' x 60' quadrangle (Porter and Wilde, 1993; revised 1999). Such subtle fold structures as this syncline and the anticline described above apparently were developed as shallow wrinkles across the broad southern limb of the Cat Creek Anticline mapped in the east-adjacent Winnett quadrangle. Unexposed

intrusive bodies that domed the sedimentary section east of the Judith Mountains have influenced the western terminations of these folds.

West of the Judith Mountains, a north-plunging syncline is mapped in the valley between the Judith and Moccasin mountains. This structure is defined by closure of the Mowry Shale just north of Lewistown, and contains Eagle Sandstone and Claggett Shale toward its center. Unmapped Quaternary gravel deposits in this valley are being dissected by the west-flowing Warm Springs Creek drainage that passes between the North and South Moccasin Mountains.

West of the Moccasin Mountains, extensive alluvial braid plain deposits (Qab) cover most of the map area. A broad syncline is mapped between the south flank of the Moccasin Mountains and the northwest flank of the Big Snowy Mountains on the basis of limited exposures of Mowry Shale and a sandstone in the lower Thermopolis Shale.

Age of Gravel Deposits (Qab)

The age of the extensive gravel deposits common to the flanks of all central Montana mountain ranges is poorly known. These deposits have been regarded as Quaternary age (Vine, 1959, Stanford-Hobson area; Lindsey, 1982, Moccasin Mountains) and as both Quaternary and Tertiary age (Vuke *et al.*, 1995, Belt quadrangle; Porter *et al.*, 1996, Big Snowy Mountains quadrangle). In the present map area, the authors were faced with the same uncertainty, and tentatively decided to consider these deposits Quaternary in age based on the following argument. Lindsey (1982), in his mapping and study of the Moccasin Mountains, reports “a preliminary estimate of about 100,000 years B.P.”, determined by the uranium series method, on the travertine deposit (Qtr) forming The Park on the south flank of the North Moccasin Mountains. He further reports that fragments of travertine are included in pediment gravels at elevations of 4,500 ft on the northeast flank of the North Moccasin Mountains, suggesting that “most, if not all, of the pediments are younger than the travertine”. While Lindsey’s map does not indicate a travertine body in the immediate area of the pediment deposit containing the fragments, elevation of the large travertine deposit at The Park is more than 1,000 ft higher than the pediment deposits, making this travertine body a plausible source for the fragments.

Whether or not most or all of the Moccasin Mountains gravel deposits are of Quaternary age, it seems likely that more than one period of pedimentation and down-slope alluvial deposition occurred along the flanks of these mountains and central Montana’s other mountain ranges. In the present report, all gravel deposits are mapped as alluvial braid plain deposits, following Vine (1956), and Lindsey (1982). This unit (Qab) includes thin veneers of gravel on pediment surfaces and several levels of thicker gravels apparently deposited in broad alluvial fans on mountain flanks and now undergoing dissection. Some unmapped terrace deposits may be included. Other workers also have not distinguished pediment gravels from alluvial braid plain deposits (Vuke *et al.*, 1995; Porter *et al.*, 1996) but these authors consider all the gravels to be of both Quaternary and Tertiary age. Clearly, more sedimentologic, provenance, and stratigraphic study is needed of all these gravel deposits.

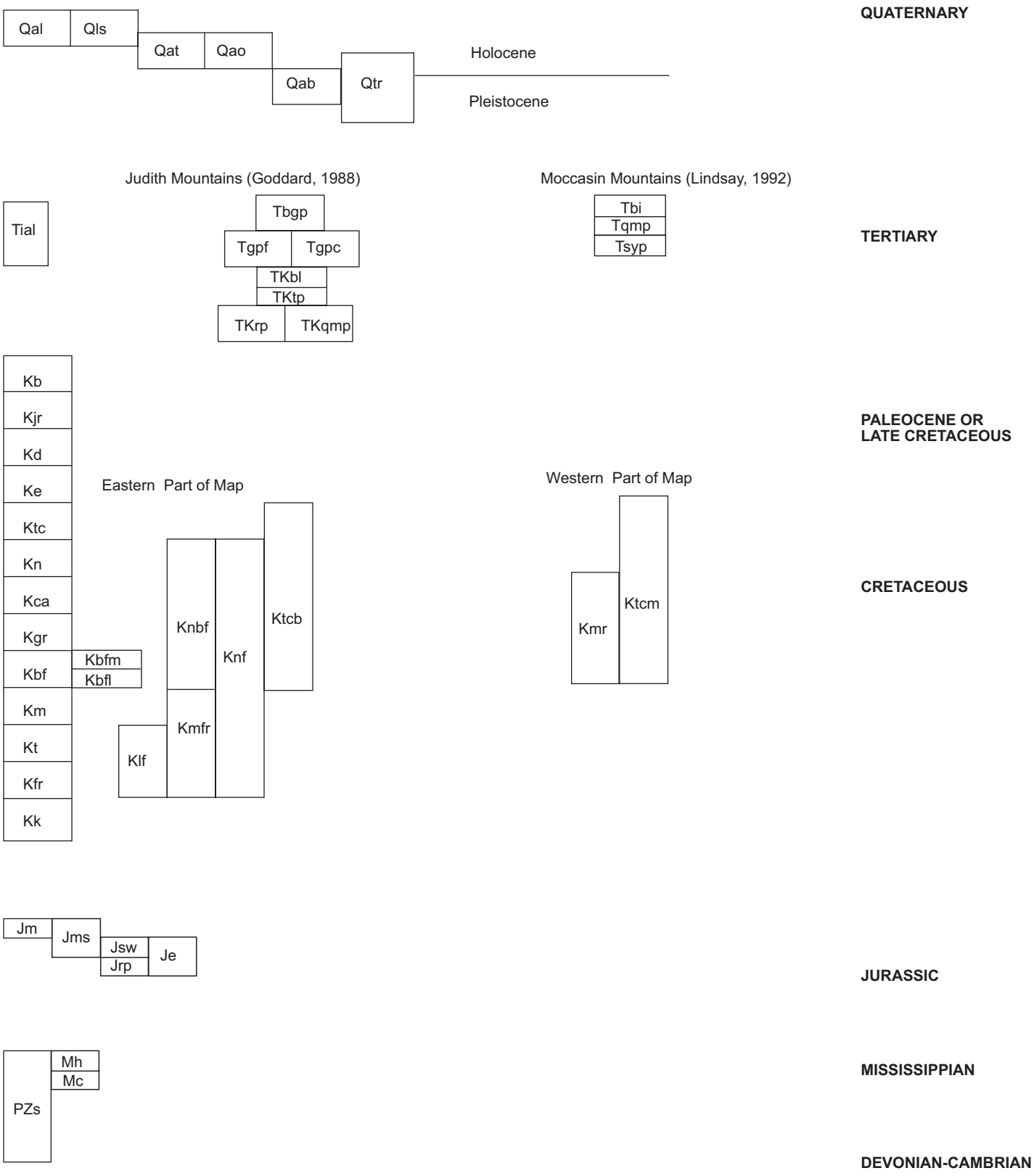


Figure 1. Age correlation chart of map units for Lewistown 30’ x 60’quadrangle.

DESCRIPTION OF MAP UNITS

Qal FLOOD PLAIN AND CHANNEL ALLUVIUM (HOLOCENE) — Yellow-tan and gray-tan, poorly to well stratified gravel, sand, silt, and clay deposited in flood plains and channels of modern streams. Locally includes some slightly older Holocene terrace alluvium, where terrace deposits not mapped separately. Thickness not measured.

Qls LANDSLIDE DEPOSITS (HOLOCENE) — Slumps and slides of incompetent bentonitic shales, commonly containing large blocks of igneous rock or travertine where these more competent rocks are undercut above Cretaceous shales on steep slopes in Judith and Moccasin mountains.

Qat ALLUVIAL TERRACE DEPOSITS (HOLOCENE) — Yellow-tan and gray-tan weathering, unconsolidated clay, silt, sand, and some pebbles, generally well stratified; occurring at slightly higher elevations than modern flood plain alluvium, and dissected by modern drainages; generally soil covered. Thickness not measured.

Qao OLDER ALLUVIUM (HOLOCENE) — Light yellow-gray weathering deposits of unconsolidated clay, silt, sand, and some finr gravel; moderately sorted; occurs along modern drainages, generally slightly above modern alluvial flood plains; includes some terrace deposits; poorly exposed except where cut by stream erosion. Unit mapped in eastern part of map along Box Elder Creek; covered by thin soils. Thickness not measured.

Qtr TRAVERTINE (QUATERNARY) — White to light gray-pink, dense, massive, finely crystalline calcite; may show banding; commonly vuggy. Weathered surfaces commonly highly pitted. These deposits southeast of Lewistown overlie "a slightly irregular erosion surface that is locally covered by thin deposits of stream gravel and unconsolidated lake silt and sand" (Gardner, 1959). Up to 30 ft thick in deposits southeast of Lewistown (Gardner, 1959); approximately 150 ft thick at Flat Mountain in southern Judith Mountains (Goddard, 1988); 198 ft thick at The Park in North Moccasin Mountains (60 m; Lindsey, 1982).

Qab ALLUVIUM OF DISSECTED BRAID PLAINS AND PEDIMENT SURFACES (QUATERNARY) — Light gray to yellowish-white and gray-brown weathering, moderately stratified deposits of unconsolidated to locally well cemented clay, silt, coarse sand, pebbles, and cobbles. Cemented intervals 1- 5 ft thick have calcareous, commonly iron-stained matrix. Cobbles predominantly rounded, light gray limestone of Madison Group derived from Big Snowy and Little Belt mountain ranges south and southwest of area and more locally from Judith and Moccasin Mountains; cobbles of alkalic igneous rocks, derived from Judith and Moccasin Mountains, common on flanks of these ranges. Deposits appear to be coalesced alluvial braid plain sediments that accumulated down slope by fluvial processes from higher elevations on flanks of adjacent mountain ranges. Unit occurs on flanks of Judith and Moccasin Mountains and forms extensive deposits in western part of map; includes thin gravel veneer on pediment surfaces and several levels of thicker alluvial braid plain deposits now being dissected; may include some terrace deposits.

A similar unit underlies at least five topographic surfaces in west-adjacent Belt quadrangle where unit is considered Quaternary and Tertiary in age Vuke *et al.* (1995). Thickness not measured; less than one to several tens of feet.

Tial ALKALIC INTRUSIVE DIKES, UNDIVIDED (PALEOCENE) — Medium brown weathering, coarsely crystalline; weathers to crumbly, coarse rubble. Mapped only in southwestern part of map; composition not studied.

Moccasin Mountains alkalic intrusive rocks (descriptions modified from Lindsey, 1982)

Tbi BRECCIA, INTRUSIVE (PALEOCENE?; = Tib of Lindsey, 1982) — Breccia pipes intrude syenite porphyry (unit Tsyp) in both the North and South Moccasin Mountains and intrude the lower part of the Colorado Shale on the north side of Hanover dome. The breccia is composed mostly of syenite fragments and a few fragments of pre-Paleocene rocks in a pulverized matrix of syenite. The matrix of breccia on Hanover dome is Colorado Shale. Breccia pipes in the South Moccasin Mountains and at Hanover dome contain mineralized rock fragments having galena, cerussite, sphalerite, chalcopyrite, and malachite. Although alteration appears to have been slight, most breccia has been propylitized and argillized, and some has been silicified and pyritized. The pipes in the South Moccasin Mountains are surrounded by bleached syenite porphyry, and the pipe in the North Moccasin Mountains is next to a crackle zone in syenite porphyry; the zone is defined by fracture fillings of quartz, a weakly bleached appearance, and minor disseminated pyrite.

Tqmp QUARTZ MONZONITE PORPHYRY (PALEOCENE; = Tqm of Lindsey, 1982) — Light-gray porphyry containing 40-50 percent phenocrysts in an aphanitic matrix. Phenocrysts are altered plagioclase (25-35 percent of the rock), fresh sanidine (5-10 percent), and quartz (3-5 percent). Ferromagnesian minerals are generally lacking because propylitic alteration has affected much of the rock. Conspicuous large (10-20 mm) euhedral phenocrysts of sanidine and small ($\leq$3 mm) partly resorbed quartz crystals serve best to distinguish the rock from syenite porphyry, which it superficially resembles. Miller (1959) called the rock leucorhyolite, but it has the texture and mineralogy of quartz monzonite porphyry. A chemical analysis shows that this unit differs from syenite porphyry (unit Tsyp) only in having more SiO_2 and less total Fe and K_2O; lower FeO may be the result of alteration. The unit crops out only in the South Moccasin Mountains, where it forms part of the core of the central intrusive complex and underlies uplifted sedimentary rocks in the eastern part of the mountains. Quartz monzonite porphyry is younger than syenite porphyry (unit Tsyp), as shown by dikes of quartz monzonite that crosscut syenite (N/2 sec. 2, T16N, R17E). A K-Ar age of 64.2 ± 1.5 m.y. on sanidine indicates emplacement soon after syenite porphyry (Marvin and others, 1980); a fission track age of 75.4 ± 8.6 m.y. on zircon is regarded as questionable because dikes of the unit intrude syenite porphyry in the South Moccasin Mountains.

Tsyp SYENITE PORPHYRY (PALEOCENE; = Ts and Tsa of Lindsey, 1982) — Dark- to medium-gray porphyry composed of 28-54 percent euhedral phenocrysts in an aphanitic matrix. Phenocrysts are sanidine (10-25 percent of the rock), plagioclase (andesine, 15-30 percent), hornblende (1-10 percent), aegerine-augite ($\geq$2 percent),

quartz (≥4 percent), biotite (≥1 percent), magnetite (≥1 percent), and traces of sphene, apatite, and zircon. Sanidine phenocrysts measure as much as 30 mm in length; plagioclase and other phenocrysts range from 5 mm to 0.05 mm in length. Chemical analyses show the syenite porphyry to be saturated with respect to silica. The rock is somewhat more siliceous and iron-poor than average calc-alkalic syenites of Nockolds (1954), but is designated syenite on the basis of mineralogy and past usage (Blixt, 1933; Miller, 1959). Syenite porphyry makes up the main intrusive complexes of the North and South Moccasin Mountains, sills in the southern part of the South Moccasin Mountains, and sill and dike-like apophyses of the main intrusive complex in each range. The main part of each intrusive complex consists of two syenite porphyry laccoliths intruded both below and, to a lesser extent, above limestones of the Madison Group. Two K-Ar ages of 64.1 ± 1.5 m.y. and 65.8 ± 1.6 m.y. on sanidine and four fission track ages on sphene, zircon, and apatite ranging from 62.1 ± 6.6 m.y. to 70.9 ± 9.0 m.y. indicate emplacement of the main intrusive complex of the North Moccasin Mountains about 66 m.y. ago (Marvin and others, 1980). In the South Moccasin Mountains, fission track ages of 64.8 m.y. on apatite, 55.6 ± 5.8 m.y. on zircon, and 62.6 ± 7.2 m.y. on sphene from syenite porphyry yield an average age of 61 m.y.; however, an age older than about 64 m.y. is indicated because the syenite porphyry has been intruded by dikes of quartz monzonite porphyry dated at 64.2 ± 1.5. One K-Ar age of 66.0 ± 1.5 m.y. on sanidine and one fission track age of 63.7 ± 6.6 m.y. on sphene from the sill in secs. 10, 14, and 15, T16N, R17E in South Moccasin Mountains yield an average of 65 m.y. (Marvin and others, 1980).

Judith Mountains alkalic intrusive rocks (descriptions modified from Goddard, 1988)

Tbgp BRECCIA, INTRUSIVE, GRANITE PORPHYRY (PALEOCENE; = Tgb of Goddard, 1988) — Brecciated alkali granite and quartz stockwork at Judith Peak.

Tgpf GRANITE PORPHYRY, FINE-GRAINED FACIES (PALEOCENE; = Tgf of Goddard, 1988) — Resembles coarse-grained facies, except phenocrysts one-third to one-fourth size; forms stock at Judith Peak and dikes east of Judith Peak.

Tgpc GRANITE PORPHYRY, COARSE-GRAINED FACIES (PALEOCENE; = Tg of Goddard, 1988) — Abundant phenocrysts of doubly terminated quartz (1 cm across), sanidine, and albite in groundmass of closely packed albite microphenocrysts; occurs at Judith Peak.

TKbi BRECCIA, INTRUSIVE (PALEOCENE OR UPPER CRETACEOUS; = TKb of Goddard, 1988) — Breccia composed mostly of porphyry fragments in pulverized matrix of same rock; occurs east of Judith Peak, at valley floor north of community of Maiden, and north of Whiskey Creek headwaters.

TKtp TINGUAITE PORPHYRY (PALEOCENE OR UPPER CRETACEOUS; = Tkt of Goddard, 1988) — Green and gray porphyry containing conspicuous tabular phenocrysts of alkali feldspar; chiefly as dikes and sills; forms Lookout Peak and numerous bodies to southeast, and forms numerous dikes and sills west of Maginnis Mountain.

TKrp RHYOLITE PORPHYRY (PALEOCENE OR UPPER CRETACEOUS; = TKr of Goddard,

1988) — Phenocrysts of potassium feldspar, plagioclase (albite and oligoclase), quartz, hornblende, and pyroxene in gray groundmass; occurs above Warm Spring Creek at western mountain front, Pyramid Peak, Maiden Peak, and in small hill on valley floor east of Maiden Canyon; locally forms dikes and sills.

TKqpm QUARTZ MONZONITE AND SYENITE PORPHYRY (PALEOCENE OR UPPER CRETACEOUS; = TKqm of Goddard, 1988) — Phenocrysts of plagioclase (oligoclase and andesine), potassium feldspar, pyroxene, hornblende, and minor quartz in gray groundmass; includes some quartz diorite, monzonite, and rhyolite porphyry; most abundant intrusive rock type in Judith Mountains, forming massive plutonic cores as well as dikes and sills; large masses of syenite-porphyry variation at Maginnis Mountain and Lewis Peak.

Mesozoic and Paleozoic Rocks

Kb BEARPAW SHALE (UPPER CRETACEOUS) — Medium-gray to brown-gray weathering, fissile, unresistant marine shale underlying low, sage-covered, gently rolling topography; thin, greenish-white bentonite layers common throughout; uppermost beds of formation 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. A thickness of 1,318 ft was measured by Cobban (1953a, p. 101) east of Winnett quadrangle. Top of unit not exposed in map area; thickness not measured.

Kjr JUDITH RIVER FORMATION (UPPER CRETACEOUS) — Composed of three distinct intervals. *Lower sandstone unit* yellow-gray weathering, very fine- or fine-grained, quartzose, massive to poorly bedded, burrowed to bioturbated; uppermost beds light-brown, ferruginous, form resistant ledge. *Middle unit* green-gray weathering, fine-grained sandstones, siltstones, mudstones, and brownish carbonaceous shale typically with conspicuous banded appearance; 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 topography. Thickness not measured in quadrangle area; 273 ft measured by Cobban (1953a, p. 98) at Mosby, MT, approximately 53 mi east of eastern map border; 620 ft along Missouri River to north (Bowen, 1915).

Kcl CLAGGETT SHALE (UPPER CRETACEOUS) — Dark gray or gray-brown on fresh surfaces, commonly weathered to soft brown; blocky to fissile, commonly sandy. Characteristic orange weathering, smooth, ovoid, calcareous concretions in middle part, commonly highly fractured with yellow calcite vein filling that weathers into mounds of small, sharp-edged orange-brown fragments. Numerous gray-white bentonite layers (1 to 5 in.) in lower part of unit. Commonly bare to sparsely vegetated. Occurs in limited, deeply weathered exposures above Eagle Sandstone between Judith Mountains and North Moccasin Mountain, and in incised drainages across open area north of mountains. Thickness not measured in quadrangle area; 200 to 400 ft mapped in Belt quadrangle (Vuke *et al.*,1995); 430 ft measured by

Cobban (1953a) at Mosby, MT approximately 53 mi east of eastern map border.

Ke EAGLE SANDSTONE (UPPER CRETACEOUS) — Composed of three distinct units: *lower unit (Virgelle Member) (*approx. 76 ft thick); white weathering, concretionary, fine- and medium-grained, friable to moderately hard, cherty sandstone, generally massive and burrowed to locally cross-stratified; forms prominent cliff; *middle unit* (175 ft) poorly exposed, thin sandstones and gray-green shale with thin lignite seams; a prominent lenticular coal about 100 ft above base of formation has been mined in the past; *upper unit* (46 ft thick) yellow-tan weathering, light gray, fine-grained, cherty sandstone, commonly cross-stratified, massive, cliff-forming. Above thicknesses provide estimated total thickness of 297 to 396 ft (90 to 120 m; Lindsey, 1982) in Moccasin Mountains. Other estimates: 142 ft (43 m; Goddard, 1988) on north flank Judith Mountains; 249 ft (Vine, 1956, p. 447), and 555 to 620 ft in Belt 30' x 60' quadrangle (Vuke *et al.*, 1995). Rice (1976) provides detailed study of Eagle in map area.

Ktc TELEGRAPH CREEK FORMATION (UPPER CRETACEOUS) — Medium to light gray weathering, noncalcareous, interbedded siltstone and fissile gray shale, sandier in upper part. Upper contact transitional, generally placed at base of lowest cliff-forming sandstone of overlying Eagle Formation. Formation mapped separately only around northeast end of Judith Mountains where exposures are fairly good and lower contact with Niobrara Formation occasionally observed. In rest of map area, Telegraph Creek Formation is mapped with Marias River Formation as unit Ktcm. Approximate thicknesses: 40 ft (12 m; Lindsey, 1982); 260 ft (87 m; Goddard, 1988).

Ktcm TELEGRAPH CREEK FORMATION and MARIAS RIVER FORMATION, UNDIVIDED (UPPER CRETACEOUS) — North and west of Judith Mountains, the term Marias River Formation is assigned to rocks from top of Mowry Shale to base of Telegraph Creek Formation (Cobban *et al.*, 1976); members of formation, not mapped in quadrangle, include, in ascending order, Floweree, Cone, Ferdig, and Kevin. Lower Kevin shale, included in Ktcm, exposed in NENE sec. 5, T18N, R15E; contains 1 ft sandy, chert-pebble and cobble bed named McGowan Concretionary Bed (Cobban *et al.*, 1959). Marias River Formation mapped with overlying Telegraph Creek Formation.

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

Kn NIOBRARA FORMATION (UPPER CRETACEOUS) — Dark to medium olive-gray, fissile shale containing numerous thin bentonite beds; weathers medium gray in lower part and characteristically yellow-orange in calcareous upper part which is stratigraphically equivalent to “first white specks zone” of subsurface terminology. Formation name carried from east-adjacent Winnett quadrangle westward to east flank of Judith Mountains, but rocks of Niobrara lithology not observed on outcrop in eastern part of Lewistown quadrangle because of extensive thin gravel cover. North and west of Judith Mountains, Niobrara interval assigned to Marias River Formation (Kevin Member); contains faunas equivalent to Niobrara Formation (Cobban and others, 1976). Medium gray-weathering, blocky, slightly sandy shale with dark red--weathering ferruginous limestone concretions, containing middle Kevin Member

fossil *Baculites codyensis*, occurs in broad syncline between Judith and Moccasin Mountains. See Porter and Wilde (1993; revised 1999) for fuller formation description where formation better exposed. Approximate thicknesses: 400 ft (subsurface) in western part of map area, (Vine, 1956); 488 ft (148 m; Lindsey, 1982).

Knbf NIOBRARA FORMATION THROUGH BELLE FOURCHE FORMATION, UNDIVIDED (UPPER CRETACEOUS)

Knf NIOBRARA FORMATION THROUGH FALL RIVER SANDSTONE, UNDIVIDED (UPPER AND LOWER CRETACEOUS) — In areas of extensive faulting and/or extensive igneous intrusion in Judith Mountains, all Cretaceous units above Kootenai Formation and below Telegraph Creek Formation mapped as single unit.

Kca CARLILE SHALE (UPPER CRETACEOUS) — Dark gray to medium gray weathering shale with three characteristic concretion horizons. Lower part: horizons of abundant oval, dark red, ironstone concretions that weather to small, angular, chippy fragments forming red, rubbly patches in blue-gray fissile shale. Middle part: zone of large, sandy, dull orange weathering concretions, commonly highly fractured and containing cone-in-cone structures. Upper part: white-gray weathering concretions. Upper contact not observed in map area; lower contact approximately located where underlying calcareous Greenhorn Formation shales exposed. See Porter and Wilde (1993; revised 1999) for fuller unit description where formation better exposed. North and west of Judith Mountains, Carlile interval assigned to Marias River Formation (Ferdig Member). Approximate thickness 129 ft; (39 m; Lindsey, 1982) .

Kgr GREENHORN FORMATION (UPPER CRETACEOUS) — Medium to light gray, calcareous shale that weathers to characteristic cream-colored, calcareous soil in occasional small patchy exposures across grassy surfaces. North and west of Judith Mountains, Greenhorn interval assigned to Marias River Formation (Cone Member). Unit equivalent to “second white specks zone” of subsurface terminology. East of Judith Mountains, lower beds occasionally observed above outcrops of underlying Mosby Sandstone Member of Belle Fourche Shale. See Porter and Wilde (1993; revised 1999) for fuller unit description where unit better exposed. North and west of Judith Mountains, Greenhorn interval assigned to Marias River Formation (Cone Member). Approximate thickness 46 ft (14 m; Lindsey, 1982).

Kbfm MOSBY SANDSTONE MEMBER OF BELLE FOURCHE FORMATION — Brown weathering, light gray, very fine-grained to fine-grained sandstone, commonly fossiliferous, locally calcareous. Occurs in thin, commonly cross-stratified beds with interbeds of dark gray shale; transitional above lower Belle Fourche shales. Unit commonly concretionary, forming low irregular ledge across grassy surfaces. Two thin, concretionary, occasionally fossiliferous, sandstone horizons observed in Lewistown quadrangle, separated by 73 ft of shale. Approximate thickness 92 ft (28 m; Lindsey, 1982).

Kbfl LOWER SHALE MEMBER OF BELLE FOURCHE SHALE, INFORMAL — Dark gray, noncalcareous shale, poorly exposed in map area. The following lithologies observed as described for Winnett quadrangle area (Porter and Wilde, 1993, revised

1999): characteristic dark purple-black ironstone concretions and associated bentonites in lower part; gray, coarse- to medium-grained, chert-pebbly sandstone about 6 ft thick frequently observed about 100 ft above base of member; prominent orange weathering, large, calcareous, sandy concretions in upper part. Approximate thickness 96 ft (29 m; Lindsey, 1982) indicates unit thinning from 303 ft reported by Johnson and Smith (1964) for east-adjacent Winnett quadrangle.

Km MOWRY SHALE (UPPER CRETACEOUS) — Contains two distinct lithologies totaling about 165 ft thick; fish scales throughout though not in all intervals. *Sandstones*: light brown-gray weathering, gray, thin- to thick-bedded, fine- to medium-grained, with thin, dark gray, clayey shale interbeds, forming 2 or 3 ledges or low ridges throughout map area; locally cross-stratified, glauconitic, and up to coarse-grained with chert pebbles in coarse fraction; thin (1/2 to 2 in.) white to orange-stained bentonite beds common throughout. *Siltstones*: light silvery-blue to white weathering, blue-gray, brittle, thin-bedded siltstone and blue-gray shale with common powdery yellow mineral (jarosite) on bedding planes; predominantly thin-bedded to laminated, commonly exposed in light-colored barren patches across slopes or ridge tops; generally developed above sandstone interval, but where sandstones poorly developed, may comprise most of formation. Lowermost part of formation, generally not exposed, brown-gray or blue-gray, fissile, laminated and bentonitic shale. Persistent 2- to 3-ft bentonite bed at base probably is Arrow Creek bed of Reeside and Cobban (1960). Approximate thickness 198 ft (60 m; Lindsey, 1982) .

Kmfr MOWRY FORMATION THROUGH FALL RIVER FORMATION, UNDIVIDED (UPPER AND LOWER CRETACEOUS)

Kt THERMOPOLIS SHALE (LOWER CRETACEOUS) — Composed 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 bentonite beds throughout. Three members recognized but not mapped separately. Generally valley-forming and poorly exposed throughout map area. *Lower part (Skull Creek Member)*: underlying Warm Spring Creek in Lewistown area and MacDonald Creek, east of Judith Mountains; composed of very black, fissile, unresistant shale with numerous thin, iron-stained sandstone laminae in lower part (“Dakota silt” of subsurface); approx. 228 ft (Lindsey, 1982), 25l ft (Porter *et al.*, 1997, Pl. 4). *Middle part (unnamed sandy member)*: generally sandy with dark reddish-purple to purple-black ironstone concretions common; 3 ledges of fine- to coarse-grained sandstone 4 to 5 ft thick separated by 40 to 60 ft of bioturbated, blocky weathering, sandy shale; sandstones contain black chert, glauconite, and locally abundant fish debris in cross-stratified and ripple-laminated beds with animal traces on bedding plane surfaces; a chert-pebble bed lies just below or at base of lowest sandstone; sandstones may be stratigraphically equivalent to Vaughn Member of Blackleaf Formation (Cobban *et al.*, 1976) as mapped farther west in parts of Belt quadrangle (Vuke *et al.*, 1995); approx. 470 ft (Lindsey, 1982), 313 ft (Porter *et al.*, 1997, Pl. 4). *Upper part (Shell Creek Shale):* dark blue-gray weathering, soft, fissile, dark black, clayey shale; generally unexposed; unit included in informal sandy member by Johnson and Smith (1964); approx.107 ft (Porter *et al.*, 1997; Pl. 4). Total formation thickness in

Moccasin Mountains 770 ft (234 m; Lindsey, 1982), 671 ft on small dome on east flank Judith Mountains, north of Maiden Creek Canyon (Porter *et al.*, 1997, pl. 5).

Ktf THERMOPOLIS FORMATION AND FALL RIVER SANDSTONE, UNDIVIDED (LOWER CRETACEOUS) — Formations mapped as single unit in areas of steep dip and/or extensive cover, generally north and west of Judith Mountains.

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. Cross-stratified and ripple-laminated in thin to thick beds with numerous very thin dark shale partings. Interbedded dark, clayey to sandy shale. Invertebrate tracks and trails on bedding plane surfaces. Base of unit sandstone or a medium gray sandy shale interval resting on Kootenai Formation red beds. Caps benches south and east of Lewistown. West of Judith Mountains, formation combined with Thermopolis Formation because of poor exposures, though occasionally seen in float. Thickness approximately 53 ft (16 m; Lindsey, 1982).

Kk KOOTENAI FORMATION (LOWER CRETACEOUS) — Dark to medium red, gray-green and minor buff-colored silty, blocky weathering shale, and fine- to coarse-grained, chert-bearing, feldspathic, commonly cross-stratified sandstone. Thick basal sandstone (up to 100 ft, Vine, 1956; Third Cat Creek sandstone of subsurface) 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 in section above basal sandstone. 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 in Moccasin Mountains 545 ft (165 m; Lindsey, 1982); in Judith Mountains, 330 to 495 ft (100-150 m; Goddard, 1988).

Jm MORRISON FORMATION (UPPER JURASSIC) — Variegated mudstones, thin gray limestones and thin brown sandstones. Mudstones tan-buff, yellow, brown-red, light gray and occasionally green-gray, generally weather blocky, commonly fine-grained sandy, noncalcareous. Sandstones very fine- to fine-grained, quartzose, nonfeldspathic, nonchert-bearing, often calcareous, generally occur as thin, reddish-brown-weathering, brown-gray or red-brown, ripple-laminated lenticular interbeds in mudstones. Several thin beds of brown-gray-weathering, medium gray, micritic, ?algal-laminated limestones interbedded with mudstones in lower part of formation. Throughout area, upper Morrison composed of a few feet to 40 ft of carbonaceous mudstones, coal and sandstones; interval absent locally. Coal may be bedded or occur as small to large transported fragments in sandstones. Sandstones gray--white, quartzose, chert-bearing, very fine-, fine- and medium-grained, locally friable, ripple-laminated and cross-stratified. Mudstones medium to light gray, generally sandy, containing root traces locally. Approximate thickness 208 to 214 ft (63 to 65 m in Moccasin Mountains; Lindsey, 1982); 221 ft (67 m in Judith Mountains; Goddard, 1988).

Jms MORRISON FORMATION AND SWIFT SANDSTONE, UNDIVIDED (UPPER AND MIDDLE JURASSIC) — These two formations mapped as single unit in South

Moccasin Mountains, south side of North Moccasin Mountains, and at Hanover Dome where they could not adequately be mapped separately.

Je ELLIS GROUP (MIDDLE JURASSIC) — Includes Piper, Rierdon and Swift formations.

Jsw SWIFT SANDSTONE — Brown weathering, gray, fine-grained to coarse-grained, glauconitic and calcareous sandstone; cross-stratified and ripple-laminated with numerous clay partings; interbedded with thin and 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; may occur as several sandstone intervals with intervening mudstones. Base of unit sharp though seldom exposed. Upper beds thin, fine-grained and slabby; contact with overlying Morrison Formation poorly exposed; where Morrison sandstone rests on Swift sandstone, contact is located on basis of mineral composition of sandstones. Formation easily recognized throughout report area where Jurassic rocks are exposed. Estimated thickness in Moccasin Mountains is 66-132 ft (20 to 40 m; Lindsey, 1982); in Judith Mountains 56 ft (17 m; Goddard, 1988); 110 ft southeast of Lewistown (Gardner, 1959).

Jrp RIERDON FORMATION AND PIPER FORMATION, UNDIVIDED — Mapped in Moccasin Mountains and in domes southeast of Lewistown only, although recognized in Judith Mountains. RIERDON: yellow weathering, gray-brown calcareous shale and thin-bedded, light gray weathering, gray limestones; locally fossiliferous, dominated by *Gryphea* sp. and other oysters; formation poorly exposed; thickness estimate in Moccasin Mountains area is 90-120 ft (Lindsey, 1982). PIPER: lithologies highly variable vertically and laterally; soft, pastel red, tan, ochre, green and gray, gypsiferous, blocky shales; interbedded shaly limestones, some oolitic; one or more massive, white gypsum beds; brown weathering, yellow-gray, thin-bedded, fine-grained, calcareous sandstones occur in upper part, forming contact with Rierdon; some black shale and dark gray limestone with underlying lighter-colored shales and gypsum have been included in the Piper by Lindsey (1982); unit poorly exposed; thickness estimate is 297 to 363 ft (90 to 110 m in Moccasin Mountains; Lindsey, 1982); 211 to 320 ft (64 to 97 m in Judith Mountains; Goddard, 1988); 0 to 325 ft south of Lewistown (Gardner, 1959).

Mh HEATH FORMATION (MISSISSIPPIAN) — Dark black, fissile carbonaceous shale; locally calcareous, fossiliferous shale; dark gray, petroliferous limestone, commonly with abundant brachiopods; yellow-gray sandstones locally bearing wood fragments and pebbles. Thickness of formation highly variable throughout central Montana owing to pre-Jurassic erosion. Approximate thickness up to 286(?) ft in domes southeast of Lewistown (Gardner, 1959); 0 to 495 ft (0 to 150 m in Judith Mountains; Goddard, 1988).

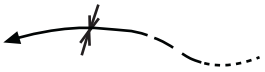
Mo OTTER FORMATION (MISSISSIPPIAN) — Tan, gray-green and some vivid green, blocky, commonly calcareous shales, and thin-bedded, light gray to white, brittle, micritic limestones; limestones locally oolitic and/or fossiliferous to coquinoid with brachiopods and crinoid columnals. Thickness of formation highly variable owing to pre-Jurassic erosion. Approximate thickness up to 334 ft in domes southeast of

Lewistown (Gardner, 1959); 0 to 145 ft (0 to 44 m in Judith Mountains; Goddard, 1988).

PZs SEDIMENTARY ROCKS, UNDIVIDED (LOWER PALEOZOIC) — Includes rocks of Cambrian, Devonian, and Mississippian age. Cambrian units include Flathead Quartzite, Pilgrim Limestone, ?Wolsey Shale, and some unassigned lithologies. Devonian unit is Jefferson Formation. Mississippian units include Madison Group and overlying Kibby, Otter, and Heath formations where not separately mapped. Refer to Goddard (1988) for these units in Judith Mountains; refer to Lindsey (1982) for these units in Moccasin Mountains.

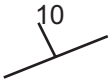
GEOLOGIC MAP SYMBOLS

Contact; dashed where approximately located, dotted where concealed.



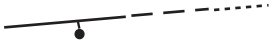
Synclinal fold showing trace of axial plane; dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge where known.

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

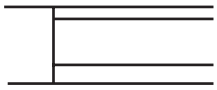


Strike and dip of bedding; degree of dip indicated.

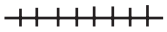
Strike and dip of overturned bedding; degree of dip indicated.



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 (1) areas of steep dip, and/or (2) inadequate outcrop for assuming approximate contact locations.



Igneous dike or plug

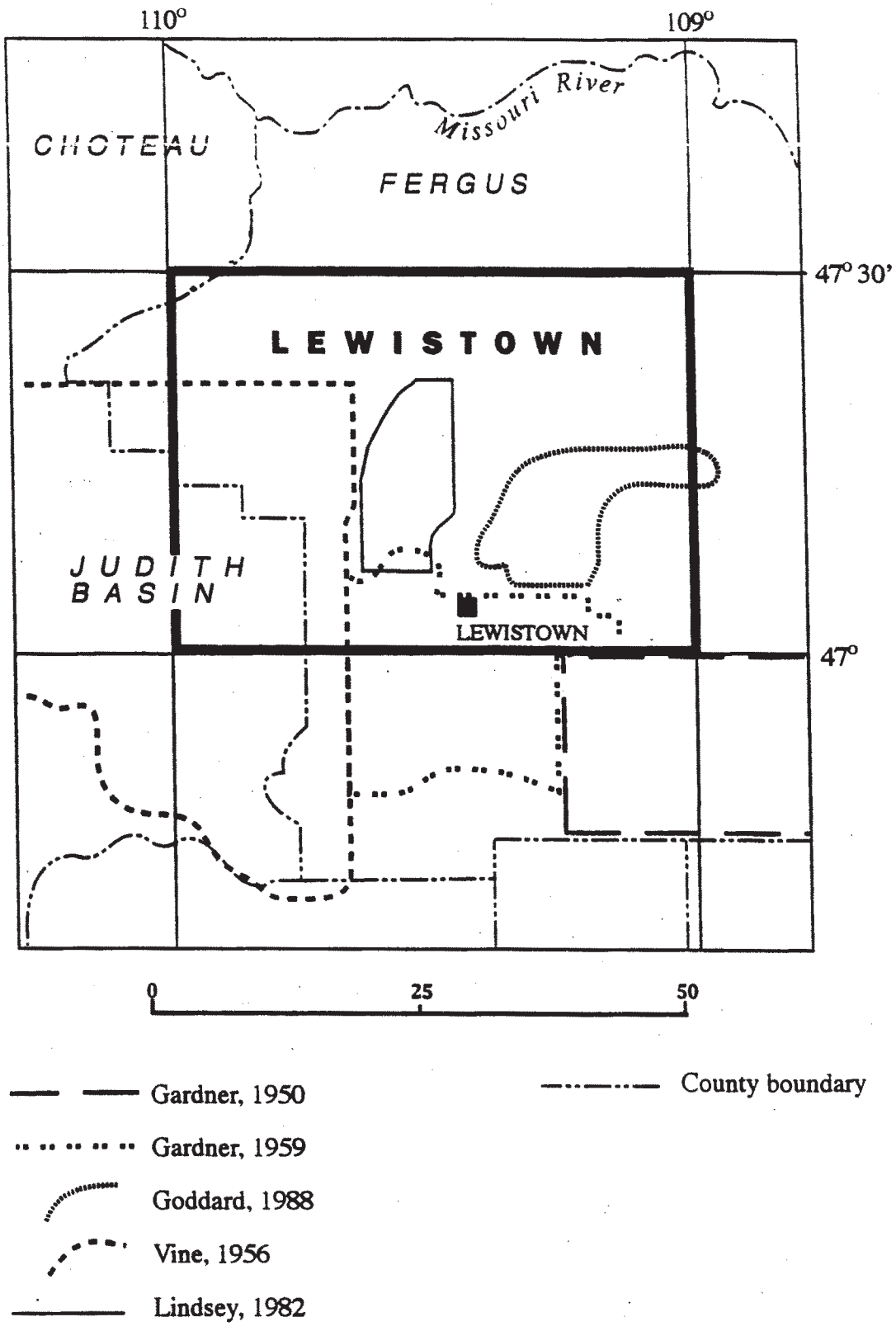


Figure 2. Index map of sources of previous geologic mapping in and adjacent to Lewistown quadrangle. See references for complete citations.

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(See text for discussion of units combined in these cross section units)

Tkqmp	Quartz monzonite porphyry
Kcl	Claggett Shale
Ke	Eagle Sandstone
Ktcm	Telegraph Creek Formation through Marias River Formation, undivided
Knf	Niobrara Formation through Fall River Formation, undivded
Kmk	Mowry Shale through Kootenai Formation, undivided
Kk	Kootenai Formation
KJkm	Kootenai Formation through Morrison Formation, undivided
Jme	Morrison Formation through Ellis Group (Piper, Rierdon, and Heath formations), undivided
PZ	Paleozoic sedimentary rocks, undivided
Mbs	Big Snowy Group (Kibby, Otter, and Heath formations)
Mm	Madison Group
DC	Devonian through Cambrian sedimentary rocks, undivided