Big Snowy and Amsden Groups and the Mississippian-Pennsylvanian Boundary in Montana

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A study of the Upper Mississippian and Pennsylvanian sedimentary formations with special emphasis on their regional correlation, variation in lithology, and age assignments

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By Edwin K. Maughan and Albert E. Roberts

ABSTRACT

The Big Snowy Group is redefined to include the Kibbey, Otter, and Heath Formations, as the group was originally established. However, the Heath Formation, and consequently the top of the Big Snowy Group, is restricted to strata beneath a Late Mississippian to Early Pennsylvanian regional unconformity. This restriction limits the Big Snowy to three closely related formations that comprise one sedimentary cycle uncomplicated by intraformational structural movements. Also, the Big Snowy Group, as restricted, closely approximates a time-stratigraphic unit of Late Mississippian age.

The Amsden Group unconformably overlies the Big Snowy or Madison Groups and consists of three formations in central Montana that are stratigraphically and lithologically nearly equivalent to the type Amsden Formation in northern Wyoming. The formations, in ascending order, are the Tyler Formation, the Alaska Bench Limestone, and Devils Pocket Formation. The Tyler Formation is locally divided into a Stonehouse Canyon Member at the base and a Cameron Creek Member at the top. Spores collected from the upper part of the Stonehouse Canyon and Cameron Creek Members are of Early Pennsylvanian age. Fusulinids from the Alaska Bench Limestone suggest a Morrow and Atoka age, and those from the Devils Pocket Formation are of Atoka or early Des Moines age.

Regional upwarp in south-central Montana and much of adjacent Wyoming took place near the end of Mississippian time. The area of uplift was bounded on the north by a system of probable faults and monoclinal folds. Rocks of the Big Snowy Group were stripped south of this structural belt, and were tilted northward and beveled north of this belt. Subsequent to erosion, the region gradually submerged during Early Pennsylvanian time. Seas inundated the region and detrital sediments of the basal part of the Amsden Group were deposited unconformably on Upper Mississippian rocks in central Montana, and on older rocks farther south in southern Montana and northern Wyoming.

INTRODUCTION

Upper Paleozoic rocks of the Big Snowy and overlying Amsden Groups of central and western Montana show wide variations in lithology and thickness and have long presented problems of identification, correlation, and dating. This paper summarizes the stratigraphy and presents revisions in nomenclature compatible with present understanding of the relations of the rocks comprising the upper part of the Mississippian and lower part of the Pennsylvanian of this region.

Study of these rocks was begun in 1957 and particular attention has been given to the problem of the systemic boundary since 1960. The authors have collected surface and subsurface stratigraphic information throughout Montana and adjacent States. Surface sections of the west half of Montana have been visited and studied in detail; subsurface sections in the east half have been studied from sample and geophysical logs. In central Montana special emphasis has been given to detailed stratigraphic correlation, description, and fossil content of individual units. New information regarding the ages of these rocks is reported, and the equivocal position of the boundary between the Mississippian and Pennsylvanian Systems is resolved. Much of this basic data has been obtained from published and unpublished reports and credit is given to the original sources throughout this report. However, interpretations of these data are those of the authors and we assume full responsibility for them.

The boundary between the Mississippian and Pennsylvanian Systems, which is believed to be at the unconformable contact of the Big Snowy and Amsden Groups, is given particular attention. Four groups of detailed columnar sections (pls. 1, 2) are presented to illustrate the unconformity between the Big Snowy and Amsden Groups and to show the regional correlation of the stratigraphic units that compose these groups.

DEVELOPMENT OF NOMENCLATURE

Quadrant Formation was first used in the Three Forks, Mont., area by Peale (1893) (as shown in fig. 1) for strata between underlying Madison Limestone (Mississippian) and overlying Ellis Formation (Jurassic). Quadrant Quartzite was applied by Weed (1896) and by Iddings and Weed (1899) (as shown in fig. 1) at its

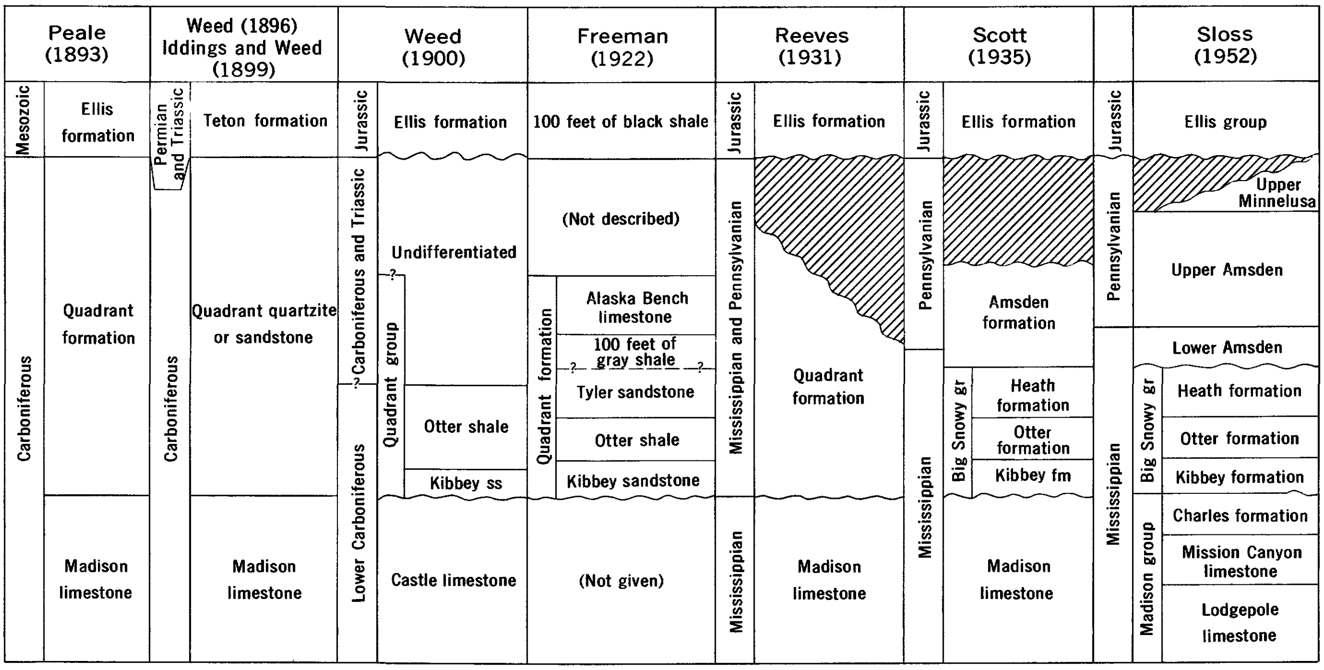

FIGURE 1.—Development of nomenclature for Mississippian and Pennsylvanian rocks in central Montana. Scott (1935) originally placed all the Amsden in the Mississippian but later (1945; 1950, p. 48) placed part in the Pennsylvanian on the basis of fusulinids.

type section on Quadrant Mountain in the northwestern part of Yellowstone National Park (fig. 2) for strata between the underlying Madison Limestone and the overlying Permian and Triassic Teton Formation. The name Teton was abandoned and replaced by the Permian Phosphoria Formation or its equivalents and the Triassic Dinwoody Formation. The more inclusive concept of Peale's Quadrant was widely used for a time in western Montana, but these strata have been subsequently separated in this region into the Big Snowy Group, Amsden Formation, Quadrant Quartzite (conforming to Weed's definition), and Phosphoria or Park City Formation or Shedhorn Sandstone. Freeman (1922) subdivided the Quadrant Formation in the eastern part of the Big Snowy Mountains into the following: Kibbey Sandstone, Otter Shale, Tyler Sandstone, and Alaska Bench Limestone (fig. 1). Reeves (1931), in his reconnaissance mapping of the Big Snowy Mountains, included all rocks between the Madison Limestone and the Ellis Formation in the Quadrant Formation rather than divide them into the units recommended by Freeman.

The Big Snowy Group, as established by Scott (1935), consisted of the Kibbey and Otter Formations, previously named by Weed (1900), for units in the Little Belt Mountains, and the Heath Formation which Scott recognized and named as a unit overlying the Otter in the Big Snowy Mountains (fig. 1). The Heath is not in the vicinity of the type sections of the Kibbey and Otter Formations in the Belt Creek area (fig. 1) where the Ellis Group of Jurassic age lies unconformably over the Otter (Easton, 1962, p. 114), but it is present a few miles east. Farther east, in the Big Snowy Mountains, Scott called red mudstone and limestone conformably overlying his Heath Formation the Amsden Formation. He assumed, as have many others, that these rocks were a northward extension of a similar sequence that comprises the Amsden Formation at its type locality (Darton, 1904, p. 396, 397) in the northern Bighorn Mountains, Wyo., and that is well exposed in the Pryor Mountains, Mont., about 95 miles south of the Big Snowy Mountains.

The base of the Big Snowy Group was lowered by Seager (1942, p. 864) to include the Charles Formation, which he described as a series of evaporite and dolomite beds lying between the basal "member" of Scott's Big Snowy Group and the Madison Group. He included strata equivalent to the lower part of the Kibbey Formation in his Charles. Seager suggested that the Charles possibly should be included with the Madison; but, as he reasoned, a time break was indicated by porosity in the underlying limestones in the upper part of the Madison. Therefore, he included the Charles in the Big Snowy Group as the basal "member." Perry and Sloss (1943) also included the Charles Formation in the Big Snowy Group. The Charles was redefined in the

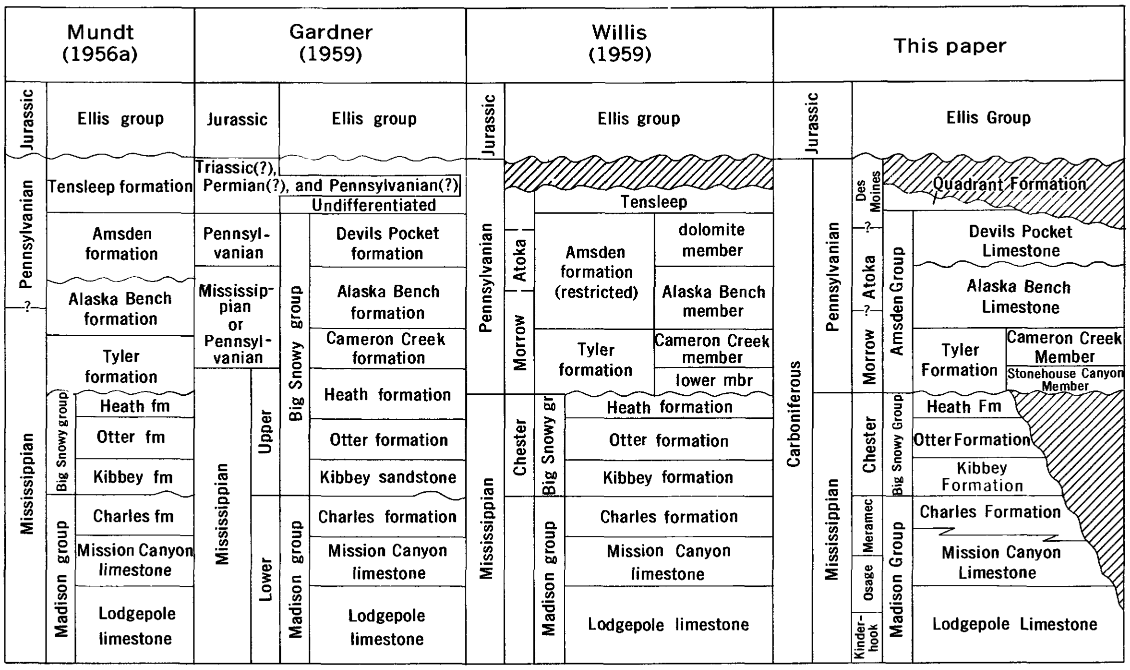

FIGURE 1.—Continued

type well and included in the Madison Group by Nordquist (1953). With the Charles included, Nordquist (1953, p. 73) lowered the upper contact of the Madison to where the lithology changes between the clastics of the Kibbey Formation and the carbonates and evaporites of the Madison Group. The Charles Formation, as thus redefined, contained characteristic anhydrites and carbonate lithology similar to that of the underlying Mission Canyon Limestone. Subsequent workers have established an intertonguing depositional relation between the Mission Canyon and the Charles, and Nordquist's assignment of these rocks to the Madison Group is now accepted by most stratigraphers. The Kibbey Formation remains as Scott defined it, the basal unit of the Big Snowy Group.

A twofold division of the Heath, as defined by Scott, was made by Beekly (1955). He separated the two units at an unconformity and restricted the name Heath Formation to interbedded black shale and thin limestone strata of marine origin which lie below the unconformity. Beekly considered the unnamed upper unit above this unconformity as a basal member of the Amsden. This unnamed member, composed of interbedded sandstone and black shale, was described by him as "a diverse facies of lagoonal, deltaic, and estuarine deposits varying from marine to nonmarine" deposited on an irregular erosional surface following deposition of the restricted Heath. He divided the remainder of the overlying Amsden into three additional members which, in ascending order, are a "Basal (sic) Amsden sand," "Amsden red beds," and "Amsden carbonates."

Mundt (1956a) restricted the Heath Formation, as Beekly did (fig. 1), to marine interstratified black calcareous shale and limestone beneath an unconformity. Rocks between the unconformity and the base of Beekly's "Amsden carbonates," Mundt called the Tyler Formation, a restricted use of the name previously introduced by Freeman (1922). Overlying the Tyler Formation, as used by Mundt, is limestone he called the Alaska Bench Formation in the same sense that this name was proposed and used by Freeman (1922) (fig. 1).

Rocks above the Alaska Bench were called the Amsden Formation by Mundt (1956a). They include cherty dolomite lying unconformably upon the Alaska Bench but are only part of the carbonate member of the Amsden Formation of other geologists in the Big Snowy area. The Amsden Formation of Mundt correlates with only the upper red shale member of the Amsden at its type section in the Bighorn Mountains, Wyo. He believed that lower strata of the formation pinch out northward and are not laterally continuous with any units present in central Montana. According to Mundt, the upper cherty dolomite overlaps these lower strata and constitutes all of the Amsden Formation in the Big Snowy area.

Gardner (1959, p. 335–337), who did not recognize the regional unconformity within the Big Snowy dep-

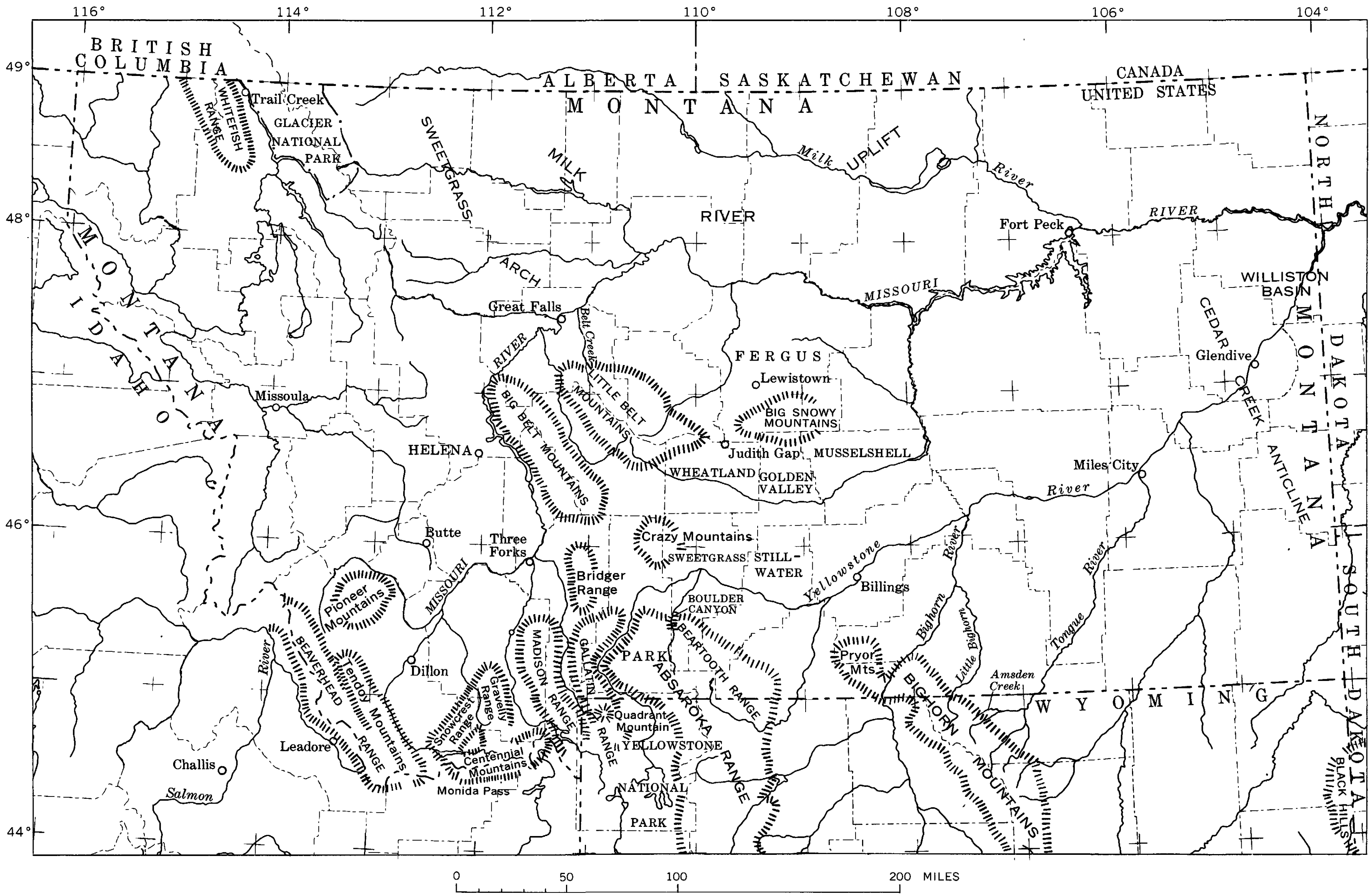

Figure 2.—Map of Montana and adjacent areas.

ositional sequence, did not accept the restriction of the Heath by Beekly and by Mundt. Instead, he returned to the definition of Scott and placed the top of the Heath at a gradational change from dark-gray beds upward into red beds. He assigned the red beds to his Cameron Creek Formation and used the Alaska Bench Limestone in the same sense as in earlier studies, but he introduced Devils Pocket Formation in place of Amsden for the overlying dolomite and sandstone unit (fig. 1). Because Gardner believed the entire sequence to be depositionally continuous, he drastically revised the Big Snowy Group and in addition to Scott's Kibbey, Otter, and Heath Formations, he raised the top of the Big Snowy Group to include the Cameron Creek, Alaska Bench, and Devils Pocket Formations.

Evidence for the Tyler-Heath unconformity was presented again by Willis (1959), who modified still further the nomenclature of the Amsden equivalents (fig. 1). He accepted Beekly's and Mundt's restriction of the Heath to the marine black shale and limestone strata beneath the unconformity and returned to the original use of the Big Snowy Group composed of Kibbey, Otter, and Heath.

Willis divided the Tyler of Mundt into two members. His lower unnamed member is predominantly dark shale interstratified with sandstone; and the upper member he called the Cameron Creek Member, adapting Gardner's name for the predominantly red shale unit.

The carbonate sequence above the Tyler was included by Willis in a restricted Amsden Formation also divided into two members, the Alaska Bench Member overlain by an unnamed dolomite member (Devils Pocket Formation of Gardner).

The development of nomenclature of these rocks shows two patterns which differ mainly by the horizon chosen for the top of the Heath and the significance attached to this contact. Basically, the nomenclature accepted by most geologists, especially those in petroleum exploration, has been that of Mundt, whereas the other system is that proposed by Gardner. Stratigraphic studies reported here suggest that the unconformity at the top of the restricted Big Snowy Group, recognized by Beekly and most subsequent workers, is indeed a widespread feature that preceded a new cycle of deposition. In the modifications of the nomenclature proposed here, this unconformity and the natural grouping of the rocks above and below it are acknowledged. Nomenclature used in this report is summarized in figure 3.

MISSISSIPPIAN SYSTEM, BIG SNOWY GROUP

The Big Snowy Group as used in this report includes, in ascending order, the Kibbey, Otter, and Heath Formations. The Heath Formation, and consequently the top of the Big Snowy Group, is restricted to dark-gray to black shale and interbedded limestone beneath a Late Mississippian to Early Pennsylvanian regional unconformity. The Big Snowy Group, then, closely approximates a time-stratigraphic unit which is mostly, if not entirely, of Late Mississippian (Chester) age. The Big Snowy, except for the restriction placed on the Heath, has the same limits as those given in its original definition by Scott (1935). The Kibbey, Otter, and Heath (restricted) are three closely related formations which are part of one sedimentary cycle and which form an integral and natural group. These formations are only briefly summarized here as they have been described in detail by Scott (1935), Walton (1946), Mundt (1956a), Willis (1959), and Easton (1962). Also, some additional discussion of the formations of the Big Snowy Group, particularly the Heath, is given in the sections entitled "Tyler Formation" and "Mississippian-Pennsylvanian boundary" to make those parts of this report more meaningful.

KIBBEY FORMATION

A predominantly brick-red sandstone sequence exposed in the cliffs along Belt Creek on the north flank of the Little Belt Mountains (fig. 2) was named the Kibbey Sandstone by Weed (1899, p. 2). He (1900, p. 295) later defined the Kibbey as the basal member of his Quadrant Formation.

The Kibbey Formation overlies, generally conformably, the Charles Formation or its equivalent in the Madison Group throughout much of Montana. Locally, near the margin of deposition, as in the vicinity of Three Forks, Mont., the Kibbey lies unconformably on the upper surface of the Madison. Local intertonguing of the Charles and Kibbey in northeastern Montana is suggested on stratigraphic section *D–D′* (pl. 2). Pre-Jurassic erosion truncated these rocks progressively from central to northern Montana (Perry, 1951, p. 57, pl. 3). The Kibbey is the most widespread formation of the Big Snowy Group. The thickness of the Kibbey is 147 feet at its type locality, about 240 feet in the Stonehouse Canyon section and as much as 275 feet in the central part of the Williston basin. This eastward thickening is chiefly due to an eastward change of facies from green shale and siltstone of the Otter into red beds of the Kibbey.

In most of central Montana the Kibbey Formation consists of grayish-red siltstone, sandstone, and shale and interbedded limestone, dolomite, and anhydrite. In eastern Montana the formation can be divided into three lithologic units on the basis of a medial unit, which is informally designated the "Kibbey limestone." This

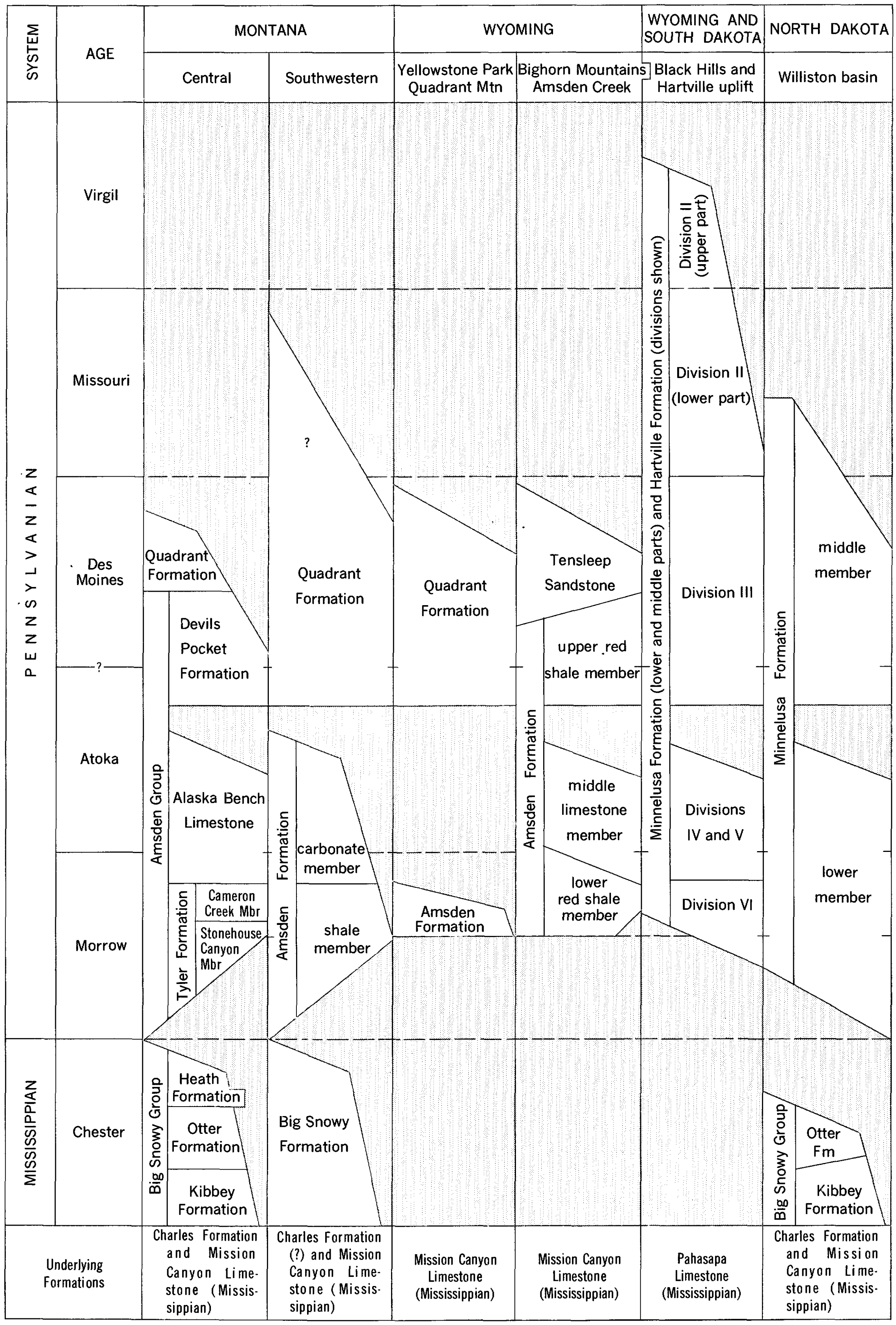

FIGURE 3.—Nomenclature and stratigraphic relations of the Upper Mississippian and Pennsylvanian rocks in Montana, Wyoming, South Dakota, and North Dakota.

unit generally consists of limestone or dolomite although it consists locally of sandstone or anhydrite according to Nordquist (1953, p. 81). This medial limestone of the Kibbey is a widespread marker bed that is easily recognized on geophysical well logs.

The Kibbey Formation is generally considered to be of Chester age as in some places it rests unconformably on beds of Meramec or older age. However, in other places (pl. 2) the basal part of the Kibbey interfingers with the uppermost part of the Charles Formation, a fact suggesting a late Meramec age. A Chester age is also indicated by fossils from lower strata in the Otter Formation, which are laterally equivalent to the upper part of the Kibbey, and by the gradational contact with the overlying Otter Formation.

OTTER FORMATION

Weed (1892, p. 307) first used the name Otter Creek Shales for exposures along Belt Creek on the north flank of the Little Belt Mountains near the type locality of the Kibbey Formation. He later (1899, p. 2) referred to these rocks as the Otter Shales and included them as part of the Quadrant Formation. The following year (1900, p. 295) he placed the Otter Shale as the upper formation of the Quadrant Group.

The Otter Formation conformably overlies the Kibbey Formation in central and east-central Montana and west-central North Dakota. In the Big Snowy Mountains the Otter is about 375–475 feet thick. Eastward, in the central part of the Williston basin, it has a maximum thickness of about 225 feet. Weed's (1892, p. 307) Otter Creek at the type locality in the Little Belt Mountains is 198 feet thick; however, at this locality the top of the formation is truncated and is overlain disconformably by the Ellis Group (Jurassic).

The Otter Formation consists predominantly of greenish-gray shale; locally it also contains gray, purple, and black shale and interbeds of yellowish-gray argillaceous limestone and dolomite and gypsum. The contacts between the Otter, Heath, and Kibbey Formations are commonly gradational and the three formations intertongue (pl. 2, *C–C′*).

Fauna collected by Weed (1900, p. 295, 296) were assigned to the Carboniferous, apparently the lower Carboniferous. Fauna studied by Scott (1942) and Easton (1962) indicate a marine environment of Chester age.

HEATH FORMATION

The Heath Formation was named by Scott (1935, p. 1028) for exposures at Beacon Hill near the town of Heath, Mont., on the north flank of the Big Snowy Mountains (fig. 4). The Heath was defined as the upper unit of his (1935, p. 1025) newly defined Big Snowy Group. Easton (1962, p. 14) revised slightly the contact between the Otter and Heath Formations by extending the base of the Heath downward to include the productid-bearing limestones that Scott placed at the top of the Otter. The Heath Formation is restricted in this paper to exclude sandstone and black shale above a regional unconformity in the same way that it is restricted by Beekly (1955) and by Mundt (1956a). The Heath Formation is unconformably overlain by the Tyler Formation or the Ellis Group (Jurassic).

The Heath Formation underlies central and east-central Montana and west-central North Dakota. The restricted Heath at the type section is 76 feet thick, and at three other localities in the Big Snowy Mountains it is 551, 270, and 322 feet thick (table 1). To the east, in the Williston basin, it is no more than about 100 feet thick.

TABLE 1.—*Comparison of thicknesses of Heath Formation and Stonehouse Canyon Member of Tyler Formation*

[Adapted from measured sections by Easton (1962, p. 117-124)]

Location	Heath Formation (restricted)		Stonehouse Canyon Member of Tyler Formation	
	Beds	Thickness (feet)	Beds	Thickness (feet)
Alaska Bench	28–30	76	18–27	288
Potter Creek Dome	13–26	551	6–12	289
Durfee Creek Dome	33–46	270	297–32	138
Stonehouse Canyon	38–66	322	24–37	101

The Heath Formation consists of interbedded dark-gray to black marine petroliferous limestone and shale and, locally, beds of gypsum. In many places the shale is calcareous and silty. Limestone is increasingly abundant from central to western Montana. Freeman (1922, p. 826) was the first to consider the Heath as the source bed for petroleum that is found in adjacent strata, particularly in the overlying sandstone reservoirs of the Stonehouse Canyon Member of the Tyler Formation which are prolific oil producers.

Scott (1935, p. 1031, 1032) considered the fauna of the Heath Formation closely related to that of the Brazer Limestone of Idaho and the Moorefield Formation of Arkansas and on this basis assigned to the Heath an age no younger than late Chester. Easton (1962, p. 14), on the basis of abundant fossil collections, also assigned the Heath Formation to the Late Mississippian (Chester).

Measured section of the type section of Big Snowy Group and reference section of Tyler Formation

[From Easton, 1962, p. 116–118; modified by Maughan, 1967]

Located along the prominent cliff forming the west end of Alaska Bench (locally called "Beacon Hill," see fig. 5) extending

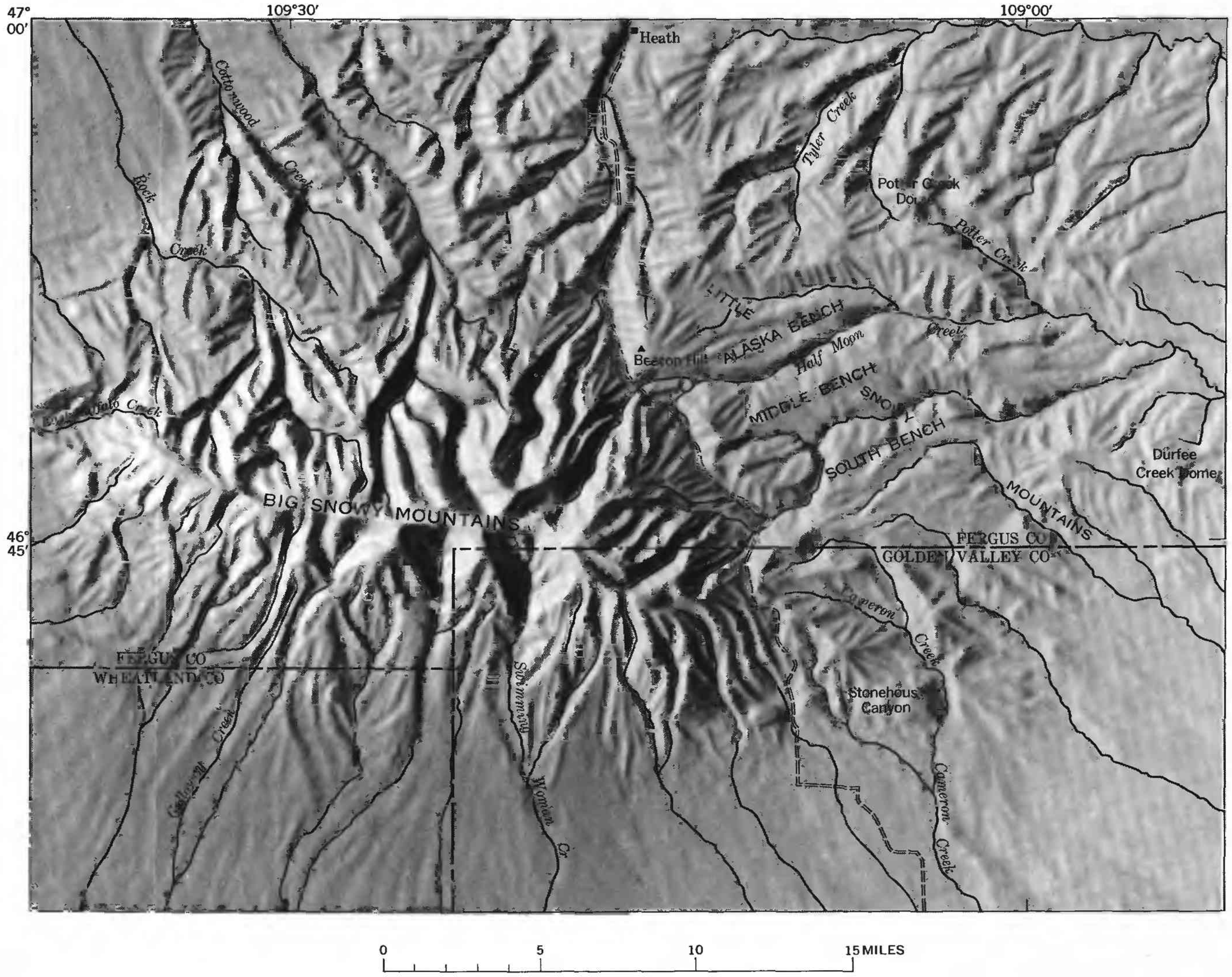

FIGURE 4.—Map of localities in Big Snowy Mountains and vicinity, Montana.

from the NE¼SW¼ sec. 25, T. 13 N., R. 19 E., to the SW¼ sec. 36, T. 13 N., R. 19 E., and thence continued to the NE¼ sec. 1, T. 12 N., R. 19 E., Fergus County, Mont.

This section can be reached by going 11.5 miles south of the gypsum plant at Heath, taking the road toward the beacon and stopping on the grade 0.2 mile north of the intersection of the gravel road eastward along Alaska Bench and the unimproved dirt road to the beacon. Most of the upper approximately 400 feet of section through the thick sandstone (bed 20) was measured here. The rest of the section can be reached from above by descending the hillside southwestward below the beacon, or from below by going 12 miles south of the gypsum plant at Heath to a point 0.3 mile south of the boundary of Lewis and Clark National Forest. The Madison Group crops out about 100 yards west of the foregoing point and the rest of the section lies along a line of sight northeast toward the beacon. An unimproved road branches off from the next road going eastward (about one-half mile south of the starting point) and leads toward the base of the cliff. This is the type section of the Big Snowy Group and of the Heath Formation as originally proposed by Scott (1935).

PENNSYLVANIAN SYSTEM

LOWER PART OF AMSDEN GROUP

	Feet
Alaska Bench Limestone (incomplete section; overlying beds eroded):	
1. Limestone, light-gray, sublithographic; beds 2–6 in. thick grades upward into brownish-gray 2- to 3-ft limestone beds; cliffmaker; locs. 13389, 13399	24
2. Limestone, yellowish-weathering, fine-grained, massive	3
3. Shale, green and red; and yellowish, argillaceous, resistant limestone; loc. 13384	1
4. Limestone, gray to buff, sublithographic to fine-grained; beds 1–2 ft thick; crystalline, hard; shale, yellow, green, in partings to beds 1 ft thick; unit forms prominent bluff; cross sections of productid brachiopods present	38
Total Alaska Bench Limestone measured	66

Tyler Formation:

Cameron Creek Member:	Feet
5. Shale, purplish-brown and gray-brown, calcareous, nonresistant	1
6. Limestone, gray, massive, resistant, fine-grained	2
7. Shale and shaly limestone, gray, 6-in. beds, hackly weathering and rather nonresistant; loc. 14220	2
8. Limestone, gray, fine-grained, vugular, massive; with laminated wavy minute beds	3
9. Shale, maroon, fissile, calcareous; limestone nodules; loc. 14221	3
10. Limestone, gray-brown, fine-grained, wavy laminations; forms resistant ledge; loc. 14223 from base of unit; 14222 from top	4
11. Shale, maroon or reddish-brown, calcareous, fissile; nonresistant slope former; base of an 8-in. impure nodular limestone lies 1.5 ft from top of unit; loc. 14226 just beneath the nodular limestone; loc. 14224 from the uppermost shale	10
12. Limestone, gray, sublithographic, hard, very resistant	1
13. Sandstone, yellowish-buff, stained red on surface, very fine grained, calcareous; prominent cliffmaker; loc. 13383 in middle of bed	7
14. Siltstone, pinkish to purplish, weathering white, shaly, calcareous; platy and wavy beds; surfaces covered with wormlike purplish lines and spots	15
15. Shale, greenish-gray, weathering red, fissile; locs. 13382, 13386	9
16. Dolomite, light-gray, very fine grained, calcareous, hard, resistant; sinuous vertical vugs in lower half; grades up into dark-brownish-gray limestone, very fine grained matrix with pebbly limestone grains, very hard, resistant; loc. 13381 in upper half	5
17. Shale; basal 5 ft calcareous, weathering yellow; upper 3 ft black, fissile; 4-in. limestone 3 ft from top; loc. 13380 in upper 3 ft	21
Total Cameron Creek Member	83

Stonehouse Canyon Member:	Feet
18. Limestone, light-gray to buff, very fine grained, seminodular, vugular, very hard, resistant	3
19. Shale and clay, yellow, greenish-gray, red, very weak (exposure dug out); loc. 13387	10
20. Limestone, buff with purple mottling, very fine grained, dolomitic, laminated, platy-weathering; cliff-maker	4
21. Shale, black, fissile; weathers to green clay at base and to red clay at top; plant fragments near base; loc. D 3121 A near base	28
22. Sandstone, light-brown, fine-grained; 2-in. beds of alternating clean porous beds and shaly beds; subangular grains; slightly resistant	9
23. Shale, black and dark-gray, fissile; loc D 3121 B near base and D 3121 C near top	28

Tyler Formation—Continued

Stonehouse Canyon Member—Continued	Feet
24. Sandstone, buff, weathering yellowish-brown, fine-grained, calcareous, porous, cross-bedded, ripple-marked; 2 in. to 2 ft beds; forms prominent bluff; loc. 13388 in 2 in. ironstone band 5 ft below top	14
25. Shale, black, brown, and gray, fissile, poorly exposed on steep slope; loc. D 3121 D near middle	108
26. Sandstone, buff to brown, fine-grained, cross-bedded, friable, calcareous, massive, cliff-making	48
(The section continues southwestward from the aerial beacon)	
27. Sandstone, brownish, conglomeratic; only basal part exposed; estimated thickness (83 ft) is average of Reeves' (1926, p. 53, 54) and Scott's 1935b, p. 1024) total possible thicknesses of associated sandy and covered units less thickness of item 26 above	36
Total Stonehouse Canyon Member	288
Total Tyler Formation	371

MISSISSIPPIAN SYSTEM

BIG SNOWY GROUP

Heath Formation:	Feet
28. Limestone, black, argillaceous, hackly-weathering, slightly resistant	10
29. Covered; probably black or dark-brown shale	56
30. Limestone, black, argillaceous, hackly-weathering	10
Total Heath Formation	76

Otter Formation:	
31. Covered; probably greenish-gray shale	83
32. Shale, greenish-gray; interbedded with argillaceous limestone; steep slope	42
33. Shale, greenish-gray to black; float of gray limestone slabs containing *Spirorbis* near top	28
34. Covered; probably shale	14
35. Limestone conglomerate, platy	5
36. Covered; probably shale	28
37. Mostly covered, upper part shale, greenish, some silty; with thin beds of oolitic limestone; limestone float to base of unit	90
Total Otter Formation	290

Kibbey Formation:	
38. Covered; greenish-gray soil; light greenish-gray limestone chips in soil at top of unit; grades downward to reddish-brown soil in lower half; silty	45
39. Sandstone, brown to reddish-brown, fine-grained, platy to flaggy, calcareous, poorly exposed	30
40. Covered; soil is reddish	115
Total Kibbey Formation	190
Total Big Snowy Group	556

REGIONAL RELATIONS

The Big Snowy Group, with one exception, rests upon the Mississippian Charles Formation or the equivalent part of the Mission Canyon Limestone where the Charles is not distinguished. The contact seems conformable in eastern Montana, but an erosional unconformity formed in western Montana prior to deposition of the Kibbey. In the Three Forks area, Scott (1935, p. 1026) noted that the Kibbey rests upon an erosional unconformity formed on the Madison Group. A karst surface described by Robinson (1963, p. 43) in this same area has local relief of as much as 100 feet along 300 feet of the basal contact of the Kibbey. At a few places elsewhere in western Montana, Big Snowy rocks rest on markedly thinned Madison. At an isolated exposure in the Pioneer Mountains southwest of Butte, Mont., Big Snowy rocks rest upon the Lodgepole Limestone (G. D. Fraser, oral commun., 1964). These relations indicate the maximum known erosion and removal of part of the Madison Group prior to deposition of the Big Snowy.

The Amsden Group overlies the Big Snowy Group throughout central Montana except for a narrow zone immediately adjacent to the northern flanks of the Belt and Big Snowy Mountains. Here pre-Jurassic erosion removed the Amsden, but not all of the Big Snowy, prior to Jurassic deposition (Perry and Sloss, 1943, p. 1292, and pl. 3). It is not possible to determine the original northern extent of the Big Snowy Group, because a short distance farther north of the truncation of the Amsden by pre-Jurassic erosion the Big Snowy Group is truncated also, and the Jurassic Ellis Group rests upon Madison strata (Perry, 1951, p. 57). The Big Snowy Group changes little in lithology northward in central and eastern Montana, although the thickness varies considerably (Willis, 1959, fig. 3, p. 1945) owing to relief of the Late Mississippian to Early Pennsylvanian unconformity.

Rocks of the Big Snowy Group were deeply eroded or were removed completely in Late Mississippian time in south-central Montana south of Musselshell, Golden Valley, Sweetgrass, and Park Counties (pl. 3). At least 550 feet of interstratified dark-gray shale and limestone of the Heath Formation (restricted) and a total of 1,189 feet of the Big Snowy Group had been deposited in central Montana (beds 13–50 of Potter Creek Dome section, Easton, 1962, p. 118, 119) prior to this period of erosion. No remnants of the Big Snowy Group are known to be preserved in south-central Montana that would indicate how far south these rocks originally may have extended; instead, these rocks are abruptly truncated, and the lithology of the Big Snowy Group now preserved immediately to the north does not suggest a shore facies (fig. 5 and pl. 1, *A–A′*).

The length of hiatus represented by the Late Mississippian to Early Pennsylvanian unconformity is not known, but it probably was relatively short. The youngest rocks of the restricted Heath Formation are of Chester age (Easton, 1962, p. 23), whereas the oldest rocks above the unconformity are either of very latest Mississippian or earliest Pennsylvanian. Certainly enough time elapsed prior to deposition of the overlying sediments for the entire Big Snowy Group to be stripped from some areas; yet similarity between shale in the Heath and in the overlying strata suggests that there was no significant change in depositional environment, although conglomerate, sandstone, and plant debris indicate a change to a shallower, near-shore environment. Additional evidence for this unconformity is presented in the discussion of the Tyler Formation.

Correlation of the Big Snowy Group west and southwest of the Big Snowy Mountains becomes increasingly difficult. Thickness and lithologic changes as well as limited exposures of the stratigraphic sequence do not permit correlation with the individual formations of the type Big Snowy Group. Thus, in parts of southwestern Montana where these rocks cannot be mapped separately the Big Snowy is of formation rank (pl. 3 and pl. 1, *B–B′*). The Big Snowy Formation is composed mostly of light-weathering dark-gray limestone and dark-gray shale which very closely resemble the limestone and shale of the Heath Formation, and which has been termed the Lombard facies by Blake (1959). In parts of southwestern Montana and western Wyoming, the Big Snowy Formation is composed only of strata equivalent to the Kibbey Formation and is a "red bed sequence" similar to the Amsden Formation. Miscorrelations have understandably been made, and some authors have used "Basal Amsden" or "Lower Amsden" for the Big Snowy Formation or its equivalent to indicate that the unit is older than the type Amsden. This misuse of Amsden has contributed to confusion in the literature and has brought the meaning of the term "Amsden" nearly into disrepute.

Equivalents or partial equivalents of the Big Snowy Group have been mapped or described in parts of southwestern Montana where Kibbey and Heath lithologies are apparent (Sloss and Moritz, 1951; Gealy, 1953; McMannis, 1955; Scholten and others, 1955; Blake, 1959; Hadley, 1960; and Robinson, 1963). Big Snowy sediments have not been recognized east of Boulder Canyon in Sweetgrass County in south-central Montana. In western Wyoming sandstone and red shale in this interval (Rubey, 1958) are similar to those in southwestern Montana: however, 50 miles west of the area mapped

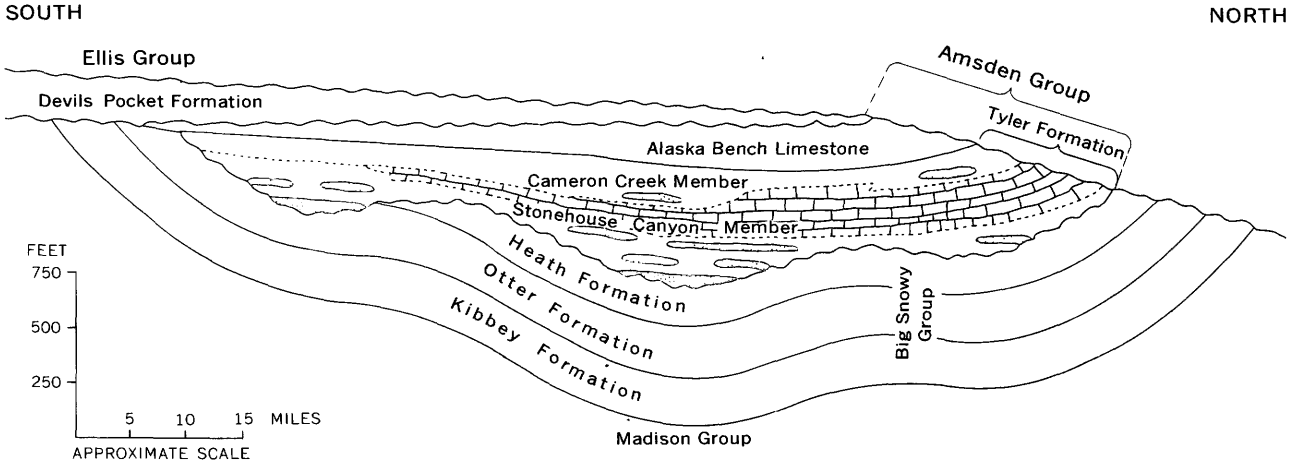

FIGURE 5.—Diagrammatic north-south section in central Montana showing relations of Big Snowy and Amsden Groups. (Modified from Mundt, 1956a, p. 1925.)

by Rubey, equivalent strata in the Chesterfield Range of southeastern Idaho are cherty limestones of the upper part of the Monroe Canyon Limestone (Dutro and Sando, 1963b, p. 1983, 1984).

E. T. Ruppel (written commun., 1964) measured and described 850 feet of mudstone, shale, and limestone in the Beaverhead Mountains near Leadore, Idaho, which he tentatively correlated with the Big Snowy Group. We have briefly studied the strata at this locality and concur with Ruppel's assignment. This is the westernmost extent of this sequence reported to date; and in the vicinity of Challis, Idaho, equivalent strata are carbonates in the White Knob Limestone (W. J. Mapel, written commun., 1963).

Branson (1937, p. 650) applied the name Sacajawea and "Lower Amsden" to a dominantly carbonate sequence in the upper part of the Madison in the Wind River Range in western Wyoming. Sacajawea was applied to strata he believed to lie between the Madison and his "Lower Amsden." He (1937, p. 653) concluded that Sacajawea is Salem to Ste. Genevieve in age, with a closer affinity to the Ste. Genevieve. He correlated this unit with a part of the Brazer in western Wyoming and with a part of the Big Snowy Group in central Montana. However, his (1937, p. 651) Sacajawea correlates with the upper part of the Mission Canyon Limestone and his overlying "Lower Amsden" may correlate with the Big Snowy Group. Failure to discriminate Sacajawea from "Lower Amsden" for younger stratigraphic units in a subsequent paper (Branson, 1939) has made the term ambiguous.

PENNSYLVANIAN SYSTEM, AMSDEN GROUP

The Amsden Group as used herein for central Montana constitutes a change in stratigraphic rank and consists of three formations, each of which we believe has counterparts in the type Amsden Formation in northern Wyoming. The formations, in ascending order, are the Tyler Formation, the Alaska Bench Limestone, and the Devils Pocket Formation. A correlation between the type section of Amsden Creek in north-central Wyoming and equivalent strata in the Big Snowy Mountains is illustrated by the detailed stratigraphic section *A–A′* on plate 1. We recognized three lithologic units in the Amsden Formation at the type section: a lower red shale member that locally is a sandstone at the base, a medial limestone member, and an upper red shale member that includes interbedded carbonate rock and sandstone.

TYLER FORMATION

Interstratified dark-gray shale and sandstone above the Late Mississippian to Early Pennsylvanian unconformity and red beds that are laterally and vertically gradational into the shale were named the Tyler Formation. These gray beds, originally included in the Heath, and the red beds have been called collectively the Tyler Formation by many geologists, including Freeman (1922) and Mundt (1956a). (See fig. 1 of this report.)

The reference section of the Tyler Formation is designated in this report as the well-exposed rocks at Alaska Bench in secs. 25 and 36, T. 13 N., R. 19 E., described in beds 5–27 of the section measured by Easton (1962, p. 116–118), and beds 11 probably through 34 of the section as described by Scott (1935, p. 1024). Both the Big Snowy Group and the Heath Formation are well exposed at this location (Scott, oral commun., 1966); although, due to inadequate maps, Scott (1935, p. 1024, 1025, 1028) incorrectly placed these exposures in sec. 6, T. 12 N., R. 20 E. Beacon Hill is also the location of excellent exposures of the strata that has been suggested for the type locality of the overlying Alaska Bench Limestone (Easton, 1962, p. 15).

The Tyler Formation is divided into two members, based largely on color and partly on lithology.

The lower member, the Stonehouse Canyon Member—a new name presented in this report—includes those strata composed of predominantly dark-gray rocks. These are beds 18–26 of Easton's (1962, p. 117) section at Alaska Bench which are here designated as the type section. Stonehouse Canyon is a name long applied to a stratigraphic section of Upper Mississippian and Lower Pennsylvanian rocks in the southeastern Big Snowy Mountains (fig. 2). The name was derived from Stonehouse Canyon in secs. 29, 31, and 32, T. 11 N., R. 21 E., Golden Valley County, Mont. and this is its reference section. The rocks at this location, described on pages B17, B18, are moderately well exposed; they have also been described by Gardner and others (1945; 1946, p. 51–54), Hadley and others (1945), Mundt (1956a, fig. 9, p. 1932), Gardner (1959, p. 338–342), and Easton (1962, p. 121–124).

The Cameron Creek Member is a reduction in nomenclatural rank, but otherwise it has the same contacts as the Cameron Creek Formation of Gardner (1959, p. 347). Willis (1959, p. 1952, 1953) made a similar proposal for the Cameron Creek when he made it a member of the Tyler Formation (fig. 1). The Cameron Creek Member is composed mostly of red beds that generally comprise the upper part of the formation and are beds 5–17 that Easton included in the Cameron Creek Formation.

The division of the Tyler into two members emphasizes that the members are lithologically similar and that the contact between them is a color change only. The boundary between Stonehouse Canyon and Cameron Creek is difficult or impossible to pick consistently at the same stratigraphic position from place to place owing to the gradation and intertonguing of one into the other. Easton (1962, p. 13) was aware of this affinity when he stated that "part of the Heath formation is a series of lenticular sandstones in black shale which occur near the top * * * and may in part belong to the overlying beds of the Cameron Creek formation." Strata equivalent to the Stonehouse Canyon Member, but mostly red, have been included in the Amsden Formation by Vine (1956, p. 424–434) along the northeast side of the Little Belt Mountains.

The unconformity at the base of the Tyler Formation is not readily observed in outcrops owing to poor exposures; however, its location can generally be established by careful tracing of beds in the rocks above and below.

Conglomeratic sandstone, less than half a foot thick at the base of the Stonehouse Canyon Member of the Tyler Formation in Stonehouse Canyon, thickens gradually westward and rests on successively older limestone and shale beds of the Heath Formation. In Stonehouse Canyon this conglomerate is 322 feet above the base of the Heath; but about 2⅓ miles west at State Road 25, the conglomerate is 10 feet thick and lies about 60 feet above the base of the Heath, a fact indicating a local westward beveling of about 100 feet per mile.

Farther north, Norton (1956, p. 58) described an exposure of the Heath-Tyler contact located in secs. 8–17, T. 12 N., R. 20 E., about one-fourth mile east of State Highway 25 (fig. 6). Here the coarse-grained sand-

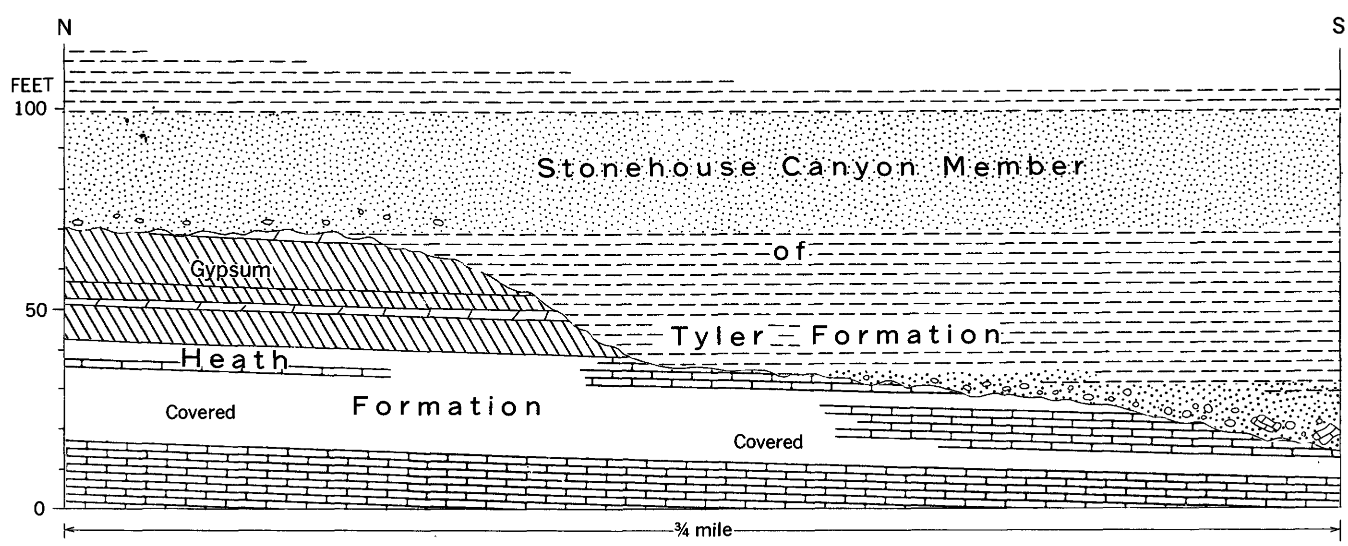

FIGURE 6.—Section of erosional unconformity between Heath Formation (restricted) and Stonehouse Canyon Member of the Tyler Formation exposed at west end of Middle Bench, Little Snowy Mountains, S½, sec. 8 to NE¼, sec. 17, T. 12 N., R. 20 E., Fergus County, Mont. (modified in part from Norton, 1956, p. 61).

stone of the basal part of the Stonehouse Canyon can be seen overlying and abutting against dark limestone and shale of the older Heath (fig. 7). The sandstone contains angular blocks of dark limestone that yield *productids*, which are common at most fossiliferous Heath horizons. These limestone blocks probably were broken away by wave action as Stonehouse Canyon seas invaded valleys carved in the limestone—dark shale unit of the Heath.

Differences in lithology between the Heath Formation and the Stonehouse Canyon Member of the Tyler Formation, although generally slight, contribute evidence for an unconformity between these two units. The limestone and shale in the Heath are thin bedded, very fine grained, and well sorted and thus indicate that deposition occurred in relatively quiet water. The clastic and carbonate beds of the Stonehouse Canyon are thick bedded, lenticular, very fine to coarse grained, and generally poorly sorted and thus indicate more turbulent conditions that must have existed at the time that these rocks were deposited. The differences in transporting energies suggested by these differences in lithology indicate an abrupt change in depositional conditions. At most places where there is sandstone at the base of the Stonehouse Canyon it is conglomeratic. Although the contact is poorly exposed, it has been mapped by Douglass (1954) as his Amsden-Big Snowy boundary in the southwestern part of the Big Snowy Mountains; and the same contact has been extensively mapped on the northeast flank of the Little Belt Mountains by Vine (1956).

The Heath seems to have been deposited at considerable distance from shore. The fossils in the Heath suggest that the Heath sea was of normal salinity; the lithology, fabric, and color of the rocks of the Heath indicate that the water was calm or even stagnant. Such conditions are likely to have prevailed in a broad, open sea and fairly deep water, probably many miles from shore.

The shore during deposition of the Stonehouse Canyon presumably was near the beveled and faulted southern edge of the underlying Big Snowy Group or within about 25 miles of the south flank of the Big Snowy Mountains. Deposition of the Stonehouse Canyon was in locally turbulent water that was probably shallower than the water during deposition of the Heath. The lithology and fabric of the rocks and the fossils in the Stonehouse Canyon indicate a near-shore marine environment for some strata, whereas other strata, notably the coaly or carbonaceous beds, suggest deposition in swampy or brackish lagoonal environments. Several environments, ranging from normal marine through brackish to possibly fresh water, may have existed simultaneously in adjacent areas as well as in rapid succession at any one place. The rocks also suggest deposition by currents ranging from moderately strong in some areas to weak or lacking in others.

Gardner (1959, p. 344) stated that "the sediments in the Big Snowy basin of deposition indicate a single essentially uninterrupted cycle of deposition rather than two cycles interrupted by a widespread erosional unconformity. The Big Snowy sequence began with sandstone [Kibbey], continued with thick shale [Otter, Heath, and Cameron Creek], and ended with a predominantly limestone sequence [Alaska Bench] * * *." A more detailed inspection of these rocks indicates that the Kibbey, Otter, and the restricted Heath in themselves represent such a cycle of deposition and, characteristically, are composed respectively of sandstone, shale, and limestone. Similarly the Stonehouse Canyon, Cameron Creek, and Alaska Bench comprise a similar depositional cycle of sandstone, shale, and limestone.

The thickness of the restricted Heath Formation varies markedly from one exposure to another in the Big Snowy Mountains. Norton (1956, p. 58) suggested that "Many of the various units of the marine Heath formation can be identified and the sandstones of the Tyler * * * may rest unconformably on any of these." In table 1 thicknesses of the Heath at four localities are compared with each other and also with thicknesses of the sandy beds that lie above the unconformity.

Subsurface examination indicates the relief and extent of the Heath-Tyler unconformity. The unconformity is present throughout eastern Montana and western North Dakota, and evidence for it is published by Beekly (1955), Mundt (1956a), Foster (1956), and Willis (1959). Four detailed cross sections (pls. 1, 2) show correlation of the Big Snowy and Amsden Groups and the unconformity between them. In addition, a paleogeologic map of the Mississippian rocks below the unconformity (pl. 3) illustrates beveling of the Heath, Otter, Kibbey, and older Mississipian rocks, contrary to Gardner's (1959, p. 344) contention that these rocks are not regionally beveled.

Mappability of the Tyler Formation and its subdivisions has been questioned. Scott (1935, p. 1029) noted that the Tyler sands, which had been named by Freeman, "are neither a lithologic, paleontologic, or mappable unit over broad areas * * *." Gardner (1959, p. 335) repeated this statement and amplified it by saying that the "Tyler is an identifiable lithic unit only in a few relatively small widely spaced areas of central Montana."

Exception is taken to these statements because we have learned from inspection of exposures of these rocks in the Big Snowy Mountains and elsewhere in central and

FIGURE 7.—Unconformable contact of the Stonehouse Canyon Member of the Tyler Formation upon restricted Heath Formation, west end of Middle Bench, NE¼, sec. 17, T. 12 N., R. 20E., Fergus County, Montana, *a*, unconformable contact; *b*, limestone beds in the Heath Formation; *c*, conglomeratic sandstone at base of Stonehouse Canyon Member; *d*, angular blocks of limestone derived from the Heath Formation.

southwestern Montana that several significant lithologic differences can be used to distinguish Tyler from Heath as readily as Heath is distinguished from Otter and Otter from Kibbey.

The Tyler Formation thickens northward from the Stonehouse Canyon section, and it thins markedly a few miles south in the subsurface. This thinning is in the same area where the underlying Big Snowy Group thins markedly by truncation, but in the Tyler the thinning seems to be depositional rather than erosional. A thin tongue of the formation extends in the subsurface southward from the Big Snowy Mountains and is continuous into the lower red shale member of the Amsden Formation at its type section as illustrated by stratigraphic section *A–A′*, plate 1. The Tyler equivalent has been identified in the northern Big Horn Mountains as the "lower clastic zone" by Gorman (1963), and is the Darwin Sandstone and Horseshoe Shale Members of the Amsden of Mallory (1967).

The Tyler generally thins from the Big Snowy Mountains eastward across Montana to about the Cedar Creek anticline as illustrated by stratigraphic section *C–C′*, plate 2. It also thickens east of the Cedar Creek anticline in the Williston basin in northeastern Montana and North Dakota. The formation is sharply truncated in the Williston basin by pre-Jurassic erosion along an arcuate trace approximately parallel with the Missouri River from northeastern Montana into south-central North Dakota.

West of the reference section, the Tyler Formation thickens; on East Buffalo Creek in the Big Snowy Mountains (fig. 4) and on the northeast flank of the Little Belt Mountains it is as much as 700 feet thick. In the latter area it was assigned by Vine (1956) to the lower part of his Amsden Formation.

Strata equivalent to the Tyler Formation are included as a part of the Amsden Formation undifferentiated in southwest Montana. In general, these strata are thick immediately northwest of a line trending northeasterly from near Monida Pass in southwestern Montana, through the Gravelly Range to about Judith Gap in central Montana (fig. 2). The equivalent rocks are thin and locally absent immediately southeast of this line, evidence suggesting erosion on the upraised side of a Late Mississippian and Early Pennsylvanian fault or fold system. In central western Montana the Tyler equivalents are relatively thin owing to overlap, probable slower rate of deposition, and beveling at the top. Complex structure, intrusion, metamorphism, and weak resistance to erosion contribute to a dearth of information about the Amsden Formation in this area.

Northwestern Montana includes only a single known remnant of rocks of Pennsylvanian age, which is in the Whitefish Range near the town of Trail Creek (fig. 2). These rocks may be equivalent in part to the Tyler Formation, but the relations of this small outlier as well as known Pennsylvanian rocks farther north in British Columbia and Alberta to the Pennsylvanian rocks in central Montana are unknown. Some speculations have been offered by Halbertsma and Staplin (1960).

ALASKA BENCH LIMESTONE

The Alaska Bench Limestone forms prominent hogbacks and dip slopes throughout the Little Snowy Mountains and along the flanks of the Big Snowy Mountains. The formation was named for the Alaska Bench, a broad mesa on the north side of the Little Snowy Mountains (fig. 4). Prominent exposures at the west edge of the bench, at a place locally known as Beacon Hill, the type section, have been described (Easton, 1962, p. 15; Mundt, 1956a, p. 1925–1928; Gardner, 1959, p. 347). The section at Beacon Hill is incomplete, however; and the section at Stonehouse Canyon (p. B17) is here given as the reference section.

The formation is composed mostly of limestone and some dolomite in 1- to 2-foot-thick beds interstratified with red or gray mudstone. Carbonate rock dominates, especially at the Beacon Hill section and elsewhere where only the lower 100 feet or so of this unit are preserved; but in a few places, where there are thicker remnants of the Alaska Bench—as at Judith Gap (pl. 1, *B–B′*)—the upper part is composed of almost equal amounts of carbonate rock and mudstone. Rocks similar to the Alaska Bench occur throughout most of Montana wherever Pennsylvanian strata are preserved. In eastern Montana this limestone unit has previously been included in the Minnelusa Formation; it also seems to correlate with Division V, and possibly in part with Division IV, of the Hartville Formation and with the equivalent of part of the lower member of the Minnelusa Formation farther south in eastern Wyoming and western South Dakota. Similar rocks are the limestone of the middle member of the Amsden Formation in southwestern Montana and Wyoming and are correlated with the Alaska Bench. These are the same as the strata identified as the "quartz deficient zone" by Gorman (1963) in his study of the Amsden Formation in the Bighorn Mountains and the lower part of the Ranchester Limestone Member of the Amsden of Mallory (1967).

The thickness of the Alaska Bench and its equivalents varies considerably throughout this region and at many places within short distances, owing chiefly to a regional erosional unconformity beneath the overlying Devils Pocket Formation. At some places the formation has been completely removed by this erosion, but at other places the Alaska Bench is as much as 143 feet thick, as at Durfee Creek Dome (Easton, 1962, p. 120), and as much as 290 feet thick as at Judith Gap (pl. 1, *B–B′*).

The Alaska Bench Limestone is gradational with the underlying Cameron Creek Member of the Tyler Formation. Lateral gradation and interbedding of red beds and limestone at the contact seems evident in the subsurface east of exposures in the Big Snowy Mountains (pl. 2, *C–C′*). It seems likely that similar intertonguing, established in the subsurface by detailed marker horizons provided by geophysical logs, may take place in surface exposures west of the Big Snowy Mountains; but this relationship has not yet been established because most data are from widely separated measured sections at outcrops of limited lateral extent.

DEVILS POCKET FORMATION

Gardner (1959, p. 347–348) named the Devils Pocket Formation and designated the type section at exposures in Road Canyon in sec. 31, T. 11 N., R. 21 E., about half a mile west of the ranch at the mouth of Stonehouse Canyon. These strata are 143 feet thick at the type section (p. B17) and 80 feet thick at Durfee Creek Dome (Easton, 1962, p. 119) and are not present farther north in central Montana owing to removal by erosion prior to deposition of the Jurassic Ellis Group. On Galloway Creek in the southwestern part of the Big Snowy Mountains (fig. 5), Douglass (1954) described 220 feet of strata lying between the Alaska Bench Limestone and quartzitic sandstone of the Quadrant Formation. These strata resemble the Devils Pocket Formation farther east, and most or all of the interval is equivalent to it. The Devils Pocket is partly truncated beneath Jurassic rocks at its type section; but the formation is gradational into the overlying Quadrant Formation on Galloway Creek. Regional correlation, illustrated on plates 1 and 2, indicates that the complete exposures on the southwest flank of the Big Snowy Mountains are the thickest sections of the Devils Pocket Formation.

The Devils Pocket is composed chiefly of dolomite, but it includes abundant red mudstone, mostly in the lower part, and sandstone or quartzite, mostly in the upper part. Equivalent strata of similar lithology extend throughout most of eastern and southern Montana. In eastern Montana they previously have been included within the Minnelusa Formation. They are correlated with the lower part of Division III of the Hartville Formation of east-central Wyoming and equivalent of part of the middle member of the Minnelusa Formation of the Black Hills. The Devil's Pocket is also equivalent to Gorman's (1963) "upper clasitic zone of the Amsden (upper red shale member in this report) and to Mallory's (1967) Ranchester Limestone Member of the Amsden (pl. 1, section *A–A′*).

An unconformity of regional extent underlies the Devils Pocket and equivalent rocks in the adjacent areas. This unconformity accounts for much of the variation in thickness and in lithologic sequence of Pennsylvanian rocks in this region, and has caused much of the difficulty that has perplexed students of the Amsden in Montana and Wyoming.

Reasons for this unconformity given by Mundt (1956a, p. 1931) are (a) a sharp lithologic break between the two formations, (b) variable thickness of the underlying Alaska Bench Limestone, (c) the overlap of the Alaska Bench by the Devils Pocket at the base of the Devils Pocket that suggests possible formation in south-central Montana, and (d) locally formed red shale of a lateritic soil on top of the Alaska Bench Limestone. These reasons are confirmed by J. G. Mompers (oral commun., 1963) and by the correlations shown on plates 1 and 2.

In a few places in southern Montana, lower strata of the Amsden are absent and the Devils Pocket rests upon rocks of the Madison Group. One of these places is near the Montana-Wyoming boundary in the northern Bighorn Mountains. About 25 feet of red mudstone (equivalent to the Cameron Creek Member of the Tyler Formation) overlain by about 80 feet of limestone (equivalent to the Alaska Bench Limestone) make up the lower and middle members of the Amsden Formation along the Little Big Horn River (Agatston, 1954, p. 569). These rocks are not present approximately a mile north of the State line, where only about 60 feet of cherty limestone and dolomite and some sandstone of the upper half of the upper member of the Amsden (equivalent to the upper part of the Devils Pocket Formation) rests upon Madison. Evidence that red beds were deposited here above the Madison, as in the exposures not far to the south, is indicated by red mudstone in the fissures and channels that compose the karst zone at the top of the Madison. At Storm Castle Mountain (pl. 1, *A–A′*) in the Gallatin Range, the Devils Pocket also overlaps the truncated Tyler and Alaska Bench.

The top of the Devils Pocket Formation at its type section is an erosional unconformity beneath Jurassic rocks of the Ellis Group. At other places where younger strata of Pennsylvanian age are preserved, the Devils Pocket Formation and the equivalent upper part of the Amsden Formation grade upward into the Quadrant Formation or Tensleep Sandstone. The boundary between these formations is generally arbitrarily placed between the dominantly carbonate sequence and the overlying dominantly quartzite or sandstone sequence. This contact is not everywhere consistently placed stratigraphically, although a relatively uniform thickness of the Devils Pocket seems to persist throughout south-central Montana. Also, the Tensleep grades eastward into dominantly dolomite strata which have been included in the middle member of the Minnelusa Formation in eastern Montana. Here, Devils Pocket is expanded to include these dolomitic rocks that are the equivalent of the Tensleep of central Montana and Wyoming.

The Devils Pocket is increasingly sandy westward, and in western Montana equivalent strata are not readily separated from the overlying sandstone. In the extreme southwestern part of the State, both Devils Pocket and Tensleep equivalents are included in the Quadrant Formation, but in other parts of the State, especially north and east of the Gallatin Range and Yellowstone National Park, the Devils Pocket is included as part of the Amsden, and the Quadrant is restricted to strata equivalent to the Tensleep farther east.

Reference section of the Amsden Group in Montana

[From Easton, 1962, p. 121–124]

Located along a line trending east-southeast from the first prominent red outcrops of Kibbey Formation in road cuts along State Road 25 where it ascends into the Big Snowy Mountains, through Stonehouse Canyon; the section extends from the center of the west line, sec. 25, T. 11 N., R. 20 E., across sec. 30 and into SW¼ SW¼ sec. 29, thence down the dry canyon running southward across N½NW¼ sec. 31, T. 11 N., R. 21 E., Golden Valley County, Mont.

Most of the section is exposed in Stonehouse Canyon. This can be reached by going 0.5 mile west of the intersection of the Red Hill Road (State Road 25) with U.S. Highway 12 at a point about 1 mile north of Lavina, then going north along State Road 25 toward the Big Snowy Mountains. Bear left and downhill at the first Y-intersection; go 26.0 miles, always taking the better road when a choice is necessary and making some right-angle turns, to a road crossing; continue north 1.0 mile to a cattleguard. By bearing right at this point, the road leads to the stone ranch house at the mouth of Stonehouse Canyon; entry to the top of the Paleozoic strata is possible through the fence on the west side of the creek 150 feet west of the house. By bearing left at the cattleguard, one can drive onto the Otter Formation in the upper reaches of Stonehouse Canyon; from the cattleguard bear left and continue roughly northward 0.8 mile to a T-intersection; turn right, crossing fence line just east of intersection; go downhill and swing northward a total of 0.3 mile; bear left on faint vehicle tracks, going 0.6 mile to northwest corner of fenced field; cross fence line, and immediately turn northward upvalley (called Road Canyon in Gardner and others, 1946, p. 49), going 0.3 mile to fence; cross fence line, bear eastward into dry wash and go a total of 0.4 mile upwash to earth dam; continue around west end of dam, swinging eastward upgrade, crossing low summit, and descend the grade into Stonehouse Canyon at another earth dam, a total of 0.9 mile.

Most of beds 1–102 may be studied east of the second earth dam or south (downstream) from it. The Otter and the Heath Formations are best exposed to the east; younger beds are best exposed to the south.

Beds 1–33 were originally published (Gardner and others, 1946, p. 52–54) as part of the Stonehouse Canyon section; beds 34–102 were originally published (Gardner and others, 1946, p. 46) as part of the State Road 25 section. The sections were originally measured by L. S. Gardner, H. D. Hadley, and C. P. Rogers, Jr. The section was sampled again by W. H. Easton, J. E. Smedley, and Kasetre Phitaksphraivan.

JURASSIC SYSTEM

ELLIS GROUP

	Feet
Swift Formation:	
1. Sandstone, brown, glauconitic, friable, impure, resistant	5
Total Swift Formation measured	5
Rierdon Formation:	
2. Siltstone, dark-red to brown, shaly, calcareous	10
3. Covered; red soil; 200 ft to east, red siltstone is in upper 13 ft of unit	16
Total Rierdon Formation measured	26

PENNSYLVANIAN SYSTEM

AMSDEN GROUP

Devils Pocket Formation:	Feet
4. Sandstone, white to mottled gray and pink, clean, porous, noncalcareous, poorly bedded; made up of medium-grained, well-sorted, clean, quartz sand; locally quartzitic to cherty, but upper 6 ft is friable and nodular. In Road Canyon, about 1 mile to the west, this interval overlain by 14 ft of breccia with Pennsylvanian fusulinids	18
5. Interbedded sandstone, siltstone, and dolomite; sandstone, white, gray, pink, and purple, fine- to medium-grained, mostly calcareous, friable, unresistant; siltstone, red, unresistant; dolomite, white, light-brown, and gray with pink tint; some sandy, some with chert nodules; beds as much as 5 in. thick	35
6. Covered; soil is light purple	2
7. Dolomite, mottled gray and pink, dense to finely crystalline, siliceous, chalky, brittle, poorly bedded	4
8. Covered	21
9. Dolomite, white to gray, sandy textured; beds to 1 ft thick	5
10. Covered; red soil on steep slope	58
Total Devils Pocket Formation	143

Alaska Bench Limestone:	Feet
11. Limestone, light-gray, dense to finely crystalline; 6-in. to 2-ft beds; top of resistant sequence forming dip slopes; loc. 13423 from upper 2 ft; colln. 44–37–69	9
12. Covered; soil is red and pink, silty and clayey	5
13. Limestone, gray; beds 2–8 in. thick, some fossils interbedded with mottled pink and gray, silty and sandy dolomite in middle 4 ft	7
14. Siltstone, red, shaly, calcareous, locally nodular	6
15. Limestone, gray, some pinkish and purplish, dense to finely crystalline sparsely fossiliferous, resistant; beds 2 in. to 2 ft thick; base of shaly interval 4 ft thick is 9 ft from base	20
16. Covered	6
17. Limestone, gray, some mottled with pink, stylolitic; 3-in. to 2-ft beds; fossiliferous	47
18. Shale, purplish-red; a few thin beds of siltstone, red, very calcareous, unresistant	6
19. Limestone, mottled gray and pink, finely crystalline; beds 1–6 in. thick; partings of red, calcareous shale; sparsely fossiliferous; loc. 13422	5
20. Limestone, dark-gray, dense, massive; veinlets of silica on weathered surfaces	1
21. Interbedded limstone and shale, mottled gray and pink	5

Alaska Bench Limestone—Continued	Feet
22. Siltstone, mottled gray and purple, argillaceous, very calcareous; probably with some beds actually of impure limestone, very fine grained; beds mostly 1–6 in. thick, some shaly partings; loc. 13421, colln. 44–37–83	10
Total Alaska Bench Limestone	127

Tyler Formation: Cameron Creek Member:	Feet
23. Covered; soil, reddish, silty	35
24. Limestone conglomerate, gray, dense, hard, tough, massive; vugs with quartz linings	2
25. Covered; soil reddish	18
26. Shale, red, very calcareous, silty, locally sandy; with thin layers of white to greenish-gray siltstone and sandstone; unresistant	6
27. Limestone, gray, dense, massive; with calcite veins	2
28. Interbedded shale and siltstone, red, very calcareous; with nodules of bluish-gray limestone; unresistant; loc. 13420; colln. 44–37–80 from siltstone	16
29. Covered; soil is red, silty	27
30. Shale, red, fissile to brittle, unresistant; with lenses and laminae of pale-yellow siltstone	26
31. Conglomerate, dark-red, very calcareous, massive; clasts angular, of red claystone, ferruginous chert, and siltstone, having diameters as much as 3 in.; matrix silt and clay, calcareous	3
32. Shale, mostly reddish, some purplish-gray, fissile, unresistant; lower 16 ft claystone, silty, gray; outcrops dug out; 2 ft of interbedded siltstone and shale with limestone nodules 41 ft from base yielded colln. 44–37–94	66
33. Sandstone, white, gray, and brownish, fine- to medium-grained, calcareous; top 6 ft mudcracked and ripple marked; beds ½–6 in. thick; bottom 4 ft massive, porous, crossbedded; loc. 13418 in basal 4 ft; mostly poorly exposed	21
Total Cameron Creek Member	222

Stonehouse Canyon Member:	Feet
34. Covered; soil is dark gray	5
35. Shale, dark greenish-gray to very dark brownish-gray, slightly calcareous, fissile, poorly exposed	20
36. Mostly covered; some black, fissile shale, poorly exposed; some dark-gray soil that is presumably weathered shale	75

	Feet
Tyler Formation—Continued	
Stonehouse Canyon Member—Continued	
37. Conglomerate, mottled yellow and gray, very calcareous, hard; contains subrounded limestone fragments, 2 in. in diameter, in fine-grained sandstone matrix; poorly exposed	1
Total Stonehouse Canyon Member	101
Total Tyler Formation	323
Total Amsden Group	593

MISSISSIPPIAN SYSTEM

BIG SNOWY GROUP

	Feet
Heath Formation:	
38. Mostly covered; shale, black, fissile, fossiliferous; alternating with siltstone, brown to medium-gray, calcareous; upper 51 ft gray soil on low slope, probably weathered shale; loc. D 3430 A, 50 ft below top, and D 3430 B, 10 ft below top	72
39. Siltstone, brown to gray, very calcareous; grading upward into limestone, black, silty to sandy, earthy, porous, poorly exposed	3
40. Covered	5
41. Shale, black, fissile, calcareous, poorly exposed; loc. 13417	3
42. Covered; soil is dark gray, probably shale, black, fissile, unresistant	25
43. Siltstone, mottled gray and yellowish-gray, calcareous, massive; contains some plant fragments; overlies shale, black, fissile, poorly exposed, 1 ft thick	3
44. Siltstone or claystone, dark-gray, weathers yellowish-gray, slightly resistant; locs. 13415, 13416, colln. 44–37–115	1
45. Covered; soil is gray; digging yields gray-buff shaly siltstone and thin conglomerate at base	10
46. Limestone, dark-gray to black, dense to finely crystalline, well-bedded, locally laminated; 2-ft layer 3 ft above base is siltstone, gray calcareous, shaly, poorly exposed; locs. 13414; 13424; colln. 44–37–117 from upper 14 ft	19
47. Shale, black, weathering gray, fissile, calcareous, poorly exposed	1
48. Limestone, dark-gray, hard	2
49. Covered; digging yielded sandstone, light-gray, calcareous, platy	9
50. Limestone, dark-gray to black, dense, brittle; beds as thick as 2 ft; loc. 13425, colln. 44–37–123	6
51. Covered; soil is dark gray	20
52. Limestone, dark-gray to black, dense	3
53. Covered; soil is dark gray	5
54. Dolomite, black to brownish-gray, dense, massive	3
55. Shale, dark-gray to black, fissile, silty, poorly exposed	12
56. Limestone, dark-gray to black, dense, massive, very fossiliferous	2
57. Covered; digging yielded shale, dark-gray to black, fissile, silty	6
Heath Formation—Continued	
58. Limestone, black to dark-gray, very silty, fossiliferous; platy beds as much as 1/4 in. thick, interbedded with shale, black, carbonaceous; loc. 13413	5
59. Shale, black, fissile; upper 33 ft poorly exposed	48
60. Shale, dark-gray, fissile, gypsiferous, fossiliferous, poorly exposed	11
61. Siltstone, greenish-gray, calcareous, poorly exposed	17
62. Covered; soil is black and contains flakes of black fissile shale	3
63. Covered; soil is gray	6
64. Shale, black, fissile, noncalcareous; contains nodules and thin lenticular layers of limestone, gray to brown, finely crystalline; loc. 13412, colln. 44–37–138	9
65. Limestone, dark-gray to brown, silty, sandy texture, poorly bedded; interbedded with greenish-gray, silty shale; loc. 13411, colln. 44–37–138	3
66. Shale, dark-gray or black, noncalcareous, locally limonitic, paper-thin beds; interbedded with greenish-gray mudstone or claystone; plant fragments	10
Total Heath Formation	322
Otter Formation:	
67. Shale, light-green to greenish-gray, fissile; some layers of limestone, silty, nodular; upper half poorly exposed; lower half with selenite on slope	10
68. Shale, green to yellow, fissile, unresistant, poorly exposed; contains basal 1-ft bed and other beds at 8- to 12-ft intervals of limestone, gray, dense, brittle, some laminated; contains some shale, gray, calcareous	45
69. Covered; soil is light-greenish-gray	3
70. Limestone, light-greenish-gray, finely crystalline, silty, porous, locally pebbly; ostracodes	2
71. Claystone and shale, green, silty, very calcareous; with thin layers of greenish-gray, finely crystalline limestone	37
72. Covered; soil is greenish gray	11
73. Siltstone, light-yellowish-green, shaly, unresistant; upper 1 ft sandstone, yellow to brown, calcareous, clayey, poorly sorted; contains clasts of fine-grained sand to angular sandstone	6
74. Limestone, gray to white, medium crystalline; basal 6 ft interbedded with siltstone, light-green and white, thin-bedded	9
75. Covered; soil is greenish gray	13
76. Limestone, light-gray to light-brown, dense to finely crystalline, dolomitic; weathers to knobby surfaces; forms resistant hogback; algal (?)	2
77. Covered; soil is gray, silty	10
78. Limestone, medium-gray, medium-crystalline, slabby, fairly resistant; colln. 44–37–156	1
79. Covered; soil is gray to greenish-gray, silty, with some float of limestone, gray, fine-grained; forms wide valley floor and rounded hogback	172

	Feet
Otter Formation—Continued	
80. Limestone, gray to white, finely crystalline, massive to poorly bedded, tuffalike; contains some sandy lenses; vugs with calcite crystals	4
81. Siltstone, light-greenish-gray, shaly, poorly exposed; interbedded with stringers of black shale; sandy near top	9
82. Limestone, light-greenish-gray, dense; beds ½–1 in. thick	4
83. Claystone, dark-greenish-gray, silty, shaly at top; agate fragments in the soil probably weather from this unit	16
84. Limestone, dark-gray to black, weathering gray to white, dense, shaly-bedded	2
85. Shale, yellowish-brown, silty, fissile, poorly exposed	5
86. Siltstone, greenish-gray, shaly to platy	13
Total Otter Formation	374
Kibbey Formation:	
87. Sandstone, gray to yellowish and brown, fine- to medium-grained; calcareous in lower half, partly friable, porous; beds as thick as 3 ft	23
88. Covered	1
89. Sandstone, yellow to gray with pink mottling, fine- to medium grained, calcareous; consists of poorly sorted quartz sand with minor impurities; beds 1 in. to 2 ft thick	16
90. Covered	12
91. Sandstone, mottled pink and yellowish-gray, calcareous, porous; beds 6–18 in. thick; medium-grained, poorly sorted quartz sand	28
92. Covered	19
93. Sandstone, greenish-yellow and brown, calcareous, medium-grained; consists of poorly sorted quartz sand with minor impurities; beds ½–1 ft thick	3
94. Covered	6
95. Sandstone, yellow or mottled red, gray, and yellow; very fine- to medium-grained, friable, porous; some grains rounded and frosted; beds 2–12 in. thick	19
96. Covered	10
97. Sandstone, yellow calcareous, fine-grained; beds 1–8 in. thick; upper three-fourths of unit grades upward from light-brown to purple, calcareous, shaly siltstone into impure, fine-grained sandstone	21
98. Covered	6
99. Sandstone, light-yellow to light-brown, fine-grained, calcareous; mostly with black spots that may be dried oil	12
100. Covered	6
101. Siltstone, reddish-brown, calcareous, locally shaly, gray-splotched; becomes progressively more sandy upward; top of unit being resistant 1-ft bed	38
Total Kibbey Formation	220
Total Big Snowy Group	885

REGIONAL RELATIONS

The nomenclature proposed here for Pennsylvanian units in central Montana is applicable to subsurface equivalents throughout the eastern part of the State. Some of these units have been extended well into the Williston basin in North Dakota by Willis (1959), but such an extension is beyond the scope of this paper. The more comprehensive term, Minnelusa Formation of the Black Hills area, is used here to include all Pennsylvanian and some Permian strata in North Dakota, South Dakota, and adjacent parts of eastern Wyoming. For the present, the State boundary is arbitrarily designated as a convenient place to separate the different nomenclatures of these two areas.

The correlation illustrated in stratigraphic section *A–A′*, plate 1, shows, as Mundt (1956a, p. 1929) has noted, that some beds in the lower part of the Amsden pinch out northward and are not present in south-central Montana; but it further shows that homologous units which are present in central Montana pinch out southward from exposures in the Big Snowy Mountain. Gardner (1959, p. 345) noted that the Amsden Formation of northern Wyoming and the Big Snowy [and Amsden] of central Montana "represent the same general interval of geologic time * * * [and] occupy distinct basins * * * separated by a divide toward which the Amsden rocks thin and vanish from the south and the Big Snowy [and Amsden] thin and vanish from the north."

In western Montana and immediately adjacent parts of Wyoming and Idaho, it is recommended that strata approximately equivalent to the Amsden Group continue to be recognized as the Amsden Formation. The Amsden Formation is widespread in southwestern Montana and western Wyoming. In the Bridger Range it is divided by McMannis (1955, p. 1402) into a basal red silty unit (11–189 ft. thick) and an upper carbonate unit (113–185 ft. thick) which grades upward into the quartzose sandstone of the Quadrant (50–165 ft. thick). The lithology of his basal unit suggests correlation with the Tyler Formation, and the lithology of the upper carbonate unit suggests correlation with the Alaska Bench Limestone and the Devils Pocket Formation. The Quadrant in the Bridger Range is correlative with the Tensleep farther southeast. However, in the Gallatin Range and farther west, the Amsden Formation is not as inclusive as farther east. In this part of southwestern Montana the Amsden is restricted to equivalents of the Tyler Formation and the Alaska Bench Limestone because the Devils Pocket equivalent here is a part of the Quadrant Formation.

MISSISSIPPIAN-PENNSYLVANIAN BOUNDARY

The Mississippian-Pennsylvanian boundary is established in Montana at the regional unconformity between the Big Snowy and Amsden Groups. It is believed that this unconformity was formed nearly contemporaneously with that unconformity which, by definition (Chamberlin and Salisbury, 1906; Cheney and others, 1945), separates these two systems in the Mississippi Valley. The paleontologic evidence in Montana seems to confirm this accepted position (pl. 4).

Early faunal collections from the Quadrant Formation, which included both Big Snowy and Amsden equivalents in Montana, were regarded by Girty (in Calvert, 1909, p. 17–19; Condit, 1919, p. 112, 116; Reeves, 1931, p. 142–143; and Calkins and Emmons, 1915, p. 8) as of Late Mississippian or of Early Pennsylvanian age. These early age assignments, although Girty made many of them tenuously, are consistent with the stratigraphic relations and age assignments of this report. Faunal collections to which Girty assigned a Late Mississippian age, wherever we have been able to determine, are from the Big Snowy equivalent; and those assigned an Early Pennsylvanian (Pottsville) age are from the Amsden equivalent.

Later workers, possibly influenced by the conclusion, now known to be erroneous, that the Amsden in central Wyoming was of Mississippian as well as Pennsylvanian age (Branson and Greger, 1918; Branson, 1937; p. B11 of the present report), considered that the Amsden in Montana also included strata of Mississippian age (L. L. Sloss, in Gardner and others, 1945, p. 6–8; Scott, 1935). Most of the faunal collections described and evaluated by Sloss were obtained from locations where Big Snowy rocks are present but were not differentiated from the Amsden. Although many species were recognized and indicated a Pennsylvanian age, Sloss based his age assignment of the Amsden on a statistical analysis and regarded the lower part of the Amsden as Mississippian because of the preponderance of Mississippian over Pennsylvanian forms. Scott gave no paleontological evidence to support his conclusion that part of the formation was Mississippian.

More recently, Easton (1962) has analyzed the fossil evidence from these rocks in central Montana. The Kibbey, Otter, and Heath (as now restricted) were firmly established by him to be of late Mississippian (Chester) age; but he also regarded the Tyler and Alaska Bench as Mississippian (Easton, 1962, p. 25). Data obtained during the present work and re-evaluation of Easton's collection in light of the present correlations indicate a Pennsylvanian age for these rocks. Plate 4 is a rearrangement of Easton's table 5 into stratigraphic order and separates fossil collections of the restricted Heath from collections of the Stonehouse Canyon Member of the Tyler Formation. This rearrangement gives greater clarity and definition of those elements of the fauna regarded as typically Pennsylvanian.

Many brachiopods restricted to the Chester occur in the Heath and Otter formations and terminate at the unconformity beneath the Tyler. According to Mackenzie Gordon, Jr. (written commun., 1965), diagnostic Mississippian (Chester) fossils in these rocks include *Diaphragmus fasciculatus* (McChesney) [identified as *Productus fasciculatus* by Easton]; *Coledium obesum* (Clark) [*Stenocisma obesa* (Clark) of Easton], *Inflatia obsoleta* (Easton) ["Dictyoclostus" *inflatus obsoletus* Easton], *Eumetria* cf. *E. vera* (Hall) and *Girtyella woodworthi* Clark.

Invertebrate fossils from the Tyler Formation are not diagnostic for age. The fauna is composed of genera that have little stratigraphic significance. Plant spores from the upper part of the Stonehouse Canyon Member are of definite Early Pennsylvanian age and this age assignment is extended to the base of the Tyler. *Petrocrania chesterensis* (Miller and Gurley [*Crania* cf. *C. modesta* White and St. John of Easton] was collected high in this member at the section on Potter Creek dome. This fossil is restricted elsewhere to the Chester, according to Gordon (written commun., 1965), and could indicate a Late Mississippian age for the lower part of the Stonehouse Canyon Member. However, the occurrence of *Petrocrania chesterensis* in association with *Chonetes pseudoliratus* Easton which may have a range restricted to the Pennsylvanian, as well as a stratigraphic position of these two brachiopods about equal to the Pennsylvanian pollen spores suggests that *P. chesterensis* may have ranged later here than elsewhere and is not restricted to the Chester in central Montana.

An Early Pennsylvanian age is attributed to the Tyler Formation by Willis (1959, p. 1959–1962). He listed *Marginifera haydenensis* Girty and *M. lasallensis?* from the lower part of the Tyler in the Lombard Hills near Three Forks, Mont., and *Marginifera muricatina* Dunbar and Condra from near the top of the Stonehouse Canyon Member at Stonehouse Canyon, and noted that this is an unusually low stratigraphic occurrence for these Pennsylvanian forms. Willis also listed faunal reports from the Tyler Formation in eastern Montana and North Dakota that were prepared by G. O. Raasch and G. A. Stewart, Canadian Stratigraphic Service, Ltd., Calgary, Alberta, Canada. These reports included many ostracodes, especially *Cypridopsis fabulina* Jones and Kirkby, which are believed to indicate Early Pennsylvanian age. Mackenzie Gordon, Jr.

(written commun., 1966) suggests that *M. muricatina* cited by Willis from Stonehouse Canyon is the same as "*M.*" *planicosta* Easton from the same location, with the notation that "*M.*" *planicosta* was described by Easton as similar to *M. muricatina*.

Collections of plant spores from the Heath and Stonehouse Canyon Member of the Tyler have helped significantly to narrow the zone of uncertainty between the Mississippian and Pennsylvanian in Montana. The spores, identified by R. H. Tschudy (written commun., 1963 and 1964), are listed in table 2; their stratigraphic positions are indicated on stratigraphic sections *A–A′* and *B–B′*, plate 1.

Spores, specifically *Monoletes*, from the upper part of the Stonehouse Canyon Member (bed 21 of the section by Easton, 1962) at Alaska Bench are of Pennsylvanian age. Tschudy noted that *Monoletes* has not been reported below the Namurian B horizon and is not represented in Upper Mississippian strata anywhere in the world (Winslow, 1959, p. 62, and fig. 9, p. 101). The overlying Cameron Creek and Alaska Bench, therefore, are of Pennsylvanian age. An Early Pennsylvanian (Morrow) age for the Cameron Creek and an Early to Middle Pennsylvanian (Morrow to early Atoka) age for the Alaska Bench agrees with the fusulinid evidence according to George Verville (oral commun., 1963).

The age of the lower part of the Stonehouse Canyon Member is also considered here as Pennsylvanian, but the evidence is less definite. Spores from beds 23 and 25 in the section at Alaska Bench "may be from a Pennsylvanian horizon not yet examined, or may represent a transitional flora between the Late Mississippian and the Early Pennsylvanian," according to R. H. Tschudy (written commun., 1963).

A nearly complete sequence of rocks that span the systemic boundary is exposed on Big Sheep Creek in the Tendoy Mountains, southwestern Montana (col. 20, *B–B′*, pl. 1). Samples from this section indicate an increasingly diverse flora upward from the Big Snowy Formation of Late Mississippian age through the lower part of the Tyler equivalent into the upper part of the Tyler equivalent (table 2). Tschudy (written commun., 1964) commented that the flora in this stratigraphic interval change abruptly and a complete series of productive reference samples embracing this stratigraphic interval must be obtained before any reliable age determinations can be provided. Nevertheless, correlation of the strata at Alaska Bench and Big Sheep Creek is definitely suggested by the occurrence of several genera of spores common to both sections—especially *Monoletes* and *Didymosporites*. Although there are no taxonomic groups reported as limited to the Mississippian or Pennsylvanian, the specimens from the lower part of the Tyler and equivalent strata have a more Pennsylvanian than Mississippian aspect according to Tschudy.

The lower part of the Alaska Bench equivalent in the Amsden Formation at Amsden Creek has yielded fusulinids of Morrow age (Gorman, 1963) identified as *Paramillerella pinguis*, *P. circuli*, *P. ampla*, *P. advena*, *P.* sp., *Millerella inflecta*, and *M.* sp. Scott (1954, p. 1195) and Mundt (1956b, p. 50) collected fusulinids, *Millerella marblensis* Thompson and *Millerella advena* Thompson, from the lower part of the Alaska Bench Limestone near Beacon Hill and believed them to indicate a Morrow age. Furthermore, *Millerella* from the Cameron Creek Member, illustrated by Easton (1962, pl. 3), may be considered Pennsylvanian as much as they may be Mississippian forms (B. A. Skipp, oral commun., 1964).

Bairdiacypris punctata described by Scott (1935, p. 153) from the upper 2 feet of his Heath (Stonehouse Canyon Member of the Tyler Formation of this report) was believed by him to be a Pennsylvanian form. His age assignment of this ostracode, which also came from the section at Alaska Bench and probably from strata a few feet above those that yielded the spores of Pennsylvanian age, is confirmed by the new spore data.

The distribution of some important guide fossils is treated in more detail below.

Chonetes pseudoliratus Easton (colln. 13396) was considered by Easton (1962) to indicate a Mississippian age. The lowest occurrence in central Montana is from the upper part of the Stonehouse Canyon Member of the Tyler Formation and was not found in older rocks. This collection is from strata about equivalent to, or higher than, those that yielded the flora of Pennsylvanian age. All other collections of *C. pseudoliratus* are from younger strata; therefore, this species possibly is restricted to the Pennsylvanian. Easton's (1962, p. 23) remark that the surface ornamentation "bears strong resemblance to that of some Pennsylvanian chonetids * * *," would seem to further strengthen its assignment to the Pennsylvanian.

Bradyphyllum (colln. 13420) and *Myalina* (*Orthomyalina*) sp. (colln. 13421) are from the Cameron Creek Member of the Tyler Formation and lie above the Pennsylvanian age flora. These genera have long been considered Pennsylvanian although Easton had questioned this age when he found them in the same formation with faunas he believed were of Mississippian age (Easton, 1962, p. 22).

TABLE 2.—*Pollen and spores recovered from Mississippian and Pennsylvanian samples from Montana*

[X, present; A abundant; C, common. Localities indicated on sections *A-A'* and *B-B'* on pl. 1]

Collection locality	Alaska Bench (Beacon Hill)				Big Sheep Creek, Tendoy Mountains						Stonehouse Canyon		Galloway Creek
Formation and member	Stonehouse Canyon Member, Tyler Formation				Big Snowy Formation		Amsden Formation (Tyler equivalent)				Heath Formation		Otter Formation
USGS Locality No.	D3121D	D3121B	D3121C	D3121A	D3429A	D3429B	D3429C	D3429D	D3429E	D3429F	D3430A	D3430B	D3431
Lycospora	X	X	X	X	X	X	A	X	X	X		X	X
Granulatisporites			X	X	X	X	X	X	X	X			X
Convolutispora	X		X	X	X		X	X	X	C	X	X	
Auroraspora?					X		X	X	X	X		X	
Punctatisporites A		X	X	X		X	X	X	X	X	X	X	X
Leiosphaera						X							
Densosporites				X			A	X	X		X		
Lycospora cf. *L. granulatipunctatus*							X	A	X				
Raistrickia							X	X	X	X			
Schulzospora		X					X		X	X			
Calamospora (small)		X	X				X						
Laevigatosporites							X	X					
Apiculatisporites	X		X	X									
Verrucosisporites	X		X	X									
N. gen. A								X	X	X			
Reticulatisporites A		X							X	X			
Punctatisporites B									X				
Granulatisporites B									X	X			
Endosporites	X	X	X	X					X	X		X	
Reticulatisporites B		X	X	X					X				
Triletes		X											
Crassispora		X											
Callisporites		X											
Didymosporites		X								X			
Endosporites? n. sp.		X											
N. gen. B									X	X			
Reticulatisporites C									X	X		X	
Knoxisporites									X	X			
N. gen. C?			X							X			
Granulatisporites (new)										X			
Florinites			X	X						X			
Acanthotriletes			X	X									
Calamospora (rough)										X			
Monoletes				X						X			
N. gen. D										X			
Grandispora										X			
Reticulatisporites D										X			X

Linoproductus nodosus (Newberry) n. subsp. are from the Stonehouse Canyon Member of the Tyler Formation or higher strata. *L. nodosus* reported in collections 13412, and 13413, which are from strata near the top of the Big Snowy Group, cannot be positively identified according to Mackenzie Gordon, Jr. (written commun., 1965). According to Gordon, those from USGS localities 13414 and 13424 have spine bases scattered randomly over the pedicle valve and are definitely not *L. nodosus*. In central Montana, as elsewhere, *L. nodosus* seems to be restricted to the Pennsylvanian.

Dicromyocrinus granularis Easton (colln. 13423) from the Alaska Bench is well above the flora of Early Pennsylvanian age. The collection is from strata that may be as young as Middle Pennsylvanian (early Atoka). An Early Pennsylvanian age is consistent with the species' stratigraphic position and its form is "* * * more advanced than Chester species and more primitive than the Moscovian (Middle Pennsylvanian) genotype" (Easton, 1962, p. 23). Easton (p. 37) preferred a Chester age for this crinoid based upon morphologic evidence, but he quoted from Edwin Kirk (written commun., 1954) that "It is obviously much later in the genetic line than the Chester forms and I would be inclined to place it as of at least Morrow age."

"*Marginifera*" *planocosta* Easton (colln. 13420 and 14221) are from Cameron Creek and are above the flora of Early Pennsylvanian age. Easton (1962, p. 23) regarded this as a proemial Pennsylvanian species. Its stratigraphic position, as well as its very close resemblance to "*Marginifera*" *muricatina* Dunbar and Condra of Pennsylvanian age, suggests that "*M*" *planocosta* is truly of Pennsylvanian age rather than proemial.

Neospirifer praenuntius Easton (colln. 13369, 13370, and 13409) are all from the restricted Heath. With the exception of a possible similar form in collection 13364 from the Alaska Bench, this species may be restricted to the Chester and possibly may serve as a guide to the Heath Formation. This stratigraphic position confirms Easton's evaluation that this species "is more primitive than the earliest Pennsylvanian *Neospirifer* and is closely allied with forms referred to *Spirifer*, with which it is associated in strata of Mississippian age."

Composita subquadrata (Hall) (colln. 13404 and 13423) and *Orbiculoidea wyomingensis* Branson and Greger (colln. 13399) are in strata of the Alaska Bench Limestone well above the Early Pennsylvanian age flora. This occurrence of *C. subquadrata* suggests that this fossil, which is an established guide to the Mississippian elsewhere, extends well into Early and Middle(?) Pennsylvanian (Morrow and possibly as late as early Atoka) in central Montana, and has not been reported from Mississippian rocks here. *O. wyomingensis* may be restricted to the Early Pennsylvanian or may range longer than previously supposed.

The Devils Pocket Formation has yielded fusulinids of Middle Pennsylvanian age (Easton, 1962, p. 16–17; Henbest, 1954, p. 50, 51). Correlative strata in the Amsden Formation in other parts of southern Montana and adjacent areas have yielded fusulinids of similar age. These fusulinids have been reported from the Pryor and northern Bighorn Mountains and are summarized by Henbest (1954, p. 50, 51). The Devils Pocket and equivalent Amsden strata, on the basis of the occurrence of *Profusulinella*, were assigned an Atoka age; but Henbest (1956) has suggested that these forms of *Profusulinella* from northern Wyoming and Montana may be as young as early Des Moines age.

TECTONIC FRAMEWORK

The following summary of late Paleozoic tectonic events places deposition of the Big Snowy and Amsden Groups into an historical framework of depositional and erosional sequences. These tectonic events are deduced from the regional distribution of the rocks, their lithologic character, and the presence or absence in some areas of rocks known elsewhere. The summary presented here is based partly on evidence presented in the foregoing sections of this paper and partly on additional evidence, deductions, and conclusions that are a part of paleotectonic research not yet completed on the Mississippian and Pennsylvanian Systems of the northern Rocky Mountains.

EARLY AND LATE MISSISSIPPIAN (MADISON GROUP)

Widespread uniformity in thickness and lithology of formations in the Madison Group indicates that the northern Rocky Mountains and adjacent plains area was a stable continental shelf or a moderately submerged segment of the craton during Kinderhook, Osage, and Meramec time. Progressive southward overlap of Lower Mississippian strata indicates the first gentle uplift in south-central Wyoming and farther south in Colorado of the ancestral Rocky Mountain ranges (Maughan, 1963, p. C26). A similar regional uplift, herein named the Milk River uplift, may have formed at this time north of Montana. This uplift is mostly inferred from the formation later in the Paleozoic and early Mesozoic of a definite positive area centered in Alberta and Saskatchewan. Uplifts in Alberta and Saskatchewan may have served in part to intermittently restrict the Madison sea southeastward in the Williston basin. Evaporites and dolomites—the Charles Formation which intertongues southwest of the Williston basin into the upper part of the Mission Canyon that is of Meramec age—formed east of a vast expanse of limestone and dolomite deposits in Montana and Wyoming that lie between the Milk River uplift on the north and the ancestral Rocky Mountains on the south. Filling of the shallow seaway between the two uplifts with carbonate sediments probably served to further restrict the sea in the Williston basin from marine water of normal salinity in the Cordilleran geosynclinal sea westward in Idaho.

LATE MISSISSIPPIAN (BIG SNOWY GROUP)

Regional tectonic movements in early Chester time are believed to have initiated the change from carbonate and evaporite deposits characteristic of the upper part of the Madison Group to the detrital deposits characteristic of the lower part of the Big Snowy Group. These tectonic movements extended from the Cordilleran geosynclinal province eastward into western Montana; parts of western Montana were uplifted and during Chester and Early Pennsylvanian time the Madison Group was subjected to erosion, leading to formation of a karst topography. Central and eastern Montana seem to have remained stable except for probable slight epeirogenic uplift. Consequently, a sea more shallow than the Madison sea extended across this part of Montana into North and South Dakota at this time. The gradation in the Big Snowy Group from dominantly sandstone in the lower part through green and red shale into black shale and limestone in the upper part suggests the gradual deepening of the sea as the region slowly subsided.

Regional uplift that began Big Snowy deposition not only reduced the depth of the sea, but also uplifted the bordering land areas higher and produced accelerated erosion. The increased detritus is evident in the Kibbey Formation; but the location of bordering lands that served as source areas for these sediments is conjectural. Only in central North Dakota are the rocks suggestive of deposition proximal to a shore. The Kibbey here, as elsewhere, is beveled and it is not certain how far east the sea may have extended at this Late Mississippian time. Nevertheless, the continental shield, or Siouxia land area, probably was not far east of this beveled edge in central or eastern North Dakota. Earlier in Mississippian time the shore probably was much farther to the east.

In central Montana there is no evidence in the Big Snowy Group to suggest the position of the shore, although the Milk River uplift to the north and the ancestral Front Range to the south may have also contributed sediments. The Big Snowy Group is more extensively beveled in this area, and the facies of these rocks are laterally very uniform throughout central Montana (pls. 1, 2). If epeirogeny enlarged the land area and decreased the area of deposition, as suggested above, it may be presumed that the incipient ancestral Front Range extended into central, or possibly northern, Wyoming. Similarly, the presumed Milk River uplift may have extended into northern Montana. These assumed land areas and their shorelines were well away from the present limits of the Big Snowy rocks preserved in central Montana (pl. 3).

EARLY AND MIDDLE PENNSYLVANIAN (TYLER FORMATION AND ALASKA BENCH LIMESTONE)

Regional upwarp, centered about the ancestral Rocky Mountains in Colorado, took place again near the end of Mississippian time. Uplift followed Late Mississippian deposition of approximately 1,200 feet of Big Snowy rocks in central Montana.

Much of Wyoming and south-central Montana was gently elevated, and Mississippian rocks that had been recently deposited in this area were partly eroded. The chief area of uplift extended across southern Montana and was bounded on the north by an arcuate system of probable faulting in the west and probable monoclinal folding in the east (pl. 3). Big Snowy rocks were completely stripped from the uplifted area south of this structural belt and were tilted northward, beveled, and partly preserved north of the structural belt in a northward-thickening wedge (pls. 1, 2). The Milk River uplift either was inactive or its influence at this time was too weak to affect rocks in central Montana. Some beveling of Big Snowy rocks beneath the Tyler Formation in northeastern Montana could reflect the influence of the Milk River uplift in this area; but instead, this beveling probably is a local feature marking structural movement along the axis of the Cedar Creek anticline. Movement along the Cedar Creek structure, either by faulting or by sharp monoclinal folding, was downward on the east, the Williston basin side, relative to the west side.

The trough-shaped depression in central Montana known as the Big Snowy or Montana trough, formed as a broad seaway during Meramec time, then probably narrowed somewhat during Chester time. The configuration of the Montana trough, however, has been emphasized by subsequent faulting and erosion. The present zero-edges of the Big Snowy Group were formed by erosion on both the north and the south and are not depositional edges. The present southern limit of these rocks was formed by erosional truncation shortly after their deposition. The northern limit of preservation was defined by a probable system of faults (pl. 3) that formed at a later time and is discussed below.

Tectonic stability probably persisted while depositional basins filled with sediments during Morrow and Atoka time. Sediments that formed the Tyler Formation accumulated in the depositional basin in central Montana north of the extended ancestral Rocky Mountain uplift. Gradual regional submergence followed the initial flood of sediments that had mostly filled the deeper basins. The sea spread southward and soon inundated southern Montana and most of Wyoming. At first, detrital sediments were deposited in this wide, shallow sea as red beds composing the Cameron Creek Member of the Tyler Formation. The source area of these sediments ceased to exist as the adjacent lowlands were inundated further, and deposition of red beds gave way to deposition of the Alaska Bench Limestone.

MIDDLE AND LATE PENNSYLVANIAN (DEVILS POCKET, QUADRANT, AND TENSLEEP FORMATIONS)

Upward epeirogeny and regional erosion is indicated by the unconformity formed after deposition of the Alaska Bench Limestone. Localized warping and probable faulting took place extensively throughout this region during this epeirogeny. These local tectonic features are indicated by the general beveling and local removal of the recently former Lower and lower Middle Pennsylvanian rocks as shown in the cross sections on plates 1 and 2. This regional uplift in Montana coincided with the chief uplift in Colorado and southern Wyoming of the Ancestral Front Range in the late Atoka to early Des Moines time. Orogenic uplift also seems to have taken place at this time in the Cordilleran geosyncline, and the Milk River uplift presumably rose importantly for the first time.

During late Atoka, Des Moines, and possibly Missouri and Virgil time, older Paleozoic rocks were probably deeply eroded in areas of Middle Pennsylvanian uplift in parts of Idaho, western Montana, Alberta, and Saskatchewan. This erosion presumably included Ordovician sandstone that seems to be the most likely source rock for sand in the Quadrant and Tensleep. The Ordovician sandstone may have been deposited originally as a continuous sheet throughout most of the northern Rocky Mountain region, but it is preserved only in remnants such as the Swan Peak Quartzite in northern Utah and southeast Idaho, the Kinnikinic Quartzite in central Idaho, the Mount Wilson Quartzite in western Alberta, the Winnipeg Sandstone in southeastern Saskatchewan and adjacent areas, and the St. Peter Sandstone in southeastern Minnesota and adjacent areas. The principal source area of the Middle and Upper Pennsylvanian sands likely was northwest of present Quadrant exposures in western Montana. Another source area may have been a large area north of Montana in northern Alberta and Saskatchewan from which Ordovician sandstone also could have been eroded, transported southward, and deposited in Montana. Erosion of similar Ordovician rocks southwestward in west-central Utah probably contributed also to the Quadrant, Tensleep, and equivalent strata in the Wells, Oquirrh, and Weber Formations (Frank C. Armstrong, oral commun., 1965).

PERMIAN TO JURASSIC EVENTS

From late in Pennsylvanian time to early in Permian time the Milk River uplift rose further, and the area of uplift extended into central Montana and northern Wyoming. Renewed uplift of the ancestral Front Range highland took place about this time also, and a lowland through central Wyoming separated this highland on the south from the Milk River uplift on the north. A basin of deposition, centered near the present-day Black Hills, formed east of these land areas and received Early Permian (Wolfcamp) sediments. Sands deposited in this basin were derived mostly from erosion of the Tensleep and equivalent Pennsylvanian rocks of these uplifts.

The Big Snowy and Amsden Groups are abruptly truncated in central Montana north of an arcuate system of probable faults, as shown on plate 3. This probable fault system may have formed as early as Late Pennsylvanian coincident with Late Pennsylvanian to Early Permian uplift. Erosion north of this fault system at this time, especially of the Kibbey Formation, and distribution of these sediments southeastward probably accounts for scattered grains of medium- and coarse-grained frosted quartz characteristic of Lower Permian rocks throughout eastern Wyoming and the Dakotas (Maughan, 1967).

The fault system defines the southern edge of a circular uplift, the Milk River uplift, with an apparent center in southern Alberta or Saskatchewan. The Milk River (fig. 2) approximately bisects this uplift. The river rises in Glacier National Park, Mont., near the projected western extension of the fault system, it flows eastward across southern Alberta and northern Montana, and it empties into the Missouri River near Fort Peck, Mont., about where the river intersects the eastern part of the arcuate fault system. The term "ancestral Sweetgrass arch" has been used to identify this positive area, but is not used here because there is little or no relationship between the Milk River uplift, a late Paleozoic and early Mesozoic structural feature and the Sweetgrass arch, a Laramide structure. Furthermore, the two features are centered in widely separated areas. The Sweetgrass arch is comparatively much smaller and is coincident with only a relatively small part of the southwestern part of the Milk River uplift. Webb (1951, p. 3) included the area of the Milk River uplift as a part of his Alberta shelf.

The Permian and early Mesozoic history of the Milk River uplift, identified as a land area centered in Montana, has been summarized by Maughan (1967). Upper Permian and Lower Triassic rocks record a gradual transgressive overlap of sediments that were deposited progressively farther north on the margins of the Milk River uplift. Renewed uplift probably took place in Middle Triassic time, and erosion of Big Snowy and Amsden rocks continued in northern Montana until the Middle Jurassic. By this time the area of the Milk River uplift was stabilized and the Middle Jurassic sea transgressed across Montana from the north. Only "Belt Island" obstructed complete regional submergence and this feature was buried by later Jurassic sediments.

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