Geology of the Duck Creek Pass Quadrangle Montana

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By WILLIS H. NELSON

CONTRIBUTIONS TO GENERAL GEOLOGY

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CONTENTS

ILLUSTRATIONS

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By Willis H. Nelson

ABSTRACT

The Newland limestone, which is a part of the Belt series of Precambrian age, is the oldest formation in the quadrangle. The lower part of the Newland limestone that is exposed in the quadrangle is very regularly bedded, medium-gray, slightly dolomitic, argillaceous, and silty limestone, in which the beds are separated by thin dark silty layers. At least 6,700 feet of this lower part of the Newland limestone is exposed in and near the quadrangle. The upper 2,800 feet of the Newland limestone contains shale and siltstone, mostly limy, in addition to argillaceous limestone like that in the lower part of the formation.

In much of the area of the Big Belt Mountains the Newland limestone has been metamorphosed, presumably by heat from intrusive rocks. The principal resulting transformation has been the combination of clay and carbonate minerals to form tremolite.

The Greyson shale, which overlies the Newland limestone, consists of somber shale, argillite, siltstone, and quartzite, and a little limestone. The lower 2,200 feet of the formation contains about 35 percent quartzite and a little conglomerate, and in the southern part of the quadrangle this unit is mapped as a lower member of the formation. The middle 6,700 feet of the formation is almost devoid of quartzite or coarser rocks, whereas the upper 1,100 feet of the formation contains 20 to 25 percent argillaceous quartzite, a little limy argillite, siltstone, and quartzite. Locally at least, the upper quartzite-bearing part of the formation and middle quartzite-free part of the formation are separated by a fault. The amount of displacement on this fault is unknown, but is not believed to be large. The upper 150 feet of the formation contains beds of reddish shale and siltstone which increase in abundance upward as part of the gradation into the overlying Spokane shale.

The Spokane shale is composed of red shale, silty shale, and siltstone, and a few beds of green shale. Many of the beds of this formation are ripple marked and mud cracked. This formation is about 3,000 feet thick at the south edge of the quadrangle.

The Belt series, which is represented in this quadrangle by the Newland, Greyson, and Spokane, is separated from rocks of Paleozoic age in this region by an unconformity which cuts across the formations of the series at a very small angle. Northward and westward from this quadrangle progressively younger rocks occur at the top of the series.

Rocks of Paleozoic age occupy about 8 square miles of the quadrangle area; from oldest to youngest, they are the Flathead quartzite, the Wolsey shale, the Meagher limestone, the Park shale, the Pilgrim limestone, about 130 feet of poorly exposed limestone and limy shale, the Jefferson dolomite, the Three Forks shales, and the lower part of the Lodgepole limestone.

Deposits of Tertiary age occupy the western part of the quadrangle, and are very light gray to moderate orange pink, mostly poorly sorted, weakly indurated, rudely bedded conglomerate, sandstone, and claystone. Most of these rocks are limy and contain shards. Some of these beds are especially rich in shards and are mapped as a separate member. Most of the detritus in these deposits is of local origin and is believed to have been transported and deposited by fluviatile processes in a closed basin that locally contained lakes and ponds. The size of the detritus decreases westward away from the Big Belt Mountains. Vertebrate fossils indicate that the deposits range from Oligocene to Pliocene in age.

Intrusive rocks in this area include diabase sills and dikes of probable Precambrian age in the Spokane shale, light-colored albitized sills in the Wolsey shale, and quartz diorite to quartz monzonite masses and associated dikes and sills in the north half of the quadrangle. The areas of exposed intrusive rocks along the east edge of the quadrangle are surrounded by an aureole of metamorphosed Newland limestone and are all assumed to be parts of a single large partly buried pluton. Most of the quartz diorite-quartz monzonite is foliated and is believed to have been intruded in Late Cretaceous time during the Laramide orogeny.

Much of the bedrock is concealed beneath a mantle of clay, silt, sand, and rock fragments. Some of the material in the mantle was derived from disaggregation of the deposits of Tertiary age, and some of it is alluvium from the mountains. The ultimate origin of most of the material from the two sources is the same.

In the south half of the quadrangle the rocks of the Belt series are part of the west limb of a large anticline, the axis of which is just east of the quadrangle and plunges south-southeastward; this structure apparently continues some distance northward, and the rocks of the Belt series in the north half of the quadrangle are in smaller scale folds superimposed on this larger fold. The rocks of Paleozoic age are folded and faulted on a smaller scale than are most of the rocks of the Belt series to the east. The Spokane shale adjacent to the rocks of Paleozoic age, however, is probably deformed on a scale comparable to the deformation in the rocks of Paleozoic age. Lack of marker beds in the Spokane shale makes accurate delineation of most of its internal structure impracticable.

Most of the structures in the rocks of the Belt series and the formations of Paleozoic age probably formed during the Laramide orogeny. The deposits of Tertiary age are separated from the older rocks by an unconformity which has considerable relief. The deposits of Tertiary age are gently folded, and probably locally faulted. In general, these deposits dip gently east-northeast.

Prospecting and attempts at mining have been carried on intermittently in this quadrangle, but no economically valuable concentrations of minerals have been found.

INTRODUCTION

The Duck Creek Pass quadrangle provides a classic area for study of the Belt series, which forms a large part of the bedrock of western Montana. In addition, the quadrangle adjoins other areas in which geologic studies are already completed or in progress. The larger area, of which the Duck Creek Pass quadrangle is a part, is adjacent to and includes part of the Boulder batholith, which is the locus of extensive rich mineralization. For this reason the geologic mapping of the Duck Creek Pass quadrangle was undertaken in part to fulfill some of the objectives of the President's Mineral Policy. The framers of this statement of policy recognized that basic research is necessary to insure a continuing adequate supply of minerals.

The fieldwork in this quadrangle occupied about 125 days during the summers of 1956 and 1957. The writer was assisted during 1956 by John S. Bader, and for 16 days during 1957 by L. J. Patrick Muffler.

Most of the stratigraphic sections that are included in this report were measured with a tape; the thicknesses of the middle part of the Greyson shale and the lower part of the Newland limestone were mapped and then measured on topographic manuscript maps of the Duck Creek Pass quadrangle, scale 1:24,000. A total of about 40 man-days was spent searching for fossils and obtaining other data from the deposits of Tertiary age.

GEOGRAPHIC SETTING

The Duck Creek Pass quadrangle lies within the Northern Rocky Mountain province. Figure 1 shows the location of the quadrangle and the adjacent areas that have been and are being mapped geologically. Most of the area of the quadrangle is a single slope between the Missouri River on the west and the crest of the Big Belt Mountains on the east.

Farming and ranching are carried on throughout most of the quadrangle. Most of the area below about an altitude of 3,900 feet is irrigated, and hay, sugar beets, and potatoes are the principal crops. Much of the flatter part of the quadrangle between an altitude of 3,900 and 5,500 feet is in dryland farms. The principal crop here is wheat along with some oats and barley. Raising livestock, principally cattle, is one of the important occupations in the area. The hay grown at lower altitudes is used for winter feed; during the summer the animals are grazed on much of the uncultivated land throughout the quadrangle and in adjacent moutain areas.

Several small independent logging operations were active in the quadrangle during 1956 and1957.

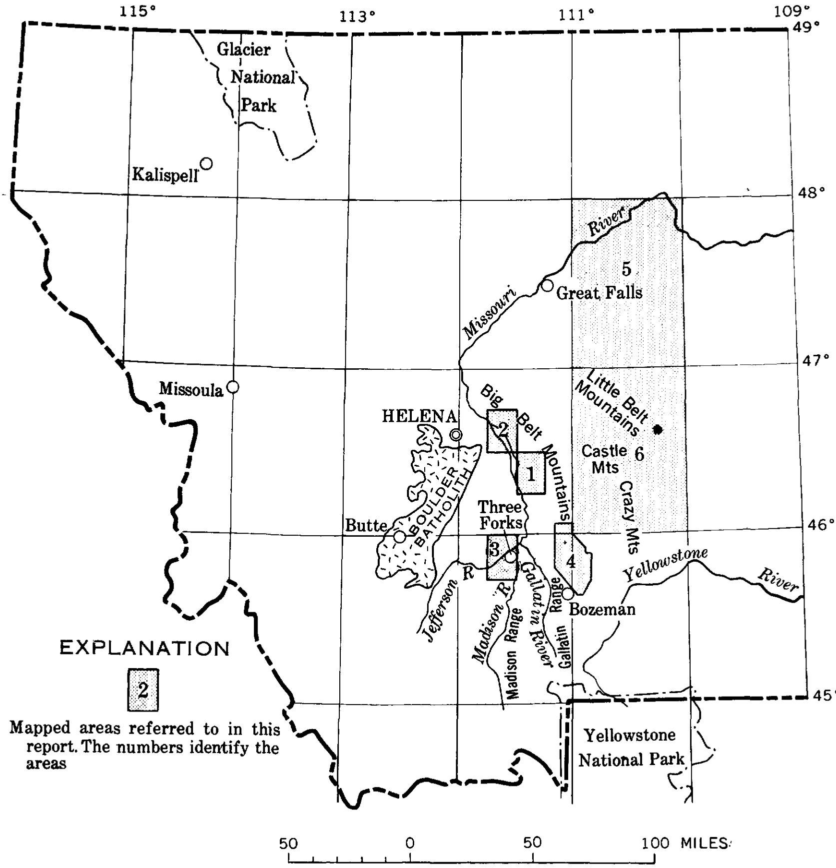

FIGURE 1.—Index map of western Montana. 1. Duck Creek Pass quadrangle; 2. Canyon Ferry quadrangle, Mertie, Fisher, and Hobbs (1951); 3. Three Forks quadrangle, Robinson (1963); 4. Bridger Range, McMannis (1955); 5. Fort Benton quadrangle, Weed (1899a); 6. Little Belt Mountains quadrangle, Weed (1899b).

BELT SERIES (PRECAMBRIAN)

NEWLAND LIMESTONE

NAME AND DISTRIBUTION

The oldest rocks exposed in the quadrangle are part of the Newland limestone of the Belt series of Precambrian age. The Newland limestone was named by C. D. Walcott (1899) from exposures along Newland Creek about 17 miles northeast of the Duck Creek Pass quadrangle. This formation crops out in the northeastern part of the Duck Creek Pass quadrangle where it forms the crest and west flank of the Big Belt Mountains. In most of the gently sloping areas the Newland limestone is exposed abundantly only along stream valleys. Outcrops are more abundant in the steeper areas, which are mostly areas where the rocks have been hardened by contact metamorphism.

DESCRIPTION

The lower part of the Newland limestone exposed in the Duck Creek Pass quadrangle is of rather uniform character, whereas the upper 2,700 feet of the formation is more heterogeneous. On either side of Deep Creek, the upper part is mapped as a separate member, and in the following paragraphs the upper member is described separately from the rest of the formation. North of the North Fork of Deep Creek, where the upper member was not differentiated, most of the rock is like the lower part of the formation; here, however, many of the westernmost rocks of the area underlain by this formation are stratigraphic equivalents of the upper member.

The lower part of the Newland limestone is composed of impure medium- gray slightly dolomitic microgranular argillaceous limestone, which weathers grayish orange. This limestone is very regularly bedded in beds that range in thickness from ⅛ to 6 inches, and most commonly are 1 to 3 inches thick. The beds are separated by dark silty seams 1/32 to ⅛ inch thick. Except for the silty seams these rocks show little variation either vertically or horizontally.

In thin section about half of the typical impure limestone is composed of carbonate grains only 1 or 2 microns across. The remainder of the impure limestone is made up of about equal parts of very fine grained quartz, sericite, and chlorite. Most of these calcite grains are isolated from one another by other minerals and have been unable to combine along mutual boundaries, thus accounting for their very small size. This isolation of carbonate grains by intervening minerals also prevents the carbonate from reacting as violently with dilute hydrochloric acid as it otherwise would. The acid applied to the surface of the rock reacts immediately with only the surface calcite grains, which extend no more than about 2 microns into the rock. The coatings of sericite and chlorite on the grains of calcite below the surface inhibit the mingling and reaction of the acid and these calcite grains.

The dark seams that separate the limestone beds contain more quartz than the intervening limestone. The dark color of these seams is due to disseminated black dust, probably carbon.

UPPER MEMBER

The upper member of the Newland limestone contains claystone, shale, and siltstone in addition to argillaceous limestone like that in the lower part of the formation. Much of the siltstone, shale, and claystone is limy. Most of these rocks are medium to dark gray, and they are composed of silt-sized quartz grains and a mixture of chlorite and sericite in various proportions. Locally, these rocks contain sand-sized quartz grains and chips of shale, siltstone, and quartzite. In a few places there are isolated beds of dark-gray relatively pure limestone, which are somewhat coarser grained (as much as 10 microns), possibly developed by recrystallization.

The following measured section is representative of the Newland limestone that is exposed in the quadrangle.

Section of the upper member of the Newland limestone along the north side of Deep Creek

	Ft	in
Greyson shale.		
Conformable contact at an altitude of 4,695 ft on the north side of Deep Creek, 1,610 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
Newland limestone, upper member:		
1. Shale, limy dark-gray (*N* 3);[1] weathers to moderate yellow (5*Y* 7/4) and rarely to light red (5*R* 6/3); thinly laminated; breaks into chips 2 to 5 mm across	150	0
At an altitude of 4,685 ft and 1,480 ft west of east edge of sec. 30, T. 7 N., R. 4 E.		
2. Limestone, medium-dark-gray (*N* 4); weathers yellowish gray (5*Y* 8/2); microgranular; beds ½ in to 1 ft thick, average 6 in. thick	6	6
3. Shale, limy like member 1	13	0
4. Interbedded limestone and limy shale; like members 1 and 2	34	0
5. Limestone, medium-dark-gray (*N* 3 to *N* 4), microgranular; beds ½ in to 1 ft thick; many beds composed of dark-gray (*N* 3) nodules of limestone, 2 to 6 in. across, in a slightly lighter gray (*N* 4) limestone matrix	5	6
6. Shale, limy like member 1	18	0
7. Limestone, like member 2	1	0
8. Shale, limy like member 1	2	0
9. Limestone, like member 2		6
10. Shale, limy like member 1	15	0
11. Limestone, like member 2	32	0
12. Concealed; probably all limy shale like member 1	15	0
At an altitude of, 4,680 ft 1,340 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
13. Limestone, like member 2	1	6
14. Limy shale and claystone, dark-gray (*N* 3); weathers to medium light gray (*N* 6) with dark-reddish-brown (10*R* 3/4) surface stains; part silty, and part includes shale chips and detrital mica	150	0
At an altitude of 4,670 ft, 1,160 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
15. Limy shale and claystone, like member 14	360	0
At an altitude of 4,720 ft, 830 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		

[1] Color designations are from "Rock-color Chart," Goddard and others, 1948.

Newland limestone, upper member—Continued	*Ft*	*in*
16. Limestone, dark-gray (*N* 4); weathers to light yellowish brown (10*YR* 6/3); microgranular, beds ¼ to 4 in. thick	80	0
In gully at an altitude of 4,690 ft, 740 ft west of east edge of sec. 30, T. 7 N., R. 4 E.		
17. Limestone, dark-gray (*N* 3); weathers to pale reddish and yellowish colors; microgranular; beds ½ in. to 2 ft thick; some beds contain stromatolites; forms a prominent ridge	65	0
18. Limestone, like member 16	60	0
19. Siltstone, dark-gray (*N* 3), argillaceous, only very slightly limy	50	0
20. Limestone, like member 16	50	0
At an altitude of 4,775 ft, 330 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
21. Limestone, like member 17; unit forms a ridge	11	0
22. Limestone, like member 16	75	0
At an altitude of 4,750 ft, 230 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
23. Limestone, like member 17	20	0
24. Limestone, like member 16	25	0
25. Siltstone, like member 19	22	0
26. Shale, limy, like member 1	75	0
In gully at an altitude of 4,720 ft and 160 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
27. Limestone, like member 16	50	0
28. Limestone, like member 17	18	0
29. Limestone, like member 16	14	0
30. Partly concealed; underlain by limestone like member 17	50	0
31. Limestone, like member 16	34	0
32. Limestone, like member 17	50	0
33. Concealed; underlain by limestone like members 16 and 17	150	0
34. Limestone, like member 17	7	0
35. Partly concealed; probably all limestone like member 16	25	0
36. Limestones, interbedded; like members 16 and 17 in about equal proportions	34	0
At an altitude of 4,750 ft 380 ft east of the west edge of sec. 29, T. 7 N., R. 4 E.		
37. Limestone, like member 17	15	0
38. Limestone, like member 16, but becoming silty and more argillaceous down the section (eastward)	260	0
In gully at an altitude of 4,720 ft and 570 ft east of the west edge of sec. 29, T. 7 N., R. 4 E.		
39. Siltstone, like member 19, becoming more limy down the section (eastward)	220	0
At an altitude of 4,750 ft and 1,870 ft east of the west edge sec. 29, T. 7 N., R. 4 E.		
40. Limestone, like member 17	23	0
41. Limestone, like member 16; some interbedded siltstone like member 19; and rare isolated beds of limestone, like member 17, as much as 3 ft thick	490	0

	Ft	in
Newland limestone, upper member—Continued		
42. Limestone, like member 17	50	0
Total	2, 827	0
Thickness of the upper member of the Newland limestone rounded to the nearest 100 ft	2, 800	

Gradational contact between lower part and upper member of the Newland limestone at an altitude of 4,680 ft and 1,570 ft east of the west edge of sec. 29, T. 7 N., R. 4 E.

	Ft	in
Newland limestone, lower part:		
43. Limestone, silty, medium-dark-gray (*N* 4); weathering results in a grayish-orange (10 *YR* 7/4) surface stain or thin rind; microgranular; argillaceous; very regularly bedded; beds range in thickness from ⅛ to 6 in. and average 1 to 3 in.; beds separated by dark silty seams 1/32 to ⅛ in. thick. (The characteristics of unit 16 of the upper member of the Newland limestone are within the range of characteristics of this unit in the lower part)	650	
Measured section crosses Bear Gulch.		
44. Limestone, silty, like member 43	550	
East edge of quadrangle at an altitude of 4,670 ft on the north side of Deep Creek.		
45. Limestone, silty, like member 43; continues without apparent interruption east of the east edge of the quadrangle	5, 500	
Structural discordance 1.4 miles east of the east edge of the quadrangle on Montana Highway 6.		
Partial thickness of the lower part of the Newland limestone	6, 700	0

METAMORPHOSED NEWLAND LIMESTONE

The Newland limestone is metamorphosed in most of the Big Belt Mountains above 6,500 feet altitude and locally below that altitude, and in a zone a few tens of feet wide around the stock in the middle of the north half of the quadrangle. The metamorphism around the stock obviously has been caused by the intrusion. Metamorphism in the Big Belt Mountains increases in intensity toward exposures of the intrusive igneous rocks in these mountains. The extent of the metamorphism in the mountains suggests that intrusive rock underlies much of the mountains at relatively shallow depths. The intrusive rocks and the related metamorphic rocks are relatively resistant to erosion.

The metamorphosed Newland limestone is light gray, commonly with a greenish hue. The metamorphism has caused the clay minerals and the carbonate minerals to combine to form new minerals, of which tremolite is the most common. Locally, some of the rocks near the quartz diorite in the mountains contain abundant new biotite.

This biotite is most abundant in rocks that apparently were originally relatively free of carbonate minerals. In places the metamorphic minerals are oriented to give the rock a weakly developed cleavage parallel to the axial planes of folds.

GREYSON SHALE

NAME AND DISTRIBUTION

The Greyson shale was named by C. D. Walcott (1899) from the area between Greyson Creek and Deep Creek in the Duck Creek Pass quadrangle.

The largest area underlain by the Greyson shale is in the southeast corner of the quadrangle and is about 8 square miles in extent. Another area of a little more than 1 square mile lies near the northwest corner of the quadrangle. Two very small areas of exposed Greyson shale are near the middle of the quadrangle and at the west edge along Montana Highway 6. The rocks of this formation break up to form small fragments in very thin soil. Over much of the two larger areas the Greyson crops out on broad gentle slopes as well as on steep slopes.

DESCRIPTION

The Greyson shale consists of a very thick sequence of shale, argillite, siltstone, and quartzite, and a little limestone and conglomerate. Both the upper and lowermost parts of the formation contain abundant quartzite beds, whereas the middle part does not. The lower quartzite-rich part is mapped as a member; the upper quartzite-rich part and the middle quartzite-poor part are mapped together as a member, because they are too poorly exposed to be separated consistently.

LOWER MEMBER

The lower member of the Greyson shale is composed of shale, siltstone, and argillite[1] interbedded with quartzite and a little conglomerate. Shale, siltstone, and argillite make up about 60 percent, and quartzite about 35 percent of the lower member of the Greyson shale.

The shale, siltstone, and argillite are medium to dark gray when fresh, and they weather to various shades of greenish, yellowish, and reddish gray. One variety of weathered argillaceous siltstone has yellowish, reddish, and greenish colors arranged in concentric rings; this variety of rock has sometimes been inappropriately called "Montana onyx." The shale, siltstone, and argillite occur in sequences that are commonly from 1 to 15 feet in thickness, and rarely exceed 25 feet. Beds range in thickness from one-fiftieth of

[1] Argillite, as used here, refers to an altered sedimentary rock that was originally a shale, but that is now composed dominantly of chlorite and sericite. It therefore resembles slate in mineralogy, but it lacks the well-developed cleavage of slate.

an inch to several inches, and many vary in thickness because the beds are bounded by irregularly scoured bedding planes. These fine-grained rocks are composed of mixtures of sericite and chlorite that contain very finely divided particles of quartz and a little feldspar and shreds of muscovit.

Most of the quartzite in this lower member is medium to coarse grained; it is commonly a somewhat lighter gray than the shale, siltstone, and argillite. The medium- to coarse-grained quartzite occurs in sequences as much as 50 feet thick and in beds from 1 inch to 2 feet thick. Some of the beds are crossbedded. About two-thirds of this quartzite consists of quartz grains, with which are mixed grains of calcite, microline, plagioclase, and argillite in a sparse discontinuous matrix of sericite and chlorite.

About 8 percent of the lower member is very fine grained quartzite that resembles the siltstone and is transitional between the siltstone and the medium- to coarse-grained quartzite.

Conglomerate, in sequences from 1 to 13 feet thick, is confined to and makes up a little less than 5 percent of the lower 700 feet of the lower member of the Greyson shale. The fragments in the conglomerate are mostly of rounded pebbles of Newland limestone. Also included are pebbles of shale, siltstone, argillite, and quartzite. These rounded fragments are commonly as large as 2 inches, but in 1 bed some of them attain diameters of 2 feet. Conglomerate was not seen north of the North Fork of Deep Creek.

The contact between the lower and upper members of the Greyson shale is placed beneath a thick sequence of siltstone and above the highest of the closely spaced quartzite beds of the lower member.

The following section, a continuation from the section of the Newland limestone, illustrates the stratigraphy of the lower member of the Greyson shale.

Section of the lower member of the Greyson shale along the north side of Deep Creek

Greyson shale, upper member.

Gradational contact on the north side of Deep Creek at an altitude of 4,560 ft, 3,960 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.

Greyson shale, lower member:	*Ft*	*in*
1. Quartzite, medium-gray (*N* 6); weathers to yellowish brown (10*YR* 6/4); medium grained; argillaceous and feldspathic; beds 2½ to 5 in. thick, with laminae 1/16 to ⅛ in. thick; many quartz veinlets about normal to bedding	39	0
2. Shale, silty, medium-gray (*N* 4); weathers to various shades of yellow and yellowish brown, which in order of prevalence are 10*YR* 6/6, 5*Y* 7/2, 10*YR* 3/2 and 10*YR* 5/6	9	0
3. Quartzite, like member 1	1	0

Greyson shale, lower member—Continued	*Ft*	*in*
4. Shale, silty; like member 2	7	0
5. Quartzite, like member 1	51	0
6. Partly concealed; mostly silty shale like member 2, and two quartzite beds 8 in. thick	9	0
7. Quartzite, like member 1	7	6
8. Shale, silty; like member 2	4	0
9. Quartzite, like member 1	3	0
10. Shale, silty; like member 2	3	0
11. Quartzite, like member 1	1	0
12. Shale, silty; like member 2	3	0
13. Quartzite, like member 1	10	0
14. Concealed; mostly silty shale like member 2; possibly a minor fault here	20	0
15. Quartzite, like member 1	10	0
16. Concealed; probably all silty shale like member 2	5	0
17. Quartzite, medium-gray (*N* 5), coarse-grained; maximum grain size about 1 mm, average grain size about ¾ mm	19	0
18. Shale, silty; like member 2	14	0
19. Quartzite, like member 17	3	0
20. Shale, silty; like member 2	5	0
21. Quartzite, like member 17	5	0
22. Shale, silty; like member 2	2	0
23. Quartzite, like member 17	1	6
24. Shale, silty; like member 2	7	0
25. Quartzite, like members 1 and 17	33	0
26. Shale, silty; like member 2	20	6
27. Quartzite, like member 17	3	6
28. Shale, silty; like member 2	3	6
29. Quartzite, like members 1 and 17	17	6
30. Shale, silty; like member 2	17	6
31. Quartzite, like member 17	2	0
32. Siltstone, medium-gray (*N* 4 to *N* 5); weathers light olive gray (5*Y* 5/2); weathering becomes more pervasive eastward; argillaceous; laminated (laminae 1/50 to ½ in. thick, average 1/25 to ⅛ in. thick); some layers show small-scale current bedding; forms sparse soil	34	0
Offset from an altitude of 4,560 ft on minor ridge on north side of Deep Creek 3,700 ft west of east edge of sec. 30, T. 7 N., R. 4 E. to a point at an altitude of 4,665 ft and 3,680 ft west of east edge of sec. 30, T. 7 N., R. 4 E.		
33. Siltstone, like member 32, and very fine grained argillaceous quartzite similar to member 32; all weathered to moderate yellowish and brownish colors (Munsell value 4 to 7) of weak to moderate saturation (Munsell chroma 2 to 4) and of red to yellow-green hue (Munsell 5*R* to 5 *GY*); hues between 10*YR* and 2*Y* are most common; colors are often in concentric bands	365	0
On the unimproved road at an altitude of 4,690 ft, 3,270 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		

Greyson shale, lower member—Continued	*Ft*	*in*
34. Siltstone and very fine grained quartzite like member 33. Weathering becomes less pervasive eastward and the lower part of this member is medium gray (*N* 6 to *N* 7), with brown (10*YR* 3/2) weathered surfaces	250	0
At an altitude of 4,675 ft on the north side of Deep Creek 2,970 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
35. Quartzite, light-gray (*N* 7 to *N* 8), coarse-grained, feldspathic	2	0
36. Siltstone and very fine grained argillaceous quartzite; like member 34	27	0
37. Quartzite, like member 35	2	0
Offset from an altitude of 4,675 ft, 2,720 ft west of east edge of sec. 30, T. 7 N., R. 4 E., to the point on the north side of Montana Highway 6, 2,600 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
38. Quartzite, like member 35	2	0
39. Siltstone, gray (*N* 4 to *N* 6), argillaceous, laminated (laminae 1/50 to 1/2 in. thick); many individual laminae are irregular in thickness due to small-scale scour and fill	5	6
40. Siltstone, like member 39; and quartzite, like member 35; quartzite occurs in sequences from 1½ to 12 ft in thickness and makes up 35 percent of the section; siltstone occurs in sequences from 1 to 15 ft in thickness and makes up 65 percent of the section	95	0
West end of road cut on the north side of Montana Highway 6, 2,520 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
41. Argillite, silty, greenish-gray (5*GY* 6/1 to 5*GY* 5/1), laminated (laminae 1/16 to 1/2 in. thick); thickness of laminae irregular due to small-scale current-bedding features	25	0
42. Quartzite, greenish-gray (5*GY* 5/1), very fine grained, argillaceous and calcareous	3	0
43. Argillite, silty, medium- to dark-gray (*N* 5 to *N* 2), laminated	2	0
44. Quartzite, medium-light-gray (*N* 6), medium-grained, argillaceous and slightly calcareous	2	6
45. Argillite, silty; like member 43	1	6
46. Quartzite, like member 44	1	0
47. Argillite, silty; like member 43	1	6
48. Quartzite, very fine grained; like member 42	1	6
49. Argillite, silty; like member 43	3	6
50. Quartzite, like member 44		6
51. Argillite, silty; like member 41	2	0
52. Quartzite, very fine grained; like member 42	2	0
53. Argillite, silty; like member 43	1	0
54. Argillite, silty; like member 41	2	0
55. Quartzite, very fine grained; like member 42	1	6
56. Argillite, silty; like member 43, but bedding is contorted as though the sediments had slumped before compaction	5	0
57. Argillite, silty; like member 41	12	0
58. Quartzite, very fine grained; like member 42	2	6

Greyson shale, lower member—Continued	Ft	in
59. Quartzite, medium-gray (*N* 5); very fine grained, argillaceous and calcareous	20	0
60. Argillite, silty; like member 43	4	0
61. Quartzite, very fine grained; like member 59	7	0
62. Argillite, silty; contorted bedding; like member 56	2	0
63. Quartzite, like member 44	6	0
64. Argillite, silty; like member 41	2	0
65. Quartzite, like member 44	3	0
66. Argillite, silty; like member 43	21	0
67. Quartzite, like member 44	10	0
68. Argillite, silty; like member 43	25	0
69. Quartzite, very fine grained; like member 42	6	6
70. Quartzite, like member 44	2	0
71. Quartzite, very fine grained; like member 59	3	0
72. Quartzite, very fine grained; like member 42	13	6
73. Concealed	21	0
74. Quartzite, like member 44	5	6
75. Quartzite, yellowish-gray (5*Y* 7/1), coarse-grained, argillaceous and calcareous	4	0
76. Argillite, silty; like member 41		6
77. Quartzite, very fine grained; like member 42		6
78. Quartzite, like member 44	6	0
79. Quartzite; grades from coarse grained, like member 75, at the base, to medium grained, like member 44, at the top	7	0
80. Concealed	3	6
81. Quartzite, like member 44	16	0
82. Concealed, probably mostly silty argillite like member 41	6	0
83. Quartzite, like member 44	17	0
84. Argillite, silty; like member 41	15	0
85. Quartzite, like member 44	12	0
86. Argillite, silty; like member 41	2	0
87. Quartzite, like member 44	10	0
88. Argillite, silty; like member 41	1	6
89. Quartzite, like member 44	3	6
90. Argillite, silty; like member 41	2	6
91. Quartzite, like member 44	4	0
92. Argillite, silty; like member 41	4	0
93. Quartzite, like member 44	5	0
94. Argillite, silty; like member 41; and some very fine grained quartzite, like member 42	9	0
95. Quartzite, like member 44	2	6
96. Quartzite, very fine grained; like member 42	1	6
97. Argillite, silty; like member 41	1	6
98. Quartzite, very fine grained; like member 42	6	6
99. Concealed	7	0
100. Quartzite, like member 44	6	0
101. Concealed	4	0
102. Quartzite, like member 44	2	0
103. Argillite, silty; like member 41	3	0
104. Quartzite, like member 44	1	0
105. Argillite, silty; like member 41	10	0

660214—62——3

Greyson shale, lower member—Continued	Ft	in
106. Quartzite, like member 44	10	6
107. Quartzite, very fine grained; like member 42	3	0
108. Argillite, silty; like member 41	2	0
109. Quartzite, very fine grained; like member 42	2	6
110. Conglomerate that includes mostly fragments of Newland limestone as much as 2 in. across; varies in thickness	1	6
111. Argillite, silty; like member 43	1	0
112. Quartzite, like member 44	1	6
113. Argillite, silty; like member 43	2	6
114. Quartzite, very fine grained; like member 42	11	6
115. Quartzite, like member 44	1	0
116. Quartzite, very fine grained; like member 42	1	6
117. Quartzite, like member 44	6	6
118. Quartzite, very fine grained; like member 42	7	0
119. Quartzite, like member 44	6	0
120. Conglomerate that includes mostly rounded Newland limestone fragments as much as 2 in. across. Matrix is medium-gray (*N* 5) coarse-grained argillaceous quartzite	1	0
121. Quartzite, like member 44	2	0
122. Concealed	6	0
123. Quartzite, like member 44	25	0
124. Quartzite, very fine grained; like member 42	4	6
125. Quartzite, medium-light-gray (*N* 6) coarse-grained; argillaceous and slightly calcareous; contains a few fragments of argillite as much as 2 in. long	11	0
126. Siltstone, like member 33	3	6
127. Quartzite, light-gray (*N* 7); weathers yellowish gray (5*Y* 7/1); coarse-grained; argillaceous; feldspathic; calcareous; contains a few lithic fragments as much as 1 in. long	1	6
128. Quartzite, like member 44; in a single bed	16	6
129. Quartzite, like member 44; in a single bed	6	6
130. Concealed	4	6
131. Quartzite, like member 44	6	0
132. Concealed	4	6
133. Quartzite, like member 44	3	0
134. Argillite, silty; like member 41	3	0
135. Quartzite, like member 44	13	6
136. Concealed	3	0
137. Quartzite, like member 44	3	0
138. Argillite, silty; like member 41	14	6
139. Quartzite, like member 44	3	0
140. Quartzite, very fine grained; like member 42		6
141. Quartzite, like member 44	3	0
142. Quartzite, very fine grained; like member 42	1	6
143. Argillite, silty; like member 41; weathers very light gray (*N* 8)	1	6
144. Quartzite, like member 44	2	0
145. Quartzite, very fine grained; like member 42		6
146. Quartzite, like member 44	2	6

Greyson shale, lower member—Continued	Ft	in
147. Conglomerate, like member 120	1	6
148. Quartzite, very fine grained; like member 42; weathers very light gray (*N* 8)	3	0
149. Quartzite, like member 44	2	0
150. Argillite, silty; like member 41	1	0
151. Quartzite, like member 44	25	0
152. Conglomerate, rounded fragments (as much as 8 in. across) of Newland limestone, gray silty argillite, and gray limy coarse-grained quartzite in a coarse-grained light-gray quartzite matrix	2	0
153. Quartzite, very fine grained, like member 42	3	6
154. Quartzite, like member 44	2	0
155. Quartzite, very fine grained; like member 42	1	0
156. Quartzite, like member 44	10	0
157. Sheared zone		6
158. Quartzite, like member 44	4	0
159. Conglomerate, rounded and oblate fragments (as much as 2 ft in diameter) of Newland limestone, gray silty argillite, and gray limy coarse-grained quartzite in a coarse-grained light-gray quartzite matrix	13	6
160. Argillite, silty; like member 43	10	0
161. Quartzite, very fine grained; like member 42	7	6
162. Argillite, silty; like member 43	7	6
163. Quartzite, very fine grained; like member 42	2	0
164. Quartzite, like member 44	3	6
165. Argillite, silty; like member 43	5	0
166. Quartzite, very fine grained; like member 59	8	0
167. Argillite, silty; like member 41	7	0
168. Quartzite, like member 44	3	0
169. Quartzite, very fine grained; like member 42	2	6
170. Argillite, silty; like member 41		6
171. Quartzite, very fine grained; like member 59	5	0
172. Quartzite, very fine grained; like member 42	1	6
173. Quartzite, like member 44	6	6
174. Quartzite, very fine grained; like member 42	4	6
175. Quartzite, like member 44	9	0
176. Conglomerate, like member 120	10	0
177. Argillite, silty; like member 41	1	6
178. Quartzite, like member 44	9	0
179. Conglomerate, like member 120	2	6
End of road cut on north side of Montana Highway 6, 1,870 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
180. Concealed	14	0
181. Quartzite, like member 44	19	6
182. Quartzite, very fine grained; like member 59	23	6
183. Argillite, silty; like member 41	23	0
184. Quartzite, like member 44	8	0
185. Concealed; probably silty argillite like member 41	8	0
186. Quartzite, like member 44	2	0
187. Concealed; probably silty argillite like member 41	6	0

Greyson shale, lower member—Continued	Ft	in
188. Argillite, sandy, medium-gray (*N* 4 to *N* 5), calcareous; contains fragments of quartz, limestone, and argillite from silt to pebble size; most fragments are between medium to coarse-sand size	13	6
189. Argillite, silty; like member 41	6	0
North side of Greyson Creek at an altitude of 4,710 ft 1,850 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		
190. Argillite, silty; like member 41	57	0
191. Quartzite, light-gray (*N* 7); weathers yellowish gray (5*Y* 7/1); very coarse grained; argillaceous; feldspathic; calcareous	20	0
192. Argillite, silty; like member 41	4	6
193. Quartzite, like member 191	30	0
194. Argillite, silty; like member 41; partly covered	12	0
195. Quartzite, like member 44	6	6
196. Quartzite, like member 44, but sheared	1	0
197. Quartzite, like member 191	2	6
198. Conglomerate, like member 120	2	0
199. Quartzite, like member 191	2	6
200. Conglomerate, like member 120	2	0
201. Quartzite, like member 44	2	6
202. Conglomerate, like member 120	4	0
203. Quartzite, like member 44	2	0
204. Conglomerate, like member 120	1	6
205. Quartzite, like member 44	6	6
206. Conglomerate, like member 120	1	0
207. Concealed; scattered outcrops of silty argillite like member 43. Above on the hillside 3 beds, 6 ft thick, of conglomerate like member 152 interbedded with beds, 1 ft thick, of quartzite like member 44 crop out	70	0
Total	2,245	6
Thickness of the lower member of the Greyson shale rounded to the nearest 100 ft	2,200	
Conformable contact at an altitude of 4,695 ft and 1,610 ft west of the east edge of sec. 30, T. 7 N., R. 4 E.		

Newland limestone, the measured section of the Newland limestone begins at this point.

UPPER MEMBER

The upper member of the Greyson shale along Greyson Creek, where best exposed, is separated into two parts by a fault. The rocks of the lower part of the upper member are dominantly siltstone and shale; silt becomes more abundant upward. The lowest rocks are dominantly shale and the uppermost rocks dominantly argillaceous siltstone. A few beds of fine-grained gray quartzite occur in the the lower 600 feet; a zone of fine-grained gray quartzite 70 feet thick occurs about 2,680 feet above the base of the member; and a few beds of quartzite occur about 6,060 feet above the base.

The shale and siltstone consist of finely comminuted quartz, a little feldspar, and detrital grains of argillite in a chlorite-sericite matrix. Shreds of detrital muscovite and patches of interstitial calcite are minor constituents.

The matrix of the quartzite is similar to the shale and siltstone and comprises as much as one-third of the quartzite.

The uppermost part of the upper member is composed of shale, siltstone, and argillite interbedded with medium-grained light-gray argillaceous quartzite that makes up 20 to 25 percent of this part of the member. All these rocks are similar in composition to the rocks that are lower in the member. The bulk of these uppermost rocks are gray or greenish gray, but about 30 percent are reddish in the upper 150 feet. Reddish rocks become more abundant upward in the section to form the transition between the Greyson and Spokane shales. The reddish rock and greenish rock are interbedded and each color occurs in sequences from 1 inch to 16 feet in thickness. The coarseness and the amount of quartzose material in the shale, siltstone, and argillite decreases upward in this part of the formation, and the uppermost 175 feet of the formation is free of medium-grained quartzite.

Limy quartzite and shale occur in the upper 544 feet of the formation where they make up about 17 percent of the section.

The amount of stratigraphic displacement on the fault that separates the two parts of the upper member is unknown, but is probably small. Neither the quartzite beds that gradually increase in abundance west of the fault nor the relatively quartzite-free siltstone east of the fault is duplicated. Also, the argillaceous siltstone sequence does not seem to be seriously interrupted.

The following measured section is representative of the stratigraphy of the upper member of the Greyson shale.

Section of the upper member of the Greyson shale along the northeast side of Greyson Creek

	Ft	in
Spokane shale.		
Gradational contact on the northeast side of Greyson Creek at an altitude of 4,960 ft and 3,950 ft west of the east edge of sec. 12, T 6 N., R. 3 E.		
Greyson shale, upper member:		
1. Shale, greenish-gray (5*GY* 7/1 to 5*GY* 5/2); weathers yellowish gray (5*Y* 7/1); silty; beds 1 to 4 in. thick, with laminae 1/16 to 1/2 in. thick; individual laminae vary in thickness due to scour and fill	11	0
2. Shale, like member 1 but massive	6	0
3. Shale, greenish-gray like member 1 interbedded with red (5*R* 5/1 to 5*R* 4/2) silty shale	7	6
4. Shale, like member 1	10	0

Greyson shale, upper member—Continued	Ft	in
5. Shale, grayish-red (5*R* 5/1 to 5*R* 4/2), silty; and a few interbedded greenish-gray shale beds like member 1	7	0
6. Concealed	7	0
7. Shale, mixed greenish-gray like member 1 and grayish-red like member 5; colors alternate every 1 to 4 in.; greenish colors dominate down section and reddish colors up section	23	0
8. Shale, like member 1	11	6
9. Shale, mixed greenish-gray like member 1 and grayish-red like member 5	4	6
10. Shale, like member 1	16	0
11. Concealed	2	0
12. Shale, mixed red and green, like member 9; greenish colors more abundant	2	6
13. Shale, like member 1	8	0
14. Shale, reddish like member 5; and a small amount of interbedded green like member 1	16	0
15. Shale, mixed red and green like member 9	18	0
16. Shale, like member 1	11	0
17. Shale, limy, light-olive-gray (5*Y* 6/1); weathers to yellowish brown (10*YR* 5/5); silty; laminated	6	0
18. Shale, like member 1	8	6
Offset from an altitude of 5,150 ft on the northeast side of Greyson Creek 3,780 ft west of the east edge of sec. 12, T. 6 N., R. 3 E., to an altitude of 5,130 ft on the northeast side of Greyson Creek 3,550 ft west of the east edge of sec. 12, T. 6 N., R. 3 E.		
19. Shale, like member 1; includes 6 beds of quartzite 6 to 8 in. thick	25	0
20. Shale, limy; like member 17	10	0
21. Quartzite, light-gray (*N* 7), weathers to light brown (5*YR* 7/2); medium grained; argillaceous; beds 4 in to 2 ft thick, average about 10 in. thick; crossbedded in part	4	0
22. Shale, like member 1	8	6
23. Quartzite, like member 21	5	0
24. Shale, like member 1	5	0
25. Quartzite, like member 21	3	0
26. Mostly concealed, probably shale like member 1; and a little quartzite like member 21	144	0
27. Quartzite, like member 21	2	0
28. Shale, like member 1	15	0
29. Sandstone, limy, light brownish-gray (5*YR* 6/1) to medium-gray (*N*6); weathers yellowish brown (10*YR* 5/2); medium grained; argillaceous; beds 4 in. to 2 ft thick; crossbedded	7	6
30. Shale, like member 1	2	6
31. Sandstone, limy; like member 29	2	0
32. Shale, like member 1	5	0
33. Quartzite, like member 21	2	0
34. Shale, like member 1	13	0
35. Quartzite, like member 21	4	6
36. Shale, like member 1	4	0

Greyson shale, upper member—Continued	*Ft*	*in*
37. Quartzite, like member 21	2	6
38. Shale, like member 1	5	0
39. Quartzite, like member 21, but slightly limy	2	6
40. Shale, like member 1	19	0
41. Shale, limy; like member 17	4	0
42. Shale, like member 1	6	0
43. Quartzite, like member 21	4	6
44. Shale, like member 1	6	6
45. Shale, limy; like member 17	22	0
46. Sandstone, limy; like member 29	2	0
47. Shale, like member 1, but slightly limy	16	0
48. Sandstone, limy; like member 29	2	0
49. Shale, limy; like member 17	1	6
50. Sandstone, limy; like member 29	2	0
51. Shale, limy; like member 17	3	0
52. Sandstone, limy; like member 29	8	0
53. Shale, like member 1	2	0
54. Quartzite, grayish yellow-green (5*GY* 6/2), clayey; beds 4 in to 2 ft thick	2	6
55. Shale, like member 1, and a few beds of grayish-red (5*R* 4/2) shale in beds 1 to 4 in. thick; also a few beds of quartzite, like member 21	15	0
56. Shale, grayish-green (5*GY* 7/2); like member 1, mixed with grayish-red (5*R* 4/2) shale; beds ½ to 4 in. thick, average about 2 in.; weathers to chips about 1/16 by ¼ in. across; reddish shale weathers to slightly smaller chips than the green	3	0
57. Shale, like member 1	5	6
58. Shale, greenish and reddish mixed; like member 56	2	6
59. Concealed	2	6
60. Quartzite, like member 54	5	
61. Shale, like member 1	2	0
62. Shale, greenish and reddish mixed; like member 56	5	6
63. Quartzite, like member 21	2	0
64. Concealed; probably all shale like member 1	25	0
Offset from an altitude of 5,080 ft on the northeast side of Greyson Creek 3,100 ft west of the east edge of sec. 12, T. 6 N., R. 3 E., to an altitude of 5,080 ft on the ridge on the northeast side of Greyson Creek 2,960 ft west of the east edge of sec. 12, T. 6 N., R. 3 E.		
65. Quartzite, like member 21	5	0
66. Concealed; float is shale like member 1	15	0
67. Quartzite, like member 21, in beds 1 to 4¼ in. thick; beds separated by thin layers of shale like member 1	1	6
68. Quartzite, argillaceous, greenish-gray (5*GY* 7/1 to 5*GY* 5/2), very fine grained; beds ⅛ to ½ in. thick; individual beds vary in thickness due to scour and fill; weathers to form small angular fragments. This rock type is gradational upward through the section into rock like member 1	66	0
69. Quartzite, like member 21	7	0
70. Quartzite, argillaceous; like member 68	5	0

Greyson shale, upper member—Continued	*Ft*	*in*
71. Quartzite, like member 21; ripple-marked	1	6
72. Quartzite, argillaceous; like member 68	11	0
73. Concealed; probably mostly shale like member 68	20	0
74. Quartzite, argillaceous; like member 68	3	6
75. Quartzite, like member 21	6	0
76. Quartzite, argillaceous; like member 68	2	0
77. Quartzite, like member 21	5	0
78. Quartzite, argillaceous; like member 68	4	0
79. Quartzite, like member 21	7	0
80. Quartzite, argillaceous; like member 68	6	0
81. Quartzite, like member 21	2	0
82. Quartzite, argillaceous; like member 68	6	0
83. Quartzite, like member 21	5	0
84. Quartzite, argillaceous; like member 68	4	0
85. Quartzite, like member 21	10	0
86. Quartzite, argillaceous; like member 68	3	0
87. Quartzite, like member 21	5	6
88. Quartzite, argillaceous; like member 68	3	0
89. Quartzite, like member 21	2	0
90. Concealed; mostly argillaceous quartzite, like member 68, and some quartzite, like member 21	39	0
91. Quartzite, like member 21	5	0
92. Concealed; probably argillaceous quartzite, like member 68, and some quartzite, like member 21	9	0
93. Shale, limy; like member 29	4	0
94. Quartzite, argillaceous; like member 68	31	0
95. Conglomerate, shale chips, like member 68; chips 1/32 to 1/16 in. wide by 1/8 to 1/4 in. long in a limy shale matrix which is greenish gray (10*G* 6/1) when fresh and weathers to light olive gray (5*Y* 6/1). This unit lenses out a short distance to the northwest	3	0
96. Quartzite, argillaceous; like member 68	15	0
At an altitude of 5,070 ft on the northeast side of Greyson Creek 2,560 ft west of the east edge of sec. 12, T. 6 N., R. 3 E.		
97. Mostly concealed; argillaceous quartzite, like member 68, and quartzite, like member 21	200	0
Fault (concealed) at an altitude of about 5,160 ft and 1,350 ft west of the east edge of sec. 12, T. 6 N., R. 3 E. This fault separates the upper quartzite-rich part of the upper member from the quartzite-poor lower part.		
98. Siltstone, partly concealed, medium gray (*N* 4 to *N* 5), and greenish-gray (5*GY* 5/1); weathers to olive gray (5*Y* 4/2); argillaceous; laminated. Some laminae pinch and swell due to current bedding features; breaks down into rock chips with sparse soil	600	0
At an altitude of 5,400 ft on ridge northeast of the above-mentioned fault.		
99. Quartzite, light gray (*N* 7), weathers to light brown (5*YR* 7/2); medium grained, argillaceous; thin bedded; faintly crossbedded in places	5	0
100. Siltstone, like member 98	12	0

Greyson shale, upper member—Continued	*Ft*	*in*
101. Quartzite, like member 99	13	0
102. Siltstone, partly concealed; like member 1	400	0
At an altitude of 5,260 ft in gully at the west edge of sec. 7, T. 6 N., R. 4 E.		
103. Siltstone, like member 98	70	0
At an altitude of 5,240 ft at crest of ridge 150 ft east of the west edge of sec. 7.		
104. Siltstone, like member 98	480	0
At an altitude of 5,180 ft in gully 550 ft east of the west edge of sec. 7.		
105. Siltstone, like member 98	160	0
At an altitude of 5,290 ft on crest of ridge 850 ft east of the west edge of sec. 7.		
106. Siltstone, partly concealed; like member 98	250	0
At an altitude of 5,200 ft in gully 1,220 ft east of the west edge of sec. 7.		
107. Siltstone, partly concealed; like member 98	200	0
At an altitude of 5,300 ft on ridge 1,660 ft east of the west edge of sec. 7.		
108. Siltstone, largely concealed, medium-gray (*N* 5), argillaceous; in part thin bedded and faintly crossbedded; in part irregularly laminated; breaks down to form rock chips in very sparse soil	260	0
At an altitude of 5,180 ft in gully 2,020 ft east of the west edge of sec. 7.		
109. Siltstone, like member 108	40	0
At an altitude of 5,190 ft on crest of ridge 2,160 ft east of the west edge of sec. 7.		
110. Siltstone, like member 108	100	0
At an altitude of 5,170 ft in gully 2,300 ft east of the west edge of sec. 7.		
111. Siltstone, like member 108	300	0
At an altitude of 5,280 ft on ridge 2,680 ft east of the west edge of sec. 7.		
112. Siltstone, like member 108	290	0
At an altitude of 5,180 ft in gully 2,940 ft east of the west edge of sec. 7.		
113. Siltstone, like member 108	100	0
114. Quartzite, medium dark-gray; weathers greenish gray (5*G* 6/1 and 5*GY* 5/1), locally with a brown surface stain (5*YR* 5/4); fine grained; argillaceous	70	0
At an altitude of 5,340 ft on ridge 3,300 ft east of the west edge of sec. 7.		
115. Siltstone, like member 108; near member 116 there is one bed of medium-gray (*N* 5) sandy limestone; weathers dark yellowish brown (10*YR* 3/2); medium grained	160	0
At an altitude of 5,360 ft, 3,640 ft east of the west edge of sec. 7.		
116. Siltstone, partly concealed; like member 108 at the west and becoming finer and more clay rich eastward	700	0
At an altitude of 5,260 ft in gully 4,640 ft east of the west edge of sec. 7.		

Greyson shale, upper member—Continued	*Ft*	*in*
117. Shale, partly concealed, greenish-gray (5*GY* 5/1); weathers to shades of brown; silty; laminated; breaks down to form rock chips in very sparse soil	740	0
At an altitude of 5,240 ft on road 360 ft east of west edge of sec. 8, T. 6 N., R. 4 E.		
118. Shale, partly concealed; like member 117; all partly weathered, common color is dark yellowish brown (10*YR* 3/2) and locally white (*N* 9)	440	0
At an altitude of 5,300 ft on ridge on the north side of Greyson Creek 1,150 ft east of west edge of sec. 8. Measured section continues along the west side of the tributary gully that enters Greyson Creek 1,200 ft east of the west edge of sec. 8.		
119. Shale, partly concealed; like member 117	290	0
Point 1,260 ft east of west edge, and 1,800 ft south of the north edge of sec. 8.		
120. Shale, partly concealed; like member 117. At top of sequence there is one bed of medium-gray (*N* 5) medium-grained cross laminated sandy limestone that weathers to medium gray (*N* 4) and yellowish brown (10*YR* 3/2)	400	0
Point 1,660 ft east of west edge and 1,300 ft south of north edge of sec. 8.		
121. Shale, partly concealed; like member 117; becomes somewhat coarser grained and more siliceous downward; contains rare beds of gray very fine grained argillaceous quartzite	220	0
Point 1,930 ft east of west edge and 1,030 ft south of north edge of sec. 8.		
122. Siltstone, like member 108; contains a few beds of fine-grained gray quartzite	390	0
Total	7, 818	6
Partial section, upper member, Greyson shale rounded to the nearest 100 ft	7, 800	

Gradational contact at the point 2,500 ft east of the west edge and 1,980 ft south of the north edge of sec. 8, T. 6 N., R. 4 E.

Greyson shale, lower member.

The total thickness of the two measured stratigraphic sections is about 10,000 feet, which is probably a fairly accurate thickness for the Greyson shale.

SPOKANE SHALE

NAME AND DISTRIBUTION

The Spokane shale was named by C. D. Walcott (1899) from the Spokane Hills, which are about 10 miles northwest of the Duck Creek Pass quadrangle.

The Spokane shale underlies about 4 square miles of hilly terrane in the southeast part of the Duck Creek Pass quadrangle. This formation is covered by only a very sparse soil, so that low outcrops are abundant even in areas of little local relief. Conspicuous outcrops are confined to gullies and canyons.

DESCRIPTION

The Spokane shale is dominantly red silty shale, which occurs in beds from 1/16 to 5 inches in thickness. Many of these beds vary in thickness due to scour and fill. Red siltstone grades into, and is interbedded with, red shale. Green shale makes up about 10 percent of the formation, and a few rare limy beds are scattered through the formation.

The rocks of the Spokane consist of finely divided detrital particles, mostly quartz and a little feldspar, muscovite, and argillite, in a matrix of chlorite and sericite.

The following measured section is typical of this formation.

Section of Spokane shale on the north side of Dry Creek

Flathead quartzite.

Contact 200 ft east of the west edge and 1,250 ft south of the north edge of sec. 30, T. 6 N., R. 4 E. This contact and the part of the Spokane shale west of the diabase sill are a short distance outside the Duck Creek Pass quadrangle to the south.

Spokane shale:	*Ft*	*in*
1. Shale, grayish-red (5*R* 5/1 to 5*R* 4/2), silty; beds 1/16 to 4 in. thick; individual beds vary in thickness due to scour and fill. Includes pale-grayish-red (2*YR* 6/2) siltstone	510	0
Diabase sill, 750 ft thick, extends from 1,300 ft east of the west edge and 1,290 ft south of the north edge of sec. 30, T. 6 N., R. 4 E., to 1,600 ft east of the west edge and 920 ft south of the north edge of sec. 30.		
2. Shale and siltstone, like member 1. Includes zones, 2 to 4 ft thick, of greenish-gray (5*GY* 7/1 to 5*GY* 4/2) silty shale in beds 1/16 to 1 in. thick	690	0
2,320 ft east of the west edge and 610 ft south of the north edge of sec. 30, T. 6 N., R. 4 E.		
3. Shale and siltstone like member 1; includes a little greenish-gray (5*GY* 7/1 to 5*GY* 4/2) silty shale	180	0
Point on unimproved road 2,510 ft east of the west edge and 590 ft south of the north edge of sec. 30, T. 6 N., R. 4 E.		
4. Shale, grayish-red (5*R* 4/2 to 5*R* 5/2), silty; beds 1/16 to 4 in. thick; individual beds vary in thickness owing to scour and fill	9	0
5. Siltstone, pale-grayish-red (5*R* 6/2); weathers grayish orange pink (5*YR* 7/2); argillaceous; beds 1/16 to 1 in. thick	3	0
6. Concealed	4	6
7. Siltstone, like member 5	2	0
8. Concealed	10	0
9. Shale, like member 4	9	0

Spokane shale—Continued	*Ft*	*in*
10. Shale, greenish-gray (5*GY* 7/1 to 5*GY* 4/2), silty; beds 1/16 to 1 in. thick	1	6
11. Shale, like member 4	7	0
12. Concealed	25	0
13. Shale, like member 4	6	6
14. Concealed, probably mostly shale like member 4	35	0
15. Shale, like member 10	3	0
16. Siltstone, like member 5	2	0
17. Shale, like member 4	9	6
18. Shale, like member 10	2	6
19. Siltstone, like member 5	1	0
20. Shale, like member 10	2	0
21. Siltstone, like member 5	1	6
22. Shale, like member 4	6	0
2,800 ft east of the west edge and 570 ft south of the north edge of sec. 30, T. 6 N., R. 4 E.		
23. Siltstone, like member 5	2	6
24. Shale, like member 4	7	6
25. Shale, like member 10	1	0
26. Shale, like member 4	31	0
27. Limestone, medium-gray (*N* 5); weathers yellowish brown (10*YR* 5/2); sandy and argillaceous	4	0
28. Shale, like member 4	31	0
29. Shale, like member 10	1	0
30. Shale, like member 4	20	0
31. Shale, like member 10		6
32. Shale, like member 4	3	6
33. Shale, like member 10		6
34. Shale, like member 4	20	0
2,900 ft east of the west edge and 570 ft south of the north edge of sec. 30, T. 6 N., R. 4 E.		
35. Shale, like member 4	180	0
3,190 ft east of the west edge and 680 ft south of the north edge of sec. 30, T. 6 N., R. 4 E.		
36. Shale, like member 10	25	0
37. Shale, like member 4	365	0
3,790 ft east of the west edge and 990 ft south of the north edge of sec. 30, T. 6 N., R. 4 E.		
38. Shale, reddish (like member 4) in zones 1 to 19 in. thick interbedded with greenish shale (like member 10) in zones 1/16 to 5 in. thick and an average of ½ to 1 in. thick	90	0
Section crosses the south edge of the Duck Creek Pass quadrangle 3,950 ft west of east edge of sec. 30, T. 6 N., R. 4 E., and continues on to east and south of the quadrangle.		
39. Shale, like member 38	425	0
4,680 ft east of the west edge and 3,420 ft north of the south edge of sec. 30, T. 6 N., R 4 E.		

Spokane shale—Continued	*Ft*	*in*
40. Shale, interbedded; reddish, like member 4, and greenish, like member 10. Proportion of greenish shale increases downward and is about 50 percent at the base of this member	230	0
Total	2, 957	6
Total thickness of Spokane shale rounded to the nearest 100 ft	3, 000	

Gradational contact at the point 5,150 ft east and 3,080 ft north of the southwest corner of sec. 30, T. 6 N., R. 4 E.
Greyson shale.

The base of the Spokane shale is arbitrarily placed where red colors become dominant in the gradational sequence of mixed red and green shale. This mixed red and green gradational sequence extends about 150 feet below and about 180 feet above the contact as it is drawn on Greyson Creek. The following measured section is of the part of this gradational sequence that is included in the Spokane shale. This section continues from the measured section of the upper part of upper member of the Greyson shale, which is included in the description of the Greyson shale and which includes the lower 150 feet of the gradational sequence.

Lower gradational part of the Spokane shale on the northeast side of Greyson Creek

Spokane shale:	*Ft*	*in*
Measured section begins at an altitude of 4,950 ft and 4,140 ft west of the east edge of sec. 12, T. 6 N., R. 3 E.		
1. Shale, grayish-red (5*R* 5/1 to 5*R* 4/2), silty; beds 1/16 to 4 in. thick; individual beds vary in thickness due to scour and fill; includes a little greenish-gray (5*GY* 7/1 to 5*GY* 5/2) shale in layers 1 to 6 in. thick	33	0
2. Shale, greenish-gray (5*GY* 7/1 to 5*GY* 5/2), silty; beds 1/16 to 1 in. thick; individual beds vary in thickness due to scour and fill	2	0
3. Shale, like member 1	2	0
4. Shale, like member 2	3	6
5. Shale, like member 1	12	0
6. Shale, like member 2; a little interbedded shale like member 1	13	0
7. Shale, like member 2; interbedded with shale like member 1	8	0
8. Shale, like member 1	41	0
9. Sandstone, limy, greenish-gray (5*GY* 5/1), fine-grained, argillaceous	11	0
10. Concealed	17	0
11. Shale, like member 2	23	0
12. Limestone, light-gray (*N* 7); weathers yellowish brown (8*YR* 4/2); silty; contains dark specks, probably magnetite	3	6

	Ft	in
Spokane shale—Continued		
13. Shale, like member 2	9	6
Total	178	6
Thickness of the lower gradational part of the Spokane shale rounded to the nearest 10 ft	180	

Gradational contact at an altitude of 4,960 ft and 3,950 ft west of the east edge of sec. 12, T. 6 N., R. 3 E. Greyson shale.

PALEONTOLOGY OF THE BELT SERIES

Recognized fossil remains in the rocks of the Belt series in this quadrangle consist of stromatolites and small conical objects that may be the shells of primitive gastropods (fig. 2). Richard Rezak examined some of these fossils; his determinations are tabulated below.

Specimen	Formation	Location	Determination
56N 48a	Newland limestone	1,200 ft east and 450 ft north of the SW cor. sec. 27, T. 8 N., R. 3 E.	This collection contains objects that may possibly be primitive gastropods.
55b	do	500 ft east and 2,700 ft north of the SE cor. sec. 30, T. 7 N., R. 4 E.	*Newlandia* sp.
56	do	300 ft west and 2,800 ft north of the SW cor. sec. 29, T. 7 N., R. 4 E.	*Newlandia major* Walcott.
67	do	800 ft east and 600 ft south of the NW cor. sec. 3, T. 7 N., R. 3 E.	*Newlandia lamellosa* Walcott.
68	do	100 ft east and 1,400 ft south of the NW cor. sec. 3, T. 7 N., R. 3 E.	*Newlandia frondosa* Walcott.
179a	Spokane shale	550 ft west and 350 ft south of the NE cor. sec. 11, T. 6 N., R. 3 E.	*Collenia undosa* Walcott.
188	Greyson shale	1,300 ft west and 2,100 ft south of the NE cor. sec. 13, T. 6 N., R. 3 E.	*Collenia frequens* Walcott.

CONDITIONS OF DEPOSITION OF THE BELT SERIES

All rocks of the Belt series of this quadrangle, except possibly the lower part of the Newland limestone, bear evidence of having been deposited in relatively shallow water in which currents were present most of the time. The lower part of the Newland limestone was deposited in quiet water, which may have been somewhat deeper than that in which the other rocks of the Belt series were deposited.

Mud cracks are prevalent in the Spokane shale, and they indicate that during the deposition of that formation the water was so shallow that the sediments were intermittently exposed to the air. Stromatolites are present in all the formations of the Belt series in this quadrangle. Rezak (1957) states that most workers agree that stromatolites can form only in shallow water, and he (p. 141–147) believes that the stromatolites in the Belt series probably formed above the low watermark, presumably in the intertidal zone.

Sedimentary structures formed by currents are widespread in the rocks of the Greyson shale and the Spokane shale, and in many of the beds of the upper member of the Newland limestone. Small-

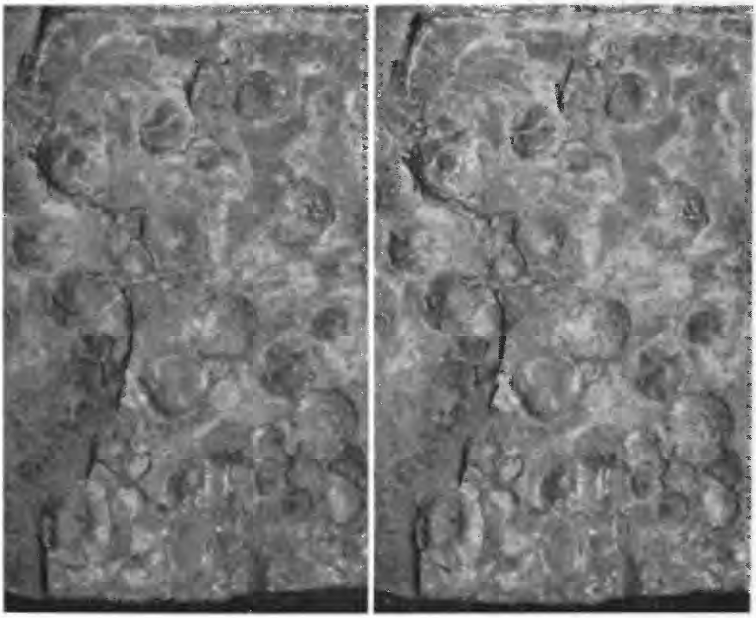

FIGURE 2.—Stereophotograph of assymetrical conical objects, which may be the remains of primitive gastropods, in the Newland limestone from locality 56N48a on the North Fork of Ray Creek. The pictures are natural size.

scale scour-and-fill structures, a fraction of an inch deep, occur in many of the beds of siltstone and finer clastic rocks of these formations. Crossbedding is common in the quartzite beds.

Small-scale symmetrical ripple marks are common throughout the rocks of the Spokane shale. The size and symmetry of the ripple marks are comparable to modern ripple marks formed by waves in very shallow stationary water.

DIABASE (PRECAMBRIAN(?))

Sills and dikes of diabase are confined to the Spokane shale and on this basis are assumed to be of Precambrian age. The diabase is dark greenish gray when fresh; it weathers reddish brown and yields granular reddish-brown soil. The diabase consists dominantly of about 45 percent euhedral to subhedral plagioclase, mostly labradorite, and about 30 percent subhedral to anhedral augite; it also contains a few percent of quartz, a few percent of intergrown quartz and orthoclase, 5 to 10 percent magnetite, a few percent of biotite, and a trace of amphibole and apatite. The outermost rocks of the larger intrusive bodies are commonly somewhat finer grained than the bulk of the diabase and probably represent chilled contact phases. The Spokane shale is a hornfels for a few feet adjacent to the diabase bodies.

PRECAMBRIAN-CAMBRIAN CONTACT

The contact at the top of the Belt series appears to be an unconformity that cuts at a very small angle across progressively younger formations of the series from southeast to northwest. In the Duck Creek Pass quadrangle the Spokane shale is the uppermost formation of the series. To the northwest in the Canyon Ferry quadrangle (Mertie and others, 1951) the Spokane shale is overlain by the Empire shale and the Helena limestone. West of Helena, Mont., the Marsh shale overlies the Helena limestone at the top of the series, and still farther northwest the Greenhorn Mountain quartzite is above the Marsh shale at the top of the series (Knopf, 1957, p. 84). South of the Duck Creek Pass quadrangle, in the Toston quadrangle, G. D. Robinson (oral communication, 1957) has found that the Spokane shale becomes progressively thinner southward and is finally cut out near the south edge of that quadrangle.

An alternate explanation of the above relations, but one that the writer does not favor, is that the younger formations of the Belt series in this region all thin eastward and southward and that each successively younger formation was less extensive, and thus terminated west of the eastern limit of the next older formation.

ROCKS OF PALEOZOIC AGE

Rocks of Paleozoic age occupy only about 8 square miles of the area of the Duck Creek Pass quadrangle. These rocks are widely exposed in the Toston and Three Forks quadrangles to the south, where they have been studied by G. D. Robinson. The reader is referred to Robinson's (1963) descriptions of the rocks of Paleozoic age in the Three Forks quadrangle, to Hanson's (1952) description of rocks of Cambrian age in southwestern Montana, and to the work of McMannis (1955) in the Bridger range for more detailed data on these rocks than is given here.

FLATHEAD QUARTZITE (MIDDLE CAMBRIAN)

The Flathead quartzite was named by A. C. Peale (1893) for exposures in the Bridger Range at Flathead Pass about 22 miles south-southeast of the Duck Creek Pass quadrangle.

The Flathead quartzite makes a narrow rocky ridge over most of its extent in the Duck Creek Pass quadrangle.

The Flathead quartzite is composed of feldspathic quartzite that ranges from grayish red (5*R* 4/2) to pinkish gray (5*YR* 8/1). Beds range from 1 inch to 3 feet in thickness and average between 8 and 10 inches. Many of the beds are crossbedded; the cross laminae range from ⅛ to ½ inch in thickness and commonly contrast strongly with one another in saturation of red. Many beds are graded and many finer grained parts of the formation are ripple marked. The quartzite varies from medium to very coarse grained and locally includes seams or laminae containing grains as much as 6 mm across. Hematite seems to be the principal coloring agent in these rocks. Thin veneers of greenish shale, similar to the Wolsey shale, occur between some of the quartzite beds. These shale layers become more abundant and an inch or more thick near the top of the Flathead.

The Flathead quartzite is 48 feet thick where measured on the north side of Dry Creek in sec. 30, T. 6 N., R. 4 E., just outside the south edge of the Duck Creek Pass quadrangle.

The Flathead quartzite appears to be a beach or near-shore deposit that is the lowermost unit laid down by a transgressing sea. According to this concept the Flathead quartzite is the coarser fraction of a sand-mud mixture from which much of the mud was winnowed out by waves and shore currents and deposited in quieter water farther from shore to form what is now the Wolsey shale. Evidence that favors this interpretation is the relatively thin blanket-like nature of the Flathead quartzite (Hanson, 1952, p. 12), the current bedding throughout the quartzite, and the interbedding of shale in the upper part of the quartzite and of quartzite in the Wolsey shale.

WOLSEY SHALE (MIDDLE CAMBRIAN)

The name Wolsey was introduced by W. H. Weed (1899a, b), who (Weed, 1900) states that "These shales * * * are well exposed at the old dam on Sheep Creek near Wolsey." Wolsey is shown on the Little Belt Mountains folio (Weed, 1899b); it was a small community at the confluence of Sheep Creek and Wolsey Creek about 29 miles northeast of the Duck Creek Pass quadrangle.

Much of the area underlain by the Wolsey shale in the Duck Creek Pass quadrangle is a shallow furrow 500 to 1,000 feet wide, but for more than 1 mile south of Deep Creek and along Dry Creek the Wolsey shale forms a steep slope below a resistant ridge of Flathead quartzite. Outcrops are scarce in most areas, but in sec. 23, T. 6 N., R. 3 E., the Wolsey shale has been hardened by intrusive rocks, and here outcrops are more abundant than elsewhere in the quadrangle.

In most places the Wolsey shale is yellowish green to greenish yellow (5*GY* 6/3 to 5Y 6/3), but locally it is grayish red (about 5*R* 4/2). Most of the shale is silty or sandy, much of it is limy, and locally the formation is a sandy limestone. Detrital mica is scattered throughout these rocks; most of the bedding planes are veneered with it, and have a conspicuous sheen. Pellets of glauconite are common in some of the beds especially in the lower part of the formation. Irregular ridges, from 1/16 to 3/16 inch wide and 1/4 inch to several inches long, that occur on many of the bedding planes are probably worm casts or coprolites.

The contact between the Wolsey shale and the underlying Flathead quartzite is gradational. Greenish shale is interbedded with many of the uppermost quartzite beds of the Flathead quartzite, and a few reddish quartzite beds occur in the lower part of the Wolsey shale. The contact is drawn at the position in which the quartzite ceases to be the dominant lithology.

The Wolsey shale is nowhere well-enough exposed in the Duck Creek Pass quadrangle to permit accurate measurement of its thickness. The widths of the areas underlain by the Wolsey shale and attitudes of the rocks suggest that it is less than 200 feet thick. This thickness is considerably less than the 300 feet of Wolsey found by G. D. Robinson (oral communication, 1957) in a well-exposed section 8 miles south of the Duck Creek Pass quadrangle near Sixteenmile Creek in the Toston quadrangle. In the Duck Creek Pass quadrangle, the Wolsey is faulted locally, and it is likely that its thickness has been tectonically modified over most, if not all, of its extent in the quadrangle.

The origins of the Wolsey shale and the Flathead quartzite are believed to be related, and the conditions of deposition of both are discussed in the section on Flathead quartzite.

SILLS IN THE WOLSEY SHALE

At most places in this region a sill a few tens of feet thick, and too small to show on the map, occurs within the Wolsey shale. In the W½ sec. 3, T. 6 N., R. 3 E., several bands of sill rock alternate with Wolsey shale. The fault that cuts out the Flathead quartzite in that area duplicates the sill, and it seems likely that other unrecognized faults in the same area probably have caused other duplications of the sill.

The sill rock consists of a very fine grained light olive-gray groundmass that includes abundant phenocrysts of very light gray feldspar from 1 to 5 mm across, laths of an altered mafic mineral as large as 1 by 6 mm, rare rounded quartz phenocrysts about 3 mm across, and scattered grains of magnetite. In one typical thin section, the groundmass was seen to be composed of subequal amounts of quartz and turbid albite and a little chlorite. The mafic minerals are now chlorite, or chlorite and magnetite, and the feldspar phenocrysts are albite that includes much disseminated clay alteration material and shreds of a clear colorless mineral with $nX>1.54$ and $nZ-nX\cong 0.025$, which may be anthophyllite. Apatite crystals are scattered through this rock. The composition of the feldspars, both the phenocrysts and those in the groundmass, as well as the extent of their alteration, suggests that this rock probably has been albitized.

MEAGHER LIMESTONE (MIDDLE CAMBRIAN)

The term Meagher was first used by W. H. Weed (1899 a, b). He did not specify the derivation of the name, but the formation is widely distributed in Meagher County which includes most of the area of the Little Belt Mountain folio (Weed, 1899b).

The main part of the Meagher limestone generally forms bold cliffs, but the uppermost and lowermost parts of the formation commonly underlie moderately sloping grassy hillsides.

The formation consists of very fine grained limestone of two colors, gray (*N* 4 to 5*Y* 4/1) and grayish orange (10*YR* 6/3); the grayish orange occurs as spots and stringers that average about one-sixteenth inch thick in the gray limestone. The grayish-orange limestone makes up about 10 percent of the formation, and is concentrated in, but is not restricted to, planes parallel to bedding.

Much of the boundary between the gray and the grayish-orange limestones is formed of segments of rude spheres, each convex toward the grayish-orange limestone. This relationship locally gives the boundary of the gray limestone a botryoidal aspect, but no concentric structure is visible within the gray limestone.

Here, as elsewhere, the Meagher limestone can be divided on the basis of bedding thickness into three members which grade into one another. The beds in the upper and lower of these members average about 2 inches, and do not exceed 6 inches in thickness, whereas the beds in the middle unit are as much as 18 inches thick. In addition, the rock of the upper and lower members splits more readily along bedding planes than does the rock in the middle member.

In thin section, the gray limestone is seen to be a mosaic of calcite that includes about 10 percent dolomite rhombohedrons. The color of the grayish-orange limestone is the result of orange dust, probably a clay mineral, disseminated through the rock.

The contact between the Meagher limestone and the Wolsey shale is believed to be gradational, but is not well enough exposed in the Duck Creek Pass quadrangle for this to be demonstrated.

The thickness of the Meagher limestone differs considerably from place to place in this quadrangle. Faults are known to cut the formation locally and probably cause much of the variation in thickness. The section described below is one of the thickest in the quadrangle and is probably not significantly modified by faulting.

Partly exposed section of the Meagher limestone just north of the unimproved dirt road in SE ¼ sec. 3, T. 6 N., R. 3 E.

	Feet
Park shale.	
Concealed contact.	
Meagher limestone:	
1. Concealed.	
2. Limestone, thin-bedded, mottled. Consists of gray (*N* 4 to 5*Y* 4/1) aphanitic limestone in beds ½ to 6 in. thick, averaging about 2 in., interbedded with irregular discontinuous layers of grayish-orange (10*YR* 6/3) argillaceous very fine grained to medium-grained limestone, in beds as much as 1 in. thick and averaging 1/16 in. The grayish-orange limestone makes up about one-tenth of the rock. Discontinuously exposed	30
3. Limestone, like member 2	17
4. Limestone, gray (*N* 4 to 5*Y* 4/1), aphanitic; beds ½ to 18 in. thick, but rock does not readily split on bedding planes; bedding planes marked by thin discontinuous layers, as much as ¼ in. thick, of grayish-orange (10*YR* 6/3) very fine grained to medium-grained argillaceous limestone	4
5. Limestone, like member 2	20
6. Limestone, like member 4	120
7. Limestone, like member 2	42
8. Concealed.	
Total	233
Partial thickness of Meagher limestone rounded to the nearest 10 ft	230
Concealed contact.	
Wolsey shale.	

PARK SHALE (MIDDLE CAMBRIAN)

The name Park shale was introduced by W. H. Weed (1899a,b). He did not specify the derivation of the name, but the formation underlies a large part of Belt Park and is mapped on either side of Big Park, both of which lie along the boundary between the Fort Benton quadrangle (Weed, 1899a) and the Little Belt Mountains quadrangle (Weed, 1899b). Belt Park and Big Park are between 40 and 50 miles northeast of the Duck Creek Pass quadrangle.

The bands of country underlain by these relatively nonresistant rocks have little relief and are commonly shallow depressions parallel to strike. Outcrops of this formation are sparse, but fragments of the shale are present in the soil.

The rocks of this formation as revealed by fragments in the soil are all very dark fissile shale; most are either dark greenish gray (5*GY* 4/1 to 5*GY* 4/2) or dark brownish gray (5*YR* 3/1).

The width of the bands underlain by the Park shale vary so much and the rocks are so poorly exposed that no accurate estimate can be made of the thickness of the formation in this quadrangle. G. D. Robinson (oral communication, 1957) reports the Park shale to be about 250 feet thick in a well-exposed section near Sixteenmile Creek in the Toston quadrangle. The Park shale in the Duck Creek Pass quadrangle is only about 8 miles north of this section measured by Robinson, and the thicknesses of the Park shale at these two localities probably are not greatly different.

PILGRIM LIMESTONE (LATE CAMBRIAN)

The Pilgrim limestone was named by W. H. Weed (1899a); although he did not specify the derivation of the name, the formation is exposed in the valley of Pilgrim Creek in the southwest corner of the Fort Benton quadrangle about 40 miles north-northeast of the Duck Creek Pass quadrangle.

The Pilgrim limestone forms cliffs over most of its extent in the Duck Creek Pass quadrangle.

This formation is composed of slightly dolomitic limestone and minor amounts of limy shale. The limestone is gray to yellowish gray. Many beds are of uniform color throughout, but in some parts of the formation the yellow and gray are mixed and give the limestone a mottled appearance. In general, the colors of the Pilgrim limestone are slightly more reddish than those of the Meagher limestone, and, in the mottled part of the Pilgrim limestone, the patches of yellowish-gray limestone are slightly more elongated and tabular than those of the Meagher limestone. The Pilgrim limestone ranges from fine to coarse grained, but is mostly medium grained. Locally, it is oolitic, contains pellets of glauconite, is a flat limestone pebble conglomerate, or has a combination of these features.

As in most places nearby, the Pilgrim limestone in this quadrangle can be divided into three members on the basis of thickness of bedding. The beds in the middle member are as much as 20 feet thick, whereas the beds in the lower and upper members seldom exceed 2 feet in thickness.

The thickness of the Pilgrim limestone in the Duck Creek Pass quadrangle is about 410 feet, as shown in the following measured section.

Section of Pilgrim limestone north of Dry Creek in NE ¼ sec. 22, T. 6 N., R. 3 E.

Scattered outcrops of the interval between the Pilgrim limestone and the Jefferson dolomite. (See section, p. 35.) contact, concealed.

	Ft	in
Pilgrim limestone, overturned:		
1. Limestone; mottled mixture of gray (*N* 4 to 10*YR* 4/1) and light brown (10*YR* 6/3); coarse grained, oolitic, and slightly dolomitic; beds 2 in to 2 ft thick	38	0
2. Limestone, like member 1, but mottling is less distinct, and beds are from 3 to 20 ft thick	119	0
3. Limestone, like member 1	73	0
4. Limestone, olive-gray (5*Y* 5/1), medium-grained; beds ½ to 4 in thick; includes irregular discontinuous layers of grayish-yellow (5*Y* 6/2) argillaceous fine-grained limestone 1/16 to 1 in. thick, interbedded with beds, 1 1/16 to 4 in. thick, of yellowish-gray (5*Y* 7/3) limy shale	42	0
5. Concealed	22	0
6. Partly concealed; probably mostly like member 4	27	6
7. Limestone, olive-gray (5*Y* 5/1), medium-grained; beds ½ to 4 in. thick; includes irregular, discontinuous layers of grayish-yellow (5*Y* 6/2) argillaceous fine-grained limestone 1/16 to 1 in. thick, interbedded with thin layers, 1/16 to 4 in. thick, of yellowish-gray (5*YR* 7/3) limy shale and a few beds of flat pebble conglomerate (pebbles as much as 2 in. long)	26	0
8. Limestone and shale, like member 4	31	0
9. Limestone, olive-gray (5*Y* 5/1), medium-grained; beds ½ to 4 in. thick; includes irregular discontinuous layers of grayish-yellow (5*Y* 6/2) argillaceous fine-grained limestone 1/16 to 1 in. thick	10	6
10. Limestone, gray (*N* 5). Grains are calcite (in part clastic and in part concretionary) and glauconite that are rounded and range from fine to very coarse sand size; includes spherical stromatolites and trilobite fragments	12	0
11. Limestone, similar to member 9	2	0
12. Limestone, gray (*N* 5), and flat pebble conglomerate (pebbles as much as 2 in. long)	1	0
13. Concealed	6	0
14. Limestone, similar to member 9	2	6
Total	412	6
Total thickness of the Pilgrim limestone rounded to the nearest 10 ft	410	

Conformable contact.
Park shale (mostly concealed).

ROCKS BETWEEN THE PILGRIM LIMESTONE AND THE JEFFERSON DOLOMITE

A sequence of relatively nonresistant rocks forms a depression parallel to the strike at many places along the boundary between the Pilgrim limestone and the Jefferson dolomite. Elsewhere in this quadrangle similar rocks may intervene at this horizon, but they have not been recognized because of lack of good exposures.

Following the suggestion of Hanson (1952, p. 17), rocks in this interval are tentatively considered to represent the Red Lion and Maywood formations originally named by Emmons and Calkins (1913, p. 61, 64) for exposures in the Philipsburg quadrangle about 75 miles west of the Duck Creek Pass quadrangle.

The rock of this sequence consists of gray, yellowish-gray, and reddish clayey limestone and limy shale. Details of the vertical distribution of these rocks at one place are given in the following measured section, which adjoins the previously described section of the Pilgrim limestone.

Section of the interval between the Pilgrim limestone and the Jefferson dolomite north of Dry Creek in the NE¼ sec. 22, T. 6 N., R. 3 E.

	Ft	*in*
Jefferson dolomite.		
Rocks of the interval:		
1. Concealed	12	0
2. Limestone, pinkish-gray (5*R* 6/1); beds ¼ to ½ in. thick	1	0
3. Limestone, light olive-gray (5*Y* 6/1); weathers yellowish gray (5*Y* 8/3 to 5*Y* 7/4); clayey; beds 1 to 2 in. thick and laminae 1/16 to ¼ in. thick	2	0
4. Limestone, yellowish-gray (5*Y* 5/1 to 5*Y* 7/1), includes about one-third medium-gray (*N* 5) limestone, as irregular spots ⅛ to ½ in. wide and ½ to 2 in. long parallel to bedding	3	6
5. Limestone, pinkish-gray (5*YR* 5/1), slightly petroliferous; beds ½ to 2 in. thick	2	0
6. Limestone, like member 4; a single bed; contains seams and patches of moderate reddish-brown (10*R* 5/6) medium-grained calcite	2	0
7. Limestone, yellow (5*Y* 7/4), clayey; includes lenticules of grayish-red (10*R* 5/2) medium-grained calcite, as much as ¼ in. thick and about 4 in. long parallel to bedding	1	0
8. Limestone, yellowish-gray (5*Y* 7/3); beds ½ to 1 in. thick; includes patches and stringers of light-gray (*N* 7) limestone ¼ to 1 in. thick and ½ to 6 in. long	1	6
9. Limestone, like member 4, but medium-gray spots make up about two-thirds of the limestone, are ¼ to 1 in. across, and resemble pebbles	4	0
10. Limestone, like member 7	1	0
11. Limestone, yellow (5*Y* 7/1 to 5*Y* 6/4), clayey; beds ¼ to 1 in. thick; bedding thickness irregular	1	0
12. Limestone, like member 4; in 1 bed	1	6
13. Limestone, like member 7	6	0
14. Limestone, like member 11	1	6
15. Limestone, grayish-orange (10*YR* 7/4), very clay rich; beds ⅛ to 1 in. thick; bedding thickness irregular	2	0
16. Limestone, medium-gray (*N* 5); beds ½ to 6 in. thick	3	6

Rocks of the interval;—Continued	*Ft*	*m*
17. Concealed; chips in soil are grayish-yellow (5*Y* 7/4) clayey limestone	85	0
Total	130	6
Thickness between the Pilgrim limestone and the Jefferson dolomite to the nearest 10 ft	130	

Contact.
Pilgrim limestone.

Lochman (1950) has demonstrated that there is an unconformity between rocks of Late Cambrian and Middle Devonian ages in this region. Possibly some of the reddish colors in these rocks may be due to weathering at the surface during the formation of this unconformity.

The rocks of this interval are about 130 feet thick along Dry Creek where the preceding section was measured. The thickness differs from place to place because, as noted, this sequence of rocks includes an unconformity.

Fossils collected from gray limestone near the top of this sequence of rocks in the NW¼ SW¼ sec. 3, T. 6 N., R. 3 E., were examined by J. Thomas Dutro (written communication, 1957), who reported that:

This single collection from the Maywood formation contains a faunule similar to that reported from the Toston and Three Forks quadrangles to the south. The age is probably early Late Devonian, the equivalent of the *Allanaria allani* zone of Warren and Stelck (1956) in western Canada. There is a slight possibility that this zone may represent the very latest Middle Devonian, but my present opinion is that it represents the earliest Late Devonian.

56. N 151, Duck Creek Pass quad., NW¼ SE¼ sec. 3, T. 6 N., R. 3 E. Collector: W. H. Nelson, 1956.

Collection contains:

crinoidal debris, indet.
strophodontid brachiopod, indet.
Allanaria cf. *A. allani* (Warren)
Atrypa cf. *A. clarkei* Warren

JEFFERSON DOLOMITE (LATE DEVONIAN)

The Jefferson dolomite was named by A. C. Peale (1893) for exposures of the formation in the canyon of the Jefferson River about 30 miles south-southeast of the Duck Creek Pass quadrangle.

The rocks of the formation are moderately resistant to erosion and commonly form cliffs and abundant outcrops.

The Jefferson dolomite is made up of medium- to thick-bedded very fine-grained to medium-grained dolomite and dolomitic limestone. These rocks have a distinctive brownish-gray color (10*YR* 5/1), and many of them are strongly petroliferous. A little light-gray chert, which weathers brown, occurs locally in thin discontinuous stringers parallel to bedding in this formation. Weathered surfaces are rough, similar to those of sandy rocks. Diagnostic fossils are rare in this formation; but small rudely cylindrical bodies of light-gray carbonate, 1/16 to 1/4 inch across by 1/4 to 3/4 inch long, which are believed to be stromatoporoidea, are common locally.

The westernmost exposures of the Jefferson dolomite along Dry Creek, especially on the north side of the creek, are a breccia made up of subrounded fragments of dolomite, which range from a fraction of an inch to as much as 8 feet across and are jumbled together in a sparse discontinuous matrix of red clay. This breccia probably formed by collapse accompaning solution of part of the rock. The clay matrix commonly contains concentrations of chert fragments, which, along with the clay, probably are insoluble residues that remained after the much more abundant carbonate fraction of the rock had been removed by circulating ground water. Some of the dolomite fragments were probably detached from the bedded rock by solution along intersecting joints and bedding planes. Locally, arrested stages of this process have resulted in incipient separation of parts of the dolomite along intersecting planes that have been widened by solution. According to this interpretation, fragmentation was due not only to detachment of blocks by solution, but also to collapse into voids produced by solution.

No complete and undisturbed section of this formation is exposed in this quadrangle, but the partial section of the formation on the ridge north of Dry Creek is at least 250 feet thick.

THREE FORKS SHALE (LATE DEVONIAN AND EARLY MISSISSIPPIAN)

The Three Forks shale was named by Peale (1893) for the exposures of the formation at the juncture of the 3 forks of the Missouri River, near Three Forks, Mont., about 22 miles south of the Duck Creek Pass quadrangle.

The rocks of this formation occupy only a very small part of the area of this quadrangle. The areas underlain by the Three Forks shale are without outcrops, and the presence of the formation is revealed by fragments of yellowish-gray shale and limy shale in the soil.

Berry (1943, p. 1–29) subdivided the Three Forks, but the small extent and the extreme sparsity of outcrops in this quadrangle preclude any attempt to subdivide it here. Haynes (1916, p. 13–54) and Sloss and Laird (1947) have also done significant work on the rocks of this formation.

LODGEPOLE LIMESTONE (EARLY MISSISSIPPIAN)

The formation was named by Collier and Cathcart (1922, p. 173) from Lodgepole Canyon about 165 miles northeast of the Duck Creek pass quadrangle in the Little Belt Mountains. Use of the name Lodgepole limestone was extended into the vicinity of the Duck Creek Pass quadrangle by Sloss and Hamblin (1942, p. 314). The Lodgepole is the lowest part of the Madison group, which was originally named the Madison limestone by Peale (1893). In this quadrangle the Lodgepole limestone underlies an area of only about one-eighth square mile, consisting of partly timbered ridgetops, on which there are only a few good exposures.

The Lodgepole limestone is composed of pale-yellowish-brown (10*YR* 6/2) to medium-gray (*N* 5) well-bedded fine-grained limestone in beds 2 to 3 feet thick that are locally intercalated with shaly limestone in beds 1 to 3 inches thick. Nodules and stringers of chert are common in these rocks.

About the lower 300 feet of the formation is present in the Duck Creek Pass quadrangle. A total thickness of 750 to 810 feet is reported by McMannis (1955, p. 1399) in the Bridger Range about 18 miles to the southeast.

ROCKS OF MESOZOIC(?) AGE

QUARTZ DIORITE (LATE CRETACEOUS(?))

The rocks described under this heading are exposed in stocks, dikes, and sills in the north half of the quadrangle.

The stock near the center of the north half of the quadrangle is exposed in a rudely oval-shaped area of about 7 square miles. The rocks of the stock are discontinuously mantled by thin grusy soil, which supports a sparse grassy cover and an open coniferous forest. Most of the stock is made up of very coarse grained light-gray rock composed of 60 to 75 percent euhedral to anhedral oligoclase, 15 to 20 percent anhedral quartz, 5 to 15 percent subhedral to anhedral orthoclase, about 5 percent biotite, some of which has bent crystal lattices, and traces of sphene, apatite, and zircon. Most of the rock is foliated, and the foliation parallels the margins of the stock.

Around much of its periphery the outermost few tens of feet of the stock are made up of very fine grained medium-gray porphyry, which probably is a chilled border phase. This porphyry consists of about 40 percent euhedral phenocrysts of normally zoned oligoclase, a few percent euhedral phenocrysts of common green hornblende, and 5 to 10 percent euhedral phenocrysts of quartz. The crystal lattices of many of the quartz phenocrysts have been strained so that between crossed nicols they show a striking mosaic pattern symmetrical to the crystal outline. The hornblende phenocrysts are rimmed with biotite, and some of them include small grains of epidote. The groundmass of this porphyry is composed of subequal amounts of anhedral quartz and feldspar, and of biotite shreds, which contribute about 5 percent to the volume of the rock. Some of this biotite surrounds, and is adjacent to, epidote, and a little of it is altered to chlorite. Apatite and magnetite are accessory.

A coarse-grained light-gray mafic-poor phase of the rock, a few tens of feet thick, lies between the border phase and the main mass of the stock along the north half of the west edge of the stock, and perhaps elsewhere. This rock is composed of 55 to 60 percent microcline and orthoclase, 35 to 40 percent quartz, and traces of oligoclase; magnetite and shreds of biotite are scattered through the rock. The feldspar and quartz are anhedral, and much of the quartz occurs as graphic intergrowths in potash feldspar. This rock seems to represent the product of the crystallization of a residual fluid between the border phase and the main mass of the stock late in the cooling of the magma.

The igneous rocks that are exposed in irregularly shaped areas in the Big Belt Mountains are coarse grained and vary from quartz diorite to quartz monzonite. They are composed of 60 to 80 percent euhedral to anhedral oligoclase, most of which is zoned; 5 to 35 percent orthoclase; 5 to 15 percent anhedral quartz; 2 to 5 percent euhedral hornblende, and traces of apatite, magnetite, and sphene. Some of the orthoclase occurs as euhedral to anhedral grains the same size as the oligoclase and quartz, but in much of this rock a few percent of the orthoclase occurs as euhedral phenocrysts as long as an inch or more. Most of these rocks, especially near the borders of the masses, are weakly foliated.

These irregularly shaped areas of igneous rocks extend into the mountains east of this quadrangle, where coarse-grained igneous rocks are more extensively exposed.

In this quadrangle, and probably in the mountains to the east, all the irregularly shaped masses of igneous rocks are confined to an area of metamorphosed sedimentary rocks, whose metamorphism probably was caused by the intrusive rocks. This aureole of metamorphosed rocks and the similarity of the igneous rocks in the several areas suggest that these intrusive bodies are all parts of a single large partly buried pluton.

The dikes and sills grouped here seem to be related in composition and space with the larger masses of igneous rocks. A few of the dikes and sills are shown on the geologic map (pl. 1), but most of them, especially in the mountains, are too poorly exposed to map at this scale. The rocks of these dikes and sills originally ranged from fine-grained porphyritic to medium grained. Many have been sheared so that the mineral grains are broken and smeared out. These rocks probably have about the same range of composition as the igneous rocks in the larger areas of exposure. The mafic minerals have been altered to biotite and chlorite, mostly penninite; and patches of sericite, perhaps derived largely from potash feldspar, are common in many of the rocks.

These intrusive rocks are intruded into rocks of the Belt series, and fragments of them are included in the deposits of Tertiary age, probably no older than Miocene. It is therefore not possible to date these intrusive rocks closely on stratigraphic evidence.

These intrusive rocks resemble those of the Boulder batholith in composition, and on that basis are believed to be related to, and to have been emplaced at, about the same time as the Boulder batholith. The batholith, which extends to within about 15 miles of the west edge of the Duck Creek Pass quadrangle, was emplaced at about the end of the Mesozoic era after the major deformation of the Laramide orogeny (Klepper and others, 1957, p. 60). The intrusive rocks in this quadrangle are foliated, indicating that they were emplaced and crystallized concurrently with deformation. This suggests that they are of a slightly different age than the rocks of the Boulder batholith, which are not foliated (M. R. Klepper, oral communication, 1956). The intrusive rocks in this quadrangle were then emplaced during a phase of deformation, perhaps late in the Laramide orogeny, and the Boulder batholith was emplaced either after the orogeny or during a period of quiet within the time of orogeny.

ROCKS OF TERTIARY(?) AGE

LAMPROPHYRE DIKE

This unit is represented by two alined dike segments in the northeast quarter of the quadrangle. The northern segment extends for about 4 miles and the southern segment less than ½ mile. Between the two segments there is no surface manifestation of the dike, but it seems likely that the two segments came in along a single fracture and are connected at depth.

The lamprophyre of this dike is composed of 40 to 50 percent chlorite, 10 to 20 percent albite, 10 to 15 percent biotite, 10 to 15 percent quartz, 5 to 10 percent calcite, 4 to 5 percent magnetite, and a trace of apatite. The chlorite occurs as shreds from 0.01 to 0.2 mm long. The albite occurs as poikolitic crystals as much as 0.8 mm long and are crowded with inclusions of chlorite, calcite, quartz, and apatite. The magnetite occurs as rounded grains from 0.01 to 0.2 mm across, generally in clusters surrounded by the biotite, which occurs as flakes from 0.01 to 0.3 mm long. The calcite is in anhedral grains from 0.2 to 0.8 mm across, and the quartz is in isolated anhedral grains as large as 0.3 mm across and as intergrowths in the plagioclase.

This dike may be the same age as the lighter colored dikes and sills related to the large intrusive masses. The relative straightness of the lamprophyre dike suggests, however, that it was intruded after the Laramide orogeny and that it is therefore Tertiary in age.

DEPOSITS OF TERTIARY AGE

The continental basin deposits of Tertiary age, which occupy much of the western two-thirds of the Duck Creek Pass quadrangle, are part of a larger area along the Missouri River that is underlain by similar deposits. This larger area is one of several similar intermontane valleys of western Montana.

Most of the areas underlain by these deposits in the Duck Creek Pass quadrangle are terraces that are partly dissected by steep-sided creek valleys and tributary gulches, along which most of the exposures occur. The undissected tops of the terraces are covered by a mantle of mixed origin.

The deposits in this quadrangle were first described and their origin discussed by Pardee (1925); later they were briefly discussed by Lorenz and McMurtrey (1956). Douglass (1902, 1903, 1907, 1908), Jennings (1920), and White (1954) describe fossils of Tertiary age from near the quadrangle, and Atwood (1916, 1917) and Blackwelder (1917) have discussed the origin of the deposits of Tertiary age in the intermontane valleys of western Montana.

DESCRIPTION

The deposits of Tertiary age in the Duck Creek Pass quadrangle range from very light gray (*N* 8) to moderate orange pink (10*YR* 8/3). They are composed of tuffaceous material, fragments of older rocks from the nearby mountains, calcium carbonate precipitated from solution, and clay minerals. Most of these deposits are poorly sorted, weakly indurated, and rudely bedded. The beds range from a few inches to many feet thick. The deposits range from fine-grained claystones to poorly sorted conglomerates that contain boulders several feet across. Many of the coarser grained layers are crossbedded, and locally their bottoms lie in channels cut in the underlying layers. The coarseness of the detritus in these deposits decreases from east to west. At the east edge of the deposits, near the mountains, most of the beds contain many pebbles and boulders; whereas in the middle of the basin, near the west edge of the quadrangle, most of the beds are composed of limy claystone.

In addition to the change in grain size from east to west there seems to be a change vertically within the deposits. The older part of the deposits in this quadrangle seems to average somewhat finer grained than the rest. This may be, in part at least, an illusion, because most of the exposures of the older part are near the west edge of the quadrangle where all of the deposits are relatively fine grained. The oldest dated beds, near the east edge of the deposits in the NW cor. sec. 2, T. 6 N., R. 3 E., however, seem to be somewhat finer in average grain size than the beds of probable late Miocene age that are about the same distance from the east edge of the basin in the NE cor. sec. 35, T. 7 N., R. 3 E.

The tuffaceous material is mostly unaltered shards of volcanic glass. The indices of refraction of glass shards from several localities are all very nearly 1.50, which suggests that they are rhyolitic glass.

A series of beds especially rich in shards provides the only mappable stratigraphic unit in the deposits. This unit is south of Deep Creek and along the Dry Creek anticline.

The detritus in these deposits includes fragments of all the older rocks exposed in the immediate vicinity. The kinds and abundance of these fragments vary from place to place, and are a direct reflection of the variety of older rocks that are exposed in the highlands to the east. For instance, the highlands north of Deep Creek for a distance of about 2 miles are composed of grayish siltstone and quartzite of the Greyson shale and grayish limestone of the Newland limestone; fragments of these rocks are dominant in the coarse-grained fraction of the deposits of Tertiary age west of the highlands. South of Deep Creek, red shale of the Spokane crops out, and red shale fragments are abundant in the deposits of Tertiary age. Quartz diorite fragments are dominant in deposits west of the quartz diorite stock, south of Duck Creek.

Calcium carbonate as cement is a minor constituent in most of these deposits. Some layers, especially finer grained ones, contain more calcium carbonate than others. Near the east edge of the deposits on both sides of Dry Creek near the center of sec. 22, T. 6 N., R. 3 E., there are several light-gray clayey limestone layers with bedding as much as 3 feet thick; two of these layers are 30 feet thick. Fine-grained lime-rich layers are interspersed with somewhat coarser grained layers near the west edge of the deposits in this quadrangle, along the central part of the basin of deposition.

Clay minerals are disseminated throughout the finer grained rocks and in the matrices of the coarser grained rocks. Four specimens of limy claystone analyzed by X-ray diffraction by A. J. Gude 3d, of the U.S. Geological Survey, all contain montmorillonite as the only clay mineral.

ORIGIN

The deposits of Tertiary age are alluvial and lacustrine sediments laid down in a closed intermontane basin. The coarser sand, gravel, and conglomeratic layers probably are parts of alluvial fans that extended from the mountains into the basin. The crossbedding, the channels, the local sources of the fragments, and the decrease in the size of the fragments westward away from the mountains all substantiate this interpretation.

There is no evidence, such as deposits of exotic rocks, to suggest that large streams passed through the basin. Indeed, the local origin of all the nonvolcanic detritus and the decrease in size of the fragments toward the center of the basin suggest interior drainage. The finer, silty, clayey, and limy layers probably were laid down in lakes.

Some of the clay in these deposits has undoubtedly been derived from weathered older sedimentary and igneous rocks. But some has been derived by weathering of glassy volcanic material. Mertie, Fischer, and Hobbs (1951, p. 34) suggest that the coexistence in these deposits of little-weathered volcanic glass, as well as clay derived from alteration of volcanic glass, indicates that originally glasses of at least two different compositions were present.

The limestone layers on both sides of Dry Creek in sec. 22, T. 6 N., R. 3 E., seem to have formed in an area that was sheltered from debris-carrying streams by an intervening ridge of rocks of Paleozoic age, a topography similar to the present topography. These, as well as the limy layers elsewhere in the basin, must have been deposited in ponds or small lakes, for they are associated with fluviatile deposits and are restricted laterally and vertically.

The abundance of tuffaceous material throughout these deposits indicates that volcanism was active not too far away during their deposition. The freshness of the relatively fragile shards suggests that they were not transported far in moving water.

CONTACT RELATIONS WITH OLDER ROCKS

The deposits of Tertiary age are unconformable on all the older rocks that are exposed in this quadrangle. They were laid down on a surface that, locally at least, had considerable relief. The irregularity of this surface is apparent on the geologic map (pl. 1) north of Deep Creek in secs. 24 and 25, T. 7 N., R. 3 E., and secs. 19 and 30, T. 7 N., R. 4 E., and south of Deep Creek east of the Kieckbusch Ranch. North of the middle fork of Ray Creek the contact between the deposits of Tertiary age and the older rocks is made up of straight fault segments.

The straight western margin of the ridge of Paleozoic rocks south of Deep Creek is believed to have come into existence before deposition of the Tertiary rocks rather than by later faulting for the following reason. The ridge seems to have been a barrier to debris-carrying streams during Tertiary time, as shown by the distribution of material in the deposits of Tertiary age west of it. Large fragments of rock of the Belt series in these deposits seem to be concentrated in fan-shaped areas which radiate from the present streams that cross the ridge; the streams are assumed, on this basis, to have occupied about their present position during Tertiary time. In areas between the streams and just west of the ridge, large fragments are relatively less abundant, and consist dominantly of rocks of Paleozoic age. Most of these rocks of Paleozoic age are relatively more susceptible to weathering than the rocks of the Belt series, and thus are less abundant.

Between the North Fork of Deep Creek and Ray Creek the contact between the basin deposits and the older rocks is concealed beneath mantle. This buried contact probably lies north of the farmhouse (now abandoned) north of the center of sec. 11, T. 7 N., R. 3 E., and east of the farmhouse just south of the road along the north boundary of sec. 24, T. 7 N., R. 3 E., because water wells at these two sites appear to penetrate the deposits of Tertiary age. The Newland limestone at the foot of the mountains this far west is unmetamorphosed, whereas most of the limestone fragments in the deposits of Tertiary age, as well as in the mantle, came from farther east and are at least slightly metamorphosed. As a result there seems to be slightly more nonmetamorphosed limestone fragments in the mantle on areas underlain by the Newland limestone than on these underlain by the deposits of Tertiary age.

Probable effects of pre-Tertiary weathering are visible at the contact between the deposits of Tertiary age and the Greyson shale in sec. 24, T. 7 N., R. 3 E., and sec. 30, T. 7 N., R. 4 E. At these places the uppermost 10 to 20 feet, and especially the upper foot or two, of the Greyson shale beneath the deposits of Tertiary age have been altered mineralogically by chemical weathering, and the color changed from gray to reddish brown. In addition to these changes the uppermost Greyson shale beneath unaltered beds of Tertiary age in sec. 30 is crisscrossed by veinlets of calcite; most of the fragments between calcite veinlets have not been rotated from the positions they occupied before they were fragmented. These features resemble the fragmentation and the illuviation in the lower parts of a soil profile, which, because they occur beneath unaltered beds of Tertiary age, may be related to weathering before deposition of the deposits of Tertiary age.

AGE

Vertebrate fossils indicate that the deposits range from Oligocene to Pliocene in age, but most seem to be Miocene or Pliocene in age. The deposits are similar lithologically from bottom to top and are, for the most part, not divisible into smaller stratigraphic units. The dips of the beds are dominatly toward the east so that, in general, the layers are progressively older from east to west.

In spite of the generalization that the deposits increase in age toward the west, fossils of early Oligocene age, which are the oldest found in these deposits, came from near the eastern edge of the deposits from 250 feet east and 580 feet south of the NW cor. sec. 2, T. 6 N., R. 3 E. These deposits are near the base of the beds of Tertiary age exposed at this locality, and they are near the west side of an arm of the basin, a probable explanation for the existence of deposits this old this far east. An alternate explanation is that these fossils of Oligocene age were exhumed by a stream from an older part of the deposits and later were redeposited in Miocene or Pliocene time. Their distribution, however, suggests that the first explanation is probably a better one. The fossil material consists of several bone and tooth fragments, all of which are restricted to a small area. G. E. Lewis, of the U.S. Geological Survey, indentified the tooth fragments as "Molar fragments of brontothere of early Oligocene age."

The first vertebrate fossil indentification below is by Prof. T. M. Stout, of the Nebraska University Geology Department and State Museum, and the others are by G. E. Lewis:

P_4 (lower fourth premolar) of *Mesogaulus* sp., closely comparable to specimens of this genus from the upper part of the Hemingford group (Lugn, 1938) of Nebraska. The stratigraphic position within the Hemingford group could be either that of the Sheep Creek fauna or the Lower Snake Creek fauna. Professor Stout would assign a late Miocene age to this specimen in either case. Collected 2,500 feet east and 1,600 feet north of the SW cor. sec. 25, T. 8 N., R. 2 E.

Small fragment of right ramus of camel with P_2 and broken P_3, cf. *Procamelus* sp. early Pliocene or late Miocene in age. Collected in a small roadcut (too small to show as Tertiary on map) on the south side of Montana Highway 6, 1,630 feet west of the east edge of sec. 34, T. 7 N., R. 2 E.

Upper cheek tooth of *Merychippus* sp., probably of late Miocene age. Collected 1,310 feet west of the NE cor. sec. 35, T. 7 N., R. 3 E.

DEPOSITS OF QUATERNARY AGE

No deposits that can be directly attributed to glaciers occur in this quadrangle, but glacial cirques are present in the Big Belt Mountains just outside the quadrangle to the east. A glacial moraine lies in the North Fork of Deep Creek just east of the quadrangle, and much of the bouldery mantle in the quadrangle west of there is probably outwash.

PROTALUS DEPOSIT

The protalus deposit consists of angular granitic boulders. Most of the deposit forms a terrace along the north side of a mountain canyon, although some of the boulders form a layer in, and along the south side of, the canyon. A little soil, which locally supports mature trees, is mixed with the boulders. These trees show no evidence of having been tilted or otherwise disturbed during growth, which suggests that the deposit is now stable. This deposit is believed to be talus that accumulated during Pleistocene time; it accumulated along the sides of the canyon, but was not deposited in the bottom of the canyon because the bottom was occupied by a tongue of ice at that time.

LANDSLIDE DEPOSITS

The landslide deposits are characterized by hummocky topography and are easily recognized on the ground and on aerial photographs. The material that makes up these deposits consists of a mixture of clay and silt that contains jumbled angular fragments of Newland limestone, and, locally, of quartz diorite; some blocks are many tens of feet across. The edges and corners of many of these blocks form ledges which resemble outcrops of the bedrock, but because they are parts of jumbled blocks, the bedding attitudes from block to block are without pattern.

A related feature of modern origin is the result of a rock avalanche which occurred during, or following, a very wet spring snowstorm in the late 1940's. This avalanche took place in the canyon just south of the center of sec. 19, T. 8 N., R. 4 E. The slide originated above an altitude of 7,200 feet, and material from there to 7,400 feet was involved. Most of the debris came to a rest along the creek between 6,200 and 6,800 feet altitude, but dikes of debris 6 feet thick are perched on the canyon sides 40 to 50 feet above the creek bottom between 6,800 and 7,200 feet altitude. All the trees were swept away between these dikes, and many of them below 6,800 feet altitude were broken and removed.

The mountain surface above the avalanche scar as high as 7,900 feet is covered with small hummocks formed by small landslides or slumps. The largest of these features are only a few tens of feet wide; they have local abnormally steep slopes above which are local gently sloping areas. Most of these features are covered with vegetation, including mature trees.

The Newland limestone, both metamorphosed and unmetamorphosed, weathers to form a very fine grained and, when wet, very slippery soil. The nature of this soil, as well as the fact that much of the bedrock dips about parallel to the mountain front above the slide areas, probably facilitated the landsliding. Most of the areas of landslide debris are covered with mature undisturbed timber, which suggests that the debris is stable and has not been added to recently. From this it is inferred that much of the landsliding probably occurred under the influence of the colder and probably wetter conditions of the Pleistocene epoch.

MANTLE

The mantle consists of a layer of clay, silt, sand, and fragments of all the formations older than the deposits of Tertiary age. The part mapped as bouldery mantle contains abundant fragments more than 6 inches across and as large as several feet across. The part mapped simply as mantle commonly contains pebbles, which vary greatly in abundance from place to place.

The material that makes up the mantle has come from two sources, either of which may be dominant locally to the exclusion of the other. Part was derived from the disaggregation of the deposits of Tertiary age, and part is alluvium. The distribution of fragments of older rock from both sources is a direct reflection of the variety of older rocks that crop out in the adjacent mountains to the east, and they decrease in size westward, away from the mountains. As a result the size and variety of material from these two sources are commonly identical.

The mantle west of the ridge of rocks of Paleozoic age is relatively free of large fragments, probably because most of the material was derived from these rocks of Paleozoic age, most of which are relatively nonresistant to weathering. Resistant fragments, mostly of rocks of Beltian age, are abundant only in fan-shaped areas that spread out westward from the canyons through the ridge. Streams flowing through these canyons probably carried resistant fragments of the Belt series and deposited them in the deposits of Tertiary age, and the resistant fragments concentrated in the mantle are residual from the deposits of Tertiary age. The concentrations of fragments in the mantle west of the ridge cannot have been transported to their present sites in the immediate past by the streams that cross the ridge, because these streams are now incised too far below the surfaces upon which the resistant fragments are concentrated.

OLDER ALLUVIUM

The material mapped as older alluvium is unindurated sand, gravel, and silt that lies on and makes up terraces above the present flood plains. These deposits contain a few pebbles and boulders of schist and gneiss. The nearest sources for such exotic rocks are upstream along tributaries to the Missouri River about 30 miles to the south.

YOUNGER ALLUVIUM

The younger alluvium deposits in this quadrangle consist of the fluviatile material which forms the flood plains and the alluvial fans which merge with them. The alluvium along the Missouri River contains exotic fragments of schist and gneiss derived from areas upstream to the south.

STRUCTURE

STRUCTURES OF THE ROCKS OF THE BELT SERIES IN THE BIG BELT MOUNTAINS

The largest structure that is apparent in the rocks of this quadrangle is the west limb of a large anticline, which is revealed by the westerly dips of the rocks of the Belt series along the south half of the east edge of the quadrangle, and by the stratigraphic sequence of the Belt series along the north edge. Along the south edge of the quadrangle some of the rocks of Cambrian age form part of this anticlinal limb. The axis of this large anticline lies in the mountains east of the quadrangle, trends about N. 30° E., and pitches gently southward. This large fold is apparent in the pattern of the topography of the Maudlow quadrangle, which adjoins the Duck Creek Pass quadrangle on the southeast. Mertie, Fischer, and Hobbs (1951, p. 51; pl. 1) show this structure continuing through the Canyon Ferry quadrangle, which adjoins the Duck Creek Pass quadrangle on the northwest.

In the north half of the quadrangle the simple homoclinal structure of the anticlinal limb has smaller intermediate scale folding superimposed on it. The axes of many of these intermediate scale folds are shown on the geologic map (pl. 1), and seem to be deflected around the quartz diorite masses that are intruded into the Newland limestone. A large intrusive mass that lies just north of the quadrangle probably is in part responsible for the pronounced westerly trend of the anticlinal axis that crosses the Middle Fork of Duck Creek near the north edge of the quadrangle.

In the Big Belt Mountains the Newland limestone is, locally at least, deformed into tight folds that are too small to be shown on the geologic map (pl. 1). Amplitudes of these small-scale folds ranges from about 1 foot to a few tens of feet; and the limbs of the folds commonly make an angle as small as 20° with one another. All this folding from largest to smallest is probably related and probably of one age. The axes of all the folds strike northwestward, and at any one locality the axial planes of all of them are parallel.

STRUCTURES OF THE ROCKS OF PALEOZOIC AGE

The rocks of Paleozoic age in the southeast corner of the quadrangle are tightly folded and faulted, and the deformation is on a smaller scale than that in the rocks of the Belt series directly to the east. The Spokane shale adjacent to the rocks of Paleozoic age, however, probably is folded and faulted on a scale comparable to the structures in the rocks of Paleozoic age. Lack of marker beds in the Spokane shale makes accurate delineation of its internal structure impracticable. Two factors that may explain the difference in response between the rocks of the Belt series and those of Paleozoic age are—

1. The structures in the rocks of Paleozoic age may be small-scale décollement structures on top of larger, but not necessarily less intense, structures in the Belt series; perhaps because the formations of the Belt series are more competent than those of Paleozoic age.
2. The structural low along which the rocks of Paleozoic age crop out may be related to a zone of weakness that localized the deformation.

It may simply not be possible to delineate the structures in the thick formations of the Belt series as clearly as it is in the thinner formations of Paleozoic age.

Many of the faults that cut the rocks of Paleozoic age, as well as those that cut the nearby rocks of the Belt series, trend generally parallel to the strike of the bedding, have steep dips, and are chiefly downthrown on the east and northeast sides.

STRUCTURES IN THE DEPOSITS OF TERTIARY AGE

Most of the desposits of Tertiary age are tilted toward the east-northeast, and they are gently folded in places as along the Dry Creek anticline (named by Lorenz and McMurtrey, 1956, p. 202) in the southwest corner of the quadrangle. These deposits must have had a slight initial dip to the west, because most of the detritus in them was derived from the east. The evidence concerning the sources of this material is noted in the description of the deposits of Tertiary age.

In the north half of the quadrangle the boundary between these deposits and the older rocks is a fault, an expectable relationship in view of the eastward dip of most of the deposits. On the north side of the North Fork of Ray Creek shearing is evident along this contact, and between Gurnett and Duck Creeks the contact is sharply defined, is discordant to the bedding on either side of it, and is marked by a reddish zone about 15 to 20 feet wide that contains considerable onyx.

Another fault or faults may be within the basin deposits and trend about N. 30° W. parallel to the contact north of Ray Creek. Lineaments such as one recognized on aerial photographs that extends through and between the Kieckbusch Ranch and the northwest corner of sec. 17, T. 7 N., R. 3 E., are suggestive of faulting. A careful search along this lineament, however, failed to reveal any evidence of displacement.

The structure along the contact near the unnamed middle fork of Ray Creek can be interpreted to show that faulting has occurred in the deposits of Tertiary age. In figure 3 it is suggested that

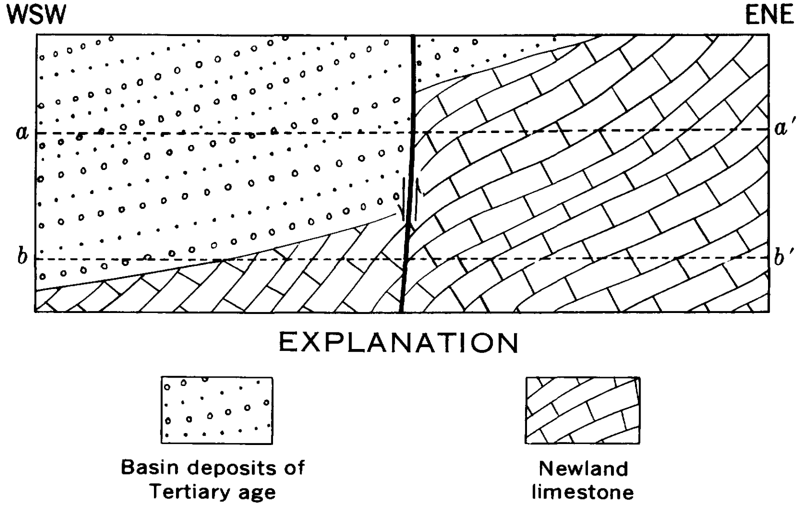

FIGURE 3.—Diagrammatic cross section near the middle fork of Ray Creek. The dashed line *a–a′* is the level of the present surface north of the cross fault along the middle fork of Ray Creek; the dashed line *b–b′* is the level of the present surface south of the cross fault. Approximate scale, 1 inch = 1 mile.

the fault north of the unnamed middle fork of Ray Creek, at the east edge of these deposits, may not have been a marginal feature originally. The northwest-trending fault is not exposed south of the middle fork of Ray Creek.

AGE OF THE STRUCTURES

The structures in this quadrangle were formed during at least two episodes of deformation. The first of these was the strongest and affected all the rocks of Paleozoic age and older, and the final phases of the second occurred after the deposits of Tertiary age had been laid down.

In this quadrangle the first deformation affects rocks as young as the Madison limestone, and eroded structures formed by this deformation are unconformably overlain by deposits as old as Oligocene in age. The major disturbance in this region during this interval was the Laramide orogeny which in nearby areas seems to have climaxed at about the end of the Mesozoic era.

As can be seen on the geologic map (pl. 1), the trends of the axial planes of the folds in the Newland limestone, which were formed during the first deformation, are influenced by the quartz diorite masses. The quartz diorite is assumed to have been intruded during the first deformation of the area, as noted in the discussion of the age of the quartz diorite. It seems likely, therefore, that the folds originated with sinuous axial planes.

Most of the deformation of the deposits of Tertiary age occurred after these deposits had been laid down, which indicates that the second episode of deformation continued at least into Pliocene time. The bedding in these deposits is too indistinct, and exposures of them are too poor to determine whether folding accompanied or was entirely subsequent to the deposition of the rocks.

The faulting which locally marks the eastern boundry of the deposits of Tertiary age occurred after most of the deposits had been laid down, and on this basis the faulting is assumed to be related to the tilting and folding of these deposits.

The cross fault that parallels the unnamed middle fork of Ray Creek and the parallel faults that cut the quartz diorite stock farther to the north are somewhat younger than the boundary fault and must therefore have developed late in the Tertiary period or during the Quaternary period.

GEOLOGIC HISTORY

The earliest geologic event recorded in this area is the deposition of the Belt series, which was laid down in a shallow sea that covered most cf western Montana, extended through northern Idaho, and may have continued far to the north and south. Minor disturbances during the deposition of the Belt series are suggested by sequences of coarse-grained rocks. The most striking zone ot coarse-grained rocks is near the base of the Greyson shale. Other coarse clastic layers near the top of the Greyson shale suggest some sort of disturbance in the region near the end of Greyson time. Following their deposition the rocks of the Belt series probably were gently warped and eroded to a relatively level surface. The diabase sills and dikes that cut the rocks of the Belt series were probably intruded during this time of warping and beveling.

The next episode in the geologic history of this region resulted in deposition of the Flathead quartzite of Middle Cambrian age upon the slightly beveled nearly flat-lying rocks of the Belt series. The Flathead quartzite probably represents the most shoreward part of a blanket of sediments on the floor of a spreading sea. Above and gradational with the Flathead quartzite is the Wolsey shale, also of Middle Cambrian age, which is composed of the finer grained sediments that were originally mixed with the sand of the Flathead quartzite. The fine-grained sediments of the Wolsey shale were floated by currents into deeper water than that in which the sand of the Flathead quartzite settled. As a continuance of the depositional sequence in the spreading sea, the Meagher limestone of Middle Cambrian age above the Wolsey shale probably was deposited still farther from shore. In this region the deposition of sedimentary rocks continued with minor interruptions through the Paleozoic and Mesozoic eras. A break in the stratigraphic record between the rocks of Cambrian age and those of Devonian age testify to local temporary uplift and erosion in the region. The Lodgepole limestone of Early Mississippian age is the youngest formation of this Paleozoic and Mesozoic time interval that is exposed in the Duck Creek Pass quadrangle.

The Laramide orogeny, near the close of the Mesozoic era, deformed the rocks of this area as well as those throughout the Rocky Mountains. In the Big Belt Mountains all the rocks were folded and locally faulted.

Large masses of igneous rock were intruded more or less contemporaneously with the deformation of the Laramide orogeny. To the west the Boulder batholith seems to have been intruded during a period of quiet or in an area free of stress; whereas the intrusive rocks in the Duck Creek Pass quadrangle seem to have been intruded in an area that was being actively deformed.

Following the Laramide disturbance, and perhaps as a result of it, intermontane basins developed and persisted throughout the Tertiary and Quaternary periods in the Rocky Mountain region. The Townsend Valley, in part in the west half of the Duck Creek Pass quadrangle, is one of these basins. During Oligocene, Miocene, and at some places during Pliocene time, this basin was the site of fluviatile and lacustrine sedimentation. The materials deposited in the basin were derived from the sedimentary rocks in the mountains that border the basin, mixed with airborne volcanic ash from unidentified, but probably not too distant, sources. The deposits of Tertiary age are all slightly deformed, and some of this deformation may have occurred during the deposition of these deposits.

Late in the Cenozoic era, probably during the Quaternary period, the upper part of the Missouri River came into existence and began to sculpture the land and leave its deposits in the Townsend Valley. During the Pleistocene epoch glaciers were present in the Big Belt Mountains and locally contributed material to the Quaternary deposits of the area.

ECONOMIC GEOLOGY

Deposits of metallic ore minerals in economically valuable concentrations are unknown in this quadrangle. A few small concentrations of sulfide minerals, containing a little gold, are associated with the stock in the middle of the north half of the quadrangle and have led to intermittent attempts at mining. The most extensive efforts to develop a mine have been made in the N½ sec. 5, T. 8 N., R. 3 E. None of these ventures has repaid the effort expended on them.

Thorium, probably in monazite, is a minor constituent of some of the dikes that are probably related to the quartz diorite and quartz monzonite of the area. An exploratory test pit that excavated parts of several of these dikes in the center of the SE¼SE¼ sec. 35, T. 9 N., R. 3 E., failed to uncover concentrations of thorium minerals of value economically at present.

During a search for oil a well was drilled to a reported depth of about 3,400 feet in the NW¼SW¼ sec. 19, T. 6 N., R. 3 E. This well was entirely within deposits of Tertiary age and encountered no oil.

Many parts of the deposits of Tertiary and Quaternary ages are rich in sand and gravel, and some of the gravels in the deposits of Quaternary age may be sufficiently clean to use as concrete aggregate with a minimum of processing. The geologic map (pl. 1) shows the locations of existing gravel and borrow pits.

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INDEX

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