Geology of the Varney and Cameron Quadrangles, Madison County, Montana

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Geology of the Varney and Cameron Quadrangles, Madison County, Montana

By JARVIS B. HADLEY

With a chapter on PALEONTOLOGY AND CORRELATION OF THE MADISON GROUP ON BALDY MOUNTAIN

By WILLIAM J. SANDO *and* J. THOMAS DUTRO, Jr.

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Description of the Paleozoic, Mesozoic, and Cenozoic stratigraphy and structure of the northern Gravelly Range, Montana

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GEOLOGY OF THE VARNEY AND CAMERON QUADRANGLES, MADISON COUNTY, MONTANA

By JARVIS B. HADLEY*

ABSTRACT

In the Gravelly Range, west of the Madison Valley in southwestern Montana, Paleozoic rocks about 1,500 m thick range in age from Middle Cambrian to Permian; Mesozoic rocks about 1,400 m thick range in age from Early Triassic to Late Cretaceous. The lithology, thickness, and age of each of 21 mapped Paleozoic and Mesozoic units and the extent of several locally distributed Tertiary and Quaternary units are summarized.

Variations from the usual Paleozoic sequence in southwestern Montana show that 245 m of Middle and Upper Cambrian and Ordovician rocks were eroded from a local uplift in pre-Late Devonian time and that 200 m of Upper Mississippian rocks (Big Snowy Group or its equivalents), present in the western part of the area, are absent in the eastern part, probably because of uplift and erosion before deposition of the Amsden Formation.

The structure of the western part of the area is dominated by Laramide folds and thrust faults, including low-angle faults on which Precambrian and Paleozoic rocks have been carried several kilometers eastward over Upper Cretaceous rocks. The eastern part of the area is dominated by high-angle faults associated with downfaulting of the adjacent Madison Valley in late Tertiary and Quaternary time. Tertiary rocks, mainly cobble gravel and various volcanic rocks probably of Eocene to Miocene age, were deposited on a surface now tilted northeastward from the crest of the Gravelly Range to near the present level of the Madison River. Farther south, the Madison Valley seems to have subsided mainly by faulting on both sides.

INTRODUCTION

The northern part of the Gravelly Range and adjacent areas were studied as a part of the U.S. Geological Survey's investigations of the structure and stratigraphy of the disturbed belt in western Montana. Geologic mapping of the Varney and Cameron quadrangles began in 1956 and was essentially complete by 1960. Final field checking of the geologic maps was completed in 1965. A preliminary report on the geology of the area was published

* Deceased.

as a part of the Billings Geological Society's symposium on the West Yellowstone-earthquake area (Hadley, 1960). The 1:62,500-scale maps of the two quadrangles, containing geologic structure sections, were published in 1969 (Hadley, 1969a, b).

This report, left in nearly completed manuscript form at the time of the writer's death in 1974, was revised and completed for publication by J. T. Dutro, Jr.

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The writer was visited in 1956, 1957, and 1958 by J. T. Dutro, Jr., and W. J. Sando, who measured the sections of the Madison Group and the Big Snowy–Amsden interval on Baldy Mountain. The results of their studies have been incorporated as a chapter in this report. W. A. Cobban helped with the field studies of the Cretaceous rocks and collected fossils from them in 1958, and R. W. Imlay gave similar assistance with the Jurassic strata in 1959.

Fossils from other stratigraphic units were identified by R. W. Brown, W. A. Cobban, H. M. Duncan, J. T. Dutro, Jr., W. H. Hass, R. W. Imlay, Estella Leopold, A. R. Palmer, John Pojeta, Jr., W. J. Sando, N. J. Silberling, I. G. Sohn, D. W. Taylor, R. H. Tschudy, J. A. Wolfe, and E. L. Yochelson. Thanks are expressed to all these people for their insights into the age significance and environmental implications of the fossils.

GEOLOGIC SETTING

The stratigraphic sequences in the Varney and Cameron quadrangles are similar, but the two areas complement each other so as to provide a complete geologic history of the region (see tables 1 and 2). For example, most of the Tertiary units are best developed in the Cameron quadrangle, and the thick sequence of Upper Cretaceous volcanic rocks is not present in the Varney

TABLE 1.—*Stratigraphic units in the Varney quadrangle*

	Thickness (meters)
Quaternary System:	
Till and cobble gravel.	
Tertiary System:	
Limestone fanglomerate, unconsolidated cobble gravel, basalt and basaltic andesite flows and associated tuff, fresh-water limestone and associated tuffaceous sediments, rhyolite ash-flow tuff.	
Unconformity.	
Cretaceous System:	
Upper Cretaceous Series:	
Frontier Formation: Medium- to fine-grained sandstone and grayish-olive to brownish-gray mudstone, minor shale and a few thin lenticular limestone and coal beds. Coarser sandstone, irregularly bedded, forms units 1.5 to 9 m thick at approximately 60-m intervals. Abundant plant debris in lower part. A unit 60 to 90 m thick, about 60 m above the base of the formation, contains bentonitic or zeolitic claystone; sandstone containing reddish-orange heulandite; also thin beds of porcellanite interbedded with greenish-gray claystone and sandstone	900±
Lower Cretaceous Series:	
Thermopolis Shale (110 m):	
Upper sandstone member: Sandstone, gray medium-grained, argillaceous, and somewhat calcareous, irregularly and discordantly thin- to thick-bedded	15–25
Middle shale member: Silty clay shale, dark-gray, moderately fissile, thin-bedded, contains thin layers, lenses, and nodules of dark-gray iron-carbonate rock, and minor thin beds of quartzose sandstone	60–80
Lower sandstone member: Sandstone, fine- to medium-grained, quartzose, commonly quartzitic and rusty, thin-bedded and commonly finely current-bedded with ripple marks. Interbeds of shale in upper and lower parts, abundant worm burrows in upper part	12–15
Kootenai Formation (120–170 m):	
Shale member: Light- to moderate-gray silty clay shale, variably fissile, increasingly sandy toward top	12–23
Limestone member: Limestone, microcrystalline to fine-grained, commonly oolitic, medium-bedded (5–60 cm), thin shale beds in upper part. Several beds are crowded with small gastropods	17
Claystone member: Claystone; lower part red, containing minor beds of argillaceous limestone and limestone pebble conglomerate; upper part gray, containing large nodules of olive- to reddish-gray, very fine grained limestone	80–90
Basal sandstone member: Light-gray, medium- to coarse-grained argillaceous sandstone containing abundant chert grains, locally pebbly, or chert-pebble conglomerate, irregularly bedded, lenticular	4.5–60

TABLE 1.—*Stratigraphic units in the Varney quadrangle*—Continued

	Thickness (meters)
Unconformity.	
Jurassic System:	
Upper Jurassic Series:	
Morrison Formation: Silty claystone or mudstone, gray, green, maroon, olive-brown, or brownish-black; upper part light to moderate gray and carbonaceous, containing minor sandstone, mostly fine grained, but locally like overlying unit	60–80
Unconformity.	
Middle and Upper Jurassic Series:	
Ellis Group: Mainly limestone, medium- to thick-bedded, commonly sandy, calcarenitic, or quartzose; indistinct fine current-bedding; interbeds of silty shale and argillaceous limestone; uppermost beds finely oolitic. About half a meter of limestone- and chert-pebble conglomerate locally at the base of the unit	40–45
Disconformity.	
Triassic System:	
Lower Triassic Series:	
Dinwoody Formation: Dolomite, shale, and sandstone; lower part is thin-bedded yellow-gray dolomite interbedded with silty or finely sandy shale; upper part is medium-bedded yellowish-gray dolomite thin- to thick-bedded, commonly finely to coarsely current-bedded	70–115
Permian System:	
Shedhorn Sandstone: Mostly sandstone, fine- to medium-grained, gray, medium- to thin-bedded; subordinate chert, thin-bedded, containing shaly partings, to massive, containing remnants of partly replaced sandstone; dolomite, light-gray, fine-grained, cherty, medium-bedded; minor dark-gray phosphatic shale	60–72
Pennsylvanian System:	
Quadrant Quartzite: Quartz sandstone, fine-grained, white, yellow, or orange, generally calcareous but locally quartzitic, indistinctly thick-bedded, locally coarsely crossbedded; lower part is locally a breccia containing abundant fragments of light-gray compact dolomite in a fine sandstone matrix	80–150
Pennsylvanian and Mississippian Systems:	
Amsden Formation: Limestone and dolomite, gray, yellow, or pink, cherty, in part argillaceous, medium-bedded, moderately fossiliferous; minor beds of gray, red, or purple shale in lower part; a basal unit, 6 to 45 m thick, of red or orange calcareous mudstone or fine quartzose sandstone, has a few lenses of limestone- and chert-pebble conglomerate containing shell fragments and fish teeth	50–75
Unconformity.	
Mississippian System:	
Upper Mississippian Series:	
Big Snowy Group, undivided: Red and gray calcareous shale, siltstone, and sandstone overlain by limestone, fine- to medium-grained to coarsely bioclastic, medium-	

TABLE 1.—*Stratigraphic units in the Varney quadrangle*—Continued

	Thickness (meters)
Mississippian System—Continued	
Upper Mississippian Series—Continued	
to thick-bedded, commonly very fossiliferous; locally dark-gray nodular chert and beds of dark-gray fissile shale; absent east of Greenhorn fault	200
Lower and Upper Mississippian Series:	
Mission Canyon Limestone: Limestone, microcrystalline to medium-grained or coarsely bioclastic, locally oolitic, generally thick-bedded (0.6–9 m); locally dolomite or dolomitic limestone; weathers light gray; large pockets of solution breccia in upper part	290–380
Lower Mississippian Series:	
Lodgepole Limestone: Limestone, medium-bedded (8–30 cm), in part finely current-bedded containing partings and beds of yellowish-brown shale, highly fossiliferous; commonly contains a 9-m unit of thick-bedded, medium- to coarse-grained limestone about 30 m below top	190–240
Mississippian and Devonian Systems:	
Three Forks Formation (70–90 m):	
Sappington Member: Argillaceous sandstone and sandy siltstone, yellowish-orange, calcareous, and indistinctly bedded, grading to shale below	20–25
Trident Member: Dark fossiliferous shale and interbedded limestone	23–28
Logan Gulch Member: Olive-gray limestone, 3 to 21 m, microcrystalline to very fine grained, thick-bedded, commonly brecciated; underlain by dolomite and limestone breccia that has abundant red argillaceous matrix, 15 to 30 m, nonbedded; probably an evaporite breccia.	
Devonian System:	
Upper Devonian Series:	
Jefferson Dolomite: Dolomite, medium-grained, moderate to dark-yellowish-brown, thick-bedded, vuggy, and petroliferous; interbedded with dolomite, compact, finely crystalline, moderate yellowish-brown to yellowish-orange, thin-bedded, locally current-bedded; minor shale and dolomite breccia; some limestone in lower 30 m	110–115
Unconformity.	
Ordovician System:	
Bighorn Dolomite: Dolomite, light-gray to white, coarsely mottled, thick-bedded; absent east of Greenhorn fault	18–43
Cambrian System:	
Upper Cambrian Series:	
Red Lion Formation: Basal red and green shale overlain by dolomite, silty or finely sandy, quartzose, thin-bedded and current-bedded, containing prominent partings and beds of red, yellow, green, or purple shale; many beds of flat-	

TABLE 1.—*Stratigraphic units in the Varney quadrangle*—Continued

	Thickness (meters)
Cambrian System—Continued	
Upper Cambrian Series—Continued	
pebble conglomerate; some fine-grained quartz sandstone in lower part; absent east of Greenhorn fault	34–58
Pilgrim Dolomite: Mostly dolomite, fine-grained, moderate- to pale yellowish-gray; lower part thin-bedded and containing many greenish or reddish shaly partings, minor silty shale, and intraformational conglomerate; upper part mostly thick- to medium-bedded, fewer partings, uppermost 6 to 18 m consisting of sandy dolomite containing lenses and thin beds of fine-grained white or pink quartz sandstone; absent east of Greenhorn fault	110–130
Middle Cambrian Series:	
Park Shale: Green or red, fissile, noncalcareous shale, minor thin beds of limestone and intraformational limestone conglomerate; upper part red, silty, and calcareous; absent east of Greenhorn fault	46–53
Meagher Limestone: Mostly dolomite, mottled light- to moderate-yellowish-brown, fine- to medium-grained, thin- to thick-bedded, locally weakly petroliferous; upper and lower parts locally are limestone, olive-gray, mottled yellowish-orange, or red, thin-bedded, shaly partings	110–120
Wolsey Shale: Green fissile shale and sandy shale containing thin beds of glauconitic sandstone; upper part is yellowish-brown or buff, fine-grained, highly calcareous sandstone grading to limestone of overlying unit	15–60
Flathead Quartzite: Yellow, orange, red, or white calcareous to quartzitic or hematitic sandstone medium-bedded and current-bedded, containing partings and thin beds of fine-grained sandstone or greenish-gray sandy shale	30
Unconformity.	
Precambrian rocks:	
Gneiss, schist, dolomite, marble, quartzite, amphibolite, phyllite, granite, pegmatite, and mafic intrusive rocks.	

TABLE 2.—*Stratigraphic units in the Cameron quadrangle*

	Thickness (meters)
Quaternary System:	
Pleistocene:	
Till, cobble gravel, and colluvial deposits.	
Tertiary System:	
Pliocene(?).	
Limestone: Pale-yellowish-gray, porous, and poorly bedded limestone; contains fresh-water pelecypods and algae	15
Rhyolite ash-flow tuff: Compact to welded rhyolite crystal tuff and poorly consolidated tuff; locally contains fragments of Precambrian rocks	18
Eocene:	
Andesite and basalt flows: Compact to vesicular olivine, andesite, and basalt	30
Gravel and tuff: Pebble and cobble gravel containing cobbles and small boulders of Precambrian rocks and sparse fragments of Paleozoic limestone, indurated tuff, and fossil wood; overlain locally by weakly indurated tuff	45
Sphinx Conglomerate: Coarse limestone fanglomerate that has silty calcareous matrix	300
Unconformity.	
Cretaceous System:	
Upper Cretaceous Series:	
Volcanic conglomerate: Well-rounded pebbles, cobbles, boulders of various volcanic rocks and sparse pebbles of chert, jasper, mudstone, sandstone, and quartzite in volcanic sandstone matrix. Subordinate volcanic breccia and few beds of volcanic sandstone or mudstone	180
Volcanic breccia: Polylithic breccia of various andesitic rocks, clasts generally 5 to 30 cm in matrix of similar composition, nonbedded. Includes some monolithic breccia and volcanic conglomerate, also a few thin andesite flows	300
Sandstone unit: Volcanic sandstone and conglomerate containing rare plant-bearing layers, medium- to dark-greenish gray, medium- to very coarse-grained, thin- to thick-bedded and locally current-bedded. Conglomerate beds 0.6 m to 9 m thick contain well-rounded pebbles of chert, quartzite, and sparse volcanic rocks, mostly 2.5 to 5 cm in diameter. Unit gradational with underlying unit over a few tens of meters	90–150
Frontier Formation and Colorado Group undivided: Shale, mudstone, calcareous sandstone, and minor sandy limestone. Sandstone, light-gray, thick- to thin-bedded, commonly lenticular, locally coarsely cross-	

TABLE 2.—*Stratigraphic units in the Cameron quadrangle*—Continued

	Thickness (meters)
Cretaceous System—Continued	
Upper Cretaceous Series—Continued	
bedded. Shale and mudstone, medium- to dark-gray, poorly bedded to laminated. Sparse plant and wood debris	1,375
Lower Cretaceous Series:	
Thermopolis Shale: Dark-gray silty shale and underlying thin-bedded quartzose sandstone. Exposed mainly along Tolman Creek	23
Kootenai Formation: Coarse-grained argillaceous sandstone and conglomerate, claystone, and limestone	54
Jurassic System:	
Upper Jurassic Series:	
Morrison Formation: Varicolored mudstone and sandstone. Poorly exposed	70
Unconformity.	
Upper and Middle Jurassic Series:	
Ellis Group: Sandstone, limestone, and shale including parts of the Swift, Rierdon, and Sawtooth Formations	55
Disconformity.	
Triassic System:	
Lower Triassic Series:	
Dinwoody Formation: Sandstone, dolomite, and dolomitic shale	60
Permian System:	
Shedhorn Sandstone and Phosphoria Formation: Cherty sandstone, dolomite, shale, bedded and nodular chert, oolitic phosphate rock	60
Pennsylvanian System:	
Quadrant Quartzite: Quartzite and calcareous quartz sandstone, white or yellow, coarsely crossbedded. Breccia of dolomite blocks near base	120(?)
Pennsylvanian and Mississippian Systems:	
Amsden Formation: Shale, dolomite, and limestone; little exposed	30(?)
Unconformity.	
Mississippian System:	
Lower and Upper Mississippian Series:	
Mission Canyon Limestone: Thick-bedded limestone and dolomite, minor nodular and bedded chert	300
Lower Mississippian Series:	
Lodgepole Limestone: Medium- to thin-bedded limestone containing shaly interbeds and partings	240
Mississippian and Devonian Systems:	
Three Forks Formation: Mainly shale. Very little exposed	30
Devonian System:	
Jefferson Dolomite: Medium- to thick-bedded dolomite ranging from dark brown and porous to light brown and compact. Sparsely fossiliferous	90

TABLE 2.—*Stratigraphic units in the Cameron quadrangle*—Continued

	Thickness (meters)
Unconformity.	
Ordovician System:	
Bighorn Dolomite: Medium-bedded, light-gray, compact dolomite. Exposed only at eastern edge of quadrangle	7.5
Cambrian System:	
Upper Cambrian Series:	
Red Lion Formation: Red calcareous sandstone and red and green sandy shale. Exposed only at east edge of quadrangle	18
Pilgrim Limestone: Dolomitic limestone, thin-bedded, nodular to laminated, commonly mottled. Few beds of compact gray dolomite	120
Middle Cambrian Series:	
Park Shale: Fissile green micaceous shale, has abundant thin limestone layers in lower part; minor nodular limestone containing green shale partings and beds in upper part	3
Meagher Limestone: Thin-bedded slabby limestone, bluish gray, with orange argillaceous mottles. Locally dolomite replaces limestone	120
Wolsey Shale: Sandstone, argillaceous and micaceous, containing abundant worm burrows, commonly highly glauconitic; green shale partings in lower part. Upper part strongly calcareous, grading to overlying unit	38
Flathead Sandstone: Quartz sandstone, slightly feldspathic, medium- to coarse-grained and locally pebbly, medium-bedded, containing green shale partings; commonly cross-bedded	7.5
Unconformity.	
Precambrian System:	
Cherry Creek Formation:	
Quartzite unit: Quartzite, gray, biotitic, variously feldspathic, locally white or green, medium- to thin-bedded, minor interbedded quartz-mica schist	300
Upper dolomite unit: Dolomite marble in units 30 to 90 m thick, interbedded with kyanite-staurolite-biotite schist and gneiss and feldspathic quartzite	460
Quartzite and schist unit: Mica schist, phyllite, and quartzite	460
Lower dolomite unit: Dolomite marble, fine- to coarse-grained, locally contains thin layers of quartzite or micaceous schist	1,500
Lower schist unit: Micaceous schist and phyllite, muscovitic to iron-rich, locally calcareous, in part of volcanic origin. Many thin persistent quartzite beds. Minor schistose volcaniclastic rocks, actinolitic green schist, dolomite, and thin-bedded magnetite-rich quartzite (iron formation)	2,450

quadrangle. On the other hand, certain Paleozoic units (such as the Big Snowy Group and the Three Forks Formation) are well exposed in the Varney quadrangle but are absent or poorly exposed in the Cameron quadrangle.

Mesozoic and Paleozoic formations are similar in the two areas, but average thicknesses vary considerably for some units. The Thermopolis Shale (of former usage)[1] thickens westward from 23 m to about 110 m. A parallel thickening of the Kootenai Formation takes place from about 53 m in the Cameron quadrangle to more than 150 m in the Varney quadrangle.

The Morrison Formation, Ellis Group, Dinwoody Formation, Shedhorn Sandstone, and Quadrant Quartzite show similar lithologic characteristics and variations in thickness across the region. The Amsden Formation is poorly developed in the Cameron quadrangle, and the Big Snowy Group, so well represented in parts of the Varney quadrangle, is not found to the east in the Cameron quadrangle.

The Madison Group, with its consistent Lodgepole and Mission Canyon Limestones, maintains a fairly consistent lithology and thickness throughout the region. The Three Forks Formation is well exposed on Baldy Mountain but is thinner and very poorly exposed in the Cameron quadrangle. The Jefferson Dolomite thickens slightly from east to west, and the Bighorn Dolomite is found only west of the Greenhorn fault in the Varney quadrangle and at the east edge of the Cameron quadrangle.

Most of the Cambrian units show similar lithologic and thickness patterns throughout the area, except for the Park Shale, which is absent east of the Greenhorn fault in the Varney quadrangle and is only about 3 m thick where it occurs in the Cameron quadrangle.

The earliest of these variations appears in the thinning of the Flathead Sandstone and Wolsey Shale (both Middle Cambrian) from a combined thickness of more than 90 m in the northern part of the Varney quadrangle to about 20 m near its southeastern corner. The Wolsey Shale, here about 15 m thick, is largely calcareous sandstone; it represents the upper part of the formation farther north and lies on 5 m or less of Flathead Sandstone. The thinning is probably due to overlap onto a rising slope of Precambrian rocks, the thin Flathead facies occupying a higher stratigraphic position here than elsewhere.

[1] The Thermopolis Shale is now geographically restricted from Montana by Rice (1976) for U.S. Geological Survey usage; its rocks are now replaced in Montana by the Muddy Sandstone, the Skull Creek Shale, the basal part of the Mowry Shale, or the Fall River Sandstone. Hadley's mapping was completed before this restriction.

PALEOZOIC ROCKS

FLATHEAD SANDSTONE AND WOLSEY SHALE

Basal Cambrian strata throughout the Varney and Cameron quadrangles are quartzite and sandstone characteristic of the Flathead Sandstone, as recognized throughout southwestern Montana and adjacent areas (Klepper and others, 1957). The lower part of the formation consists of red-, orange-, pink-, or brown-weathering medium- to coarse-grained orthoquartzite, medium bedded and commonly crossbedded; the upper part consists largely of finer grained calcareous sandstone, thinner bedded, and containing partings and thin beds of green micaceous shale. Red colors, presumably due to syngenetic hematite, are more pronounced in the lower beds; most of the higher beds are pale yellowish gray or white. Layers and lenses of quartz-pebble conglomerate 30 cm or less thick occur mostly in the lower part of the formation. Rare fragments of quartz, as much as 8 cm across and generally more angular than the smaller fragments, are confined to the basal meter of the formation, especially where it rests on Precambrian granitic rocks containing pegmatite. Such large clasts may be accompanied by large fragments of feldspar, but the quartzite and sandstone beds are not conspicuously feldspathic and nowhere contain more than 10 percent feldspar. The upper part of the Flathead is generally calcareous sandstone, medium to fine grained, locally quartzitic in beds 10 to 30 cm thick. Shaly partings are commonly coated with fine clastic mica and marked by abundant worm castings and trails.

The base of the Wolsey Shale is marked in most places by a poorly exposed interval containing float of greenish fissile to silty shale and thin-bedded fucoidal glauconitic sandstone. Rarely, a little dark-red glauconitic limestone appears in this interval. The upper beds of the Wolsey throughout the Varney quadrangle are dominantly sandstone, pale orange to yellowish gray and thin bedded. They are everywhere moderately to strongly calcareous and locally grade to slabby, very sandy limestone. Sandstone and sandy limestone of this type occupy most of the upper half of the formation throughout the eastern part of the Gravelly Range.

On Baldy Mountain and southward in the Greenhorn Range, the upper part of the Wolsey consists of 18 m or more of fine-grained sandstone, which is argillaceous and dolomitic rather than calcareous, and moderate to dark yellowish orange. It locally contains abundant glauconite, forming greensand beds several centimeters thick. Similar beds of greensand in the Wolsey on Indian

Creek in the eastern part of the Cameron quadrangle are as much as 30 cm thick.

Because the upper limit of the Flathead Sandstone is rarely exposed, the thickness of the formation is not precisely known. Measurement of the beds in the better exposures along the eastern side of the Gravelly Range indicates that the Flathead is at least 19 m thick near the mouth of Dry Hollow and decreases in thickness southeastward to less than 6 m on Hyde Creek in the southwest part of the Cameron quadrangle. Less well exposed sections to the north and west indicate a thickness of as much as 27 m on Baldy Mountain and only slightly less throughout most of the Greenhorn Range. In the two best exposed sections on the western flank of the Madison Range in the eastern part of the Cameron quadrangle, the Flathead is 7.5 to 12 m thick.

The full thickness of the Wolsey Shale is not revealed in any exposures in the Varney or Cameron quadrangles, but, in general, its thickness varies with that of the underlying Flathead. Its maximum thickness is about 75 m near Dry Hollow and farther north; thickness decreases southeastward to a minimum of about 15 m at Cherry Creek and at Hyde Creek. On Baldy Mountain and in most of the Greenhorn Range, the Wolsey is 60 m or less thick; in the Cameron quadrangle, it is estimated at 20 to 37 m.

MEAGHER LIMESTONE

The Wolsey Shale is succeeded by 105 to 120 m of carbonate beds that are assigned to the Meagher Limestone (Deiss, 1936). This formation consists of two contrasting lithologic facies—a thin-bedded nodular limestone facies and a brown, less distinctly bedded dolomite facies. The dolomite facies is confined to the upper part of the formation on the eastern side of the Gravelly Range in the Varney quadrangle, but it occupies most of the formation throughout the Greenhorn Range.

The limestone facies of the Meagher consists largely of thin- to medium-bedded, fine-grained to aphanitic limestone, light to moderate bluish, olive, or reddish gray characterized by pale-yellowish-orange or yellowish-brown argillaceous mottles. It is variably argillaceous and much of the limestone consists of layers of small carbonate lumps 2.5 to 5 cm across in a matrix of argillaceous limestone or dolomitic shale. Local thin units of limestone are evenly thin bedded or laminated and contain thin beds of fossiliferous calcareous shale. (See stratigraphic section 1.)

The dolomite facies consists typically of light- to moderate-brownish-gray, yellowish-brown, or, rarely, dark-brown dolomite,

Stratigraphic section 1

[Flathead Sandstone and Meagher Limestone, north side of Dry Hollow, sec. 1, T. 8 S., R. 2 W., Varney quadrangle. Measured by J. B. Hadley]

	Thickness (meters)
Basal Devonian beds	
Unconformity.	
Meagher Limestone:	
27. Limestone, light-olive to brownish-gray, bright-orange silty mottles, very fine grained, thin-bedded, and somewhat nodular. Most beds partly, many beds wholly, altered to dolomite preserving the orange mottling. Upper 0.5 m is limestone containing abundant *Girvanella*	3
26. Dolomite as in the two underlying units, but including large remnants of limestone, yellowish-orange-mottled, thin-bedded, nodular. Units as much as a meter thick pass laterally from limestone to dolomite within a few centimeters	8.5
25. Dolomite, moderate-brownish-gray with pale yellowish-brown mottling, thin-bedded, nodular; bedding similar to that of limestone of lower units	5
24. Dolomite, dark-brown, coarsely crystalline, in calcareous matrix	0.6
23. Dolomite, light- to moderate-brown, medium- to very fine grained, thin- and evenly bedded	4.5
22. Dolomite, grayish- to yellowish-brown, weathering gray, calcareous, mostly massive, little bedding; darker medium-grained dolomite surrounded by finer grained lighter colored dolomite	16
21. Dolomite, in alternating layers 2 to 35 cm thick, fine-grained, light-grayish-brown and medium-grained dark-reddish-brown; moderately calcareous. Most of interval shows indistinct thin bedding	7
20. Dolomite, moderate-yellowish-brown, fine-grained; bedding indistinct and masked by dolomitization. The yellowish silty mottling and the bedding characteristics of the limestone are faintly preserved. Grades into underlying limestone through 30- to 50-cm interval	8
19. Limestone, like underlying unit, but containing many ramifying bodies of brownish-gray dolomite. Abundant "tube structures"	2.7
18. Limestone, light- to moderate-olive-gray mottled with pale yellowish orange, grading to medium yellowish brown; largely massive and having indistinct bedding	8.8
17. Limestone, moderate-olive-gray, little mottling, medium-bedded to 25 cm	2.7
16. Limestone, very thin bedded and containing abundant yellow shale beds; abundant trilobite fragments	0.9
15. Limestone, mottled, thin-bedded, nodular; abundant trilobite fragments	3.7

Stratigraphic section 1—Continued

	Thickness (meters)
Meagher Limestone—Continued	
14. Limestone, nodular, very shaly	0.9
13. Limestone, mottled, thin-bedded, nodular, contains several beds of reddish-gray aphanitic limestone 15 to 30 cm thick	3.7
12. Limestone, light-olive-gray with light- to dark-orange-yellow mottles, fine-grained to aphanitic; thin-bedded, strongly nodular near base; lower 1.2 m shaly, containing more scattered limestone nodules	24
11. Covered. Thickness probably 9 to 15 m	12
10. Limestone, mottled light-olive-gray and pale-reddish-brown, weathers light olive gray with dark-yellowish orange mottles; thin-bedded (2–15 cm), finely crystalline; bedding even, finely nodular; abundant trilobite fragments	7.6
Total thickness Meagher Limestone	120
Covered. Largely Wolsey Shale	80
Flathead Sandstone:	
9. Poorly exposed. Sandstone, like underlying unit, but somewhat thinner bedded. Near top of interval, 2 to 5 cm of red, coarsely crystalline limestone contains hematite ovoids and glauconite. Glauconitic sandstone float	4.6
8. Sandstone, very pale orange with limonite spots, thin-bedded (2–8 cm), fine-grained, somewhat calcareous; partings micaceous, pale-green, shaly, containing abundant worm casts. Bedding surfaces very lumpy	3.7
7. Covered. Float is thin-bedded quartzitic sandstone containing chips of green shale	1.2
6. Sandstone, pale-orange quartzitic, medium-bedded, to coarse-grained. Clayey sandstone pellets form lenses or pockets as much as 30 cm long	3
5. Sandstone, very fine grained, silty, micaceous and fissile; wavy bedded	1.5
4. Orthoquartzite	0.3
3. Granule sandstone containing angular fragments of quartz and minor feldspar to 15 mm in diameter	0.6
2. Quartz sandstone and quartzite, white to very pale orange, variably carbonatic, fine- to medium-grained; beds 15 cm to 1 m thick	2.5
1. Quartz sandstone, grayish-orange, fine- to medium-grained, variably siliceous cement; basal 0.6 m hematitic, moderate reddish brown, micaceous partings	1.5
Total thickness Flathead Sandstone	19
Unconformity.	
Precambrian basement:	
Calcite marble, upper part decomposed and reddish; poorly exposed.	

showing variously preserved remnants of sedimentary structures characteristic of the limestone facies. The characteristic mottling is commonly preserved as lighter brown mottles in darker brown dolomite. Bedding is, however, commonly obscured so that the dolomite facies appears thicker bedded and is more resistant than the limestone facies. Most fossils have been obliterated in the dolomite facies, but characteristic tubes or branching twiglike structures filled with white calcite are abundant in some beds.

From a mapping standpoint, the contacts between the two facies are fairly well defined, although the thickness of the limestone facies of the Varney quadrangle varies from about 15 m in the southeastern part to somewhat more than 60 m in the east-central part. The limestone is about 45 m thick on Baldy Mountain but appears to be only 9 to 15 m thick where sandwiched between dolomite units in the lower part of the formation, farther south in the Greenhorn Range. Limestone appears at or near the top of the Meagher in several places throughout the Varney quadrangle. Where the rocks of the two facies are in contact, there is abundant evidence of progressive replacement of limestone by idiomorphic saccharoidal dolomite. Limestone units 3 to 6 m thick are penetrated by irregularly ramifying bodies of dolomitized and partly dolomitized rock in which dolomite rhombohedra are increasingly abundant in the more calcic or aphanitic parts of the limestone beds, and the finer grained and lighter colored argillaceous material remains.

PARK SHALE

The name Park Shale was given by Weed (1899) and emended by Deiss (1936) to designate a unit between the Meagher Limestone and the overlying Pilgrim Dolomite or Limestone in the Little Belt Mountains of west-central Montana. The term has since been applied to a remarkably persistent shale unit of Middle and Late Cambrian age throughout southwestern Montana. This unit succeeds the Meagher Limestone throughout the Greenhorn Range and in the Madison Range; it is absent, however, in the northern part of the Gravelly Range east of the Greenhorn fault, where it and the overlying Cambrian and Ordovician rocks were removed by erosion before deposition of the Jefferson Dolomite in early Late Devonian time.

The Park Shale is poorly exposed in most places but is approximately 55 m thick in the least deformed sections, where its thickness could be estimated. On the east ridge of Baldy Mountain, the lower part of the unit consists largely of dark-greenish-gray noncalcareous clay shale containing many thin beds of purplish- or reddish-gray limestone and a few beds of intraformational limestone conglomerate and brownish-gray limestone containing abundant fragments of a small linguloid brachiopod. The upper part of the unit in this section is dominantly red and green silty shale that becomes calcareous upward.

An unusually complete exposure of the Park Shale on the northern slope of Sheep Mountain (sec. 21, T. 8 S., R. 3 W.) shows 30 m of fissile noncalcareous grayish-green shale, red in the upper 4.5 m. The upper 9 to 12 m of this section contains nodular layers of dark-brown dolomitic siltstone less than 2.5 cm thick. In the only good exposure of the formation seen in the Cameron quadrangle on the north side of the canyon of Indian Creek, the Park Shale is much reduced in thickness by faulting. What is left consists of green fissile shale that contains many regular beds less than 2.5 m thick of nodular limestone as well as thin-bedded nodular limestone containing green shale partings.

PILGRIM DOLOMITE OR LIMESTONE

A thick carbonate unit overlying the Park Shale is referred to the Pilgrim Dolomite or Limestone in accordance with recent usage in western Montana (Hanson, 1952; Klepper and others, 1957; Robinson, 1963). The Pilgrim is a conspicuously exposed formation 110 to 120 m thick in the western part of the Varney quadrangle and near the eastern border of the Cameron quadrangle. It is absent, however, throughout the eastern flank of the Gravelly Range, where Devonian rocks rest directly on the Meagher Limestone. Although the Pilgrim consists largely of limestone in its type locality and throughout much of western Montana (Deiss, 1936, p. 1333–1335; Hanson, 1951, p. 56; McMannis, 1955, p. 1394-1395), it is nearly all dolomite in the Varney quadrangle.

On Baldy Mountain and throughout the Greenhorn Range, the Pilgrim can be divided somewhat loosely into four lithologically distinct parts: (1) a lowermost unit consisting of thin-bedded silty or shaly dolomite, (2) a middle unit of limestone, (3) an upper medium- to thick-bedded dolomite, and (4) an uppermost unit of quartzose sandy dolomite.

The lowermost unit consists of thin-bedded, light-yellowish-gray or light-yellowish-brown dolomite containing greenish- or yellowish-gray silty laminae or partings and weathering to platy fragments. Medium-bedded mottled dolomite forms subordinate units in some sections of the lowermost unit, and the basal 3 to 9 m is commonly of this type. Thin beds of flat-pebble conglomerate containing fragments of dolomite 0.8 cm thick and 6.5 cm long are associated with sandy and silty, current-bedded dolomite in the upper part of this unit on Baldy Mountain. The thickness of the lowermost, thin-bedded dolomite ranges from 43 m to 72 m (see fig. 1).

The upper dolomite is 12 to 50 m thick and is characterized by beds of light-yellowish-gray dolomite, 0.3 to 0.9 m thick, locally interbedded with thinner bedded or laminated dolomite. Thicker beds commonly have a distinctly mottled or brecciated appearance on weathered surfaces. This unit also shows small-scale current bedding at many places.

The dolomite of both these units is generally finely crystalline and compact and rarely shows the coarse idiomorphic dolomite replacement texture characteristic of the Meagher Limestone. Details of sedimentation, such as lamination and current bedding, are better preserved, and the rocks are nowhere dark or petroliferous.

The middle limestone unit consists of modular or thin-bedded blue-gray limestone mottled orange or yellowish orange, much resembling parts of the Meagher Limestone and dissimilar to most of the Pilgrim in the area. Silty, shaly, or fine sandy interbeds are somewhat coarser than the detrital material in the Meagher. The limestone beds are generally confined to a unit 15 to 25 m thick in the middle and lower parts of the formation (fig. 1). They first appear about 60 m above the base of the formation in the northeastern part of sec. 4, T. 8 S., R. 3 W. Farther southwest, the limestone is much lower in the formation, but a well-exposed section of the Pilgrim in sec. 4, T. 9 S., R. 3 W., shows no limestone at all.

The uppermost part of the Pilgrim throughout the Greenhorn Range is characterized by medium- to thick-bedded dolomite containing fine- to medium-grained quartz sand in widely varied amounts. Sandy beds range from slightly sandy dolomite to dolomitic quartz sandstone in beds or lenses a few centimeters to a meter in thickness. They are conspicuously crossbedded in many places. This sandy interval increases in thickness southward from 6 m on Baldy Mountain to 21 m in sec. 22, T. 8 S., R. 3 W. A similar unit can be recognized farther south in the Greenhorn Range but is not sufficiently exposed there to provide estimates of its thickness.

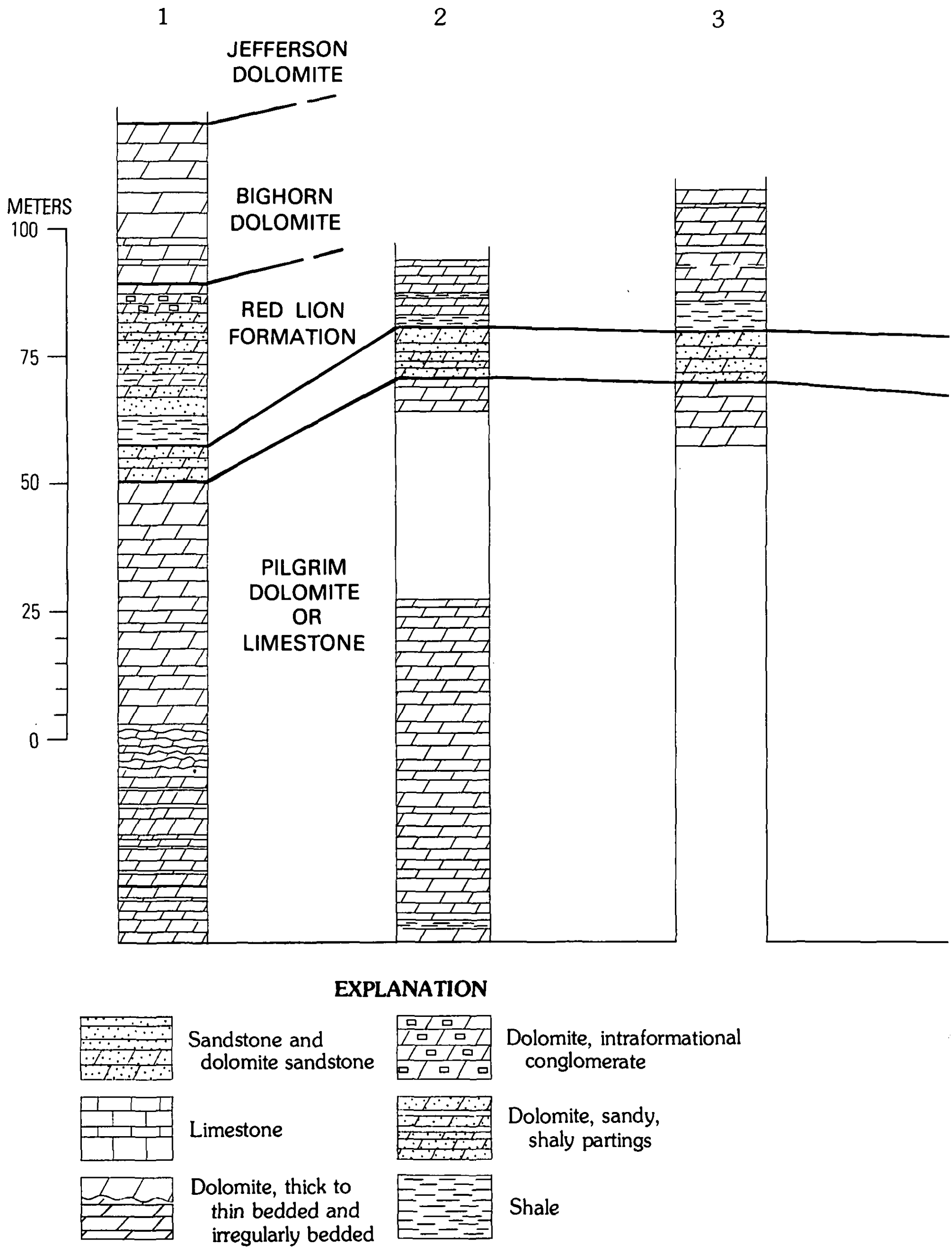
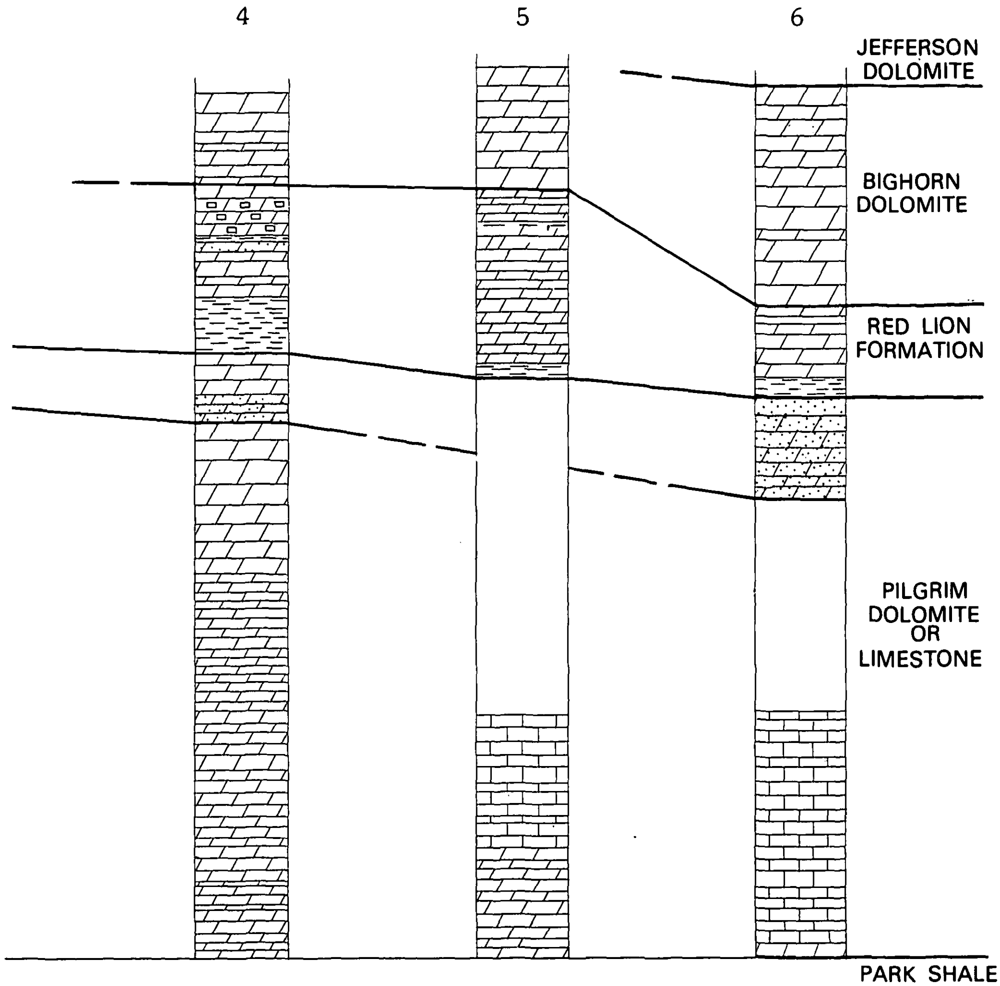


FIGURE 1.—Columnar sections of the Bighorn Dolomite, Red Lion



LOCATION OF SECTIONS

1. Baldy Mountain, sec. 27, T. 7 S., R. 3 W.
2. Steep gully in west half, sec. 27, T. 7 S., R. 3 W.
3. Baldy Mountain, west ridge, sec. 33, T. 7 S., R. 3 W.
4. NE¼ sec. 4, T. 9 S., R. 3 W.
5. NW¼ sec. 23, T. 8 S., R. 3 W.
6. SE¼ sec. 20, T. 8 S., R. 3 W.

Formation, and Pilgrim Dolomite or Limestone, Varney quadrangle.

In the limited exposures of the Pilgrim along the eastern border of the Cameron quadrangle, the formation has about the same thickness as in Varney quadrangle but is composed almost entirely of limestone. The limestone is generally medium to thin bedded and nodular, locally laminated by beds of dolomitic siltstone or silty dolomite. Yellowish-orange or pale-red mottling is common, and a few thin beds in the lower part of the formation contain abundant glauconite.

The basal contact of the Pilgrim on the underlying Park Shale is not exposed in the Varney quadrangle, but the presence of thin limestone beds in the upper part of the Park, as indicated by float at several places, suggests a transition from shale to carbonate deposition. At altitude 2,200 m, on the north wall of the canyon of Indian Creek in the Cameron quadrangle, the contact is fully exposed and shows a transitional interval at least 12 m thick in the upper part of the Park Shale.

RED LION FORMATION AND BIGHORN DOLOMITE

Immediately above the Pilgrim Dolomite or Limestone on Baldy Mountain and throughout the Greenhorn Range is about 30 m of thin-bedded dolomite, calcareous siltstone, and dolomitic pebble conglomerate, underlain by a thin basal red or green shale. This sequence contains trilobite and brachiopod fragments of Cambrian aspect and is considered to be the equivalent of the Red Lion Formation of the Philipsburg district (Emmons and Calkins, 1913, p. 61–63) and the Snowy Range Formation recognized in south-central Montana (Dorf and Lochman, 1940, p. 545–547; Grant, 1965). According to recent usage in southwestern Montana, the unit is assigned to the Red Lion (Hanson, 1952, p. 17, 30, 37; Klepper and others, 1957, p. 12–14). This unit is overlain throughout most of its extent by a conspicuously exposed thick-bedded to massive light-gray dolomite, which has been assigned to the Bighorn Dolomite of Middle and Late Ordovician age by Hanson (1952, sec. 9, p. 30, sec. 22, p. 37, and sec. 8, p. 28). Like the other Upper Cambrian rocks, the Red Lion and the overlying dolomite are absent throughout the eastern flank of the Gravelly Range, having been removed by pre-Late Devonian erosion.

Although the basal beds of the Red Lion Formation are generally concealed, they are everywhere represented by abundant chips of red and green fissile to sandy shale in the soil cover. The interval is estimated to be 3 to 10 m thick.

The main part of the Red Lion in the Greenhorn Range consists of variegated light-yellowish, pinkish, or brownish-gray dolomite, thin bedded, commonly silty or fine sandy, and weathered to slabby or slaty fragments. Greenish, tan, or reddish-gray shaly interbeds and partings are characteristic of the unit, as are crinkly or strongly wavy bedding surfaces. Many thin beds of dolomite pebble conglomerate occur in the upper 9 to 12 m of the formation in the vicinity of Baldy Mountain. The lower part tends to be sandy and includes a few beds of glauconite-bearing quartzose sandstone or dolarenite (fig. 1). Fragments of trilobite molts and shells of *Billingsella* and *Eoorthis* were found in shaly beds in most sections of the formation. According to A. R. Palmer (written commun., 1959), these genera are associated characteristically in beds of early Franconian (middle Late Cambrian) age.

These rocks differ considerably from the limestone and interbedded shale characteristic of the Red Lion and Snowy Range Formations in their type areas, and correlation with subdivisions such as the Sage or Grove Creek Limestone Members of the Snowy Range does not seem feasible. The basal red and green shale, however, is probably the same as the Dry Creek Shale Member of the Snowy Range, as defined by Lochman-Balk (1950) and by Grant (1965, p. 10–12). The rest of the formation more nearly resembles, in its sandy and silty beds, the dominantly clastic sequence described as Red Lion Formation in the southern Elkhorn Mountains some 100 km to the north (Klepper and others, 1957, p. 10–12).

The rocks in the Greenhorn Range provisionally assigned to the Bighorn Dolomite of Middle and Late Ordovician age by Hanson (1952, p. 22) are massive to medium-bedded, light-gray or white dolomite, commonly irregularly mottled darker gray. Beds a few meters thick of laminated nonfissile dolomite also occur. They rest directly on thinner bedded variegated dolomite of the Red Lion and form a prominent bedrock rib between the less resistant rocks of the Red Lion and the lower part of the Jefferson Dolomite. The exposed thickness of the unit ranges generally from 18 to 43 m; the 128 m assigned to the Bighorn on Sheep Mountain in sec. 21, T. 8 S., R. 3 W., by Hanson (1952, p. 30) represents the maximum thickness of 43 m repeated by faults, together with infaulted beds of the overlying Jefferson Dolomite.

No fossil evidence indicating the age of this dolomite unit has been found, and correlation with the Bighorn was made apparently on the basis of its stratigraphic position and lithologic similarity to the rocks in the Madison Range to the east, previously regarded as marking the western limit of the Bighorn in south-central Montana (Sloss and Moritz, 1951, p. 2147–2148). Both the Bighorn and the Red Lion are missing, apparently because of pre-Jefferson erosion, in the narrow belt of Paleozoic rocks in the vicinity of Indian Creek in the eastern part of the Cameron quadrangle. In the northeastern corner of sec. 32, T. 8 S., R. 2 E., a few hundred feet east of the quadrangle boundary, however, the Pilgrim is overlain by 18 m of poorly exposed red calcareous sandstone and green sandy shale and 7.6 m of medium-bedded light-gray dolomite that probably represent the Red Lion and Bighorn, respectively.

JEFFERSON DOLOMITE OR LIMESTONE

The rocks immediately overlying the Cambrian sequence and the Bighorn Dolomite in the Varney and Cameron quadrangles are regarded as belonging to the Jefferson Dolomite or Limestone of Late Devonian age. Originally described from exposures near Three Forks, Mont., 65 km north of the present report area, the Jefferson has been recognized throughout a wide area in Montana and adjacent parts of the neighboring States (Sloss and Laird, 1947). In the present area, the Jefferson is 75 to 120 m thick and consists largely of dolomite and minor interbedded shale, claystone, and limestone. Beds equivalent to the Maywood Formation (Middle and Upper Devonian) of the Philipsburg area may be present, but they are lithologically distinct from the Maywood as described in nearby areas and are here included in the Jefferson.

The Jefferson consists mainly of yellowish or brown dolomite, medium to thick bedded, commonly unusually dark and petroliferous. Much of it forms alternating sequences of light-yellowish-gray compact dolomite and contrasting dusky-brown dolomite that is medium to coarsely saccaroidal, porous, and strongly petroliferous (stratigraphic section 2). The latter rock type weathers to large float blocks that mark the presence of the Jefferson in many places where the other rocks are not exposed. Calcite-filled solution cavities, lenses of collapse breccia, and sparse ovoid or irregularly bedded dark chert are other features that serve to distinguish the Jefferson from the Cambrian dolomites. The fomation is moderately fossiliferous, although dolomitization has obscured or destroyed organic remains in many places. The most commonly observed forms are *Amphipora* and *Phillipsastrea*, which can be found in almost any large exposure of the forma-

Stratigraphic section 2

[Three Forks Formation and Jefferson Dolomite, north side of Ruby Creek near junction with Beartrap Canyon, Varney quadrangle. Measured by J. B. Hadley and W. D. Long]

	Thickness (meters)
Lodgepole Limestone (incomplete):	
Calcarenite, coarsely crystalline, containing fragments of yellow sandy siltstone; sharp contact with underlying unit	1.0
Three Forks Formation:	
Sappington Member:	
44. Siltstone, dark-yellow-orange, argillaceous and calcareous, becoming more sandy upward, indistinctly bedded, partings 2.5 to 25 cm apart	9.0
Trident Member:	
43. Poorly exposed. Few outcrops of limestone like unit 42 (Fault, nearly vertical, northwestern side down about 3 m)	29.0
42. Limestone, pale-grayish-yellow, argillaceous, thinly and indistinctly bedded, platy weathering	4.0
Logan Gulch Member:	
41. Limestone, moderate-grayish-brown, microcrystalline, nonbedded, much broken and slumped into underlying breccia	3.0
40. Breccia, coarse, chaotic, consisting of fragments of yellowish-brown and yellowish-gray dolomite, both compact and thin bedded, in a grayish-yellow, argillaceous, silty, and calcareous matrix. Fragments are 2.5 to 60 cm in diameter; many in upper half of unit are limestone similar to overlying unit	15.0
Total thickness Three Forks Formation	61
Jefferson Dolomite:	
39. Covered. Probably similar to underlying unit	5.2
38. Dolomite, moderate-grayish-orange to pale-red, argillaceous and calcareous, thin-bedded and platy containing argillaceous partings	1.5
37. Dolomite, light-yellowish-gray, compact, nonbedded, fractured and rubbly weathering	9.9
36. Mostly covered. Probably shale, lower part red	4.6
35. Shale, red and yellow, dolomitic, 0.4 m yellow argillaceous dolomite	1.3
34. Dolomite, pale- to moderate-yellowish-brown; lower 1.5 m compact and blocky; upper 2.1 m porous, thick-bedded, and indistinctly current bedded; similar to unit 28	3.6
33. Dolomite, dark-yellowish-brown, indistinctly bedded, blocky weathering, moderately petroliferous	4.6
32. Dolomite, grayish-yellow, argillaceous, grading upward to more compact dolomite as in unit 1	1.2
31. Claystone, grayish-yellow to yellowish-gray, dolomitic, poorly exposed; contains brachiopod fragments; forms slope below 8-m cliff	3.6
30. Dolomite, like unit 28	1.4

Stratigraphic section 2—Continued

	Thickness (meters)
Jefferson Dolomite—Continued	
29. Poorly exposed. Lower part is dolomite, moderate-reddish-orange to very pale olive-gray, microcrystalline, argillaceous; middle part is moderate to dark-brown dolomite; upper part is dolomitic claystone and shale	2.9
28. Dolomite, moderate-yellowish-brown, medium crystalline; lower part compact and brecciated, upper part friable, laminated; sandy texture is due to leaching of calcium carbonate	1.3
27. Dolomite, compact like unit 1, blocky weathering	2.1
26. Dolomite, compact, nonbedded, weathering to irregular rubble	0.9
25. Dolomite, pale-yellowish-brown, compact, 25-cm beds, jointed like unit 1	0.9
24. Dolomite, moderate- to dark-yellowish-brown, finely crystalline, mostly thin bedded, partly porous and indistinctly bedded, weathers to small blocks	5.5
23. Shale and claystone, red and yellow as in basal part of unit 21, dolomitic; basal contact sharp, top sharp but undulating	1.2
22. Dolomite, moderate- to dark-yellowish-brown, poorly bedded, locally a breccia. Thirty-centimeter bed 0.6 m above base contains abundant poorly preserved corals and brachiopods	3.0
21. Dolomite, yellowish-brown, finely crystalline, grading downward to pale-yellowish-brown argillaceous dolomite and this in turn to a basal 30 cm of red and yellow silty shale containing fragments of yellow dolomite and dark chert	1.4
20. Dolomite breccia consisting of fragments of dark-brown, medium-crystalline dolomite in a matrix of dark-yellowish-orange dolomite. The basal 30 cm is very fine grained, pale-yellowish-brown dolomite	1.0
19. Dolomite, dark-yellowish-brown, medium crystalline, irregularly laminated, containing abundant egg-shaped chert nodules 4 cm in diameter. Lower part is finely crystalline compact dolomite like unit 1, brecciated, argillaceous and yellow at base. Base of unit contains lenses as much as 10 cm thick of fragmental microcrystalline quartz	1.4
18. Dolomite, like unit 16 but lacks chert; somewhat brecciated and fossils less abundant; abundant algal structures in top 30 cm grades into unit 17	3.7
17. Dolomite, moderate-yellowish-brown, finely crystalline. Lower part is thin bedded, containing lenses of argillaceous siltstone; middle is dolomite breccia containing dark-brown chert nodules as much as 13 cm in diameter; upper is compact like unit 1	1.2

Stratigraphic section 2—Continued

	Thickness (meters)
Jefferson Dolomite—Continued	
16. Dolomite, moderate- to dark-yellowish-brown, medium crystalline, porous, locally vuggy and strongly petroliferous; lower part medium bedded; upper part current bedded. Basal 1.5 m contains sparse chert nodules as much as 5 cm diameter and abundant corals	4.2
15. Dolomite, pale-yellowish-gray, very finely crystalline, blocky weathering; two beds 20 cm thick containing parting of pale-greenish-yellow shale	0.4
14. Dolomite, dark-yellowish-brown, medium crystalline, compact to moderately porous, moderately petroliferous; impersistent partings 5 to 10 cm apart, blocky weathering; contains poorly preserved *Phillipsastrea*. Upper 30 cm is laminated and current bedded and grades into unit 13	1.5
13. Shale and dolomite. Shale is pale-greenish-yellow (10*Y* 8/4)[1], dolomitic, contains fragments and thin beds of pale-red argillaceous dolomite, grades upward into compact dolomite, variegated yellowish gray, orange, and brown, finely crystalline	0.8
12. Dolomite, dark-yellowish-brown to grayish-brown (5*YR* 3/2), finely crystalline, moderately porous and petroliferous, beds 2 to 15 cm thick, blocky weathering; upper meter lighter colored and more compact	4.7
11. Dolomite, pale-yellowish-gray (5*Y* 7/4), finely crystalline, compact	0.3
10. Dolomite, finely crystalline to microcrystalline; alternating laminae yellowish-brown and grayish-red argillaceous dolomite, in part brecciated, platy weathering	1.0
9. Dolomite, moderate—yellowish-brown (10*YR* 5/4) to pale-yellowish-brown (10*YR* 7/2), finely crystalline, thin-bedded to laminated, porous, thin lenses of fine breccia	1.4
8. Dolomite, grayish-red (10*R* 4/2), finely crystalline, laminated	0.5
7. Dolomite, pale-yellowish-orange, yellowish-brown and moderate-reddish-orange, finely crystalline, bedding 3 to 25 mm; irregular lenses of reddish dolomite breccia	0.5
6. Dolomite, mostly like unit 2 but more compact; top 8 cm laminated	0.6
5. Dolomite, moderate-brown (5*YR* 4/2), finely crystalline, laminated by reddish partings; grades into unit 4	0.4
4. Dolomite, dark-yellowish-brown (10*YR* 3/2), finely crystalline, compact, bedding thin and indistinct	0.9
3. Dolomite, dark- to moderate-yellowish-brown, finely crystalline, compact, medium-bedded, vertically jointed	0.8

[1] Color designations are based on the "Rock-Color Chart" of the National Research Council (Goddard and others, 1948).

Stratigraphic section 2—Continued

	Thickness (meters)
Jefferson Dolomite—Continued	
2. Dolomite, dark-yellowish-brown, finely crystalline, partly thin bedded and compact, partly porous and brecciated, the latter type forming lenses and irregular crosscutting bodies 2.5 to 30 cm thick; moderately petroliferous	1.0
1. Dolomite, yellowish-brown, compact, finely crystalline, beds 15 to 25 cm thick, close vertical joints, weathers to small smooth-surfaced blocks and chips	0.3
End of good exposure.	
Partial thickness Jefferson Dolomite	82.7

tion. Brachiopod remains, crinoid columnals, and columnar algal stromatolites appear in some of the better exposed sections.

Claystone or shale, generally associated with argillaceous dolomite, is present in units 0.3 to 4.6 m thick throughout the middle and upper parts of the formation but appears rarely in outcrops. In an unusually well exposed section of the middle and upper parts of the formations on Ruby Creek in the southeastern corner of the Varney quadrangle (stratigraphic section 2), shale and claystone amount to nearly 15 percent of the formation. These argillaceous beds are calcareous and generally thin; they weather prominently red, yellow, or brownish gray. They commonly grade to argillaceous dolomite or limestone.

Limestone is rare in most of the Jefferson in the Varney quadrangle, but it is an important constituent of the lowermost 30 m of the formation along the eastern slope of the Gravelly Range. These basal beds are largely concealed on gentle slopes below the more resistant and typical dolomite beds of the Jefferson and above the cliff-forming dolomite of the Meagher Limestone. Reasonably complete exposures of this unit were found, however, on the crests of two narrow ridges on the northern side of Morgan Gulch in SW¼ sec. 13, T. 8 S., R. 2 W., and south of Cherry Creek in SW¼ sec. 6, T. 9 S., R. 1 W. (stratigraphic section 3). In these three sections, the basal unit of the Jefferson is 27 to 38 m thick and consists largely of interbedded dolomite and limestone. The dolomite beds are compact, fine to medium crystalline, light yellow to medium dark brown, generally thin bedded or laminated, and commonly silty. The limestone is light colored, yellowish, olive, or brownish gray, or faintly pink; it is medium to thin bedded or platy and forms units 0.3 to 6 m thick, locally altered to dark-brown petroliferous dolomite like the typical Jef-

Stratigraphic section 3

[Lower part of Jefferson Dolomite, north side of Morgan Gulch, SW. corner, sec. 13. T. 8 S., R. 2 W., Varney quadrangle. Measured by J. B. Hadley]

	Thickness (meters)
Top of section (incomplete):	
14. Dolomite, dark-brown, moderately well bedded	
13. Limestone, medium-olive-gray with pink tinges, indistinctly bedded; contains a few thin-shelled brachiopods	5.5
12. Covered	4.6
11. Dolomite, dark-brownish-gray, petroliferous, indistinctly bedded, beds 25 to 45 cm thick	4.6
(Section offset 150 m)	
10. Dolomite, light-yellowish-brown mottled with light brownish-gray, finely crystalline, medium-bedded, blocky weathering	2.1
9 Limestone, moderate-olive-gray, medium-bedded	3.4
8. Dolomite, very light yellowish gray, laminated, slabby to blocky weathering	3.4
7. Limestone, like unit 4	0.9
6. Limestone, light- to moderate-brownish-gray, fine-grained, laminated to thin-bedded. Top bed is limestone, 15 to 25 cm thick, microcrystalline, indistinctly fragmental, dark-olive-gray	3.7
5. Largely covered interval. Few small exposures of limestone like unit 4	6.1
4. Limestone, light-brownish- to yellowish-gray with abundant pink and orange tints, fine-grained to microcrystalline, medium- to thin-bedded and platy; 7.5-cm chert layer near top; a few thin beds in upper part contain *Amphipora*	4.0
3. Dolomite like unit 2, but includes beds 15 cm thick of laminated and lighter colored dolomite	2.1
2. Dolomite, medium- to dark-brownish-gray, medium crystalline, nonbedded, strongly petroliferous	3.7
1. Dolomite, yellow, fine-grained, platy-weathering (float only)	3.0
Partial thickness of Jefferson Dolomite	47
Unconformity	
Meagher Limestone:	
Dolomite, pale- to moderate-grayish-yellow, thin-bedded, 15-cm layer containing *Girvanella* at top	3.4

ferson. The limestone is found throughout all but the basal 6 to 9 m of the unit and makes up 35 to 60 percent of the three best exposed sections. *Amphipora,* thin-shelled brachiopods, and dark chert, all characteristic of the Jefferson, occur in small quantities in various parts of the unit.

In a well-exposed section on Baldy Mountain, the lower part of the Jefferson is entirely dolomite; the basal bed lies, with an essentially conformable contact, on 23 m of thick-bedded, light-gray dolomite assigned to the Bighorn. Farther south in the Greenhorn Range, the lower 30 m of the Jefferson is very poorly exposed, but no evidence of limestone was seen.

According to J. T. Dutro, Jr. (written commun., 1957, 1975), four collections of fossils from the Jefferson Dolomite in the Varney quadrangle indicate a Late Devonian (Frasnian) age for the formation. Three of these collections are from the section on the north slope of Baldy Mountain (NW¼ sec. 27, T. 7 S., R. 3 W.). *Amphipora*? is abundant 10 m above the base of the formation, thamnoporoid and alveolitid corals are found about 18 m above the base, and the colonial rugose coral *Phillipsastrea* was collected 66 m above the base. Brachiopods from low in the Jefferson on the northern side of Morgan Gulch (SW¼ sec. 13, T. 8 S., R. 2 W.) include *Atrypa* sp. and *Cyrtospirifer* sp. No occurrences of *Atrypa* above the Frasnian are known, and *Phillipsastrea* is a common Frasnian coral in many parts of western North America.

Devonian rocks underlying the Jefferson Dolomite or Limestone have been reported from several areas in southwestern Montana, but they are difficult to correlate because they are poorly exposed and their thickness and lithologic character vary considerably from place to place. A sequence of light-gray and buff-weathering limestone and shale 60 to 90 m thick, which has a prominent sandstone near the base, was termed the Maywood Formation in the Philipsburg district by Emmons and Calkins (1913, p. 64–65). The upper part of this sequence resembles the basal part of the Jefferson unit described herein, but the latter contains no sandstone and, unlike the Maywood, does contain fossils and chert like those in the overlying Jefferson. In the Three Forks area, beds assigned to the Maywood by Robinson (1963, p. 24–26) consist of 9 to 30 m of highly colored siltstone and mudstone and interbedded limestone in the upper part. The lower part contains thin lenses of siltstone pebble conglomerate in a few places. As in the southern Elkhorn Mountains, where 12.5 m of silty dolomite, dolomitic siltstone, shale, sandstone, and very minor limestone were assigned to the Maywood (Klepper and others, 1957, p. 13), the Maywood is mostly a clastic rather than a carbonate unit and is not readily correlatable on lithologic grounds with the basal part of the Jefferson in the Varney quadrangle. No dense dark limestone comparable with that found in the main part of the Jefferson at other localities, such as at Logan, Mont. (Sloss and

Laird, 1947, p. 1409), occurs in the lower part of the Jefferson sequence in the Varney quadrangle.

THREE FORKS FORMATION

The rocks that overlie the Jefferson Dolomite or Limestone throughout the Varney quadrangle are assigned to the Three Forks Formation as defined by Sandberg (1965). Subdivisions proposed by Sandberg include the Logan Gulch Member, which lies directly on the Jefferson Dolomite, followed in ascending order by the Trident and Sappington Members. All three of these members can be recognized in the Varney quadrangle, where they have a combined thickness of about 90 m.

Logan Gulch Member.—The Logan Gulch Member of the Three Forks Formation consists of a lower unit of limestone and dolomite breccia about 30 m thick, overlain by an easily recognizable brownish, purplish-gray, or chocolate-colored limestone generally 15 to 22 m thick. The breccia unit consists of abundant fragments of pinkish- or reddish-orange limestone and light-yellowish-gray or grayish-orange dolomite 30 cm or less to a meter in diameter, randomly embedded in a matrix of coarse calcite and red argillaceous nonbedded limestone. Even where it is not exposed, the presence of the breccia is commonly marked by red soil. Large fragments of the overlying brown limestone appear in the upper part of the breccia unit in the better exposures, supporting interpretations by previous workers that the breccia unit is a collapse breccia caused by removal of easily soluble evaporite minerals. The presence of similar though much thinner breccia beds in the upper part of the Jefferson (unit 20, stratigraphic section 2) also supports Sloss' contention that the red breccia represents a continuation of sedimentation in restricted basins under the conditions of semiaridity that characterize parts of the Jefferson and contemporaneous formations in the northern Rocky Mountains (Sloss and Laird, 1947, p. 1410).

In contrast to the red breccia, the limestone of the Logan Gulch Member is commonly exposed and forms a conspicuous narrow ridge between the breccia and the overlying Trident Member. In most exposures, the limestone unit is recognized by its finely crystalline to aphanitic texture and characteristic purplish- or chocolate-brown color. It is generally massive, in part thin bedded or laminated, and is commonly brecciated and veined by white calcite. The limestone unit ranges in thickness from a minimum of 13 m at Dry Hollow to 22 m on the northwestern slope of Baldy Mountain. It is nearly unfossiliferous, although brachiopods, identified as *Cyrtospirifer* by J. T. Dutro, Jr. (oral commun., 1958), were found at one locality on the north slope of Baldy Mountain.

Trident Member.—As defined by Sandberg (1965), the Trident Member of the Three Forks Formation includes dark fossiliferous shale and interbedded limestone that were the basis for the original description of the Three Forks (Peale, 1893, p. 29–32). The only good exposure of the Trident in the report area is in a roadcut on Call Road at the north side of Dry Hollow, where approximately 12 m of greenish- to dark-gray shale and interbedded fossiliferous limestone overlies about 15 m of poorly exposed light-yellowish-gray or yellowish-orange platy argillaceous limestone that, in turn, overlies the chocolate-brown limestone of the Logan Gulch Member. Somewhat farther south, in Morgan Gulch, the yellow limestone in the Trident is 22 m thick and also lies on the limestone of the Logan Gulch. The Trident, very rarely exposed in the report area, is usually represented by a covered interval in which fragments of the platy yellow limestone are the only indication of its presence. Because of lack of exposure, the thickness of shale and interbedded limestone in the Trident is not well known but is probably not much greater than that at Dry Hollow.

Sappington Member.—The upper part of the Three Forks Formation throughout the report area consists of distinctive yellowish-orange calcareous siltstone and fine calcareous and silty sandstone corresponding to the Sappington Sandstone Member of earlier reports (Sloss and Laird, 1947, p. 1411; Sandberg, 1962). Except for the limestone unit of the Logan Gulch Member, the Sappington Member is the most commonly exposed part of the Three Forks in the Varney and Cameron quadrangles and is commonly recognized as float in poorly exposed intervals. It consists largely of yellow-weathering, strongly calcareous or argillaceous siltstone and fine silty quartz sandstone, locally grading to very argillaceous limestone. The sand component typically increases upward; the limestone is generally found in the lower part and resembles the yellowish-orange limestone in the lower part of the Trident. The base of the member is not exposed in the report area, but in the better exposed sections, the Sappington is at least 18 m thick. It is overlain by the basal beds of the Madison Group, and this contact is exposed at several places on Baldy Mountain and in the section on Ruby Creek (stratigraphic section 2). In these exposures, the uppermost sandy beds of the Sappington are overlain by coarse bioclastic calcarenite 0.6 to 0.9 m thick that locally contains small fragments of the underlying sandstone. The black shale, which in other areas intervenes between the Sappington and the Madison Group (McMannis, 1955, p. 1397; Sloss and Laird, 1947, p. 1411), is not present.

MADISON GROUP

The Three Forks Formation is overlain by a very thick succession of carbonate rocks known throughout the region as the Madison Limestone or Group. These rocks are well exposed in the Varney quadrangle, notably on Baldy Mountain and in the lower part of the canyon of Wigwam Creek. They also form the high peak in sec. 21 and 22, T. 8 S., R. 3 W., and are prominent in the belt of Paleozoic rocks at the eastern edge of the Cameron quadrangle. Their average thickness in these areas is about 550 m. Following the usage established by Sloss and Hamblin (1942), the Madison Group in the Varney and Cameron quadrangles is divided into a lower thinner bedded formation, the Lodgepole Limestone, and an upper thicker bedded formation, the Mission Canyon Limestone. The type sections of the Madison Group and its constituent parts were recently described in detail by Sando and Dutro (1974).

LODGEPOLE LIMESTONE

The Lodgepole Limestone consists of thin- to medium-bedded, bluish- to brownish-gray limestone characterized by thin interbeds and partings of yellowish- or brownish-gray calcareous shale or argillaceous limestone. Thicker beds are generally 0.3 to 0.9 m thick, are commonly calcarenitic, and contain bioclastic material, especially in their lower parts. Thinner beds are 2.5 to 12 cm thick and generally consist of calcilutite and fine calcareous sandstone. Although the lower parts of many beds are somewhat coarser than the upper parts, graded bedding like that in turbidites is not common; the dominant bedding consists of parallel beds of laminae and small-scale cross lamination indicating deposition by rather weak currents. Shaly beds are generally 1 to 10 cm thick, but, locally, shale and (or) argillaceous limestone form stratified units as much as 1 m thick. Chert is not abundant anywhere in the formation; where present, it is commonly porous rather than compact and occurs as irregular ramifying masses or small discontinuous bodies along the bedding.

Argillaceous beds diminish in number and thickness upward in the Lodgepole, and intervals 1 to 9 m thick of thicker bedded, coarser limestone are found in the upper 30 m or so on Baldy Mountain and elsewhere. One such unit, 9 m thick and 38 m below the top of the formation, is recognizable in several exposures in the northeastern part of the Varney quadrangle. The top of the Lodgepole is placed, for convenience, at the upper limit of conspicuously thin- or medium-bedded limestone containing shaly partings, and the transition to the thicker bedded, essentially nonargillaceous limestone of the Mission Canyon is generally abrupt. The base of the Lodgepole is well defined at many localities where the basal bed is a moderately coarse bioclastic limestone 0.6 to 0.9 m thick that lies directly on yellow calcareous sandstone or siltstone of the Sappington Member of the Three Forks Formation.

Thickness of the Lodgepole, as calculated from map data in the better exposed areas, ranges from 190 m in the southern part of the Greenhorn Range and 200 m at Morgan Gulch to 240 m at Baldy Mountain and in the Wigwam Creek Canyon. The last figure agrees well with the thickness of 230 m reported by Sando and Dutro (1960, pl. 1) in a measured section on Baldy Mountain. The Lodgepole is also about 240 m thick at the eastern edge of the Cameron quadrangle.

MISSION CANYON LIMESTONE

The Mission Canyon Limestone is conspicuously thicker bedded than the Lodgepole, lacks argillaceous beds and partings, and has mostly coarser beds. Thin-bedded limestone or dolomite appears locally but is generally not argillaceous. Many of the thicker beds, 1 to 1.5 m thick, are bioclastic or epiclastic calcarenite that may be cross laminated in parallel or concave sets 30 cm or more thick. A few beds in the middle and upper parts of the formation are oolitic. In contrast to the Lodgepole, a considerable part of the Mission Canyon is dolomite, generally somewhat darker and browner than the normal limestone but usually detectable only by chemical means. Nearly one-third of the formation, as recorded by Sando and Dutro (1960), is dolomite, as is a large part of both thin- and thick-bedded rocks in the section in Wigwam Creek Canyon. Nodular or ovoid chert is sparingly present in the lower part of the formation but is more abundant and more regularly bedded in the upper part. Lenses of solution or collapse breccia 1 to 6 or more meters thick are fairly common in the uppermost 30 to 60 m of the formation, especially in the vicinity of Wigwam Creek. They are commonly partly filled with reddish argillaceous deposits and are considered to have been produced during erosion of the Madison Group before deposition of the overlying Amsden Formation.

The thickness of the Mission Canyon, calculated from map measurements, ranges from about 300 m on Baldy Mountain and 305 m on Wigwam Creek to 370 m or 380 m in the central part of the Greenhorn Range and on Ruby Creek in the southeastern part of the Varney quadrangle. It appears to be about 300 m thick in the Cameron quadrangle.

PALEONTOLOGY AND CORRELATION OF THE MADISON GROUP ON BALDY MOUNTAIN

By William J. Sando and J. Thomas Dutro, Jr.

An excellent section of the Madison Group is exposed on the north flank of Baldy Mountain in the northwestern quarter of the Varney quadrangle. This section was studied in detail in the summer of 1958 as a part of biostratigraphic studies of the Madison in the northern Rocky Mountain region. A description of the section is presented below.

Section of Madison Group on Baldy Mountain

[Section begins at base of Lodgepole Limestone exposed in SE¼NW¼ sec. 27, T. 7 S., R. 3 W., Madison County, at an altitude of about 2,700 m and proceeds upspur above Garrison mine to unit 48 in Mission Canyon exposed at crest of ridge. Units 48–51 measured in S½ sec. 26. Section measured by W. J. Sando and J. T. Dutro, Jr., 1958. U.S. Geol. Survey upper Paleozoic fossil localities (USGS –PC; see table 3) given in parentheses]

	Thickness (meters)
Big Snowy-Amsden sequence:	
52. Covered. Red-weathered, fine-grained sandstone and siltstone intermingled with limestone float from below; one bed seemingly in place at contact; about 9 m of relief noted along contact.	
Madison Group:	
Mission Canyon Limestone:	
51. Limestone, fine-grained, like unit 12; probably most of unit is pelletal; crinoidal and other bioclastic debris 5 percent or less; chert about 20 percent; beds 0.3 to 0.9 m thick; forms massive benches on slope (USGS 17493–PC from lower 6 m)	38.0
50. Covered. Limestone and chert float from unit below	24.0
49. Limestone, dark-yellowish-brown, fine-grained, weathering medium light to light gray; oolitic in part, very little bioclastic debris; about 20 percent orange-weathering irregular chert sheets; beds 1 to 1.5 m thick; forms massive bench (USGS 17492–PC, 21 m above base-	16.0
48. Limestone, dark- to pale-yellowish-brown, weathering medium light to light gray, fine-grained, no bioclastic debris; 10 percent brown-weathering chert nodules; beds 0.6 to 1.5 m thick; unit partly	

Section of Madison Group on Baldy Mountain—Continued

	Thickness (meters)
Madison Group—Continued	
Mission Canyon Limestone—Continued	
brecciated, breccia is dominantly limestone having a carbonate matrix; forms south slope of ridge (USGS 17963–PC, 15 m above base; 17964–PC from lower 6 m)	16.6
47. Limestone breccia; limestone fragments 3 cm or less in diameter, fine-grained, weathering medium light gray in yellowish-weathering matrix; about 90 percent covered	11.3
46. Dolomite, like unit 45; about 90 percent covered	19.8
45. Dolomite, pale- to dark-yellowish-brown, weathering yellowish gray to pale yellowish brown, mostly fine-grained, finely laminated; bioclastic debris 5 to 10 percent; indistinct beds; chert about 20 percent, consists of brownish to jaspery nodules, feathery stringers, some subspherical nodules having concentric bands; beds 3 to 30 cm thick, platy; much brecciation and evidence of faulting	26.0
44. Limestone, medium- to coarse-grained, crinoidal, like unit 42; chert 10 percent; upper contact gradational; top of unit is at crest of ridge, cairn marks top (USGS 17961–PC 0.6 m above base)	3.7
43. Dolomite, dark-yellowish-brown, weathering light olive gray to yellowish gray, fine- to medium grained, scattered coarse crinoidal debris; about 20 percent brown and pink smooth chert nodules; beds 6 to 30 cm thick; both contacts gradational	3.0
42. Limestone, colors like unit 41, medium- to coarse-grained, crinoidal; chert as in unit 41 about 20 percent, crossbedded	7.0
41. Limestone, mostly dark-yellowish-brown, weathering medium light to light gray, fine-grained; about 10 to 20 percent coarse bioclastic debris; 10 percent smooth brown-weathering chert nodules and tabular lenses; scattered brownish-weathered dolomitic nests; beds 1 to 1.5 m thick; forms massive cliffs (USGS 17959–PC, float from lower 15 m; 17960–PC, 9 to 15 m above base, 17962–PC, 9 m above base)	21.4
40. Dolomite, colors like unit 34; fine-grained, very little bioclastic debris; about 5 percent smooth, brown-weathering chert nodules; beds 0.3 to 0.6 m thick; forms prominent notch below top of ridge	16.2
39. Limestone, medium- to coarse-grained, crinoidal, like unit 22, massive	10.0

Section of Madison Group on Baldy Mountain—Continued

	Thickness (meters)
Madison Group—Continued	
Mission Canyon Limestone—Continued	
38. Dolomite, colors like unit 34, medium- to coarse-grained, crinoidal; beds 0.3 m thick	2.4
37. Limestone, medium- to coarse-grained, crinoidal, like unit 22; about 10 percent smooth brown-weathering chert nodules; beds 1 to 1.5 m thick; travertine-filled joints; forms massive cliffs (USGS 17958–PC, 0.6 m below top)	11.0
36. Dolomitic limestone, medium- to coarse-grained, crinoidal; upper contact gradational	0.6
35. Limestone, medium- to coarse-grained, crinoidal, like unit 22; upper contact gradational (USGS 17957–PC, from upper half)	0.6
34. Dolomite, dark-yellowish-brown, weathering light olive gray to yellowish gray, fine- to medium-grained; many beds have 1- to 5-mm lamination; worm burrows common; bioclastic debris 5 percent or less; about 10 percent brownish-weathering chert in smooth and feathery irregular nodules, mostly in lower half; beds 0.3 to 0.6 m thick	4.6
33. Limestone, medium- to coarse-grained, crinoidal, like unit 22; a 0.3-m bed of fine-grained dolomitic limestone 1.5 m below top; about 10 percent jaspery, brown-weathering irregular chert nodules; crossbedded	7.0
32. Dolomite, like unit 30; crinoidal and bryozoan debris throughout and concentrated in lower 1.2 m; 5 percent brownish chert nodules and stringers; beds 0.3 to 0.9 m thick (USGS 17956–PC, float at middle)	20.7
31. Limestone, coarse-grained, crinoidal, like unit 22; crossbedded; a single bed that forms massive cliff; gradational into unit above	5.5
30. Dolomite dark-yellowish-brown, weathering light olive gray to yellowish gray, fine- to medium-grained; interbedded micrite and bryozoan-crinoidal debris; less than 5 percent dark-brown chert nodules and stringers; beds 9 to 60 cm thick; forms rubble-covered notch (USGS 17955–PC, float from unit)	15.5
29. Limestone, medium- to coarse-grained, crinoidal, like unit 22; crossbedded; beds 0.2 to 1.1 m thick; grades into unit above	2.7
Total Mission Canyon Limestone	284
Lodgepole Limestone:	
Woodhurst Limestone Member:	
28. Limestone, like unit 25 but bedding averages a little thinner (3 to 9 cm) and nodular bedding is more common; upper 1.5 m dolomitic; unit	

Section of Madison Group on Baldy Mountain—Continued

	Thickness (meters)
Madison Group—Continued	
Lodgepole Limestone—Continued	
Woodhurst Limestone Member—Continued	
forms massive cliff because silty beds do not weather free	14.5
27. Limestone, like unit 25 (USGS 17953–PC, from float throughout; 17954–PC, 0.6 m below top)	21.4
26. Limestone, like unit 25; bedding deformed by fault that cuts across bedding at an angle of 40° to 60°	3.4
25. Limestone, fine- to coarse-grained; fine-grained limestone beds 6 to 15 cm thick compose about 80 percent of unit; yellowish- to purplish-weathering silty partings are about 10 percent of unit; coarse-grained crinoidal limestone beds as much as 30 cm thick are about 10 percent of unit; fossils mostly in silty partings, *Zoophycos* and other trace fossils common (USGS 17951–PC, 4.3 to 4.6 m above base; 17952–PC, 10 m above base)	12.5
24. Limestone, medium- to coarse-grained, crinoidal, like unit 22; beds 0.3 to 0.9 m thick (USGS 17950–PC, 1.5 to 2.4 m above base)	2.7
23. Limestone, fine- to coarse-grained, like unit 20; forms notch	2.0
22. Limestone, dark- to pale-yellowish-brown, weathering medium light to light gray, medium- to coarse-grained; consists of medium- to coarse-grained crinoidal debris in micrite matrix; crossbedded; beds 15 to 60 cm thick; forms prominent cliff	4.3
21. Limestone, like unit 20, but coarse bioclastic beds constitute about 30 percent of unit; many yellowish-weathering silty beds (USGS 17947–PC, 3 m above base; 17948–PC, 4.3 m above base; 17949–PC, 1.8 m below top)	9.0
20. Limestone, fine- to coarse-grained, like unit 18; includes several 30-cm beds of coarse bioclastic limestone; nodular-bedded in part; bedding planes weather yellowish and purplish; abundant worm tracks; many cross joints filled with dog-tooth spar; upper half mostly covered by talus (USGS 17945–PC, 5.8 m above base; 17946–PC, float 25 m above base probably from bed in upper meter)	27.4
19. Limestone, fine- to coarse-grained; micrite to fine calcarenite (50 percent), silty beds (10 percent), coarse bioclastic beds (20 percent); about 20 percent chert as in unit 17; beds 6 to 30 cm thick (USGS 17944–PC, 1.2 to 1.5 m above base)	5.6

Section of Madison Group on Baldy Mountain—Continued

	Thickness (meters)
Madison Group—Continued	
Lodgepole Limestone—Continued	
Woodhurst Limestone Member—Continued	
18. Limestone, fine- to coarse-grained; micrite to fine calcarenite (70 percent), silty beds (10 percent), coarse bioclastic beds (20 percent); beds 6 to 30 cm thick (USGS 17941–PC, from lower 30 cm; 17942–PC, 7.3 m above base; 17943–PC, 9.5 m above base)	11.0
17. Limestone, olive-gray to light-olive-gray, weathering medium to light gray, fine- to coarse-grained; micrite to fine calcarenite (65 percent), silty, yellowish-weathering beds (10 percent), coarse bioclastic beds (5 percent); brownish-weathering chert in spongy irregular sheets and nodules (20 percent); worm tracks; forms prominent bench (USGS 17939–PC, 0.9 m above base; 17940–PC, 4.6 m above base)	7.8
16. Limestone, fine- to coarse-grained; micrite to fine calcarenite (50 percent); silty, argillaceous platy beds (20 percent), coarse bioclastic beds (30 percent); bedding planes weather yellowish and purplish; limestone is olive gray, weathering medium light and light gray; *Zoophycos* and other trace fossils; unit is poorly resistant (USGS 17936–PC, 1.2 m above base; 17937–PC, float 1.5 m above base; 17938–PC, from upper 0.6 m)	7.9
15. Limestone, like unit 14 but contains more bioclastic beds (about 20 percent) and about 10 percent fuzzy tabular lenses of incipient brown chert; forms bench; first occurrence of *Vesiculophyllum* 0.6 m below top (USGS 17930–PC, from lower 30 cm; 17931–PC, 3 m above base; 17932–PC, float throughout; 17933–PC, 5.2 m above base; 17934–PC, 1.5 m below top; 17935–PC, 0.6 m below top)	12.2
14. Limestone, fine- to coarse-grained; interbedded micrite to calcarenite (90 percent) and coarse bioclastic debris in thin beds and lenses (10 percent); platy beds weather yellowish and purple; *Zoophycos* and other trace fossils common; beds 6 to 30 cm thick, bedding irregular; forms cliffy slope (USGS 17927–PC, float 3 m above base; 17928–PC, 7.6 m above base; 17929–PC, 10.7 m above base)	12.5
13. Limestone, medium-gray to olive-gray, weathering medium light gray with much orange stain, coarse-grained, bioclastic; contains about 10 percent pebbles of fine-grained limestone; cross-	

Section of Madison Group on Baldy Mountain—Continued

	Thickness (meters)
Madison Group—Continued	
Lodgepole Limestone—Continued	
Woodhurst Limestone Member—Continued	
bedded; first occurrence of *Homalophyllites* (USGS 17926–PC, from throughout unit)	1.5
Total Woodhurst Limestone Member of Lodgepole Limestone	155.8
Paine Shale Member:	
12. Limestone, fine-grained, argillaceous, like unit 4; well-laminated, faint irregular laminae 1 to 4 mm thick; contains mud-ball structures, worm tracks poorly exposed, forms rubbly slope	10.4
11. Limestone, fine-grained, argillaceous, like unit 3; weathers platy and hackly; laminae 1 to 2 mm thick; forms prominent bench	1.8
10. Limestone, fine- to medium-grained, argillaceous; interbedded micrite, like unit 4 (85 percent), and fine calcarenite, like unit 5 (15 percent); upper 15 m poorly exposed; forms rubbly slope (USGS 17920–PC, 0.3–0.6 m above base; 17921–PC, 3 m above base; 17922–PC, 6 m above base; 17923–PC, float from lower 6 m; 17924–PC, float throughout unit; 17925–PC, float from upper 16 m)	22.5
9. Limestone, medium-grained, like unit 5; 10 percent incipient ferruginous chert in layers; mudcracks(?)	0.9
8. Limestone, fine-grained, like unit 4 (USGS 17919–PC from throughout unit)	1.5
7. Limestone, mottled orange, medium-grained, like unit 5, crossbedded	0.2
6. Limestone, fine-grained, like unit 4; purple bedding surfaces common in silty beds (USGS 17918–PC, 1.8 m above base)	3.7
5. Limestone, grayish-brown, weathering brownish gray, medium-grained; laminated, crossbedded fine calcarenite; small nodules of orange-weathered ferruginous chert; one bed	0.2
4. Limestone, fine-grained, argillaceous, like unit 3 but more conspicuously bedded; beds 6 to 15 cm thick, separated by 3- to 12-cm beds of silty, purplish platy limestone; limonite concretions: spaghettilike worm markings; forms rubbly slope (USGS 17916–PC, 4.5 m below top; 17917–PC, upper 0.9 m)	13.7
3. Limestone, olive- to light-olive-gray, weathering medium light to light gray, fine-grained, argillaceous; micrite and silt-sized carbonate; beds 9 to 30 cm thick; silty layers define bedding planes but are not conspicuous; about 5 percent	

Section of Madison Group on Baldy Mountain—Continued

	Thickness (meters)
Madison Group—Continued	
Lodgepole Limestone—Continued	
Paine Shale Member—Continued	
scattered hematite nodules 3 cm in average diameter; forms prominent hackly bench (USGS 17911–PC, from lower 0.6 m; 17912–PC, 2 to 3 m above base; 17913–PC, 5.5 to 7 m above base; 17914–PC, 8.2 to 10 m above base; 17915–PC, 11 to 14.5 m above base)	16.8
2. Limestone, olive-gray, weathering medium to medium light gray, mottled orange; coarse-grained, crinoidal; beds 30 cm thick	0.9
Total Paine Shale Member of Lodgepole Limestone	73.7
Total Lodgepole Limestone	229.5
Total Madison Group	513.5
Three Forks Formation:	
Sappington Sandstone Member:	
1. Quartz sandstone, dark-yellowish-brown, fine-grained fucoidal; beds 30 cm thick; mostly covered.	

A rich invertebrate fauna collected from the Baldy Mountain section permits biostratigraphic zonation of the Madison Group according to the scheme originally published by Sando and Dutro (1960). The results of subsequent study, by B. L. Mamet, of foraminiferal samples from this locality were incorporated in Sando, Mamet, and Dutro (1969). A list of megafossils from Baldy Mountain, showing their distribution in the Madison, is given in table 3.

All the lithic divisions of the type Madison are recognized in sequence, and representatives of Kinderhookian, Osagean, and lower Meramecian divisions of the type Mississippian have been established by means of the fossils (table 3). Zone boundaries are recognized principally on coral ranges. Zone A, originally reported by Sando and Dutro (1960) in the section, is no longer recognized here because of the lack of certain critical coral species. No brachiopods characteristic of Zone A occur in the section, and the presence of *Leptagonia* cf. *L. analoga* (Phillips) in the lowest collection confirms the evidence of the corals that the earliest fossils here are assignable to Zone B.

Characteristic Zone B brachiopod assemblages are found in the strata identified as this zone on the basis of corals. However, ranges of some brachiopod species are greater than those found in other sections in southwestern Montana. For example, *Cyrtina*

TABLE 3.—*Invertebrate fossils collected from the Madison Group on Baldy*

[Fossils collected by W. J. Sando and J. T. Dutro, Jr., and identified by Helen Duncan (bryozoans), J. T. Dutro, Jr. (brachiopods and

MEGAFOSSILS	PAINE SHALE MEMBER												
	ZONE B												
	17911	17912	17913	17914	17915	17916	17917	17918	17919	17920	17921	17923	17922
Corals:													
Cyathaxonia cf. *C. tantilla* (Miller)	X		X	X	X								
Permia? sp.	X	X	X		X								
"*Amplexus*" sp.		X	X	X									
Zaphrentites spp.													
Homalophyllites spp.													
"*Menophyllum*" sp.													
Canadiphyllum? sp.													
Vesiculophyllum sp.													
Horn corals, indet.										X			
Diphyphyllum sp.													
Lithostrotionella microstylum (White)													
Michelinia cf. *M. expansa* White													
M.? sp.													
Aulopora sp.					X								
Syringopora aculeata Girty													
S. surcularia Girty													
S. aff. *S. surcularia* Girty													
S. sp. indet.													
Syringoporoid coral				X	X								
Bryozoans:													
Cliotrypa? sp.				X	X								
Eridopora sp.					X								
Fistuliporoid bryozoan													
Ramiporalia sp.			X										
Fenestella cf. *F. tenax* Ulrich													
F. spp.			X	X	X	X			X	X		X	
Polypora sp.													
Ptiloporella sp.													
Fenestrate bryozoan	X												
Penniretepora sp.					X	X						X	
Ptilopora sp.													
"*Rhombopora*" sp.													
Streblotrypa? sp.													
Rhomboporoid bryozoan						X			X			X	
Cystodictya sp.						X			X	X		X	
Dichotrypa sp.													
Trepostomatous bryozoan, ramose form													
Bryozoan, indet.													

Mountain (NW¼ sec. 27 and sec. 26, T. 7 S., R. 3 W., Madison County, Montana)

echinoderms), W. J. Sando (corals), and E. L. Yochelson (mollusks). Collections are arranged with lowest on left and highest on right.]

LODGEPOLE LIMESTONE																															MISSION CANYON LIMESTONE											
		WOODHURST LIMESTONE MEMBER																																								
		ZONE C_1																													ZONE C_2							ZONE D				
		USGS Upper Paleozoic Fossil Localities (-PC)																																								
17924	17925	17926	17927	17928	17929	17930	17931	17933	17934	17935	17932	17936	17937	17938	17939	17940	17941	17942	17943	17944	17945	17946	17947	17948	17949	17950	17951	17952	17953	17954	17955	17956	17957	17958	17959	17962	17960	17961	17964	17963	17492	17493
																				X																						
						X		X	X			X					X	X									X	X	X				X								?	
		X				X		X	X	X		X	X		X		X	X	X			X	X	X		X	X			X			X	X	X	X	X	X				
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		X	X				X																																			
																	X																									

TABLE 3.—*Invertebrate fossils collected from the Madison Group on Baldy Mountain*

MEGAFOSSILS	PAINE SHALE MEMBER												
	ZONE B												
	17911	17912	17913	17914	17915	17916	17917	17918	17919	17920	17921	17923	17922
Echinoderms:													
Cryptoblastus sp.					X								
Actinocrinitid crinoid columnals and plates													
Platycrinites sp.													
Platycrinitid crinoid columnals and plates													
Echinoid plates													
Brachiopods:													
Philhedra sp.					X					?			
Rhipidomella sp.										X			
Schizophoria cf. S. swallovi (Hall)													
Leptagonia cf. L. analoga (Phillips)	X												
Schuchertella sp.												X	?
Schellwienella sp.													
Orthotetid brachiopod													
Caenanoplia? logani (Norwood and Pratten)			X		X	X			X	X	X	X	X
Rugosochonetes loganensis (Hall and Whitfield)							X	X	X			X	X
R. sp.													
Chonetoid brachiopod													
Orbinaria sp.					?	X				?	X		
Marginatia cf. M. burlingtonensis (Hall)													
M. cf. M. fernglenensis (Weller)													
M. sp.												X	X
Buxtonia? cf. B.? viminalis (White)													
B.? sp.											X	X	X
Ovatia sp.												X	X
Echinoconchus cf. E. alternatus (Norwood and Pratten)													
Dictyoclostid brachiopod													
Productoid brachiopod						X					X		
Axiodeaneia platypleura Clark									X			X	
"Camarotoechia? sp.											X	X	
Tetracamera? sp.													
Rhynchonelloid brachiopod					X					X			
Eumetria sp.													
Actinoconchus? sp.													
Composita madisonensis (Girty)												X	X
C. humilis (Girty)					X								
C. sp.													
Cleiothyridina cf. C. tenuilineata (Rowley)											X		
C. cf. C. incrassata (Hall)												X	
C. aff. C. obmaxima (McChesney)													
C.? sp.													X
Crurithyris? sp.					X								

(NW¼ sec. 27 and sec. 26, T. 7 S., R. 3 W., Madison County, Montana)–Continued

LODGEPOLE LIMESTONE																															MISSION CANYON LIMESTONE											
		WOODHURST LIMESTONE MEMBER																																								
		ZONE C_1																													ZONE C_2							ZONE D				
		USGS Upper Paleozoic Fossil Localities (-PC)																																								
17924	17925	17926	17927	17928	17929	17930	17931	17933	17934	17935	17932	17936	17937	17938	17939	17940	17941	17942	17943	17944	17945	17946	17947	17948	17949	17950	17951	17952	17953	17954	17955	17956	17957	17958	17959	17962	17960	17961	17964	17963	17492	17493
	X								X		X										X								X													
X			X										X	X					X			X					X	X	X													
		X		X			X	X	X							X	X			X			X																			
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																							X																			

TABLE 3.—*Invertebrate fossils collected from the Madison Group on Baldy Mountain*

MEGAFOSSILS	PAINE SHALE MEMBER												
	ZONE B												
	17911	17912	17913	17914	17915	17916	17917	17918	17919	17920	17921	17923	17922
Ambocoelid brachiopod	X		X	X	X								
Cyrtina cf. C. burlingtonensis Rowley						X						X	X
C.? sp.							X						
Unispirifer cf. U. centronatus (Winchell)						X		X			X	X	X
U. sp.				?									
Amesopleura? cf. A.? semifurcatus (Girty)					X								
A.? sp.												X	X
Imbrexia sp.												X	X
Spirifer cf. S. rowleyi Weller												X	
"Spirifer" cf. "S." biplicoides Weller													
S. sp. (small)													
Anthracospirifer aff. A. keokuk (Hall)													
A. sp.													
Tylothyris? sp.													
Martinia rostrata Girty						X						X	
Torynifer cf. T. cooperensis (Swallow)													
T.? sp.													
Brachythyris cf. B. suborbicularis (Hall)												X	X
B. sp.					?								
Spiriferoid brachiopod													
Syringothyris sp.													
Punctospirifer cf. P. solidirostris (White)													
P. sp.									?				
Hustedia? sp.												X	
Beecheria? chouteauensis (Weller)		X											
B.? sp.													
Terebratuloid brachiopod				X	X								
Brachiopod fragments, indet.					X		X			X			
Gastropods:													
Straparollus (Euomphalus) cf. S. (E.) subplanus (Hall)													
S. (E.) sp. indet.													
Rhineoderma cf. R. pealeana (Girty)													
R. sp. indet.													
Pleurotomariacean gastropod cf. Eotrochus													
Mourlonia sp.													X
"Pleurotomaria" cf. "P." brazeriana Girty													
Pleurotomariacean gastropod cf. Worthenia													
Platyceras (Platyceras) n. sp. (spinose)													
P. (P.) spp.													
P. (Orthonychia) sp.								X					
High-spired gastropod cf. Loxonema													
Meekospira? elegans (Girty)													

(NW¼ sec. 27 and sec. 26, T. 7 S., R. 3 W., Madison County, Montana) – Continued

LODGEPOLE LIMESTONE — WOODHURST LIMESTONE MEMBER — ZONE C_1 (17924–17954); MISSION CANYON LIMESTONE — ZONE C_2 (17955–17960); ZONE D (17961–17493)

USGS Upper Paleozoic Fossil Localities (-PC)

17924	17925	17926	17927	17928	17929	17930	17931	17933	17934	17935	17932	17936	17937	17938	17939	17940	17941	17942	17943	17944	17945	17946	17947	17948	17949	17950	17951	17952	17953	17954	17955	17956	17957	17958	17959	17962	17960	17961	17964	17963	17492	17493
									X							X		X				X																				
																X																										
X		X				X	X	X	X		X		X	X	X	X				X	X					X	X	X														
			X											X			X	X						X												X						
	X	X		X					X				X														X															
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cf. *C. burlingtonensis* Rowley, previously thought to be confined to Zone B, ranges upward as high as USGS 17940–PC (U.S. Geological Survey upper Paleozoic fossil locality).

Zone C_1 marks the advent of the corals *Homalophyllites* and *Vesiculophyllum* in the sequence as well as *Lithostrotionella microstylum* (White) and *Michelinia* cf. *M. expansa* White, which are indices of the zone. This zone in this section has most of the brachiopod taxa that characterize the zone in many places in the northern Rockies, but, again, some of the ranges are modified. *Rugosochonetes loganensis* (Hall and Whitfield) begins lower in this section than normal, being found as low as USGS 17917–PC. However, it does range above Zone C_1, and the C_1–C_2 boundary is a sharp one.

An interesting rhynchonelloid species, common in this section but rare elsewhere, is *Axiodeaneia platypleura* Clark. This elongate and straight-sided shell, first described from the Baldy Mountain locality, ranges through the upper part of Zone B into the lower part of Zone C_1 (USGS 17919–PC through 17932–PC).

Zone C_2 is characterized by continuation of the corals *Homalophyllites* and *Vesiculophyllum.* Zone D is recognized by the appearance of the new coral elements *Diphyphyllum* and *Zaphriphyllum.* Zones C_2 and D have very few brachiopods, but those that do occur are indicative forms. *Anthracospirifer* cf. *A. keokuk* (Hall), *Cleiothyridina* aff. *C. obmaxima* (McChesney), and a large *Spirifer* are found in Zone C_2; *Anthracospirifer* sp., *Tetracamera*? sp., and a large orthotetid brachiopod occur in Zone D.

Zone B is regarded as Kinderhookian in age. Osagean-age beds include Zones C_1 and C_2. Zone D is of early Meramecian (Salem) age.

BIG SNOWY GROUP AND AMSDEN FORMATION

The rocks that overlie the Madison Group in central and western Montana consist of a varied assemblage of limestone, shale, and red beds, whose age and stratigraphic relations have been debated for many years. In central Montana, the rocks in question have been generally assigned to the Big Snowy Group (Scott, 1935; Gardner, 1959); in Wyoming, they usually have been referred to the Amsden Formation and the Sacajawea Formation of Branson (1937).

In the Varney quadrangle, the rocks between the Madison Group and the Quadrant Quartzite are represented by two quite different sequences. One sequence, exposed in the Gravelly Range east of the Greenhorn fault, is less than 75 m thick, appears to be largely of

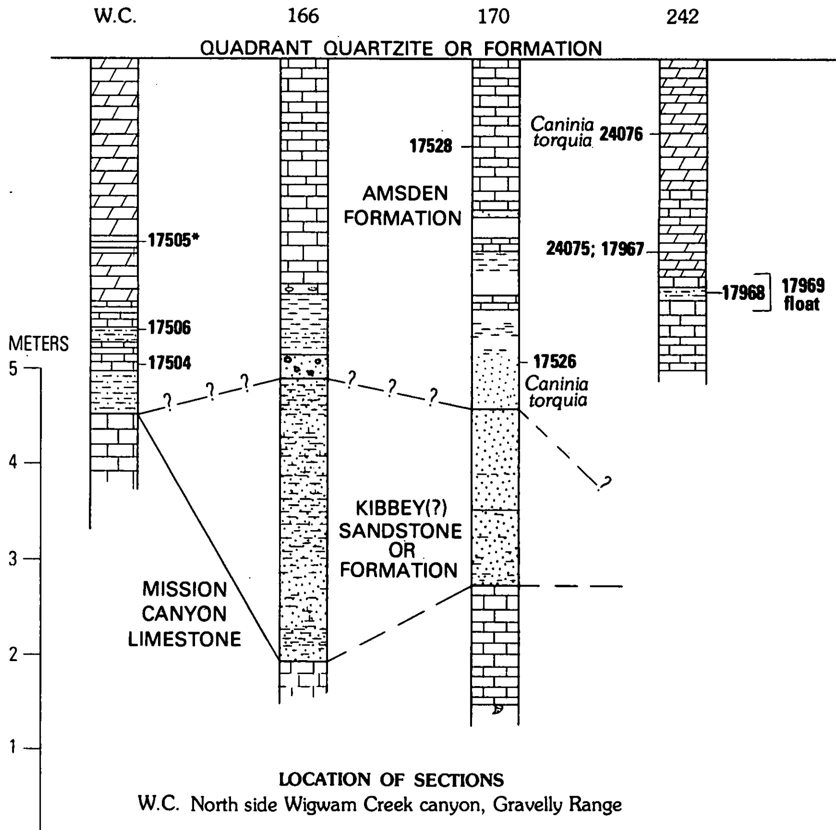
Early Pennsylvanian age, and is tentatively correlated with the upper part of the Amsden Formation of north-central Wyoming. The other sequence, exposed in the vicinity of Baldy Mountain and farther south in the Greenhorn Range, is nearly 275 m thick and includes beds of Pennsylvanian age as well as beds of Late Mississippian age, which are correlated with the Big Snowy Group.

Rocks assigned to the Big Snowy Group can be traced for several kilometers in the Greenhorn Range along the ridges leading east and south from Baldy Mountain and across the floor of the cirque at the head of Arasta Creek. Measured sections in this belt are shown in figure 2. The lower 60 m or so of the Big Snowy Group is generally covered, but appears to consist largely of silty clay shale and calcareous sandstone and minor interbedded greenish-gray cherty limestone. The clastic rocks are characteristically red, although greenish-gray shale is locally abundant. Sandstone and red color are more common in the lower part of this interval; interbedded limestone is more common in the upper part. These dominantly clastic rocks are overlain by a sequence 76 to 110 m thick of thin- to thick-bedded limestone, generally pale olive gray and commonly very fossiliferous. A unit of coarse bioclastic limestone 7.6 to 12 m thick (unit 7, stratigraphic section 4) was traced for several miles, and a bed containing abundant corals of the species *Caninia excentrica* in growth position, identified by W. J. Sando, was found in two of the sections studied. The interbedded shale in this dominantly limestone interval is silty clay shale, nowhere sandy, generally dark greenish or olive gray, and lacking megafossils.

Little correlation could be established with the six formations of the Big Snowy Group as described in the Big Snowy Mountains, 275 km northeast of the Varney quadrangle (Gardner, 1959). The basal 60 m of red silty shale and sandstone, however, is similar to the Kibbey Sandstone or Formation that rests unconformably on the Madison Limestone in the Big Snowy Mountains (Scott, 1935, p. 1026). The overlying sequence of fossiliferous limestone and shale in the Varney quadrangle may contain equivalents of the Otter and Heath Formations, but direct correlation has not been made.

Fossil collections by J. T. Dutro, Jr., and W. J. Sando from parts of section 147 (fig. 2) contain an abundant shelly fauna of Late Mississippian age (J. T. Dutro, Jr., written commun., 1970).

The thinner post-Madison rocks east of the Greenhorn fault (fig. 2, columnar sections W. C., 166, 170, 242) consist largely of



LOCATION OF SECTIONS

W.C. North side Wigwam Creek canyon, Gravelly Range

166. 1.6 km northwest of Crockett Lake, Gravelly Range

170. 1.6 km southwest of Crockett Lake, Gravelly Range

242. Head of Middle Fork, Warm Springs Creek, Gravelly Range

147. Floor of cirque on Arasta Creek, Greenhorn Range

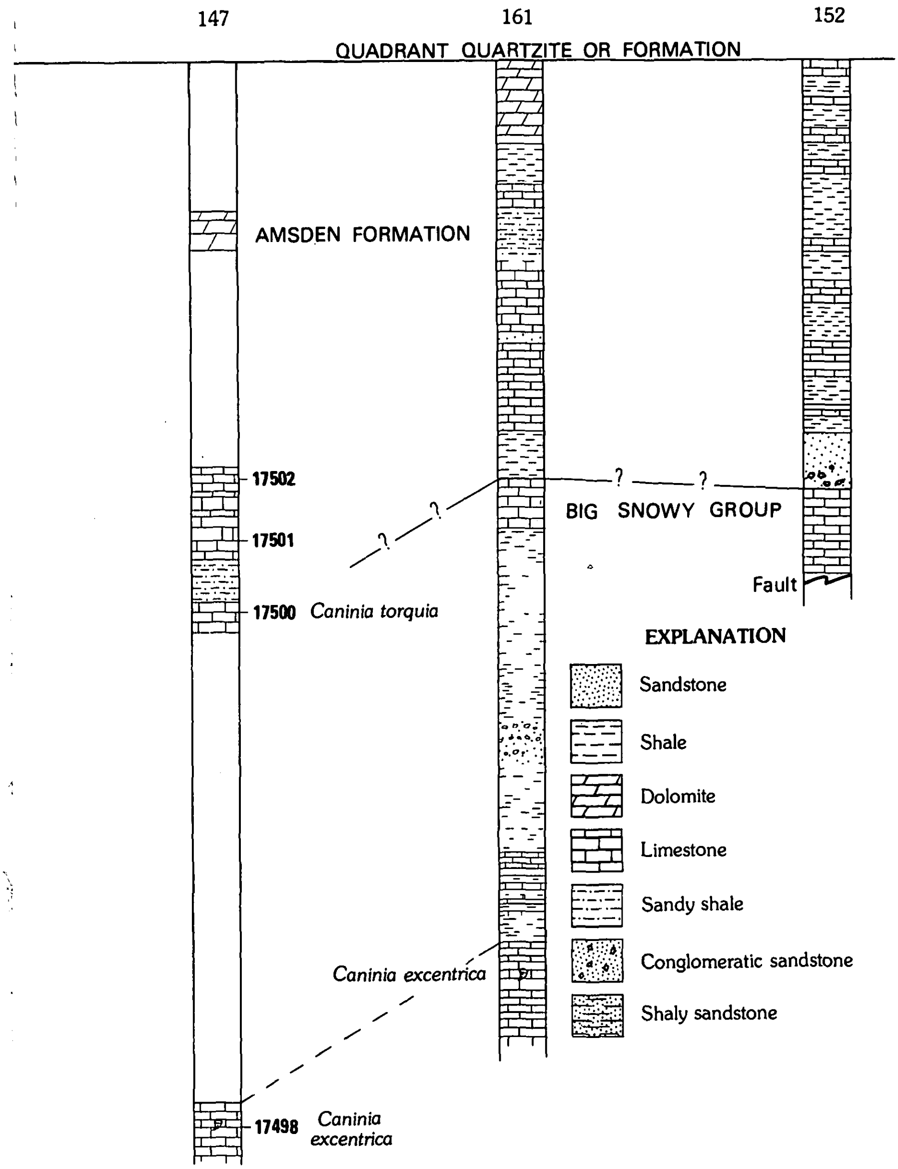
161. South ridge Baldy Mountain, Greenhorn Range

152. South ridge Baldy Mountain, Greenhorn Range

* USGS Upper Paleozoic locality number

FIGURE 2.—Columnar sections of the Amsden For

varicolored limestone, dolomite, and shale; shale becomes increasingly abundant in the lower part of the unit. The top of the unit is fairly well defined by the appearance of clean, well-sorted white



mation and underlying beds, Varney quadrangle.

quartz sandstone of the Quadrant Quartzite or Formation, which commonly contains unoriented fragments of light-gray dolomite. The clastic rocks of the lower part of the unit are dominantly red, sandy, or silty shale or mudstone and fine-grained red silty sandstone. They lie directly on the Mission Canyon Limestone; a variation in thickness apparently reflects karst topography. This relation is well exposed on the north wall of the Wigwam Creek Canyon (fig. 2, columnar section W. C.), where the basal clastic unit, 1 to 6 m thick, which consists of unsorted reddish-brown mudstone and scattered small fragments of chert, appears to represent a residuum accumulated on the underlying limestone and little reworked during deposition of the overlying rocks. Elsewhere, the clastic beds are a good deal thicker and more distinctly bedded (fig. 2, columnar sections 166 and 170). Interbeds of medium- to fine-grained calcareous sandstone are locally current bedded and contain well-rounded pebbles of chert and various types of limestone along with waterworn shells and fish teeth. Fossil collections from two of these sections (fig. 2, columnar sections W. C. and 242) yielded only Early Pennsylvanian species, with the single exception of a chaetetiform bryozoan, possibly of Mississippian age (J. T. Dutro, Jr., written commun., 1970).

Correlative sections west of the Greenhorn fault (fig. 2, columnar sections 152 and 161) lie on beds assigned to the Big Snowy Group, as previously described. These sections contain significantly more shale in their upper parts than do the sections to the east, but they otherwise contain similar varicolored limestone and dolomite. Fossils collected from beds 52 to 72 m below the Quadrant Quartzite (columnar section 147) are Early Pennsylvanian (J. T. Dutro, Jr., and W. J. Sando, written commun., 1970).

Although the upper part of the post-Madison, pre-Quadrant sequence in the Varney quadrangle is clearly of Early Pennsylvanian age, correlation with the type Amsden Formation of north-central Wyoming is questionable. Possibly one or more of the thin sandstone units shown in columnar sections 161, 166, 170, and 152 (fig. 2) may be the Darwin Sandstone Member, considered to be the basal member of the Amsden in nearby parts of northwestern Wyoming (Sando and others, 1975), but which, if any, of these thin sandstone units may have regional significance is not known.

Stratigraphic section 4

[Amsden Formation and Big Snowy Group, NW¼ sec. 35 and SW¼ sec. 26, T. 7 S., R. 3 W., Varney quadrangle. Measured by J. B. Hadley and E. H. McKee]

	Thickness (meters)
Quadrant Quartzite (incomplete):	
20. Dolomite, massive, brecciated, medium to coarsely crystalline, calcareous; in part contains abundant white quartz grains and fragments of light-gray fine-grained dolomite and white quartzite	12

Stratigraphic section 4—Continued

	Thickness (meters)
Quadrant Quartzite (incomplete)—Continued	
19. Sandstone, white, weathering light brown, calcareous, poorly bedded, abundant well-rounded grains.	
18. Covered	18
Amsden Formation:	
17. Dolomite, light-yellowish-gray to pale-yellowish-orange, medium- to coarse-grained; in part thin bedded (1–10 cm); in part massive and brecciated, containing fragments of limestone and dolomite in limestone matrix. Upper meter is limestone, aphanitic, containing prominent calcite grains, light olive gray	4.6
16. Covered	26
15. Limestone, light-yellowish-gray, and dolomite, fine- to medium-crystalline, highly calcareous; thick to thin bedded, containing beds of fine sandstone, moderate reddish brown to pale red and dolomitic, and grayish-pink sandy dolomite. Thin bed of white quartz sandstone in upper part. Top bed of unit is light-gray limestone, 55 cm thick, like unit 13. Fossil collection USGS 17052–PC, 1.5 m below top of unit	6
14. Lower 4.5 m poorly exposed, probably mudstone; chips in soil are fine sandy mudstone, pale green, purplish gray, and red, dolomitic. Upper part is limestone, light-yellowish-gray to pale-yellowish-orange variegated, fine-grained to aphanitic, thin- to medium-bedded. Considerable compact chert, reddish to brownish, in nodules and thin lenses. One 60-cm bed bioclastic calcarenite. Fossil collection USGS 17501–PC, 3.7 to 7 m above base of unit	11
13. Limestone, yellowish-gray to pale-brown, aphanitic to finely crystalline, medium-bedded; minor yellowish- to reddish-brown compact chert in lenses 5 cm and less thick. Fossil collection USGS 17500–PC, 3.7 m above base of unit	4.6
12. Covered	50
Big Snowy Group:	
11. Limestone	3
10. Covered	6
9. Limestone, lower part olive gray to brownish gray, medium bedded, containing thin argillaceous beds; upper part, medium dark gray to olive gray, medium bedded, finely crystalline, considerable olive- to dark-gray chert lenses and nodules. Fossiliferous, 30- to 60-cm *Caninia* reef. Fossil collection USGS 17498–PC, from beds in upper part of unit	6
8. Covered	7.5
(Section offset 1.2 km to northwest)	
7. Limestone, thick-bedded, in part cross laminated, coarsely crystalline and bioclastic, locally aphanitic; forms promi-	

Stratigraphic section 4—Continued

	Thickness (meters)
Big Snowy Group—Continued	
nent ridge. Fossiliferous, prominent zone of horn corals 3 m below top of unit. Fossil collections USGS 17496–PC and 17497–PC	11
6. Limestone, grayish-orange to pale-brown, mainly thin bedded, platy, in part argillaceous, interbedded with 8-cm beds olive-gray limestone; like unit 4, but less argillaceous	7
5. Poorly exposed on crest of ridge. Limestone, yellowish-brown and dark-gray, medium to moderately thin bedded, ramifying chert; upper 0.6 to 6 m coarsely bioclastic. Fossil collection 4.6 m below top, USGS 17495–PC	20
4. Limestone, light-olive-gray, medium–bedded, aphanitic to medium crystalline containing beds of yellowish-gray, yellowish-orange, and reddish variegated argillacous limestone, few nodules dark-gray chert in lower part. Fossil collection from upper 7 m, USGS 17494–PC	15
3. Shale, dark- to dusky-yellowish-brown, calcareous, silty, fissile, interbedded with olive-gray argillaceous, medium-bedded limestone. Bedding disturbed; thickness approximate	15
2. Largely covered. Includes at least 30 m clastic red beds	55
Mission Canyon Limestone:	
1. Limestone, moderate-yellowish-brown and aphanitic to light-brownish-gray and medium to coarsely crystalline, some bioclastic. Two coral zones 40 to 45 m below top	84

The following fossil collections were made by J. T. Dutro, Jr., and W. J. Sando from beds between the Mission Canyon Limestone and the Quadrant Quartzite in the cirque valley at the head of Arasta Creek, just east of Baldy Mountain. The corals were identified by W. J. Sando; bryozoans, by Helen Duncan; pelecypods, by John Pojeta, Jr.; gastropods, by E. L. Yochelson; and brachiopods, by J. T. Dutro, Jr., all of the U.S. Geological Survey.

Upper Mississippian:

USGS 17494–PC. Big Snowy Group about 30 m above the basal red-bed unit. Unit 4, stratigraphic section 4.

trepostomatous bryozoan (encrusting form), undet.
Fenestella sp.
Septopora sp.
rhomboporoid bryozoan, genus indet.
Orbiculoidea sp.
Orthotetes? sp.
Nix angulata Easton
Ovatia cf. O. ovata (Hall)
Flexaria sp.
Inflatia cf. *I. inflata* (McChesney)

Upper Mississippian—Continued

USGS 17494–PC—Continued

Crurithyris? sp.
Punctospirifer transversus (McChesney)
Limipecten sp.
Aviculopecten sp.
?*Pteronites* sp.
Myalina sp.
Cypricardella sp.
Nuculopsis sp.
Phestia sp.
Septimyalina sp.
Parallelodon sp.
?*Sphenotis* sp.
crassatellacean, indet.
Platyceras sp.
Bellerophon sp.
Straparollus (*Euomphalus*) sp.
pleurotomarian gastropod, indet.
Euphemites cf. *E. sacajawensis* Branson
"*Bulimorpha*" sp.
Knightites (*Retispira*) sp.
Paleostylus (*Pzeudozygopleura*) sp.

USGS 17495–PC, Big Snowy Group about 45 m above the basal red-bed unit. Unit 5, stratigraphic section 4.

crinoid columnals, indet.
echinoid plates and spines, indet. cidarid
Zaphrentites? sp.
Inflatia sp.
Anthracospirifer sp.
Composita sp.
Crurithyris sp.
Punctospirifer transversus (McChesney)
Reticulariina spinosa (Norwood and Pratten)
Eumetria sp.
Cranaena? sp.
terebratuloid, indet.

USGS 17496–PC, Big Snowy Group about 60 m above the basal red-bed unit. Unit 7, stratigraphic section 4.

crinoid columnals, indet.
echinoid plates and spines, indet. cidarid
Pentremites sp.
Zaphrentites? sp.
Michelinia cf. "*Pleurodictyum meekanum?*" of Nelson (1962)
ramose and fenestrate bryozoans, undet.
Orthotetes sp.
Nix angulata Easton

Upper Mississippian—Continued

USGS 17496–PC—Continued

chonetid, indet.
Inflatia sp.
Flexaria sp.
Ovatia sp.
Avonia? sp.
productoid fragments, indet.
Anthracospirifer sp.
Composita sp.
Eumetria sp.
Punctospirifer transversus (McChesney)
Reticulariina spinosa (Norwood and Pratten)
Girtyella? sp.
terebratuloid, indet.
Cypricardella sp.
Parallelodon sp.
?*Nuculopsis* sp.
Septimyalina sp.
Cypricardinia sp.
nuculoid pelecypod, indet.
pelecypods, indet.
Euphemites sp.
Bellerophon sp.
cf. *Pleurotomaria brazeriana* Girty
Knightites? sp.
Naticopsis sp.
Agnesia? sp.
Straparollus (*Euomphalus*) sp.
gastropod, indet.
orthoconic cephalopod, undet.

USGS 17497–PC, Big Snowy Group. Unit 7, stratigraphic section 4; essentially same level as USGS 17496–PC.

echinoderm columnals, indet.
Pentremites sp.
Zaphrentites? cf. *Z.*? *spinulosa* Milne-Edwards and Haime
Michelinia cf. "*Pleurodictyum meekanum*?" of Nelson (1962)
chaetetiform bryozoan, undet.
Inflatia sp.
Flexaria sp.
Krotovia? sp.
Avonia? sp.
Spirifer brazerianus Girty
Anthracospirifer aff. *A. curvilateralis* (Easton)
Composita sp.
Torynifer? sp.
Septimyalina sp.

Upper Mississippian—Continued

USGS 17497–PC—Continued

Phestia sp.
cf. *Palaeoneilo* sp.
cf. *Similodonta* sp.
aff. *Nuculopsis* sp.
"*Phanerotrema*" *brazeriana* Girty
cephalopod, indet.
bone and tooth fragments, indet.

USGS 17498–PC, Big Snowy Group about 75 m above the basal red-bed unit. Unit 9, stratigraphic section 4.

Caninia excentrica (Meek)
Fenestella sp.
rhomboporoid bryozoan, undet.
Chonetes sp.
Inflatia spp.
Flexaria sp.
Krotovia? sp.
Spirifer brazerianus Girty (abundant)
Anthracospirifer n. sp.
Cleiothyridina aff. *C. sublamellosa* (Hall)
Composita cf. *C. subquadrata* (Hall)
Torynifer cf. *T. setigera* (Hall)
Reticulariina spinosa (Norwood and Pratten)
Dielasma? sp.
Cranaena? sp.
Conocardium sp.
Straparollus (*Euomphalus*) sp.
bellerophontacean gastropod, indet.
trilobite pygidium, undet.

Lower Pennsylvanian:

USGS 17500–PC, Amsden(?) Formation about 46 m below the Quadrant Quartzite. Unit 13, stratigraphic section 4.

Caninia cf. *C. torquia* (Owen)
Antiquatonia cf. *A. pernodosa* Easton
Rugoclostus? sp.
Linoproductus cf. *L. nodosus* (Newberry) of Easton
Anthracospirifer cf. *A. occiduus* Sadlick

USGS 17501–PC, Amsden(?) Formation, about 43 m below the Quadrant Quartzite. Unit 14, stratigraphic section 4.

echinoid plates and spines, indet.
trepostomatous bryozoan, indet.
Derbyia sp.
orthotetid, indet.
Antiquatonia cf. *A. pernodosa* Easton
Linoproductus cf. *L. nodosus* (Newberry) of Easton
Rugoclostus? sp.
productoid fragments, indet.
Anthracospirifer sp.
Composita? sp.

Lower Pennsylvanian—Continued

USGS 17502–PC, Amsden(?) Formation, about 30 m below the Quadrant Quartzite. Unit 15, stratigraphic section 4.

Fasciculiamplexus cf. *F. contortus* Easton
Schizophoria cf. *S. depressa* Easton

The following fossil collections were made from the Amsden(?) Formation at other localities. Identifications were made as indicated above.

USGS 17506–PC, Amsden(?) Formation 33 m below Quadrant Quartzite, north side of Wigwam Creek Canyon, Varney quadrangle.

stenoporoid and rhomboporoid bryozoans, undet.
echinoderm debris, indet.
echinoid plate and spine, indet.
orthotetid, indet.
Chonetes cf. *C. pseudoliratus* Easton
Antiquatonia sp.
Linoproductus cf. *L. nodosus* (Newberry) of Easton
Anthracospirifer cf. *A. occiduus* Sadlick
Composita cf. *C. sulcata* Weller
cf. *Wilkingia* sp.
pteriacean pelecypod, indet.
trilobite pygidia, indet.

USGS 24075–PC, Amsden(?) Formation 24 m below Quadrant Quartzite, SE corner, sec. 8 (unsurveyed), T. 9 S., R. 2 W., Varney quadrangle.

echinoderm debris, indet.
ramose bryozoans, undet.
Orbiculoidea sp.
Chonetes pseudolirata Easton
Linoproductus cf. *L. nodosus* (Newberry) of Easton
Antiquatonia sp.
Rugoclostus? sp.
Anthracospirifer cf. *A. occiduus* Sadlick
cf. *Septmyalina* sp.
straparollid gastropod, undet.

The overall aspect of the faunas in the Big Snowy Group is that of the assemblage found in the Heath Formation in the type area in the Big Snowy Mountains (Easton, 1962). An exception is the fauna of unit 9 (USGS 17498–PC) which has, in addition, two major elements from the upper part of the Monroe Canyon Formation of southeastern Idaho. This locality and a similar occurrence of these western faunas at Indian Creek, Mont., were reported by Dutro and Sando (1963). Thus, this sequence on Baldy Mountain is of considerable importance in regional correlations, for it suggests interrelationships between central Montana platform deposits of the Big Snowy Group and the thicker miogeosynclinal sequence of southeastern Idaho.

The Pennsylvanian faunas of the Amsden Formation contain a distinctive assemblage that includes *Caninia* cf. *C. torquia* (Meek) and *Anthracospirifer* cf. *A. occiduus* Sadlick. The age of these faunas is Middle Pennsylvanian, probably post-Morrowan.

QUADRANT QUARTZITE OR FORMATION

The beds provisionally assigned to the Amsden Formation in the Varney quadrangle are succeeded by 110 m of clean quartz sandstone or quartzite referred to throughout the region as the Quadrant Quartzite or Formation of Pennsylvanian age. The larger part of the formation consists of quartz sandstone, variably calcareous or quartzitic, weathering white or pale yellowish or pinkish gray. The rock consists almost entirely of quartz grains and calcareous or siliceous cement and is generally fine to very fine grained, although a few quartz pebbles as much as 1 cm in diameter were seen in the basal beds at one or two places. It is typically thick to medium bedded and commonly contains thick sets of steeply inclined parallel crossbeds or laminae. Characteristic exposures are ledges or large blocks rounded and pitted by solution of the carbonate cement.

The lower part of the formation includes pale-yellowish-gray or white, medium- or thin-bedded dolomite, either as interbedded units 0.6 to 3 m thick or as detached blocks chaotically embedded in structureless sandstone. In one of the better exposed sections of the Quadrant, on Wigwam Creek, interbedded dolomite amounts to 60 percent of the lower 25 m of the formation. Elsewhere, as in most exposures in the vicinity of Baldy Mountain, dolomite in the lower part of the Quadrant occurs largely as blocks, probably fragmented before lithification of the enclosing sandstone. Similar dolomite-sandstone breccia also occurs near the top of the formation, notably on the ridge northwest of Crockett Lake, where the basal beds of the overlying formation are also dolomite.

The contact between the basal part of the Quadrant and the variegated dolomite of the underlying Amsden Formation appears to be conformable and is marked by the abrupt appearance of one or more beds of clean sandstone 0.3 m or more thick, above which similar sandstone is abundant if not the dominant lithologic type. In contrast to the generally fossiliferous Amsden, the Quadrant is essentially devoid of megafossils in the Varney area.

The Quadrant throughout the Varney quadrangle is 90 to 110 m thick. It is somewhat thicker in localities a few kilometers to the south and southwest, where 113 m of Quadrant is reported in the Snowcrest Range and 163 m, in the southern part of the Gravelly Range (Mann, 1960, p. 117).

SHEDHORN SANDSTONE

Rocks of Permian age, 43 to 72 m thick, overlie the Quadrant Quartzite and are overlain conformably by the Dinwoody Formation of Triassic age throughout the Varney and Cameron quadrangles. The rocks in this stratigraphic interval in southwestern Montana and adjoining areas have received much detailed study because they contain phosphate and other minor elements. From these studies, two systems of stratigraphic nomenclature have emerged; in one system, the rocks between the Quadrant and the Dinwoody are assigned to unnamed lithostratigraphic subdivisions of the Phosphoria Formation (Cressman, 1955; Sheldon, 1957); in the other, the rocks of the same interval are assigned to the Phosphoria Formation, Park City Formation, and Shedhorn Sandstone (McKelvey and others, 1956). In the Varney and Cameron quadrangles, these rocks are less than 75 m thick in contrast to much thicker sections in nearby parts of western Montana and southeastern Idaho. The rocks are largely sandstone, chert, and minor dolomite belonging to the upper unnamed divisions of the Phosphoria, that is, to units C, D, and E of Cressman (1955), or to the Shedhorn Sandstone (Cressman and Swanson, 1959). Correlated sections of the Shedhorn Sandstone and Phosphoria Formation are shown on figure 3. Dark mudstone and phosphate rocks similar to the Phosphoria of southeastern Idaho are thin and inconspicuous in the Varney and Cameron quadrangles.

Most of the Shedhorn Sandstone in these two quadrangles is pale- to moderate-gray, yellowish-gray, or grayish-orange sandstone, variably cherty, calcareous, or quartzitic. It is mostly fine to medium grained and well sorted, although fine- to coarse-grained, poorly sorted or pebbly sandstone occurs sparingly near the base and top of the formation. It is variably medium to thin bedded or indistinctly thick bedded, especially where cherty. The sandstone of the Shedhorn differs from that of the Quadrant by its darker color, more varied grain size and sorting, abundant dark grains of chert and other minerals, and yellowish-brown chert replacing the sandstone in various degrees. In many samples of the cherty sandstone or sandy chert, tiny rodlike sponge spicules are visible when a hand lens is used, and thin sections also reveal variously shaped grains and ooliths of phosphorite and chert.

Bedded or massive chert, in 3- to 15-m-thick units, makes resistant beds, which are exposed as low ridges and cliffs within the formation throughout the Varney quadrangle. The chert is light gray, reddish or brownish gray, or dusky yellow, massive to thinly and irregularly bedded, and more or less sandy. Massive chert and partly chertified sandstone are commonly full of voids, which are apparently caused by weathering of the parts of the sandstone that retained a carbonate cement; this feature gives to outcrops a disorganized rubbly appearance. All gradations exist, from calcareous sandstone to sandy chert containing 5 to 20 percent of corroded quartz grains. In thin section, the chert is seen to have replaced quartz grains, ooliths, and tubular structures probably of organic origin.

Dolomite is confined to the lower part of the formation, where it occurs in units a meter to as much as 15 m thick including minor sandstone beds. The dolomite is mostly light gray, compact and finely crystalline, and medium bedded. In the southwestern end of the Greenhorn Range, dolomite is interbedded with chert.

Reasonably complete exposures of the Shedhorn Sandstone are found on the north wall of the Wigwam Creek Canyon just south of sec. 33, T. 7 S., R. 2 W., on the ridge northwest of Crockett Lake in the southwestern corner of sec. 12, T. 8 S., R. 3 W., and on the northern side of Warm Springs Creek in sec. 22, T. 9 S., R. 3 W. Detailed study of these sections and other exposures in the Varney quadrangle and published sections of the formation on Indian Creek just east of the Cameron quadrangle (Cressman, 1955, pl. 1) and at Lazyman Hill (Swanson and others, 1953, p. 13–15), 2 or 3 km south of the Varney quadrangle, indicates that the formation in the Varney and Cameron quadrangles includes units C, D, and E of the Phosphoria Formation. At Warm Springs Creek, 8 m of unit A and 0.6 m of mudstone and phosphate rock of unit B have been reported (Swanson and others, 1953, pl. 12), but these units were not found elsewhere in the area.

Unit E, 29 to 40 m thick in the Varney quadrangle, consists of sandstone, cherty sandstone, and chert. The most conspicuous chert unit is 12 to 18 m thick and occurs at the base of unit C; it consists of well-bedded chert in the lower part, overlain by increasingly sandy and less well bedded chert, grading upward to cherty sandstone. A thinner discontinuous unit, about 3 m thick, of thin-bedded chert containing shaly partings, is found 8 to 11

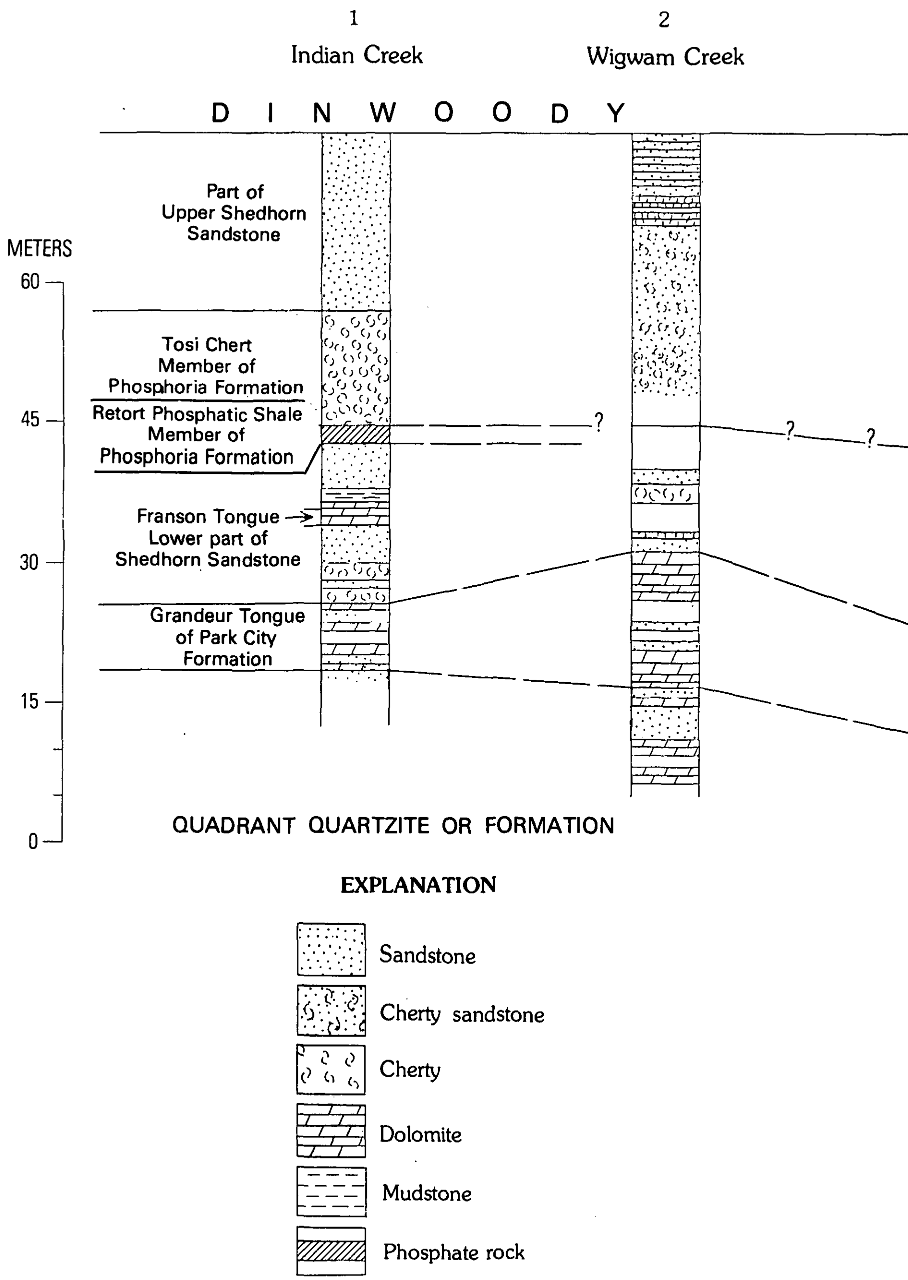
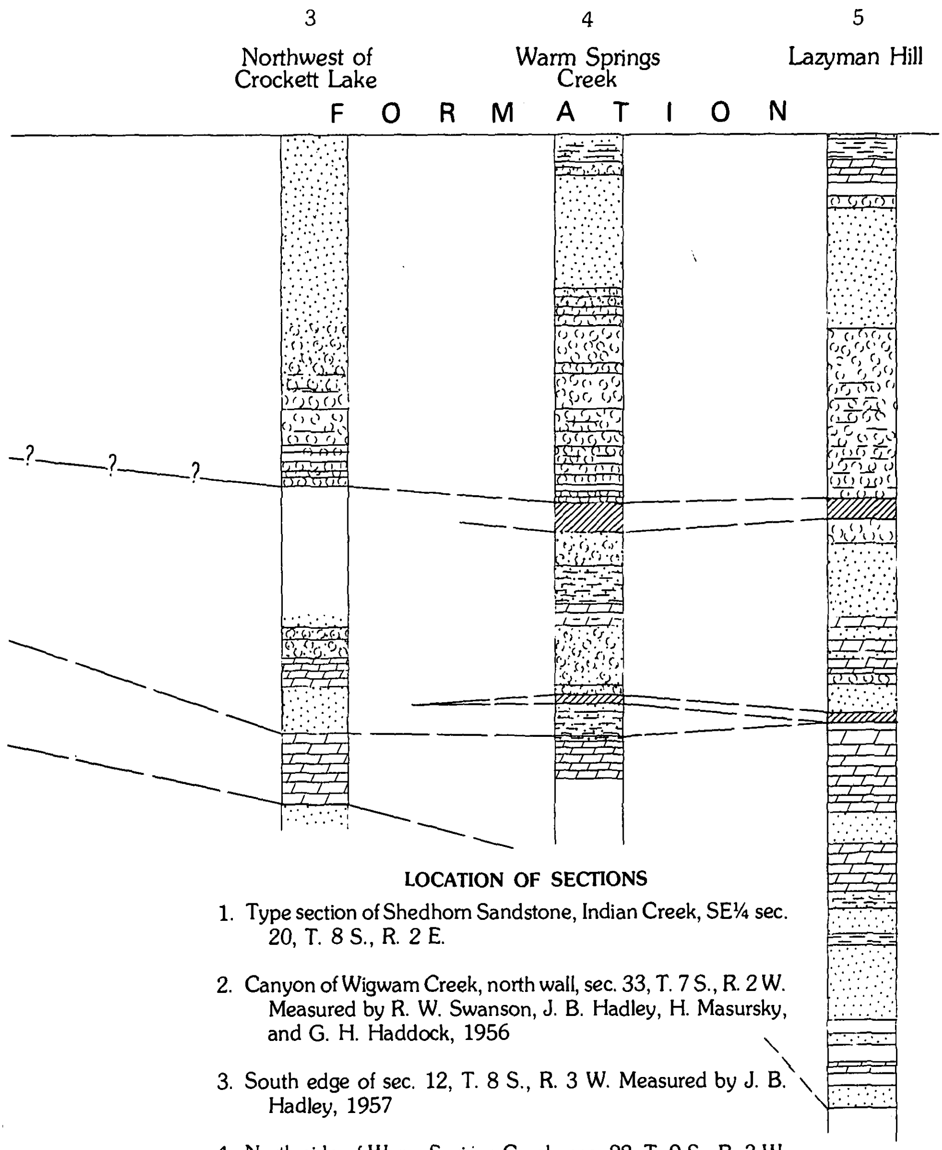


FIGURE 3.—Columnar sections of the Shedhorn Sand

m below the top of the formation at Wigwam Creek. Mapping in the Varney quadrangle indicates that the thickness of both these chert units is variable and that massive chert replacing



LOCATION OF SECTIONS

1. Type section of Shedhorn Sandstone, Indian Creek, SE¼ sec. 20, T. 8 S., R. 2 E.
2. Canyon of Wigwam Creek, north wall, sec. 33, T. 7 S., R. 2 W. Measured by R. W. Swanson, J. B. Hadley, H. Masursky, and G. H. Haddock, 1956
3. South edge of sec. 12, T. 8 S., R. 3 W. Measured by J. B. Hadley, 1957
4. North side of Warm Springs Creek, sec. 22, T. 9 S., R. 3 W. From Swanson and others (1953, p. 11–12)
5. Lazyman Hill, crest of Gravelly Range 2.4 km south of Varney quadrangle. From Swanson and others (1953, p. 13–15)

stone and Phosphoria Formation, Varney quadrangle.

sandstone occurs at other stratigraphic positions in unit E. Sandstone in the upper 9 to 15 m of unit E includes poorly sorted, thin-bedded, and crossbedded sandstone and sandy dolomite, commonly containing glauconite and well-worn fragments of bryozoans and molluscan shells.

The beds immediately below the main chert of unit E are rarely exposed except by trenching. At Warm Springs Creek, they are reported as including 3 m of phosphate rocks and mudstone assigned to unit D (Swanson and others, 1953, p. 11–12). Similar rocks were found in small landslide deposits or float in the concealed interval at a few other places in the quadrangle, but none were exposed in place. Six m of dark mudstone and 15 cm of phosphatic sandstone were found near the crest of the southern end of the Greenhorn Range just west of the Varney quadrangle boundary 1.5 km or so north of the Ruby River water gap. Dark-brown oily shale 0.6 m thick and a few centimeters of oolitic phosphate rock were found in the canyon of Tolman Creek (sec. 10, T. 7 S., R. 1 E.) near the northern border of the Cameron quadrangle. Presumably these beds represent unit D, but in both places, the beds are strongly overturned, folded, or faulted; hence, their stratigraphic position is uncertain.

Because of insufficient exposure of unit D and the underlying beds, the lower part of the Shedhorn Sandstone is not well defined in the Varney quadrangle. It consists largely of gray sandstone and light-gray, variously calcareous dolomite in isolated beds or units as much as 15 m thick at or near the base of the formation. These rocks are lithologically similar to those of unit C, as described from localities not far west and southwest of the quadrangle (Cressman, 1955). According to the terminology of McKelvey and others (1956), the thicker dolomite units are considered to represent tongues of the Park City Formation in or below the Shedhorn Sandstone.

MESOZOIC ROCKS

DINWOODY FORMATION

The Shedhorn Sandstone is overlain throughout the Varney and Cameron quadrangles by the Dinwoody Formation of Early Triassic age. The formation consists largely of interbedded silty shale, argillaceous and calcareous sandstone, and yellow-weathering, platy to blocky dolomite or silty limestone, all poorly exposed in most of the area.

The lowermost part of the Dinwoody in most localities is easily recognized platy, grayish-yellow dolomite, commonly containing specimens of *Lingula* on the bedding surfaces; this dolomite is found as float in an interval that is probably mostly shale. Higher beds are thicker bedded dolomite that becomes increasingly argillaceous and calcareous upward and is interbedded with silty shale or mudstone and very fine grained argillaceous and dolomitic sandstone. In the section on the North Fork of Warm Springs Creek, several cyclic units appear, in each of which medium-bedded dolomite is succeeded gradationally by thinner bedded dolomite, which becomes increasingly argillaceous and sandy and interbedded with sandstone toward the top of the unit. The uppermost beds are commonly medium-bedded argillaceous sandstone overlain, with sharp contact, by dolomite of the next cycle. Some of the thicker dolomite beds are bioclastic and show fine current bedding.

Although the lower boundary of the Dinwoody is quite well defined in the Varney quadrangle, the upper boundary is not. For example, in areas immediately south of the Varney quadrangle, the Dinwoody is overlain by red silty sandstone, siltstone, and shale of the Woodside Formation (Moritz, 1951, p. 1791; Mann, 1960, p. 117–120). Although similar beds appear in the Ruby River water gap at Canyon Camp just west of the Varney quadrangle boundary, no red beds occur in the few exposures of this interval in the quadrangle. The upper 12 to 30 m of the Dinwoody in the central part of the Varney quadrangle and on Indian Creek, although not red, is largely yellowish-brown sandstone and shale that might represent a featheredge of the Woodside Formation.

Mollusks in the Dinwoody are sparse and poorly preserved. All those collected were long-ranging species found in rocks of late Paleozoic and Early Triassic age (N. J. Silberling, written commun., 1958). Linguloid brachiopods are in general agreement with *Lingula borealis* Bittner, described by Newell and Kummel (1942) from the Dinwoody of western Wyoming, southeastern Idaho, and southwestern Montana. The *Lingula* zone was established by Newell and Kummel as the lowermost Triassic zone in this area. Nevertheless, these brachiopods are also similar to representatives of *Lingula* ranging from Cambrian to Holocene. *Lingula,* in the absence of normal marine forms such as articulate brachiopods and cephalopods, is commonly used as an indicator of brackish or poorly oxygenated water (N. J. Silberling, written commun., 1956).

ELLIS GROUP

A succession of sandy siltstone, shale, and interbedded limestone, 45 to 60 m thick, that overlies the Dinwoody throughout the

Varney and Cameron quadrangles represents the Ellis Group of Middle and Late Jurassic age. All three formations of the group, as defined in northwestern Montana some 325 km northwest of the report area (Cobban, 1945; Moritz, 1951, p. 1802–1813), can be recognized in the Varney quadrangle.

The uppermost of these formations, the Swift Formation or Sandstone, consists of massive grayish-orange, fine-grained sandstone, 4.6 m thick in the northern part of the Gravelly Range and 12 m thick in the Greenhorn Range. The basal few centimeters commonly contain small well-rounded pebbles of chert and rest with sharp contact on a unit of light-brown oolitic limestone and interbedded clay shale 4.6 to 6 m thick. The oolitic limestone is characteristic of the Rierdon Formation. The remainder of the Ellis Group in the Varney quadrangle consists of 40 to 55 m of interbedded argillaceous and sandy limestone, shale, and sandstone, most of which has been assigned to the Sawtooth Formation by previous workers in the region (Moritz, 1951, p. 1804). Shale and sandstone predominate in the lower part of the formation, limestone and shale, in the upper part, which is generally better exposed. In the section on French Gulch (fig. 4, columnar section 2), the base of the Sawtooth is assumed to be a 3-m bed of brownish-gray limestone containing abundant angular granules and pebbles of chert in the basal 0.3 to 0.9 m, which rests on medium-bedded grayish-orange dolomitic sandstone. The base of this chert-pebble bed may represent the regional disconformity between the Ellis Group and the underlying Dinwoody or Woodside. Elsewhere in the report area, however, no clear lithologic break marks this boundary.

In the absence of such a break, the base of the Ellis was taken at the upper limit of the cyclic dolomite and sandstone beds of the upper part of the Dinwoody.

The limestone of the Ellis Group in the Varney quadrangle is generally fossiliferous and yielded the following species, identified by R. W. Imlay (written commun., 1958), probably all from the Sawtooth:

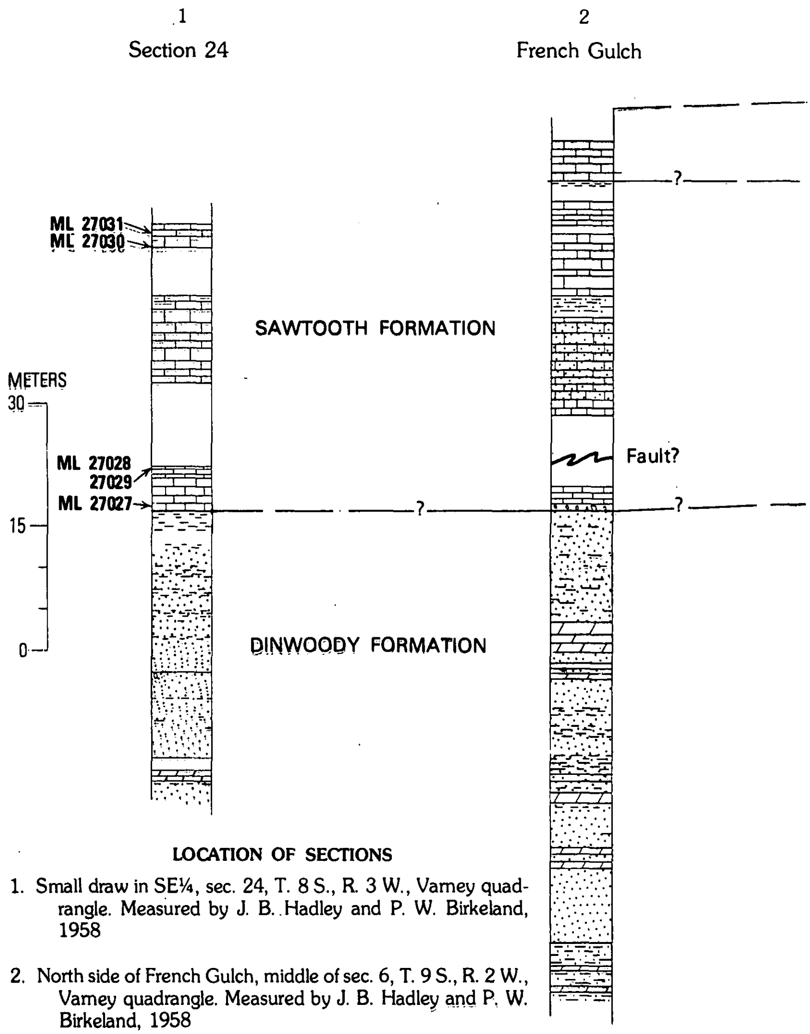
Pentacrinus asteriscus Meek and Hayden
Pleuromya subcompressa (Meek)
Astrocoenia hyatti Wells
Lima (*Plagiostoma*) *occidentalis* Hall and Whitfield
Trigonia americana Meek
Camptonectes platessiformis White
Unidentified species of *Ostrea*, *Pinna*, *Isognomon*, *Quenstedtia*?, and worm tubes

In his regional study of the Twin Creek Limestone, Imlay (1967) discussed and correlated all the related Middle and lower Upper Jurassic units in the central and northern Rocky Mountains. Imlay considered the lower part of the Sawtooth Formation to be of late Bajocian age, the upper part of the Sawtooth to be of Bathonian age, and the Rierdon Formation to be of late Bathonian and early Callovian age.

Stratigraphic section 5

[Ellis Group and Dinwoody Formation, north side of French Gulch near middle of sec. 6 (unsurveyed), T. 9 S., R. 2 W., Varney quadrangle. Measured by P. W. Birkeland and J. B. Hadley]

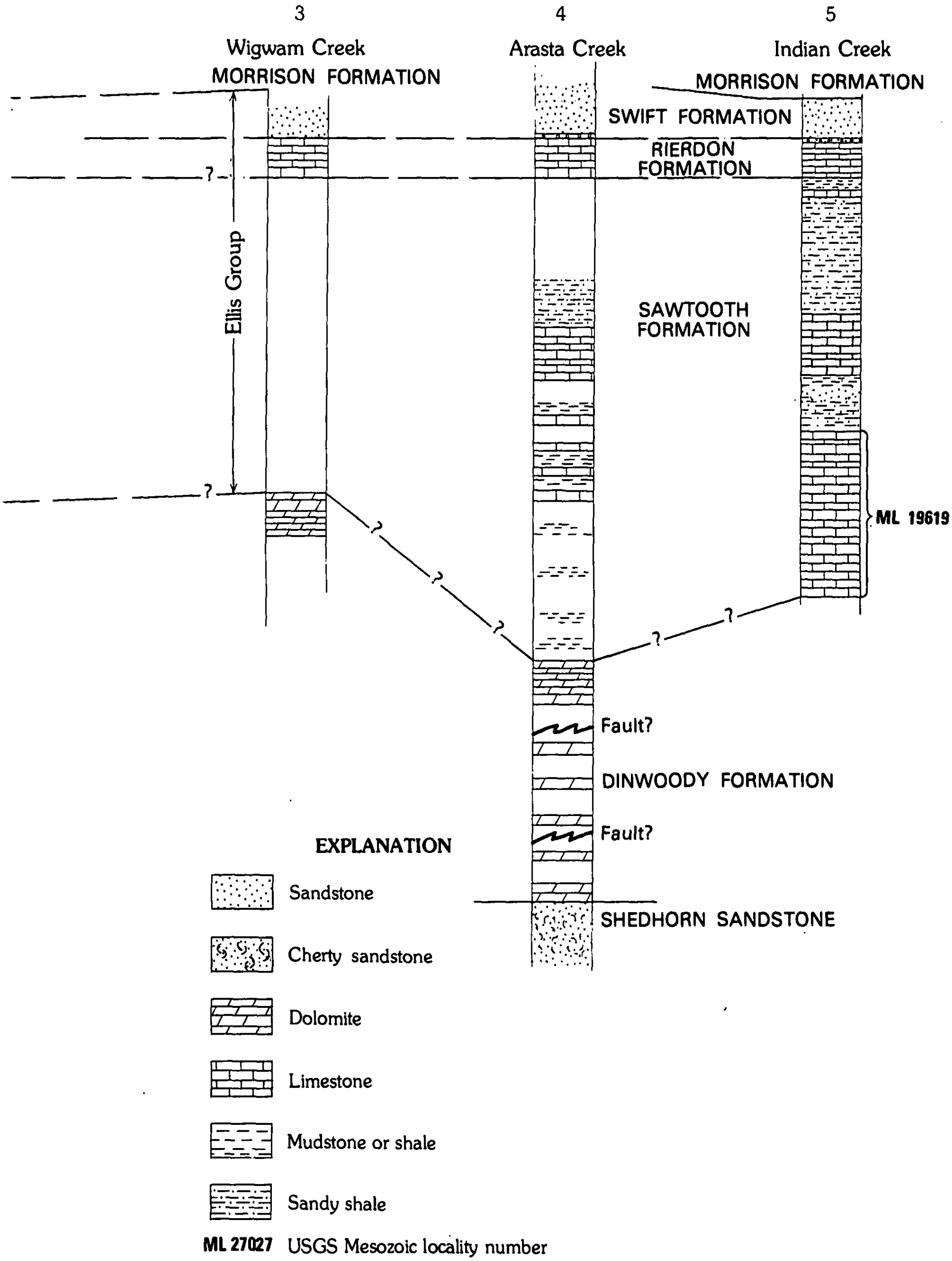
	Thickness (meters)
Ellis Group, near base of Morrison Formation:	
21. Limestone, upper 2.8 m, moderate-brownish-gray, finely oolitic, bedding indistinct 10 to 25 cm, forms cliff along crest of ridge. Lower 1.8 m, dark-greenish-gray to yellowish-brown, silty to finely sandy, variable to large amounts of fine quartz sand and minor sandy and argillaceous beds, thinly current bedded	4.6
20. Mostly covered. Upper part is clayey, calcareous, yellowish-brown siltstone	2.4
19. Limestone, moderate-yellowish-brown, massive, calcarenitic. Lower part abundantly fossiliferous; forms low cliff	1.5
18. Covered. Upper part, exposed by digging, is moderately fissile argillaceous limestone	2.1
17. Limestone, moderate- to dark-yellowish-brown, finely crystalline to fine sandy, fine quartz sand throughout, bedding medium to thick, few impersistent shaly partings, abundant fine current lamination on weathered surfaces. Finely laminated calcilutite at top and oolitic limestone at base; forms cliff	8.8
16. Covered. Probably mostly yellowish-brown, finely current bedded siltstone	2.8
15. Limestone, light-brownish-gray, very fine sandy, quartzose, massive, indistinct current lamination. Upper 30 cm is dark brownish gray, oolitic, petroliferous	2.1
14. Mudstone, moderate-yellowish-brown, fine sandy, mostly covered	1.5
13. Limestone, massive, finely clastic, conchoidal fracture. Fine calcarenite to calcilutite. Many fossil fragments	8.5
12. Mostly covered. Probably argillaceous limestone and shale. Basal 3 m exposed in offset part of section 75 m to the north is dark- to light-brownish-gray, fine- to medium-grained, porous and somewhat petroliferous, poorly bedded limestone. Basal 30 cm is breccia, including small angular chert fragments and rounded claystone fragments in limestone matrix, in sharp contact with underlying beds	12
Total thickness of Ellis Group	47



LOCATION OF SECTIONS

1. Small draw in SE¼, sec. 24, T. 8 S., R. 3 W., Varney quadrangle. Measured by J. B. Hadley and P. W. Birkeland, 1958
2. North side of French Gulch, middle of sec. 6, T. 9 S., R. 2 W., Varney quadrangle. Measured by J. B. Hadley and P. W. Birkeland, 1958
3. North side of Wigwam Creek, sec. 4, T. 8 S., R. 2 W., Varney quadrangle. Measured by J. B. Hadley, E. W. McKee, and J. J. Branco, 1957
4. South side of Arasta Creek, W½ sec. 36, T. 7 S., R. 3 W., Varney quadrangle. Measured by Harold Masursky, J. B. Hadley, and G. H. Haddock, 1956
5. Canyon of Indian Creek, secs. 21 and 22, T. 8 S., R. 2 E., Sphinx Mountain quadrangle. Gardner and others (1946)

FIGURE 4.—Columnar sections of the Ellis Group



and the upper part of the Dinwoody Formation.

Stratigraphic section 5—Continued

	Thickness (meters)
Dinwoody Formation:	
11. Sandstone, lower 3 m fissile, remainder grayish-orange, light-yellowish-gray, and pale-orange, medium-bedded (5–60 cm), fine-grained, dolomitic, forms cliff	13
10. Dolomite, lower part interbedded with equal amount of fissile dolomitic sandstone; upper 4 m light-gray, thick-bedded to massive, porous, and containing poorly preserved fossil fragments; forms cliff	7
9. Poorly exposed. Basal 1.8 m is sandstone, thin bedded and laminated like unit 5; top meter is more fissile sandstone; remainder is probably fissile sandstone and silty shale	9
8. Mostly covered. Massive dolomite 1.5 m thick, like unit 10 in lower part; remainder probably fissile dolomitic sandstone and shale	7
7. Sandstone, dolomitic, fine-grained, and quartzose, thick bedded and current laminated, some crossbed sets 20 cm thick; forms cliff	3.3
6. Mostly sandstone, dolomitic, very fine grained, and fissile. Two or more beds, 38 cm thick, of yellowish- to light-greenish-gray dolomite; one contains small poorly preserved gastropods and is somewhat petroliferous	5.5
5. Sandstone, light-yellowish-brown, fine-grained, beds 5 to 30 cm; in part finely laminated and current-bedded; a few partings coated with very fine grained muscovite; forms cliff	8
4. Largely covered. One outcrop plus float indicates silty to fine sandy, thin- to very thin bedded, micaceous and finely laminated, platy-weathering dolomite. Considerable silty shale probably present. Contains poorly preserved specimens of *Myalina*	7.6
3. Dolomite, like unit 1, somewhat thicker bedded (2–30 cm)	2.1
2. Covered. Probably dolomite shale and thin-bedded dolomite	2.8
1. Dolomite, pale-yellowish-brown to yellowish-gray, finely crystalline, thin-bedded; two beds in lower part are 30 cm thick; argillaceous partings common, also thin interbeds dolomitic mudstone	6.7
Partial thickness of Dinwoody Formation	72
Base of measured section about 45 m above Shedhorn Sandstone	

MORRISON FORMATION

Immediately succeeding the Ellis Group is a thick unit of nonresistant clayey rock referred to the Morrison Formation of Late Jurassic age. It is characteristically very poorly exposed, but, because of its highly plastic and unstable consistency, it can be commonly recognized by a distinctive hillock-and-sag-pond topography—a result of gravity sliding. In several places, especially in the drainage of the South Fork and Middle Fork of Warm Springs Creek, the sag ponds have been enlarged by beaver dams.

Judging from the few good exposures, such as those just northwest of Moose Lake in sec. 25, T. 8 S., R. 3 W., on the north slope of the ridge 1.3 km west-southwest of bench mark 8523 on the Gravelly Ridge road, and on the ridge south of Arasta Creek in sec. 36, T. 7 S., R. 3 W., the Morrison Formation consists mainly of dark-greenish-gray to reddish-brown or maroon claystone and mudstone, poorly bedded, and containing sparsely distributed calcareous concretions and thin indurated beds of calcareous mudstone. Thin beds of fine- to very fine grained orange-weathering sandstone are commonly present in the middle and upper parts of the formation; sandstone seems to be unusually abundant in a poorly exposed section on the north side of the Wigman Creek Canyon southeast of Horse Hill.

No fossils were found in the formation, but distinctive well-rounded and polished chert pebbles, found nowhere else in the area, are sparsely scattered throughout its outcrop area. A few large dinosaur bones displayed by residents of Ennis are said to have been found in the Morrison farther south in the Gravelly Range.

The Morrison Formation lies on various beds of the Ellis Group, apparently on sandstone of the Swift Formation in the vicinity of Wigwam and Arasta Creeks and on the Rierdon or Sawtooth elsewhere in the area. Thickness of the Morrison is estimated at about 75 m in most places.

KOOTENAI FORMATION

The Kootenai Formation, widely distributed and having many distinctive lithologic features, marks the beginning of Cretaceous time throughout much of western Montana and adjacent areas. The formation is exposed at many places along the crest and western slopes of the Gravelly Range and locally in the Greenhorn and Madison Ranges. Throughout this extent, four well-defined members can be recognized—a basal sandstone unit, succeeded by a thick unit of clayey mudstone, a thinner unit of limestone, and a top unit of variably fissile clay shale and sandstone. The formation as a whole is 140 to 170 m thick.

Basal sandstone.—The lowest member of the Kootenai consists of light-gray, medium- to coarse-grained argillaceous sandstone and chert-pebble conglomerate, marking an abrupt change from the dark clay of the underlying Morrison Formation. The sandstone is typically composed of quartz grains and large quantities of dark chert grains that give the rock the distinctive "salt and pepper" appearance commonly reported in the literature. The largely white clay matrix contains little or no carbonate cement. The lower beds of the unit are typically medium to thick bedded (1–3 m) and commonly show abundant steeply inclined planar crossbeds. Lenses and thin layers of conglomerate contain chert pebbles 5 to 25 mm in diameter. The upper beds of the unit are generally somewhat finer grained, more argillaceous and quartzose, and thinner and more regularly bedded. At a few places they contain small particles of coaly material. In some sections, for example, the section exposed just southeast of Moose Lake, the basal sandstone unit has two major upward-fining sequences, each about 15 m thick. Impressions of leaves and stems of plants were found in the unit in a few places; in exposures northwest of Moose Lake, compressed tree trunks are represented by fluted molds as much as 2 m long and 22 cm wide, marked by narrow ridges 2 to 5 cm apart at right angles to the fluting.

Thickness of the basal Kootenai sandstone unit is generally about 30 m, although it ranges from less than 15 m in some places to more than 38 m in others.

Mudstone unit.—The basal sandstone unit is overlain by poorly to moderately bedded mudstone and claystone ranging from light olive gray to dusky red or reddish brown. The lower part of this unit is commonly mudstone containing scattered grains of quartz and dark chert like that in the underlying beds; also present are thin units of thin-bedded sandstone, sandy or silty limestone, and limestone conglomerate. The upper part of the unit is generally somewhat more clayey, is indistinctly bedded in layers 0.6 to 0.9 m thick, and is generally gray rather than red. An unusually good exposure of the lower 43 m of the mudstone unit was found near the top of the ridge about 1 km north of the canyon in the lower part of the Warm Springs Creek (sec. 22, T. 9 S., R. 3 W.). Thickness of the unit as a whole is estimated at about 75 m in most places.

Limestone unit.—Above the mudstone unit lies a persistent and easily recognizable unit about 15 m thick, consisting almost wholly of pale-yellowish-brown or yellowish-gray limestone, thin to medium bedded and somewhat argillaceous. Some of the limestone beds are composed of limestone fragments ranging in size from coarse sand to small pebbles; others are conspicuously oolitic. Still others are crowded with small gastropods of one or two species, resulting in a distinctive rock recognized throughout large areas where the Kootenai Formation is known. The limestone unit is 17 m thick in the best exposed section, just west of the canyon of Warm Springs Creek (stratigraphic section 6), and is about this thick at most other places in the area, except on the ridge south of Arasta Creek, where it is about 25 m thick.

Stratigraphic section 6

[Limestone unit in Kootenai Formation, north side Warm Springs Canyon, NW corner sec. 22, T. 9 S., R. 3 W., Varney quadrangle. Measured by J. B. Hadley]

	Thickness (meters)
Covered.	
8. Limestone, like unit 6, medium- to thick-bedded, lacking shale interbeds; abundant gastropods in several beds; top bed 45 cm thick is microcrystalline to oolitic. Upper 1.5 m partly covered, may be shaly	4.9
7. Limestone, microcrystalline, like units 2 and 4	0.6
6. Limestone, moderate-brownish-gray, medium- to thick-bedded (5–60 cm), finely crystalline; contains beds of shale 5 to 30 cm thick showing crumpling and duplication by low-angle reverse faulting. Upper 30 to 60 cm is highly oolitic; at base is 60 cm moderately gray fissile shale containing thin limestone beds	5.3
5. Limestone, like unit 3; upper 60 cm highly oolitic	1.7
4. Limestone, like unit 2, medium-bedded (8–35 cm)	2.1
3. Limestone, moderate-brownish-gray, darker than unit 2, microcrystalline to finely crystalline and oolitic, medium-bedded (8–30 cm), abundant gastropods	1.2
2. Limestone, moderate-brownish-gray, strong close jointing, at right angles to bedding, weathers to wedge-shaped chips	0.8
Mudstone unit:	
1. Mudstone, light-brownish-gray, calcareous, nonbedded	1.5

A fossil collection from the upper part of the limestone unit, 375 m east-northeast of the southwest corner of sec. 13, T. 9 S., R. 3 W. (fig. 5), USGS paleont. loc. D–1765, yielded the following lacustrine species identified by W. A. Cobban and I. G. Sohn (written commun., 1958, 1959):

Pelecypoda	*Unio farri*, Stanton
Gastropoda	*Reesidella montanensis* Stanton
Ostracoda	*Cypridea*? *anomala*? Peck

Shale unit.—Above the limestone unit and below a characteristic marine sandstone at the base of the Colorado Group, is a little-exposed interval, 15 to 30 m thick, of dark-brown to medium-gray clay shale and claystone, variably fissile and sandy. It is well exposed only on the Warm Springs Creek road just east of Davis Creek in sec. 22, T. 8 S., R. 3 W., where a small collection of lacustrine ostracodes and pelecypods was made. I. G. Sohn and W. A. Cobban (written commun., 1958, 1959) give the following species:

Ostracoda	*Cypridea wyomingensis* Jones, sensu Peck 1941
	Cypridea anomala Peck 1941
Pelecypoda	*Eupera onestae* (McLearn)

Three samples of shale from the upper shale unit on the Warm Springs Creek road 0.16 km east of Davis Gulch (fig. 5, USGS paleobot. loc. D–1830) yielded abundant gymnosperm pollen along with the fresh-water alga *Botryococcus;* no angiosperm pollen was present (R. H. Tschudy, written commun., 1962). Each of four samples from the mudstone unit of the Kootenai proved to be barren of both pollen and spores.

THERMOPOLIS SHALE [1]

Above the gray shale and sandstone of the upper part of the Kootenai Formation is a unit about 110 m thick, consisting largely of dark-gray shale. This unit is recognized throughout northern Wyoming, where it is referred to as the Thermopolis Shale; it is mapped as far east as the Black Hills, where it is called the Skull Creek Shale. It grades downward into thin-bedded rusty quartz sandstone, marked by worm casts and trails, and lenticular, clean, current-bedded quartz sandstone, which is taken as marking the base of the formation. In northern Wyoming, the rusty sandstone beds are generally included in the upper part of the Cloverly Formation, which is equivalent to the Kootenai Formation of Montana. Above the dark shale is 15 m or less of dirty, coarser grained, thicker bedded sandstone that has been mapped with the Thermopolis Shale, but it equally well might be considered the basal unit of the overlying Frontier Formation.

A conspicuous characteristic of the basal sandstone of the Thermopolis in the Varney quadrangle is the presense of 6 m or less of clean quartz sandstone or quartzite that is strongly current bedded, overlain by thin-bedded gray or rusty sandstone marked by shaly partings and abundant worm casts and burrows. These basal sandstone beds are a minor ledge maker and can be recognized at many places, either in outcrop or in float. On Arasta Creek, they overlie 13 m of fine-grained fissile argillaceous sandstone and sandy shale assigned to the upper part of the Kootenai

[1] The name Thermopolis Shale is now geographically restricted from Montana by Rice (1976) for U.S. Geological Survey usage; rocks in Montana formerly called Thermopolis Shale are now called the Muddy Sandstone, the Skull Creek Shale, the basal part of the Mowry Shale, or the Fall River Sandstone. Hadley's mapping was completed before this restriction.

Formation. Although unfossiliferous, the sandstone at the base of the Thermopolis and in the uppermost part of the Kootenai appears to indicate a rather abrupt transition from nonmarine to marine conditions of deposition.

Although nonresistant and rarely well exposed, the dark-shale unit can be seen near the confluence of the Middle and South Forks of Warm Springs Creek and on the west bank of Davis Creek just above its junction with Warm Springs Creek. The shale is generally medium gray to very dark gray and moderately fissile; its upper part is commonly silty or sandy and less fissile. Dark-red ironstone has resulted from weathering of thin lenses and nodules of ferruginous carbonate. Thickness of the shale unit is estimated at 75 to 82 m.

The dark-shale member is overlain throughout the Varney quadrangle by a prominent sandstone unit approximately 15 m thick, which is similar in lithologic character and stratigraphic position to the Muddy Sandstone farther east and northeast in Montana. In the Varney quadrangle, this sandstone is a minor ledge maker; it is medium gray, medium grained, argillaceous, and calcareous and is generally "dirty," containing abundant dark grains. Clay galls and fragments are common in some beds. Bedding characteristics range from thin bedded and flaggy weathering to thick bedded and coarsely current bedded. This sandstone unit is similar in many respects to those in the overlying Frontier Formation.

The Thermopolis is sparingly fossiliferous. Palynomorphs found in three samples from near the base, middle, and top of the dark-shale unit (fig. 5, USGS paleobot. loc. D–1422, 1423, 1424) were identified by E. B. Leopold as follows:

Classopolis cf. *torosus* (Reiss) Couper (the dominant species)
Inaperturopollenites dubius Pot.
Pityosporites labdacus Pot.
Abietineaepollenites cf. *dunrobensis* Couper
Gleicheniidites senonicus Ross
Monocolpopollenites (Gingko type)
Eboracia cf. *lobofolia* (Phill.) Thomas
Stereisporites psilatus Ross

"The assemblage is identical in all three samples. The sediments contain about 300 pollen and spore grains per gram. The forms present are land plants of the gymnosperm and fern groups, and no higher plant (dicot) pollen could be found. I conclude the materials are of Lower Cretaceous age and that the

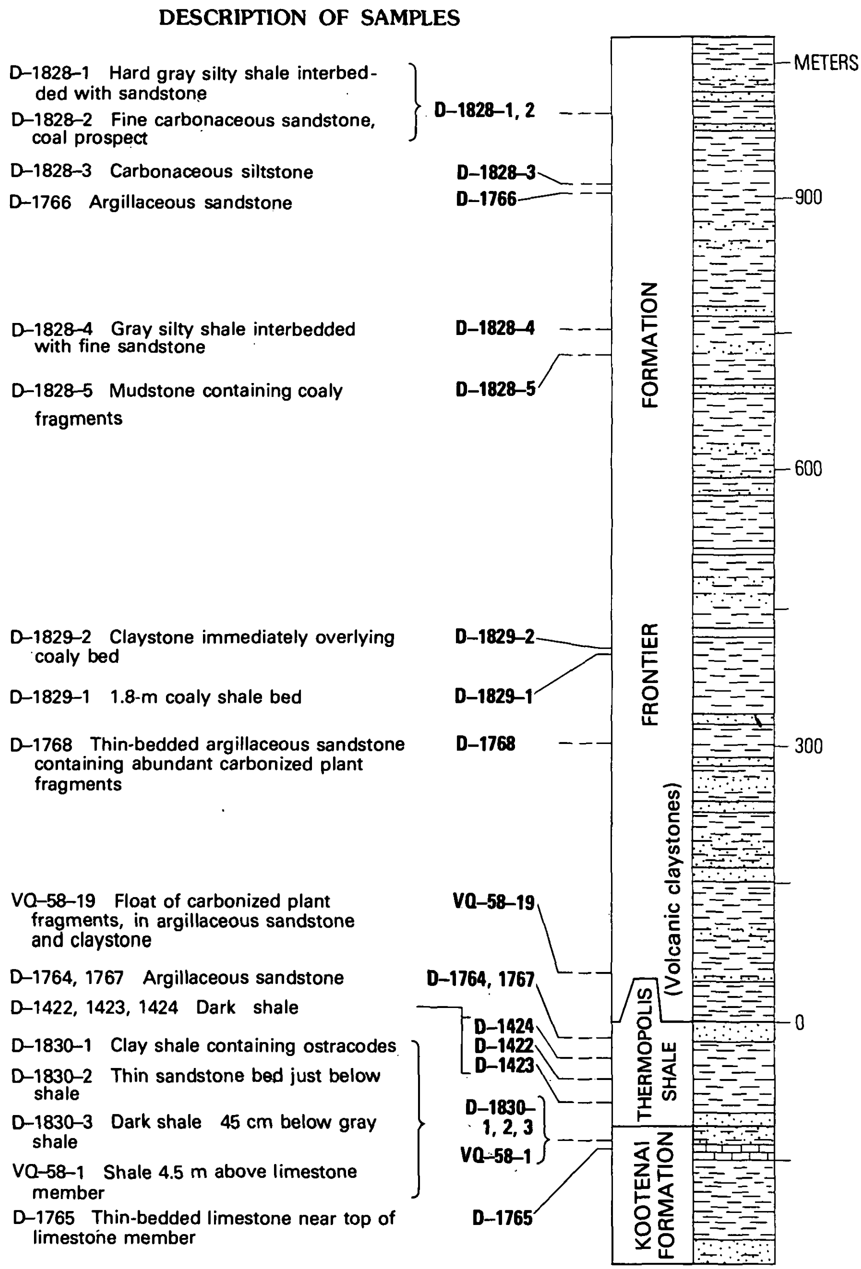


FIGURE 5.—Columnar section showing position of numbered fossil collections from Cretaceous rocks, Varney quadrangle.

depositional environment could be either nearshore marine or continental lacustrine." (E. B. Leopold, written commun., 1959).

Fossils collected from the upper sandstone member of the Thermopolis Shale near the NW corner of sec. 23, and southeast of the NW corner of sec. 15, both in T. 9 S., R. 3 W., (fig. 5, USGS paleont. loc. D–1764, 1767) consist entirely of the shallow-water marine species *Ostrea anomioides* Meek (W. A. Cobban, written commun., 1958.)

FRONTIER FORMATION

The rocks above the Thermopolis Shale in the Varney and Cameron quadrangles constitute several thousand meters of sandstone, mudstone, and shale and minor coal and limestone, of mixed fluviatile and shallow-marine or estuarine origin. Because rocks of nonmarine or estuarine origin appear to be dominant, they are assigned to the Frontier Formation of Late Cretaceous age. Bentonitic claystone, thin beds of porcellanite, and pink or reddish zeolite-bearing beds indicate a strong volcanic contribution in the basal 110 m of the formation. The best exposures are along the Ruby River road west of Warm Springs Creek and in low bluffs along the west side of Warm Springs Creek west and southwest of Warm Springs Cow Camp.

Most of the Frontier Formation in the two quadrangles consists of gray mudstone or claystone and drab or olive-gray sandstone, fine to medium grained, in beds 30 to 90 cm thick. Coarser sandstone occurs in discontinuous units 3 to 12 m thick every few hundred meters throughout the formation. This sandstone is typically medium to coarse grained, is coarsely and irregularly crossbedded, and appears to be fluviatile. Clay galls and rare chert pebbles occur in some beds. Much of the finer grained sandstone and mudstone is highly calcareous and grades locally to finely sandy or argillaceous limestone in lenses 30 to 60 cm thick. Much of the finer noncalcareous sandstone, especially in the lower 600 m, contains abundant coalified plant debris, and thin coal-bearing beds in the middle and upper parts of the formation have been explored in prospect workings at two places near the Ruby River road.

The basal unit, which is rich in volcanic materials (stratigraphic section 7), consists largely of soft-grayish-olive and greenish-gray claystone and subordinate argillaceous sandstone. Much of the claystone shows "popcorn" weathering surfaces, resulting from swelling of bentonite, or is variegated salmon pink, pale orange, or reddish brown because of the presence of minute crystals of heulandite. Thin resistant beds in the claystone are silicified tuffaceous layers (porcellanite) or reddish indurated zeolitic sandstone containing abundant highly altered shards. Most sandstone of this unit is quartz-poor and contains abundant angular clasts of plagioclase, feldspar, chert, biotite, and, rarely, pyroxene. Similar bentonitic and zeolitic rocks are reported in the basal part of the Frontier or in the underlying Mowry Shale and equivalent rocks at localities in northern Wyoming and northwestern Montana (Love and others, 1948; Cobban, and others, 1959).

The stratigraphy of the upper part of the Frontier Formation in the Cameron quadrangle is complicated by the presence of many concordant and semiconcordant intrusive sheets of andesite porphyry abundantly exposed on Cedar Mountain and adjacent ridges. Thick shale units on some of these ridges in the upper part of the sequence on Cedar Mountain may be more properly correlated with members of the Colorado Group farther east.

Stratigraphic section 7

[Basal volcanic unit of Frontier Formation, west side of Warm Springs Creek, W½ sec. 14, T. 9 S., R. 3 W., Varney quadrangle. Measured by J. B. Hadley and P. W. Birkeland]

	Thickness (meters)
End of exposure.	
12. Clay, grayish-olive (10*Y* 4/2) to dark-yellowish-brown and zeolitic or grayish-brown (5*YR* 4/2); probably bentonitic with "popcorn" surface	7.6
11. Sandstone, moderate- to pale-reddish-orange, medium- to fine-grained, indistinctly current laminated. Coarser material contains abundant heulandite and possibly shards. Blocky weathering, resistant	1.2
10. Claystone, olive-gray, soft. Thin sandstone bed at top	3.0
9. Lower 1.2 m is sandstone containing abundant dark mica, overlain by clayey reddish-brown sandstone, purplish (zeolitic) toward top. Upper part is mainly olive-gray to reddish claystone. At top is dark-gray claystone 0.6 m thick containing abundant heulandite, overlain by 25 cm medium-dark-gray porcellanite, weathering light gray, irregularly laminated	5.8
8. Claystone, variegated reddish-brown, olive-gray, and dark-gray with red flecks; mostly zeolitic	4.6
(Section offset 120 m to south at top of unit 7)	
7. Claystone, olive-gray and greenish-gray, mostly nonresistant. Two darker gray resistant beds contain cavities filled with red heulandite and green sepiolite	4.9
6. Sandstone, 1.5 m thick, medium- to fine-grained, argillaceous, micaceous, and fissile, overlain by olive-gray claystone that has minor fissile sandstone in lower part	8.8
5. Covered	4.0

Stratigraphic section 7—Continued

	Thickness (meters)
4. Claystone and sandstone like unit 2, nonresistant; 15 cm resistant dark-greenish-gray claystone at top; similar bed 2.8 m below top	8.2
3. Claystone, medium-dark-gray, resistant, interbedded with softer claystone	1.5
2. Claystone as in unit 1, interbedded with sandstone, argillaceous, nonresistant, grayish-yellow (5*Y* 7/4). Bedding units 5 cm to 1.2 m thick. Includes several thin beds of resistant silty or fine sandy claystone; "popcorn" surface	18.0
1. Claystone, light-olive-gray to olive-black (5*GY* 5/2 to 5*Y* 2/1), silty. Interbeds 8 to 15 cm thick of siltstone and fine-grained calcareous "salt-and-pepper" sandstone. Upper 3 m is fine-grained argillaceous friable sandstone, moderately fissile, nonresistant	10.7
Upper sandstone unit of Thermopolis Shale.	

The easily deformed rocks of the Frontier Formation underlie major thrust faults in both the Varney and Cameron quadrangles, so that it is difficult to make proper allowance for repetition by folding and thrusting in estimating the thickness of the formation. Approximate measurements along the Ruby River road suggest that beds at least 1,070 m thick are present above the Thermopolis Shale. The formation may be thicker in the Cameron quadrangle, where it is overlain by Upper Cretaceous volcanic and volcaniclastic rocks. A thickness of 1,100 m has been estimated in the Sphinx Mountain area immediately east of the Cameron quadrangle (Beck, 1960, p. 131).

Both plant and invertebrate animal remains are found throughout most of the Frontier Formation in the Varney quadrangle. A collection from argillaceous sandstone containing abundant plant debris, about 300 m above the base of the formation in Golden Sucker Gulch (fig. 5, USGS paleont. loc. D–1768), yielded the following (W. A. Cobban, written commun., 1958): *Ostrea* sp.; *Anomia* aff. *A. micronema* Meek; *Corbicula* sp.; *Corbula* n. sp. Another collection, about 900 m above the base (fig. 5, USGS paleont. loc. D–1766) northwest of Schoolmarm Gulch, yielded the following species: *Ostrea soleniscus* Meek; *Corbicula* sp.; *Corbula* n. sp. Cobban reported that these collections represent brackish-water faunas, the lower one of late Colorado age and the upper one of probable late Colorado age.

A small collection of plant leaves and stems of early Late Cretaceous aspect, associated with silicified logs in the lower part of the volcanic unit at the base of the formation near Vigilante Ranger Station (fig. 5, field loc. VQ–58–19), was studied by R. W. Brown, who listed the following (written commun., 1958): *Anemia fremonti* Knowlton; *Cladophlebis readi* Brown; *Gleichenia nordenskioldi* Heer; *Sequoia* or *Araucarites;* coniferous wood; dicotyledenous leaves.

Samples of claystone and shale from several horizons in the Frontier Formation in the section exposed along Ruby River in secs. 17 and 20, T. 9 S., R. 3 W. (fig. 5, USGS paleobot. loc. D–1828, –1829), were studied for palynomorphs by R. H. Tschudy (written commun., 1962). Of 14 samples collected, 7 were barren; these included 3 samples of silty claystone and shale from the middle of the Frontier section and all 4 samples of claystone from the basal volcanic unit. Samples of silty shale, mudstone, and fine argillaceous sandstone, especially those containing carbonized plant debris, yielded sparse to abundant angiosperm pollen as well as considerable amounts of gymnosperm pollen and pteridophyte spores. Three samples of silty shale and fine sandstone from the upper part of the section yielded histrichospheres, suggesting, according to Tschudy, marine conditions of deposition. In only one of the seven productive samples (D–1828–5) were the materials sufficiently abundant and well preserved to permit grain counts. Palynomorphs in the other six samples were either too poorly preserved or too sparse to reveal more than the presence of a few forms.

UPPER CRETACEOUS VOLCANIC AND VOLCANICLASTIC ROCKS

No Mesozoic rocks younger than the Frontier Formation appear in the Varney quadrangle; in the northeastern part of the Cameron quadrangle, however, the Frontier is succeeded by more than 600 m of volcaniclastic rocks of Late Cretaceous age. These rocks are well exposed on the ridges south of Cedar Mountain and along the several forks of Bear Creek and extend several kilometers eastward into the Sphinx Mountain quadrangle, where they have been correlated with the Livingston Group (Beck, 1960, p. 131–132). In the Cameron quadrangle, these rocks can be readily divided into a basal unit of volcanic sandstone, siltstone, and pebble conglomerate; a middle unit of polymictic volcanic breccia; and an upper unit of coarse volcanic conglomerate. They are overlain unconformably by the Sphinx Conglomerate of Eocene age.

Volcanic sandstone unit.—The base of the volcanic sandstone unit is marked by the abrupt appearance, above the light-colored "salt-and-pepper" sandstone of the Frontier Formation, of dark-greenish-gray or brownish-gray, medium- to very coarse-grained sandstone, consisting largely of crystals, crystal fragments, and volcanic rock fragments similar to those in the overlying breccia and conglomerate. Angular fragments and nearly euhedral crystals of twinned and zoned plagioclase are the most abundant constituents; other minerals are clinopyroxene, magnetite, hornblende, and biotite in order of decreasing abundance. Chert and quartz grains are generally rare, and the ferromagnesian minerals are commonly wholly or partly altered to chlorite.

The sandstone is generally well bedded and commonly cross-bedded, showing sorting and concentration of the heavier minerals, especially magnetite, by current action. Lenses of pebble conglomerate containing subangular clasts of dark chert and well-rounded pebbles of various volcanic rocks and some quartzite occur throughout the unit. Volcanic clasts are generally fewer in the stratigraphically lower lenses but become predominant in the higher ones. Units 15 or more meters thick of lighter colored feldspathic sandstone of Frontier aspect occur within the basal unit at several places. Some beds also contain abundant carbonized plant debris and impressions of leaves and stems of several species of plants.

Beds of soft, white-weathering tuff containing quartz or biotite crystals were found in a few places in the volcanic sandstone unit. Three such beds, 30, 60, and 150 cm thick, occur in the upper part of the unit on the ridge between North and Middle Forks of Bear Creek.

The basal volcanic sandstone unit is generally too poorly exposed or too much deformed to permit detailed measurement of its thickness. The thickness as measured from map data ranges from 90 to 210 m.

Volcanic breccia unit.—The volcanic sandstone unit is abruptly succeeded by a thick mass of poorly bedded rock composed largely of angular fragments and blocks of andesite or basaltic andesite. The fragments range from less than 3 cm to a meter or so in diameter and include several types of pyroxene-, hornblende-, or biotite-bearing andesite firmly cemented in a matrix consisting of finer particles of the same materials. These rocks are dark greenish gray, olive gray, or reddish gray depending upon their state of oxidation. Units 15 m or more thick commonly show little or no sorting or bedding, but interbeds of finer grained tuff-breccia or coarse volcanic sandstone are fairly common. Most fragments are highly angular and show little abrasion, but well-rounded cobbles and small boulders are locally intermixed, and layers composed largely of rounded fragments appear locally, especially in the upper part of the unit.

Thin sections of 12 samples of the larger fragments in the breccia unit were taken from fresh talus along the North Fork of Bear Creek in the northwest corner of sec. 31, T. 7 S., R. 2 E. The rocks studied are all porphyritic; nearly all contain 10 to 35 percent phenocrysts of calcic andesine or labradorite, and most contain 3 to 20 percent phenocrysts of augite. A few contain phenocrysts of hornblende rather than augite, and some contain small amounts of highly altered biotite in addition to augite. The moderately felsic matrix contains abundant plagioclase laths 0.1 mm long and finer grained ferromagnesian constituents. Some reddish-gray samples are so strongly oxidized that most of the ferromagnesian minerals have been replaced by hematite and quartz. Many samples contain collapsed vesicles filled by chlorite and chalcedonic quartz.

In a few places in the breccia unit, thick bodies of unusually uniform and little brecciated pyroxene andesite may represent lava flows in place. At several places, the breccia unit is cut by dikes of amygdaloidal andesite porphyry characterized by prominent tabular plagioclase phenocrysts 3 to 10 mm long. No well-defined or mappable units were found, however.

Thickness of the breccia unit, as estimated from map measurements, is 300 to 400 m.

Volcanic conglomerate unit.—Overlying the volcanic breccia unit is a few hundred meters of cobble and boulder conglomerate essentially composed of the various kinds of volcanic rocks that make up the breccia. The clasts are generally well rounded, and their common large size in a given bed ranges from 12 to 30 cm. Boulders 60 to 90 cm in diameter are fairly common, however, and a few are as large as 150 cm in diameter. The matrix is coarse, dark-greenish- or reddish-gray volcanic sandstone, like that in the basal sandstone unit but less well sorted. Conglomerate forms beds several meters thick of poorly sorted material like that in mudflows or alluvial-fan deposits, containing much matrix separating adjacent clasts. Beds of volcanic sandstone and siltstone and lenses of pebble conglomerate that have mixed volcanic and nonvolcanic components are locally present, as are minor amounts of breccia like that in the underlying unit.

Maximum thickness of the conglomerate unit is about 180 m.

Correlation and age.—Although Peale (1896) and Beck (1960) correlated the volcaniclastic rocks of the Madison Range with the Livingston Group (Livingston Formation of Weed, 1893), the unusually coarse texture and dominantly volcanic composition of these rocks suggest that they are part of the Elkhorn Mountains volcanic field and are best correlated with the lower member of the Elkhorn Mountains Volcanics in the southern Elkhorn Mountains, 100 km north-northwest of the Cameron quadrangle (Klepper and others, 1957, p. 32–33). This unit is described as 900 m of fragmental andesitic rocks, mainly poorly sorted to unsorted breccia, and volcanic conglomerate, whose fragments are commonly 30 cm or less in diameter. The rocks in the Cameron quadrangle seem to fit this description, whereas rocks found throughout the Livingston Group in its type area are finer grained and contain greater proportions of nonvolcanic material (Roberts, 1963; Klepper and others, 1957, p. 40).

No new information on the age of these volcanic rocks was found in the Varney-Cameron area, and the age assignment of Klepper and others (1957) is followed. The basal volcanic sandstone unit seems to be an integral part of the overlying depositional sequence, but whether it lies conformably or unconformably on the Frontier Formation is not clear in the area studied because of the lack of detailed stratigraphic information in the upper part of the Frontier. The abrupt appearance of pebble conglomerate in the basal unit, however, suggests a radical change in regional stream gradients, presumably resulting from uplift to the north and northwest in Late Cretaceous time.

CENOZOIC ROCKS

SPHINX CONGLOMERATE

The oldest of the Cenozoic deposits in the Varney-Cameron area is a distinctive red limestone fanglomerate, the Sphinx Conglomerate, conspicuously exposed on Sphinx Mountain, 1.6 km east of the Cameron quadrangle. About 600 m of this rock is exposed in The Helmet (sec. 5, R. 8 S., T. 2 E.; not the prominent hill of Precambrian dolomite so labeled on the geologic map (Hadley, 1969a)). Three much smaller remnants of the Sphinx Conglomerate were found on the crest of the Gravelly Range in the southern part of the Varney quadrangle. Apparently the unit was once far more extensive and has been largely removed from the Varney-Cameron area.

The Sphinx Conglomerate typically consists of subrounded to well-rounded cobbles and boulders of various Paleozoic and Mesozoic rocks in a matrix of coarse, pale- to moderate-reddish-brown, calcareous and argillaceous sandstone or mudstone. The common large size of the rock fragments is 20 to 25 cm in the Gravelly Range and 60 cm on The Helmet; the largest boulders seen were about 90 cm in diameter. Sorting is poor and bedding indistinct except for a few thin lenses of pebbly sandstone here and there. In extensive exposures in the cirque wall on the northeast side of Sphinx Mountain, Beck (1960, p. 132–133) described large-scale planar cross stratification of units as much as 90 m thick and ascribed this structure to coalescing alluvial fans along an ancestral mountain front.

Although fragments of many of the Paleozoic and Mesozoic formations are represented in most exposures of the fanglomerate, their proportions vary from bed to bed and from place to place within the formation. An exposure of 18 m of the basal part of the formation in the Gravelly Range, for example, contains abundant fragments of limestone of the Madison Group and Amsden Formation and sandstone or quartzite of the Quadrant Quartzite and Shedhorn Sandstone. Fragments of the Meagher Limestone and Flathead Quartzite are present in small amounts, and a very few small fragments of phyllite and other Precambrian rocks also appear in this exposure. The basal fanglomerate in The Helmet contains many large cobbles and boulders, including sandstone of the Quadrant, the Shedhorn, and the Kootenai and dolomite or limestone of the Mission Canyon, the Amsden(?), and the Shedhorn(?). Other Paleozoic rocks are poorly represented, and no Precambrian rock types were seen there. This kind of variation suggests a strong influence of local sources on the fanglomerate deposits.

The Sphinx Conglomerate was somewhat arbitrarily assigned to the Eocene by Peale (1896, p. 3), who reported no fossil evidence; little has been found since to improve on that assignment. The formation in the Cameron quadrangle and on Sphinx Mountain unconformably overlies sharply folded and thrust-faulted rocks, here correlated with the Elkhorn Mountains Volcanics, yet the fanglomerate on The Helmet is folded in a syncline which has beds dipping at least 25° and subordinate folds of even sharper flexure. Thus, the Sphinx Conglomerate is clearly contemporaneous with Laramide regional deformation but, unfortunately, has provided no biostratigraphic evidence on which to date more precisely these Laramide structures.

TERTIARY VOLCANIC ROCKS AND GRAVEL

Volcanic rocks.—The Gravelly Range owes its name to patches of unconsolidated cobble gravel found at many places along its crest. These patches are commonly associated with basalt lavas and tuff and are remnants of once more extensive deposits laid down probably in Eocene to early Miocene time. They appear to record a period of lower altitude and relief and a more humid climate in the region than those that existed there during earlier Tertiary or later Cenozoic time.

The best exposed rocks of this sequence are basalt lava flows which occupy a large area in the north-central part of the Varney quadrangle and a similar area in the adjacent Virginia City quadrangle. The rocks in the Varney quadrangle consist of about 300 m of interbedded compact and vesicular olivine basalt, vesicular basalt breccia and agglomerate, and sandy tuff. A continuously exposed section 75 m thick in the cliffs above Blue Lake, at the northern edge of the main basalt area, includes at least six separate flows that have weakly amygdaloidal bases and highly vesicular and fragmental tops, separated by 0.6 to 3 m of indurated vitric tuff. The individual flows are 9 to 18 or more meters thick; many of the thicker flows form low scarps on the gentler slopes. Interbedded, less resistant, parts of the sequence consist of thick layers of amygdaloidal basalt breccia and agglomerate filled and cemented by snow-white calcite (fig. 6).

Outcrops of compact basalt in the central parts of the flows commonly show an indistinct and variably developed platy structure that in most places dips gently northeast. This structure is parallel to flattened amygdules seen near the bases of the better exposed flows; thin-section studies indicate that it represents a fluidal structure marked by alinement of plagioclase crystals. Other outcrops of compact basalt are parts of dikes a few tens of meters thick, in which the flow structure is parallel to more steeply dipping walls. Such dikes cut the flows at several places in secs. 21, 23, 26, and 27, T. 7 S., R. 2 W.

The flows and dikes consist of uniform porphyritic olivine basalt, which contains 10 to 15 percent olivine and nearly equal amounts of augite, 70 percent calcic plagioclase, and 2 to 5 percent magnetite-ilmenite. The phenocrysts, most of which are olivine, amount to 5 or 10 percent of most samples studied. Small amounts of alkali feldspar or feldspathoids and traces of biotite were found in several samples of both intrusive and extrusive basalts. The lava of the two areas on the north side of Johnny Gulch in the Varney quadrangle is unusual in that it is highly

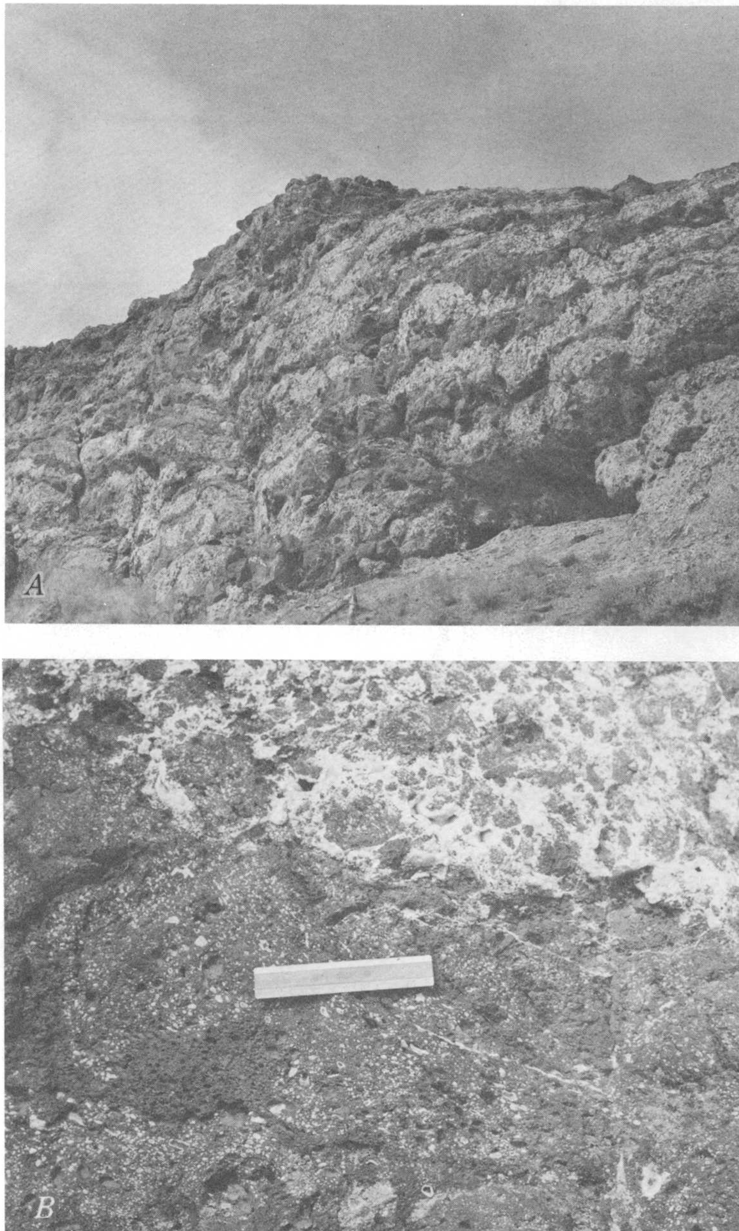


FIGURE 6.—Tertiary volcanic rocks, S½ sec. 23, T. 7 S., and R. 1 W., Varney quadrangle. Photographs by Harold Masursky. *A*, Interbedded highly amygdaloidal basalt and scoria breccia. *B*, Detail of contact between amygdaloidal basalt and overlying breccia. White matrix is mainly crystalline calcite. Scale is 18 cm long.

porous, low in olivine, and rich in opaque iron oxide, apparently replacing olivine and possibly other iron-silicate minerals. Chemical analysis shows that the lava is andesitic or latitic in composition, but it appears to have been considerably altered, possibly by gas fluxing during eruption.

Marvin and others (1974) presented K-Ar age determinations on igneous rocks from the nearby Virginia City and Black Butte areas. Ages range from 50 m.y. for Eocene andesite-dacite porphyry to 33 m.y. – 34 m.y. for the overlying Oligocene basalts to 23 m.y. for the lower Miocene basalt plug near Black Butte, just south of the Varney quadrangle. Concerning these ages, the writers (p. 17) stated:

> The K-Ar ages reveal a more complex Tertiary igneous history than was previously known. In the Virginia City area, the difference of about 16–17 my between the Eocene andesite-dacite porphyry (50 my) and the overlying Oligocene basalts (33–34 my) was not apparent from geologic mapping. The basalts occurring at various places along the crest of the Gravelly Range, from the area of Virginia City southward to the vicinity of Black Butte, would have been considered contemporaneous; however, if the Black Butte plug was a source of adjacent basalt flows, the volcanic activity spanned about 10 my from mid-Oligocene (34 my) to early Miocene (23 my).

In most of the areas described, the lava lies on gravel or tuff, the tuff being more widespread than the gravel. Tuff is especially abundant in the vicinity of the Axolotl Lakes, which are sag ponds on a thick sliding blanket of tuff beneath the main lava sequence. Good exposures of the tuff are rare, but its presence is commonly revealed around small animal burrows. In the better exposures, it is a light-gray rock with orange or pink tinges, composed of fine sand- to silt-sized particles. It is generally poorly sorted and lacks stratification, but generally not indurated, and weathers to small blocky fragments in a viscous clayey mud, which flows readily. In a few places, the tuff is distinctly bedded and contains thin lenses of pebble gravel.

Samples of tuff examined under the microscope consist of shards and other glassy material (70–98 percent) and angular grains of various minerals of volcanic and detrital origin (2–25 percent). Plagioclase, olivine, and augite, which are approximately the same ratio as in the lava, make up most of the crystalline component. Other minerals, present only in trace amounts, include hornblende, biotite, muscovite, epidote, tremolite, and tourmaline, mostly derived from Precambrian rocks. Most of the nonvolcanic components are fine particles presumably mixed with the tuff during eruption rather than during deposition.

In general, the tuff appears to represent ash falls deposited at a considerable distance from eruptive sources and locally reworked by water. Most of it appears to have fallen before the eruption of the main lava sequence and to have filled depressions between ridges of eroded Paleozoic and Mesozoic rocks. Essentially similar tuff between individual flows, however, indicates that explosive volcanism continued during the accumulation of basalt flows.

Gravel.—On the basis of geographic location and local stratigraphic relations, the Tertiary gravel can be assigned to three groups of deposits. One is found in a narrow linear belt at 2,500 to 2,600 m altitude, trending north-northwest along the crest of the Gravelly Range across the Greenhorn fault into the northern part of the Greenhorn Range. Another group, at lower altitudes, is north of Wigwam Creek and west of the large area of tuff and basalt in the northern part of the Varney quadrangle. The third group is in low hills nearly buried by alluvial fans at the foot of the Madison Range in the southern part of the Cameron quadrangle.

The gravel in the linear belt along the crest of the Gravelly Range consists of well-rounded cobbles and boulders, some as much as a meter in diameter, mainly of Precambrian granitic and gneissic rocks similar to those exposed northwest of the Greenhorn fault. Other rock types in this gravel are Paleozoic quartzite and sandstone and especially well rounded cobbles of hard gray quartzite, possibly derived from the Belt Supergroup, whose nearest exposures are now nearly 80 km north or west of the Varney quadrangle. Minor amounts of local limestone are represented in the gravel; however, in several exposures, the gravel contains largely resistant quartzite, chert, and sandstone, and limestone fragments are conspicuously absent. At two places in this belt, the gravel is associated with blocky accumulations and jumbled outcrops of olivine basalt that are topographically higher than the gravel and apparently overlie it. At another place, 300 m southwest of the junction of Warm Springs Road and Gravelly Ridge Road, the gravel is apparently overlain by tuff. An exceptional exposure in a landslide scar at the northwest edge of the gravel hill west of Crockett Lake revealed the following section of gravel and interbedded volcanic rocks:

Stratigraphic section 8

[Tertiary gravel and interbedded volcanic rocks, east side sec. 25, T. 8 S., R. 3 W., Varney quadrangle]

	Thickness (meters)
8. Gravel containing well-rounded pebbles, cobbles, and boulders as large as 1.5 m; mainly Precambrian rocks, such as quartzite, granite, and gneiss; few large angular blocks Kootenai sandstone and Shedhorn cherty sandstone; no limestone. Smaller clasts of deeply weathered sandstone and volcanic rocks. Matrix is coarse yellow clayey sand, noncalcareous, leached and oxidized. No sign of glacial origin	30
7. Basalt flow, compact base, vesicular top	6
6. Andesite(?) porphyry, purplish-gray, weathered, possibly intrusive	6(?)
5. Volcanic breccia interbedded with compact olivine basalt in layers 30 to 90 cm thick	8
4. Tuff, light-gray, sandy; plant fragments	1.5
3. Bentonitic clay	0.3
2. Sand, light-gray, tuffaceous, moderately coarse, well-bedded	1.2
1. Cobble gravel, well-rounded clasts in coarse sand matrix, poorly bedded; common large size smaller than in upper gravel	15+

Outcrops of compact olivine basalt in the gravel on the narrow ridge in the northwestern part of sec. 9, T. 8 S., R. 3 W. appear to be part of a dike that cuts the gravel, confirming evidence elsewhere that the gravel, in part at least, is older than the olivine basalt flows.

The outcrops east of the Madison River in the Cameron quadrangle show a similar sequence of gravel overlain by tuff and olivine basalt flows. Pebbles and small cobbles in this gravel include several kinds of Precambrian granitic and gneissic rocks as well as basaltic lava, tuff, and some Paleozoic limestone. This gravel is considered to be equivalent in age to the gravel on the crest of the Gravelly Range.

A sequence of boulder and cobble gravel overlain by tuff and agglomerate as much as 150 m thick, which in turn is overlain by olivine basalt flows, was reported by Mann (1954, p. 37–43) from localities farther south along the crest of the Gravelly Range. Vertebrate fossils in the tuff from these localities are early Oligocene in age, according to Mann.

The gravel north of Wigwam Creek is more problematical; it is poorly exposed, and its relation to the adjacent volcanic rocks is obscure. It consists almost wholly of fragments of locally derived Precambrian rocks and contains only minor amounts of younger rocks, which are commonly large angular blocks or slabs of Cambrian quartzite or limestone, obviously of very local origin.

Some large blocks of Precambrian rocks are 1.5 to 3 m in longest dimension and cannot have traveled far from their sources, presumably in the adjacent Precambrian terrane. Cobbles and small boulders of basalt appear in this gravel at several places. In the only good exposure (NE corner sec. 7, T. 7 S., R. 3 W.), large pebbles and small cobbles are embedded in a matrix of yellow, variably clayey sand, which is poorly sorted and poorly stratified. The exposed thickness of the gravel at this locality may be as much as 30 m.

The stratigraphic relation of this gravel to the adjacent tuff and basalt flows is not clear from exposures seen in the Varney quadrangle. Abundant cobbles and small boulders lie on the olivine basalt of the isolated outcrop areas in secs. 7 and 31, T. 7 S., R. 3 W., prompting an earlier conclusion that the gravel was interbedded in the lower part of the basalt sequence. However, the gravel is not known to underlie any of the basalt flows and does not appear at the margin of the flows or tuff northeast or south of the main basalt pile. Rounded pebbles, small cobbles, and a few large boulders are scattered here and there in the large area of tuff in the Axolotl Lakes area, but whether these fragments represent gravel beneath the tuff or whether they have been moved down from the gravel areas to the west during the extensive landsliding of the tuff is not clear. On balance, the evidence seems to favor the interpretation that this gravel is younger than the volcanic rocks and occupies valleys cut perhaps in later Tertiary time. The large blocks may even have been deposited by local glaciers during the Pleistocene.

LOWER TERTIARY EROSION SURFACE AND COLLUVIAL DEPOSITS

The gravel and volcanic rocks previously described were deposited on a surface of folded and eroded Precambrian, Paleozoic, and Mesozoic rocks whose relief was considerably less than that of the present landscape and which has been tilted or downwarped northeastward since the lower Tertiary materials were laid down. This surface extends for long distances at altitudes of 2,500 to 2,600 m along the crest of the Gravelly Range; it appears to have continued as a valley floor across the Greenhorn fault about 360 m below the highest summits of Baldy Mountain and the peak in sec. 28, T. 8 S., R. 3 W. Beneath the large area of basal flows and tuff, the surface slopes northeast toward the Madison Valley at 50 to 75 m/km; a similar slope is found by comparing the altitudes of gravel, tuff, and lava remnants in the southern part of the Varney quadrangle. As this slope is considerably less than the average or even the minimum dip of the flow structure in the basalt, it seems likely that the basalt pile was thickest near its northwestern edge and that the direction of flow was generally northeastward.

Massive movements of blocky colluvium appear to have taken place on this surface somewhat later than the deposition of the gravel and volcanic rocks. These movements are principally recorded in two anomalous areas of very large blocks of chert and cherty quartzite of the Shedhorn Sandstone. The larger of these areas occupies about 0.6 km^2 south of Horse Hill on the north side of Wigwam Creek Canyon. Blocks as much as 18 m long litter this area, lying in red clayey soil on the mudstone of the Kootenai Formation. The probable bedrock source for these blocks is the outcrop belt of Shedhorn across the canyon to the southeast, and the blocks presumably moved by gravity northwestward on the precanyon slope.

RHYOLITE ASH-FLOW TUFF

Extensive remnants of rhyolite in the southern parts of the Varney and Cameron quadrangles record the arrival of what was probably a large sheet of ash-flow tuff that spread northward from a source somewhere near the margin of the Yellowstone volcanic field. The field evidence indicates that most of the deposits were produced during a single eruption; they filled valleys whose floors were about 150 m above the present levels of Ruby Creek and Ruby River.

Along the west side of the Madison River in the southwestern part of the Cameron quadrangle the rhyolite is at least 18 m thick, although the better exposures include only 7 to 11 m of the more resistant lower and middle parts of the sheet (fig. 7). The main part of the sheet is compact lithic rhyolite containing conspicuous crystal fragments of sanidine and quartz. It is chalky and pinkish gray or pale red to medium brownish gray or reddish brown. Some layers are strongly spherulitic and contain elliptical voids, 1 to 2 cm long, flattened parallel to a megascopic platy structure in the more compact rhyolite. The lithic parts of the sheet are underlain in several places by a basal layer 30 to 90 cm thick of medium- to dark-gray glassy rock, which also contains abundant crystal fragments. Upper parts of the sheet grade upward to less compact tuff, part of which has been stripped away, leaving broad benches like that in secs. 35 and 36, T. 9 S., R. 1 W. In several places, the more resistant parts of the tuff lie on crudely bedded vitric tuff containing abundant rounded frag-

FIGURE 7.—Faulted rhyolite ash-flow tuff exposed in bluffs along west side of the Madison River valley, sec. 1, T. 10 S., R. 1 W., Cliff Lake quadrangle. View west from highway 0.8 km south of Cameron quadrangle.

ments of pumice and subangular fragments of various local Precambrian rocks, 0.5 to 6.5 cm in diameter. On Johnny Gulch in E½ sec. 9, T. 9 S., R. 1 W., the rhyolite lies on approximately 18 m of volcanic mudflow deposits, including vesicular and compact olivine basalt.

A few smaller remnants of essentially similar rhyolite were found in the valley of Ruby River in the southwestern part of the Varney quadrangle. In the larger remnants, compact crystal-lithic tuff at least 12 m thick is underlain by 30 to 60 cm of dark-gray glassy rock, which lies directly on bedrock.

The rhyolite is everywhere composed of shards, small pumice fragments, and angular crystal fragments of sanidine, quartz, sodic plagioclase, and, rarely, pyroxene. The rock ranges from loosely cemented nonwelded to extremely compact welded tuff. The light-colored lithic parts are partially to completely devitrified, but the dark obsidianlike basal layers, although highly welded, are still largely glass. In some specimens of the basal welded tuff, the shards have been folded on a microscopic scale, apparently by small movements within the flow after deposition. Devitrification has produced a variety of axiolitic and spherulitic textures similar to those described by Ross and Smith (1961) in ash-flow tuff from many localities throughout the world.

The eruption of the flow took place when the topography of the region was similar to that of today but before maximum downfaulting of the Madison Valley and deposition of the Quaternary alluvial gravels on the valley floor. Fragments of olivine basalt in and beneath the base of the tuff sheet indicate that the rhyolite is younger than the basalt lavas in the Gravelly Range and on the floor of the Madison Valley. However, moraines and outwash gravels, probably of Bull Lake age, are found along Ruby Creek and Ruby River in terrace remnants only 60 m lower than the rhyolite, which, therefore, may be not greatly older than the Bull Lake Glaciation. Although a late Tertiary age has been assumed for the rhyolite, it may be as young as early Pleistocene.

FRESHWATER LIMESTONE

An extensive unit of freshwater limestone is exposed in a series of low hills just west of the Madison River in the northeastern part of the Varney quadrangle and the northwestern part of the Cameron quadrangle. This rock is easily recognizable, pale yellowish brown to light brownish gray, moderately to poorly indurated, crudely bedded, and commonly porous and permeated by small solution cavities along the bedding. It commonly con-

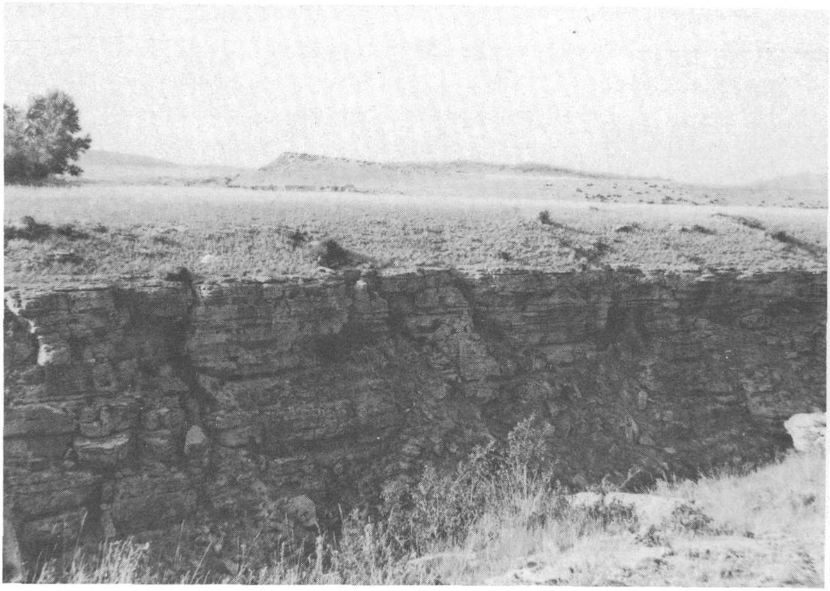


FIGURE 8.—Tertiary limestone in lower canyon of Wigwam Creek, near line between secs. 24 and 25, T. 7 S., R. 1 W., Varney quadrangle. Ridge on center skyline is same limestone uplifted and tilted eastward 11°.

tains lenses and fragments of crustiform or banded limestone or flowstone within more massive limestone, as well as layers of spongy tufalike material. The best exposure of the unit (fig. 8) is in a narrow canyon cut below the fan gravels of Wigwam Creek in secs. 24 and 25, T. 7 S., R. 2 W., where a section 21 m thick was measured (stratigraphic section 9).

A collection of snails from unit 2 of this section was described by Dwight L. Taylor as follows (written commun., 1959):

Freshwater snails:
- *Valcata* cf. *V. lewisi* Currier
- *Stagnicola* sp.
- *Physa* sp.

Land snail:
- cf. *Euconulus fulvus* (Muller)

On account of the poor preservation of the fossils, specific identification is impossible. So far as the material goes, however, it may all represent species living locally. This evidence tends to suggest a Pleistocene rather than Pliocene age. No late Pliocene fossils from the area are known for comparison, but the middle Pliocene mollusks from the northern Rocky Mountains are strongly distinct. The habitat represented is a perennial fresh water body, either a lake or perhaps a gently flowing stream. The single land snail is recorded by only one specimen, which might have been transported for some distance from the original habitat.

Stratigraphic section 9

[Tertiary limestone, SE¼ sec. 24, T. 7 S., R. 2 W., Varney quadrangle]

	Thickness (meters)
5. Limestone, like unit 3, more weathered, abundant solution cavities; much flowstone and tufalike material; overlain by gravel	7.6
4. Limestone, light-brownish-gray, nonresistant, laminated with cross-fibrous calcite in straight even layers	1.5
3. Limestone, similar to unit 2, less compact and less distinctly bedded; locally platy or laminated; contains porous interlayers	3.7
2. Limestone, mostly light yellowish brown, porous and vuggy; many solution cavities to 5 cm in diameter. Bedding indistinct but even, locally curved and truncated by overlying beds. Locally spongy and tufalike, containing hollow tubes 4.5 or less in diameter. Lower part more compact and resistant; includes fossiliferous lens 30 cm by 4 m near base of unit	6.8
1. Limestone, light-brownish-gray, porous to compact; locally includes flowstone mantling more compact limestone. Contains rounded pebbles 0.5 to 13 cm in diameter of upper Paleozoic and Mesozoic sandstone and quartzite, upper Paleozoic limestone and chert, Precambrian granite, and olivine basalt	2.1
Base not exposed.	

Bedding in the limestone unit dips generally eastward 3° to 12°; locally, however, beds dipping as much as 20° were seen. The variations probably represent originally nearly horizontal beds tilted eastward by late Cenozoic faulting in the Madison Valley. In the excellent exposures on Wigwam Creek, however, dip variations of as much as 10° occur within the unit; structural relations suggest that the steeper dips may have resulted from fault movements during deposition of the limestone.

The geomorphic and structural relations of the Tertiary limestone are similar to those of the ash-flow tuff, which, therefore, may have been deposited at about the same time. Both limestone and tuff contain fragments of olivine basalt presumably derived from the lava nearby to the west, and both have been displaced about the same amount by the normal faults of the Madison Valley floor.

QUATERNARY DEPOSITS

GLACIAL DEPOSITS

Direct glacial deposits in the Varney and Cameron quadrangles consist of till deposited by valley glaciers flowing from cirques on isolated summits in the Gravelly and Greenhorn Ranges and from several strongly glaciated valleys in the Madison Range. They may also include some considerably older deposits of bouldery material found in unusual topographic situations on the eastern flank of the Gravelly Range. Glaciers on Baldy Mountain in the northwestern part of the Varney quadrangle and on Specimen Butte at the head of Ruby Creek just south of the quadrangle boundary were all short, originating in cirques at about 2,750 m altitude and descending the northern and eastern slopes for distances of 1.5 to 6.5 km. Glaciers in the Madison Range were somewhat longer; those in the canyons of Wolf Creek and the South Fork of Indian Creek flowed 11 to 13 km from cirques at about 3,000 m in altitude and reached the range front at 1,890 to 1,950 m. A glacier of similar length occupied the valley of Noman Creek just east of the Cameron quadrangle and flowed into the main valley of Indian Creek, ending at an altitude of 1,950 m about 3 km short of the range front.

The extent of the ice is recorded by many discontinuous lateral moraines in the lower parts of the valleys and by well-developed lobate end moraines of those glaciers that reached the alluvial floor of the Madison Valley. The surfaces of the morainal deposits are generally characterized by more or less well-rounded boulders, some as much as 3 to 4.5 m in size, derived from bedrock sources within the glaciated valleys. For example, the moraines on the headwaters of Wigwam Creek on the east side of Baldy Mountain contain only Paleozoic and Mesozoic rocks, whereas the adjacent Tertiary gravel contains abundant Precambrian clasts. However, a few Precambrian clasts derived from the gravel were incorporated in the basal parts of these moraines. The deposits show well-developed morainal ridges as much as 18 m high, with intervening swales and a few undrained depressions in spite of their relatively steep overall slopes.

End-moraine complexes at the mouths of the canyons of Wolf and Indian Creeks in the Cameron quadrangle are especially well preserved. As Alden (1953, p. 180–181) pointed out, the moraines on Indian Creek were deposited by a glacier descending the South Fork while the lower part of the main valley remained unglaciated. These morainal complexes contain many well-defined lobate morainal ridges, unbreached depressions, and large blocks scattered about their surfaces.

On both Wolf Creek and the South Fork of Indian Creek, subdued lateral moraines along the canyon walls reach altitudes of 150 to 180 m above the present valley floors. They represent ice either at a somewhat higher and older level of erosion, or thicker than that which produced the end moraines, for the gradients of these higher moraines suggest that their terminal lobes would have extended farther out on the alluvial valley floor than the existing end moraines. Older, more extensive end moraines may have been depressed by faulting and partly buried beneath the alluvial fan. This is best shown at the mouth of Wolf Creek canyon, where a lateral moraine at an altitude of 2,200 m on the north wall appears to be cut off abruptly at the canyon mouth more than 120 m above the surface of the younger end moraine on the valley floor just outside the canyon.

Evidence for older and younger, or higher and lower level, glaciations is not so clear in the other glaciated valleys of the area. Lateral moraines 120 to 135 m above Ruby Creek in the southeastern part of the Varney quadrangle may correspond to the higher lateral moraines in the Madison Range. The ice on Ruby Creek did not extend beyond the mapped moraines, for the lower part of the canyon shows no evidence of glacial action. Remnants of bouldery terrace deposits on the north wall of the canyon about 45 m above the present streambed suggest that the valley floor at the time of maximum glaciation was graded approximately to the surface of the alluvial fan at the mouth of the valley.

The existence of more than one stage of glaciation in the Madison Range was suggested by Alden (1953, p. 63, 180–181), who assigned most of the moraines on Indian Creek and elsewhere in the range to Iowan or Illinoian and higher level deposits to early Pleistocene glaciation. Subsequently, Richmond (1964, p. 225–227) recognized deposits in the nearby Yellowstone Park area as belonging to the Bull Lake and Pinedale Glaciations, as well as to one or more pre-Bull Lake glaciations. He suggested that the Pinedale is approximately contemporaneous with the Wisconsin Glaciation in the midcontinent region and that the Bull Lake Glaciation is either early Wisconsin or represents a pre-Wisconsin, post-Illinoian glaciation not recognized in the midcontinent. Whether the higher and lower moraines I have mapped as older and younger till in the Madison Range represent two glaciations separated by an interval of extensive deglaciation is debatable, but they were formed probably during one or both of the two stades of the Bull Lake Glaciation recognized by Richmond. Comparable morainal deposits in the valley of Beaver Creek, a tributary to the Madison River just northwest of Hebgen Lake in the adjacent Hebgen Dam quadrangle, were assigned to the older stade of Bull Lake Glaciation by Richmond. These moraines are smoothed and resemble the older or outer moraines—for example, those on Baldy Mountain and the older moraines in the Madison Range. Moraines of the Pinedale Glaciation, according to Richmond, are confined to the upper 3 to 5 km of glaciated valleys in the Hebgen Lake area. Nevertheless, the state of preservation of the end moraines on Indian and Wolf Creeks suggests that these may be of Pinedale age (see Richmond, 1965, p. 224).

BOULDER DEPOSITS OF UNCERTAIN ORIGIN

Unusual deposits of subangular blocks in a dark-brown clayey matrix occupy interfluve areas extending in a horseshoe-shaped pattern across the headwaters of Morgan Gulch, Cherry Creek, and Johnny Gulch in the east-central part of the Varney quadrangle. The deposits consist of angular to subangular blocks and moderately rounded cobbles of various Paleozoic and Mesozoic rocks, among which the most conspicuous are cherty sandstone of the Shedhorn Sandstone, Quadrant Quartzite, sandstone and conglomerate of the Kootenai Formation, Flathead Quartzite, and much weathered Precambrian granite and gneiss. The material is not well exposed, but the matrix appears to be very clayey and the deposits unsorted. Most of the fragments are of local origin. Blocks of the Kootenai Formation are abundant in the western part of the deposits on Morgan Gulch, but they become obviously fewer eastward, as do, in succession, blocks of the Shedhorn and the Quadrant. In the eastern part of the deposit farther down Morgan Gulch, Precambrian granitic blocks, some as much as 4.6 m long, are abundant as well as blocks of Flathead Quartzite. Near the head of Johnny Gulch, the bouldery deposits contain many small fragments of dark-gray phyllite and iron-rich quartzite that can have come only from areas of Precambrian rocks at lower altitudes to the east.

The surface of these deposits, especially in the headwaters of Morgan Gulch, includes small undrained depressions resembling subdued knob-and-kettle topography comparable with the more recent morainal deposits southeast of Baldy Mountain. Although landsliding might explain the depressions, the clear evidence of transportation westward from topographically lower source areas and the horseshoe shape of the deposits as a whole strongly suggest that they are morainal material deposited by a broad tongue of ice that moved westward from highlands in the Madison Range. Presumably this took place before the present Madison structural valley was formed, for there is no evidence of similar deposits on the floor of the valley, and moraines in the Madison Range barely reach the present range front.

Remnants of formerly extensive glacial deposits at levels 300 or more meters above present valley floors at many places in the Madison Range and nearby areas have commonly been referred to the "Buffalo Till," presumably of pre-Wisconsin age. Those in the northern part of the Madison Range have been described by Hall (1960, p. 197–199) as being on the eastern slope of the range, 30 to 50 km east of the deposits under discussion, and having come from source areas nearer the crest of the range to the west. Hall also pointed out that similar bouldery deposits on the crest of the Gravelly Range near Black Butte contain striated stones and lie on a striated pavement that indicates ice movement in the direction N.65°W. These were described by Atwood and Atwood (1945) as till of Eocene age and later by Mann (1954, p. 37–43; 1960, p. 122–123) as representing mudflow deposits of probable Oligocene age. Whether the deposits in these widely separated places are closely related in time and process is still conjectural. As Hall (1960) pointed out, they may have resulted from widespread glacial activity, probably of pre-Wisconsin age, whose deposits have been radically dismembered by late Cenozoic normal faulting and canyon cutting in the region.

ALLUVIAL FANS AND GRAVEL OF THE MADISON VALLEY

Most of the floor of the Madison Valley is occupied by variably coarse cobble gravel carried into it by the larger streams on either side. These deposits have formed a series of partly coalescing alluvial fans on both sides of the valley, which originally merged with a narrow northward-sloping alluvial plain in the axial part of the valley. Although this surface of alluviation has been eroded and dissected in many places, large remnants are preserved in the north-central part of the Cameron quadrangle in what is called the Cameron Bench and in many of the fans on the west side of the river. Because the altitude is higher and the relief is greater in the Madison Range to the east than in the Gravelly Range to the west, the fans east of the river have grown larger than their counterparts west of it, producing the present asymmetrical position of the river. Since construction of the Cameron Bench, the Madison River has cut its channel nearly 60 m below its former alluviated valley floor. Concurrently, Indian Creek, Wolf Creek, Ruby Creek, and other tributaries have become entrenched in their respective fans, and the Madison has carved a distinctive set of erosional terraces. Most of the larger fans east of the river have been eroded to some degree, leaving remnants of the original constructional surfaces 1 to 6 m or more above the present fan surfaces. Most of this erosion appears to have resulted from lowering the bed of the Madison River; some erosion near the fan heads may be due to relative uplift of the mountain block along the Madison Range fault system.

A series of somewhat older and steeper fans and aprons, of mixed alluvial and colluvial material, mantle the lower slopes of the Madison Range front. All these have been eroded, some rather deeply—for example, those south of Bear Creek and adjacent to Corral Creek. These deposits appear to have been brought down by short streams descending the mountain front on steep gradients and to have been tectonically raised relative to the axial part of the valley. They are surmounted and locally overlapped by landslide material from the actively rising bedrock slopes of the mountain front.

Alden (1953, p. 71) thought that the Cameron Bench was early Pleistocene in age, thereby implying that the associated fan gravels were early Pleistocene or older. Although this may be true for much of the underlying valley fill, relations between the larger fans and the glacial deposits in the Varney and Cameron quadrangles indicate that construction of the fans and the Cameron Bench continued at least until the beginning of Bull Lake Glaciation, which Richmond (1970, p. 15) believed followed the Sangamon Interglaciation 120,000 to 130,000 years ago. The younger end moraines on Indian Creek and on Wolf Creek appear to have been laid down on the apices of the fans shortly before the erosion previously described. Thus, the age of the Cameron Bench and the associated alluvial fans of the Madison Valley is probably at least as young as Sangamon in terms of the American midcontinent Pleistocene sequence. If the end moraines produced at older and higher ice levels have indeed been dropped and partly buried by the fans, this fact would suggest that building of the fans continued into early Wisconsin time.

GRAVEL OF THE RUBY RIVER VALLEY

Thin gravel caps spurs and dissected terraces adjacent to Ruby River and Warm Springs Creek in the southwestern part of the Varney quadrangle. This deposit is largely cobble gravel and a few small boulders composed mainly of Paleozoic sandstone and limestone. The gravel along Warm Springs Creek also contains clasts of Precambrian rocks and Tertiary basalt and rhyolite. The Precambrian rocks and basalt presumably were derived from Tertiary gravel and lava in the Gravelly Range. The gravel generally is not more than 6 or 9 m thick and appears to be remnants of a sheet that sloped steeply toward Ruby River and Warm

Springs Creek and whose lowest points were about 30 m above the present streams. Prevalence of Quadrant Quartzite in the gravel south of the confluence of Warm Springs Creek shows that this particular gravel came largely from the Snowcrest Range west of Ruby River.

Remnants of a depositional surface not eroded or covered by the gravel are preserved on several steep spurs sloping eastward from the Greenhorn Range along Timber Creek and on a similar spur sloping westward along the south side of Squaw Creek. In these places, the surface is mantled by large and small colluvial blocks derived from the surmounting slopes. By analogy with the Quaternary deposits in the Madison River valley, the gravel in the Ruby River valley probably was also deposited near the time of the latest glacial maximum and has been undergoing erosion since then.

LANDSLIDE DEPOSITS

Evidence of large-scale mass movement of exposed rocks down the present topographic slopes is widespread in the Gravelly Range and along the steep faulted front of the Madison Range. The results range from the irregular ridges and sag ponds, characteristic of outcrop areas of the Morrison Formation, to visible landslide scars surmounting chaotic masses of disturbed bedrock. Where landslide movements have been sufficient to carry significant amounts of one formation over another, these deposits have been mapped as colluvial or landslide deposits. Such deposits include earthflows of mudstone of the Morrison Formation in the South Fork of Warm Springs Creek, of Kootenai Formation and Thermopolis Shale east of Romy Lake, and a mudflow of softened Sphinx Conglomerate in Grindstone Gulch, all in the Gravelly Range. Also included are a landslide mass of Precambrian dolomite just north of the Bear Creek Ranger Station and several earthflows of Cretaceous mudstone and sandstone farther north along the front of the Madison Range.

A similar origin may be ascribed to an unusual pile of angular blocks of the basal sandstone of the Kootenai Formation 2.5 km north of the Crockett Lake Ranger Station in the Gravelly Range. Many of the blocks in this area are 3 m in diameter, and some are as large as 9 m. They are adjacent to two outcrop areas of the Kootenai Formation, from which they were probably derived by slumping of the underlying Morrison Formation.

Some of the landslides have obviously taken place within the past decade or two, but most are grassed over or forested. Most of the activity, therefore, probably coincided with the colder climate during glacial advances in the region, when melting of accumulated ice and snow provided excessive soil moisture and opportunities for intensive frost action.

STRUCTURAL GEOLOGY

The structural pattern in the Phanerozoic rocks of the Varney and Cameron quadrangles has resulted from two distinct periods and contrasting types of deformation. Episodes of Laramide orogeny, essentially compressional in character, produced two major belts of thrust and tear faults along with northwest-trending folds and associated high-angle thrust faults in the Paleozoic and Mesozoic rocks. Later orogenic events were, by contrast, largely extensional. They resulted in relative depression of a major structural block in the Madison Valley, complementary strong uplift of the western side of the Madison Range, and attendant steep normal faults in both the Madison and Gravelly Ranges. Most of this deformation took place in late Cenozoic time, and it continues to the present.

LARAMIDE STRUCTURAL FEATURES

Laramide structural features are concentrated in two belts of faults and folds, a western belt in the Greenhorn Range, continuing northeastward across the northern end of the Gravelly Range in the Varney quadrangle, and an eastern belt along the west front of the Madison Range in the Cameron quadrangle. The eastern belt is much obscured by normal faulting and is covered by basin fill in the northern part of the Cameron quadrangle, but it becomes more visible as it trends away from the range front in the east-central part of the quadrangle and continues southeastward in the adjacent Sphinx Mountain and Hebgen Dam quadrangles.

A major fault zone extends along the east side of the Greenhorn Range from a point about 1.6 km northeast of Ruby River to the northern part of the Varney quadrangle, where it disappears beneath gravel and volcanic rocks of Tertiary age. This fault was first recognized by Mann (1954, p. 52), who called it the Greenhorn thrust. It represents a major structural break bringing complexly deformed Precambrian and Paleozoic rocks eastward over less deformed Upper Cretaceous rocks. The minimum stratigraphic displacement is 3,000 m, and the horizontal displacement is probably 8 km or more. Attempts to contour the fault surface along the outcrop belt between Ruby River and the North Fork of Wigwam Creek suggest that much of its irregular trace results from local variations in attitude. The strike of the fault along segments 1.5 to 3 km long appears to vary from nearly due north to N. 40° E., and the dip may range from less than 20° to considerably more at various places. The fault trace is offset by right-lateral tear faults, notably just west of the quadrangle boundary, where the Greenhorn fault is offset more than 1.5 km on a steeply dipping fault trending N. 30° W. (fig. 9).

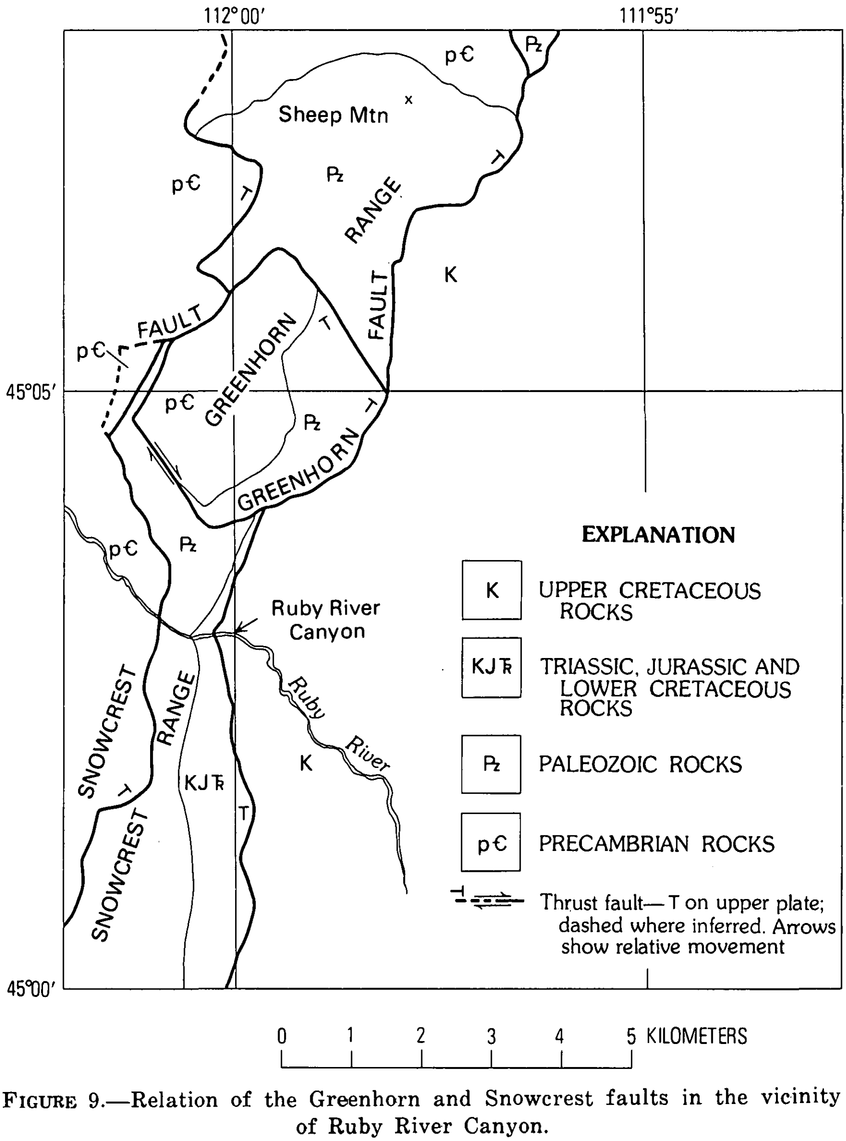


FIGURE 9.—Relation of the Greenhorn and Snowcrest faults in the vicinity of Ruby River Canyon.

The Greenhorn fault has not been located north of the cover of Tertiary rocks in the northern part of the Varney quadrangle. One intriguing clue to its location, however, is provided by the small outcrops of Precambrian dolomite surrounded by tuff in sec. 8, T. 7 S., R. 2 W. If these outcrops are part of the Greenhorn thrust block, the northern continuation of the fault must be between them and the outcropping Jurassic rocks nearby to the east. The fault has also not been traced in detail southwest of the Varney quadrangle. It may continue across the Ruby River into the Snowcrest Range, or it may be overlapped by a second major fault, the Snowcrest fault, which has been mapped for many kilometers along the west side of the Snowcrest Range (fig. 9).

Southwest of Ruby River, the Thermopolis Shale, the Kootenai Formation, and older Mesozoic and Paleozoic formations appear at the northern end of a belt of steeply dipping and overturned strata that extends southwestward the full length of the Snowcrest Range (Klepper, 1950, pl. 16). This belt represents the western limb of a major syncline whose eastern limb includes the gently dipping rocks of the southern part of the Gravelly Range and whose axis is approximately along the upper course of the Ruby River.

East of the Greenhorn fault in the Varney quadrangle, two major northwest-trending anticlines appear in the Paleozoic and Mesozoic rocks—the Warm Springs anticline and a larger anticline near the center of the quadrangle. Both folds are cut longitudinally by high-angle thrust faults; similar faults cut the west-dipping beds throughout the central part of the quadrangle. Small compressional folds a few meters in amplitude and minor bedding-plane thrust faults are found locally almost to the eastern limit of the Paleozoic rocks in the Gravelly Range.

Structural features of the eastern Laramide fault belt are similar to those of the western belt. They are best seen in the ridges on either side of Indian Creek, in the Cameron quadrangle, where steeply dipping and strongly overturned Paleozoic rocks are associated with a major thrust fault that brings Precambrian gneiss and dolomite eastward over rocks as high in the section as the Frontier Formation. Beds immediately beneath the fault are locally overturned as much as 60°; beds farther east are folded and sliced by subsidiary thrust faults. Similar relations north of Bear Creek are obscured by younger normal faults which give rise to peculiar structural relations along the Madison Range front. For example, a small block of Precambrian granitic rock exposed between Burger and Mill Creeks (secs. 22 and 27, T. 7 S., R. 1 E.)

apparently represents part of the overthrust dropped by normal faulting against the much younger Cretaceous rocks beneath the fault. How complex these relations can get is well shown in the exposures on the range front at Tolman Creek near the northern quadrangle boundary.

The youngest formation affected by the Laramide deformation is the Sphinx Conglomerate of Eocene age. Although this unit lies unconformably on folded and faulted rock ranging from Mississippian to Late Cretaceous age, including the volcanic and volcaniclastic rocks in the Cameron quadrangle, the Sphinx Conglomerate at the eastern border of the quadrangle is strongly folded on northwest-trending axes parallel to other folds of late Mesozoic to early Tertiary age.

CENOZOIC NORMAL FAULTS

The eastern part of the Gravelly Range and the west front of the Madison Range are dominated structurally by normal faults resulting from regional deformation beginning in middle or late Tertiary time and continuing to the present. In contrast to the compressional deformation of the Laramide orogeny, the late Cenozoic deformation has resulted in crustal extension and relative depression of major structural features like the Madison Valley. It was accompanied by extensive volcanism not far south of the Varney and Cameron quadrangles.

The master feature in this area is the Madison Range fault, recognized and named by Pardee (1950, p. 369) as a system of en echelon faults along the western front of the Madison Range and the eastern border of the Madison Valley. The course of the frontal fault system is marked by easily visible recent fault scarps on the gravel fans and colluvial slopes throughout the Cameron quadrangle and for many kilometers north and south of it. Detailed mapping in the Cameron quadrangle shows that the range-front fault system consists of three parallel overlapping segments about 5 km apart, each trending north-northwest along the north-trending range front. Each of the downdropped blocks bounded by these faults has been tilted northward and probably westward, like a series of piano keys hinged at their southern ends. The three main fault segments are largely concealed by the accumulated surficial deposits along the foot of the range, but their traces are outlined by prominent fault scarps in these deposits. In particular, the location of the western fault is indicated by two distinct scarps that were overlooked during the fieldwork but are readily seen on air photographs. One of these scarps trends

N. 10 E. through secs. 7 and 18, T. 7 S., R. 1 E.; the other trends N. 5° W. in the western part of secs. 9 and 16, T. 8 S., R. 1 E.

Only one locality provided bedrock exposures of any of the faults. A 9-m zone of brecciated granitic gneiss trending N. 40° W. can be traced along the western slope of The Wedge in the southeastern corner of the Cameron quadrangle. Abundant slickensided fault surfaces within the breccia dip steeply westward and show striae about parallel to their dip. Angular fragments of gneiss and fault gouge are cemented by carbonate, amorphous silica, and iron oxide. Some fragments also show argillic alteration.

Estimates of the amount of movement on the faults of the Madison Range system are difficult because no well-defined features can be correlated across them. Tertiary gravel and volcanic rocks that appear on the downdropped blocks along the eastern side of the Madison Valley may have been eroded from some of the higher blocks, but similar deposits have not been found in the Madison Range in the vicinity of the range front. Nevertheless, cumulative depression of the valley floor on these faults in the northern part of the Cameron quadrangle must amount to a few thousand meters.

Much smaller displacements are found on many of the faults that cut the Paleozoic rocks along the west side of the Madison Valley. Stratigraphic displacements on these faults are easily measurable and range from less than 30 m to a maximum of 750 m on the faults shown near the west end of structure section B–B′ on the geologic map of the Cameron quadrangle (Hadley, 1969a).

Many of these faults are in a zone trending about N. 40° W., extending roughly parallel to the major segments of the Madison Range fault system into the north-central part of the Varney quadrangle. Others form a set of faults trending east-northeast, parallel to foliation and lithic boundaries in the adjacent Precambrian rocks. Relative displacement is down on the east side of most of these faults, contributing toward depression of the western margin of the Madison Valley. In general, these displacements are larger on the southern faults of the group, indicating increasing downfaulting of the western side of the valley in this direction.

The normal faults displace the youngest bedrock units in the area, including the upper Tertiary(?) limestone and ash-flow tuffs. The recent fault scarps show that major movements have taken place on some 50 km of the Madison Range fault probably within the past 1,000 years. Minor movements took place on the same fault system several kilometers south of the Cameron quadrangle during the Hebgen Lake earthquake of 1959 (Myers and Hamilton, 1964, p. 77–78). Relations of faulted moraines at the range front on Wolf Creek in the southeastern part of the Cameron quadrangle, previously described, indicate downfaulting of the floor of the Madison Valley by as much as 120 m since Bull Lake Glaciation about 30,000 years ago.

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