A Geologic Reconnaissance of Parts of Beaverhead and Madison Counties Montana

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A GEOLOGIC RECONNAISSANCE OF PARTS OF BEAVERHEAD AND MADISON COUNTIES, MONTANA

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ABSTRACT

This report covers the geologic reconnaissance of approximately 1,300 square miles in parts of Beaverhead and Madison Counties, southwestern Montana. The area lies between parallels 44°30′ N. and 45°10′ N. and meridians 112°00′ W. and 112°50′ W., and includes the Blacktail Mountains, most of the Snowcrest Range, the southern part of the Ruby Range, the upper part of Ruby River Valley, and parts of the valleys of Beaverhead and Red Rock Rivers. Upper Cretaceous and Tertiary sedimentary and, to a lesser extent, volcanic rocks underlie the valleys and lowlands; Cretaceous, Triassic, and Paleozoic sedimentary rocks, pre-Cambrian metamorphic rocks, and Tertiary volcanic rocks form the mountains and highlands.

Pre-Cambrian metamorphic rocks, which may be equivalent in part to the Cherry Creek group and in part to the Pony series of Tansley, underlie the southern part of the Ruby Range, the southeastern half of the Blacktail Mountains, and a narrow belt along the west flank of the Snowcrest Range. The Paleozoic rocks consist of the Flathead quartzite and overlying carbonate rocks and shales of Cambrian age, the Jefferson (?) dolomite and Three Forks (?) shale of Devonian age, the Madison limestone, Amsden (?) formation, and Quadrant formation of Carboniferous age, and the Phosphoria formation of Permian age. These formations are exposed in the northern part of the Blacktail Mountains and along the west slope and the crest of the Snowcrest Range. The Dinwoody and Thaynes (?) formations of Triassic age and the Kootenai formation of Lower Cretaceous age occupy a belt west of the Paleozoic rocks in the Snowcrest Range. Upper Cretaceous shales and sandstones underlie the upper part of the valley of Ruby River. Upper Cretaceous and Tertiary sedimentary rocks occur around the margins of the mountains and in basins between the mountains. These rocks were mapped as a single unit, although they fall into three distinct groups: the lower, which may be Upper Cretaceous, consists of partly tuffaceous sandstones, shales, and grits; the intermediate, which is probably early Tertiary, consists of fanglomerate and conglomerate with subordinate interbedded limestone and tuffaceous sandstone and siltstone; and the upper, which is early or middle Tertiary, consists of dominantly tuffaceous sandstone and siltstone. Rocks of the lower and intermediate groups have not been dated with certainty. The upper group contains rocks of Eocene, Oligocene, and possibly Miocene age.

Rhyolitic and intermediate flows and tuffs of early Tertiary age and basalt flows of probable Pliocene age occur in a few places. Two small granitic intrusive bodies, probably of late Cretaceous and early Tertiary age, were identified.

During the Laramide orogeny, at or near the close of the Cretaceous period, the rocks of the area were strongly folded and faulted. In the early stages of this orogeny the rocks were warped into broad folds and later modified by more intense folding and by overthrusting. The orogeny was followed by a period of comparative crustal stability during which the early Tertiary mountains were worn to a surface of relatively low relief, and fluviatile and lacustrine sediments were deposited in the intermontane basins. Subsequent to planation (probably during the Pliocene period) the region was uplifted and, as a result of differential movement along block faults, the major present-day topographic features began to form.

Talc, gravel and sand, clay, volcanic rock, and quartzite are currently produced. Crystalline graphite and coal have been mined in the past, and sillimanite deposits of possible commercial significance have been discovered recently. Substantial reserves of phosphate rock and some oil shale occur in low-grade deposits in the Snowcrest Range. Under present economic conditions these deposits are probably noncommercial, but they should not be overlooked as a possible future source of phosphate and distillable hydrocarbons. A more detailed study of the petroleum possibilities of parts of the area is believed to be warranted.

INTRODUCTION

The geology of southwestern Montana, between Red Rock River and Ruby River, has been little known. G. S. Lambert made a geologic reconnaissance of part of the area during the 1920's and W. C. Alden and J. T. Pardee mapped some of the valleys during the 1930's. The observations of these geologists were included in the geologic map of Montana published in 1944, but none of the details of their studies have been published. A reconnaissance was made by the writer during May and June 1947 to obtain information for a revised edition of the geologic map of Montana that is currently being compiled by the Geological Survey in cooperation with the Montana Bureau of Mines and geology. The study indicates that the principal mountain masses in the area are composed mainly of folded and faulted sedimentary rocks that range in age from pre-Cambrian to Upper Cretaceous, and that the intermontane basins are filled with fan, fluviatile, and lacustrine deposits of Upper Cretaceous (?), Tertiary, and Quaternary age. The accompanying reconnaissance map (pl. 16) shows only the broad general relationships of the rocks of the area, but it should serve to indicate parts of the area that might profitably be studied in greater detail, particularly in the search for oil and gas, and for phosphate rock.

An area of about 1,300 square miles in the southwestern corner of Montana was mapped. It is bounded on the west and south by Red Rock River, on the north by the Sweetwater Road and Sweetwater Creek, and on the east by Ruby River and Long Creek. A branch of the Union Pacific Railroad and U. S. Highway 91 extend along the western margin of the area from Dillon, near the northwest corner, to Monida.

The area is one of small mountain masses and intermontane basins. In general, the mountains trend north and are composed principally of Early Cretaceous and older rocks; the basins are underlain by Late Cretaceous and younger rocks. From west to east the ranges are the Blacktail Mountains,[1] the southern end of the Ruby Range, and the Snowcrest Range. Red Rock River and Sage Creek lie southwest of the Blacktail Mountains. Blacktail Creek (also known as Blacktail Deer Creek), in the next basin to the northeast, originates in the Snowcrest Range and flows northwest, between the Blacktail Mountains and the south end of the Ruby Range. No large stream occupies the area between the Ruby Range and the Snowcrest Range. The Ruby River originates at the head of the basin between the Snowcrest Range and the Gravelly Range and flows northward between these two ranges.

The lowest point in the area is 5,098 feet, at Dillon; the highest is 10,605 feet, at the summit of Hogback Mountain in the Snowcrest Range.

The geology of Beaverhead County was plotted on air-photo index maps at a scale of approximately 1:66,000, and then transferred to a planimetric base map of the Beaverhead National Forest (Forest Service, U. S. Department of Agriculture, 1947) at a scale of 2 miles to the inch. In transferring the geology from the photo-index sheets to the Beaverhead National Forest map, General Land Office section corners and quarter corners, road intersections, stream intersections, and other recognizable features were used as controls. Only about 10 percent of the corners in the area were located in the field, and these are not so spaced as to give optimum control.

The writer mapped the area during May and June 1947, and in September spent 2 days examining Cretaceous rocks of the area with John B. Reeside, Jr. During the field season, stimulating and enlightening conferences were held with C. P. Ross, Ralph Imlay, V. E. McKelvey, W. R. Lowell, and W. B. Myers, all of the United States Geological Survey; E. S. Perry and E. W. Heinrich of the Montana Bureau of Mines and Geology; L. L. Sloss of Northwestern University; and A. J. Eardley of the University of Michigan.

GEOLOGY

PRE-CAMBRIAN ROCKS

Pre-Cambrian rocks crop out in the southern part of the Ruby Range, in the southeastern half of the Blacktail Mountains, and locally along the west front of the Snowcrest Range.

[1] A local name for the small but conspicuous mountainous area between Beaverhead and Red Rock Rivers on the west and Blacktail Creek on the east. As far as the writer knows, this name has not heretofore been used in a U. S. Geological Survey report.

The rocks in the Ruby Range and in the Blacktail Mountains are similar in lithology and structure and probably are continuous beneath the valley of Blacktail Creek, where they are covered for a width of 1 to 2 miles by an unknown thickness of Quaternary, and possibly by upper Tertiary, fan deposits and alluvium. The pre-Cambrian rocks trend northeast and dip 30° northwest to vertical. In the Blacktail Mountains granitic gneiss or gneissic granite predominates; mica gneiss, hornblende gneiss, garnet gneiss, aplite, and pegmatite occur locally. Near the north end of the mountains the pre-Cambrian rocks pass unconformably beneath the Flathead quartzite of Cambrian age.

In the southeastern part of the Ruby Range, the pre-Cambrian rocks are also mainly gneisses of granitic aspect, cut by many small bodies of aplite and pegmatite. Northwestward these granitic gneisses grade through a complexly injected zone of metamorphosed sedimentary rocks into marble and dolomitic marble, in the lower part of which are interbedded quartzite, hornblende gneiss, mica schist, and intrusive granitic gneiss. This sequence of metamorphosed sedimentary rocks was not observed west of Blacktail Creek where, presumably, it underlies the Paleozoic rocks that are exposed in the northern part of the Blacktail Mountains. Small and comparatively unmetamorphosed masses of ultrabasic rocks have intruded the granitic gneisses in the extreme southeastern part of the Ruby Range and along Jake Creek in the Blacktail Mountains (Winchell, 1914, p. 39). Nickel minerals are associated with at least two of these small intrusive masses.

In this reconnaissance the metamorphic rocks received only scant attention and all were mapped as a single unit, but this cursory examination indicated the possibility that two major groups of rocks older than the Belt series may occur within the area. The group of gneisses and schists in the southeastern part of the Ruby Range and in the Blacktail Mountains contains the same rock types as does the Pony series, as defined by Tansley, Schafer, and Hart (1933, pp. 8–9 and map) in northern Madison County, and the rocks originally assigned to the Archean (Peale, 1896) in the Three Forks quadrangle; however the marbles, quartzites, and intercalated gneisses and schists in the southwestern part of the Ruby Range closely resemble the Cherry Creek group of adjacent areas. Tansley, Schafer, and Hart (pp. 9–11) cite evidence that strongly suggests that in the Tobacco Root Mountains the Cherry Creek group lies unconformably upon the Pony series as defined by them.

The similarity in lithologic sequence of the oldest rocks in the Tobacco Root Mountains and of those in the area herein described suggests that the geologic history of the two areas during early pre-Cambrian time may have been similar. If Tansley, Schafer, and Hart are correct, thick blankets of sedimentary rocks were deposited over

Madison and eastern Beaverhead Counties twice during pre-Belt time, and each period of deposition was followed by folding, metamorphism, intrusion, mountain building, and planation. However, the writer believes that the parallelism of foliation and the absence of a clearly defined contact between the metamorphic rocks in the Ruby Range that are similar to the Cherry Creek group and Tansley's Pony series indicate that only one thick sedimentary blanket was deposited over the area during pre-Belt time, and that the differences in lithology and degree of metamorphism between the two units may be the result of more intense injection and metasomatism of the older and originally more deeply buried part of this sedimentary sequence. Considerable detailed geologic work will be required to demonstrate beyond question the stratigraphy and structure of these pre-Cambrian rocks.

Gneissic rocks, probably of pre-Cambrian age, also crop out along the western front of the Snowcrest Range between the Middle Fork and the East Fork of Blacktail Creek, and are found as far north as the west slope of Olson Peak. North of the East Fork, slightly foliated granitic rocks occur in an area underlain by rocks predominantly gneissic. Although exposures in this locality are poor, the distribution of outcrops and float suggests that the granitic rocks cut both the pre-Cambrian gneisses and the overlying lower Paleozoic rocks. Probably, if this interpretation is correct, the granitic rocks were emplaced during late Cretaceous or early Tertiary time, about simultaneously with the granitic intrusives in northwestern Beaverhead County. Near the mouth of the Ruby River Canyon (secs. 7 and 18, T. 9 S., R. 3 W.) also, altered and limonite-stained granitoid igneous rocks crop out in an area underlain predominantly by rocks that are probably of pre-Cambrian age. The writer believes that the granitoid igneous rocks were intruded into the gneissic rocks and are correlative with the granitic rocks north of the East Fork.

Rocks of the Belt series of late pre-Cambrian age occur in Madison County northeast of the area mapped, and in Beaverhead County west of the area, but have not been identified within the area of this report. If a blanket of rocks of the Belt series was deposited over Beaverhead and Madison Counties it has been stripped by erosion from much of this area, and was stripped from part of the area prior to Middle Cambrian time, for in the Blacktail Mountains the Flathead quartzite of Middle Cambrian age rests unconformably on the rocks similar to those of the Pony series of Tansley, Schafer, and Hart.

SEDIMENTARY ROCKS

CAMBRIAN AND DEVONIAN ROCKS

Cambrian and Devonian rocks are well exposed along a few miles of the east front of the Blacktail Mountains and poorly exposed in places along the west flank of the Snowcrest Range. No rocks of Ordovician or Silurian age were recognized in the area.

In the Blacktail Mountains, the Cambrian and Devonian section is best exposed in the steep walls of Ashbough Canyon. The Flathead quartzite (Middle Cambrian), which is as much as 150 feet thick, unconformably overlies pre-Cambrian gneiss. The basal 10 feet of the Flathead is red, gritty to pebbly, arkosic quartzite; the remainder is white, pink, and red, medium-grained quartzite. The Flathead quartzite is overlain by 50 to 75 feet of red and green shale, which probably is a correlative of the Wolsey shale to the north (Weed, 1899a, 1899b). The shale is overlain by approximately 1,700 feet of limestone and dolomite with interbedded units of calcareous shale and shaly carbonate rock. This part of the section probably includes rocks of both Cambrian and Devonian age and, perhaps, correlatives of most of the formations recognized in the Three Forks region (Peale, 1893, pp. 22–25; Berry, 1943, pp. 8–14; Deiss, 1936, pp. 1311–1317). Rocks similar to the distinctive dark, fetid Jefferson dolomite that occurs elsewhere in Beaverhead County and in the Three Forks area were not definitely recognized. The boundary between Cambrian and Devonian beds in the Blacktail Mountains was placed arbitrarily at the top of a unit of mottled pink- and buff-weathering limestone and dolomitic limestone that contains many shaly beds (equivalent? of Pilgrim limestone and Dry Creek shale) and at the base of a dominantly buff-weathering dolomitic sequence (Jefferson ? dolomite) that grades upward into calcareous shale (Three Forks? shale). A more detailed study of the Cambrian rocks in the Blacktail Mountains is needed to establish correlations with better known sections to the northeast, east, and southeast (Deiss, 1936, pp. 1303–1325).

Cambrian rocks are present locally but are very poorly exposed in the western part of the Snowcrest Range. No section was found that was sufficiently complete to be compared with the section in Ashbough Canyon. Rocks of Devonian age are somewhat better exposed than those of Cambrian age in at least one locality in the Snowcrest Range, along the West Fork of Blacktail Creek. The Devonian rocks here differ conspicuously from those in Ashbough Canyon. Along the West Fork at least 100 feet of shale that weathers brownish yellow is exposed in the crest of an anticline. This shale, which is probably the Dry Creek shale of late Cambrian age (Peale, 1893, pp. 29–32; Deiss, 1936, pp. 1335–1337), is overlain by the Jefferson dolomite, which consists of 1,000 to 1,500 feet of dark-gray to black, sugary, fetid, generally very poorly bedded dolomite. The dolomite is overlain by a few hundred feet of dark-gray shale with intercalated limestone, which is probably the Three Forks shale (Peale, 1893, pp. 27–32). In the Snowcrest Range the Cambrian and Devonian rocks were mapped as a unit, except along the West Fork of Blacktail

Creek, where the Upper Cambrian shale and the combined Jefferson and Three Forks formations were mapped separately.

CARBONIFEROUS ROCKS

Mississippian and Pennsylvanian rocks are exposed almost continuously along the crest of the Snowcrest Range and in the higher north-central part of the Blacktail Mountains. These rocks are generally better exposed than the Cambrian and Devonian rocks. They also seem to be more uniform in lithology throughout the region.

The Madison limestone, of Mississippian age (Peale, 1893, pp. 33–39; Berry, 1943, pp. 16–18), which is as much as 2,000 feet thick, is the conspicuous ridge-former in the area. It consists of a lower member of thin-bedded, dense, blue-gray limestone; a middle member of thickly and poorly bedded, gray limestone; and an upper member of cherty gray limestone. In most localities the Madison limestone is overlain by several hundred feet of poorly exposed red- and buff-weathering shale with interbedded limestone and siltstone. This unit, which is probably equivalent to part of the Amsden formation (Darton, 1904, pp. 394–401; Scott, 1935, pp. 1011–1032; Berry, 1943, pp. 18–19) or the Brazer limestone (J. S. Williams, oral communication), or both, was included with the Madison in mapping, although part or all of it may be of early Pennsylvanian age.

The poorly exposed, dominantly argillaceous unit is overlain by the Quadrant formation of Pennsylvanian age (Peale, 1893, pp. 39–43), which consists of 600 to 1,000 feet of white, but locally brown- or pink-stained, quartzite and sandstone. The degree of induration of this formation varies greatly within short distances along the strike. Where highly indurated, it tends to form conspicuous rocky ridges whose slopes are aproned by quartzite talus; where moderately or weakly indurated, it crops out inconspicuously, if at all.

PERMIAN ROCKS

The Phosphoria formation of Permian age (Richards and Mansfield, 1912, pp. 683–689) forms a narrow strip 32 miles long east of the crest of the Snowcrest Range. The phosphatic and shaly part of the formation rarely crops out, but at several localities siliceous rocks of the middle and upper part of the formation form ribs or low hogbacks. Where the formation has been exposed by excavation and carefully studied at two localities in the area and at several localities a few miles north and west of the area, five members are identified. In the following discussion they are designated members A to E, in ascending order. From the quartzite of the underlying Quadrant formation, member A within a few feet grades into a series of beds predominantly sandstone and dolomite. Member B is a thin unit of interbedded phosphatic mudstone and phosphate rock. Member C is a comparatively thick unit of carbonate rock, chert, and sandstone and quartzite. Member D consists of interbedded bituminous mudstone, phosphatic mudstone, and phosphate rock. Member E, at the top of the formation, consists of quartzite, sandstone, and chert and is overlain with apparent conformity by shaly beds of the lower part of the Dinwoody formation. The following sections of the Phosphoria formation within the area were measured during an investigation of Montana phosphate deposits sponsored by the Mineral Deposits Branch of the Geological Survey:

Section in gully on northeast flank of Sawtooth Peak (SW¼ sec. 10 T. 12, S., R. 5 W.)

[Measured by F. S. Honkala and O. A. Payne, August 1948. Color designations according to Rock-color Chart, distributed by National Research Council, 1948.]

	Feet
Dinwoody formation, not measured.	
Phosphoria formation:	
Member E:	
Quartzite, light brownsh-gray, thin-bedded, cherty	2½
Sandstone, pale-brown, porous	4
Quartzite, yellowish-gray and light brownish-gray	10
Sandstone, yellowish-gray and pale-brown	13
Quartzite, medium-gray, blocky	13½
Sandstone, pale-brown, quartzitic	5
Quartzite, light brownish-gray	4
Sandstone, pale-brown quartzitic	10
Quartzite, medium-gray, conglomeratic	5
Total thickness of member E	67
Member D:	
Phosphate rock and quartzite, light-brown and medium-gray	3½
Phosphate rock, dark-gray, very oolitic, bituminous and phosphatic shale interbedded in lower 1 foot	3
Shale, black to brownish-black, phosphatic and bituminous	4½
Phosphate rock, black, very oolitic	½
Shale, brownish-black, bituminous	½
Phosphate rock, black, oolitic, argillaceous, bituminous	1½
Shale, brownish-black, bituminous, argillaceous phosphatic	5
Phosphatic shale and phosphate rock, dark-gray and black	7½
Phosphate rock, brownish-black and black, fossiliferous	3
Shale, brownish-black, bituminous, moderately oolitic	28
Total thickness of member D	57

Phosphoria formation—Continued

	Feet
Member C:	
Chert, dark-gray, with fissile mudstone partings	2½
Sandstone, pale-brown and grayish-brown	11
Sandstone, pale-brown, phosphatic (?)	2
Sandstone, dark-gray quartzitic	3½
Quartzite, medium-gray	3
Chert and mudstone, medium-gray	3
Chert conglomerate, dark-gray matrix with light-gray "pebbles"	½
Chert, banded yellowish-white and brownish-gray	4
Limestone, yellowish-gray, coarsely crystalline	10
Limestone, pale yellowish-gray, sandy	17½
Limestone, yellowish-gray, in part fossiliferous	22½
Dolomite, pale-brown, sandy	2
Limestone, pale-brown, dense	3
Chert, pale-brown	1
Dolomite, pale-brown, nodular	13½
Dolomite, pale-brown	1½
Limestone, yellowish-gray, fossiliferous	4
Limestone with interbedded chert; limestone yellowish-gray, chert pale yellowish-orange; both are hard and compact	15
Limestone, yellowish-gray, aphanitic to medium crystalline, fossiliferous	36½
Limestone, light-gray, dolomitic	4
Chert, moderate-brown; contains some drusy cavities	3½
Sandstone, yellowish-gray, calcareous	1½
Chert, light-gray, dense, arenaceous	51
Sandstone, moderate orange-pink to brownish-gray	3
Chert, pale yellowish-orange	1
Chert, medium-gray to light olive-gray, locally argillaceous or quartzose	29
Total thickness of member C	249
Member B:	
Phosphate rock, dark-gray, very oolitic	½
Mudstone, light-brown, moderately oolitic	2½
Phosphate rock, brownish-black, very oolitic	½
Mudstone, moderate-brown, moderately oolitic	3
Shale, moderate-brown and brownish-black, phosphatic and bituminous	3
Phosphate rock, brownish-black, oolitic to pisolitic	2½
Phosphate rock, pale yellowish-orange, oolitic, fossiliferous	1
Phosphate rock, black and moderate brown, oolitic, pisolitic, and conglomeratic, fossiliferous	3
Total thickness of member B	16

Phosphoria formation—Continued

Member A:

	Feet
Chert, moderate orange-pink, dense, fossiliferous	2
Dolomite, pinkish-gray, dense, argillaceous	4
Sandstone, dark yellowish-orange, argillaceous	1
Mudstone, greenish-black and dark yellowish-orange, in part oolitic	3½
Sandstone, light-brown, calcareous	31½
Dolomite, yellowish-gray, arenaceous	30
Total thickness of member A	72
Total thickness of Phosphoria formation	461

Quadrant formation not measured.

Section in trenches near Wadhams Spring (NE¼ sec. 28 and SE¼ sec. 22, T. 13 S., R. 7 W.)

[Measured by D. A. Bostwick and E. R. Cressman, July 1948. Color designations according to Rock-color Chart, distributed by National Research Council, 1948.]

Dinwoody formation, not measured.

Phosphoria formation:

Member E:

	Feet
Siltstone and chert, yellowish-orange, thick bedded	3½
Siltstone and sandstone, predominantly yellowish-orange	6
Sandstone, grayish-brown, and siltstone, yellowish-orange	9½
Siltstone, dusky-yellow, and chert, light-gray, platy	11
Siltstone, yellowish-orange, with interbedded sandstone and chert	16½
Chert, light-brownish gray, thick-bedded	8
Siltstone, yellowish-orange, and chert, gray	54½
Chert, gray, coarsely oolitic, sharp lower contact	1
Total thickness of member E	110

Member D:

	Feet
Phosphate rock, yellowish-gray, coarsely oolitic, argillaceous	4
Mudstone, pale-brown and grayish-brown, in part phosphatic	9
Mudstone and phosphate rock, pale-brown, thin-bedded	½
Mudstone, yellowish-gray and brown; lower 1½ feet phosphatic	3½
Phosphate rock, yellowish-gray, finely oolitic	½
Mudstone, dusky-brown, with thin layers oolitic phosphate rock in lower 1 foot	2
Mudstone, pale yellowish-green and pale brown, thin-bedded	2
Mudstone, pale-brown and brownish-gray, phosphatic	2½
Mudstone, yellowish-brown, and phosphate rock, pale-brown	3½
Mudstone, pale-brown, in part phosphatic and calcareous	4

Phosphoria formation—Continued	Feet
Member D—Continued	
Mudstone, yellowish-gray and moderate-brown, and phosphate rock, pale-brown, finely oolitic	6
Concealed	29
Total thickness of member D	66½
Member C:	
Siltstone, yellowish-gray, calcareous, fossiliferous; cherty in upper 6½ feet	44½
Siltstone, upper half yellowish-gray, lower half yellowish-orange; calcareous and fossiliferous throughout	33½
Mudstone, pale yellowish-orange, calcareous, thick-bedded, contains chert lenses near base	17½
Mudstone, pale-brown, calcareous, thick-bedded	20½
Siltstone, very pale brown, contains a few cherty lenses and calcite-lined vugs	12
Limestone, light brownish-gray, medium crystalline, thick-bedded	2½
Siltstone, upper 20 feet white and yellowish-white, calcareous, massive, fossiliferous; lower 13 feet, yellowish-gray, calcareous with calcite grains (?) locally abundant, thick-bedded, fossiliferous	33
Siltsone, yellowish-white, yellowish-gray and yellowish-orange, calcareous, thick-bedded; contains chert lenses in middle part and calcite grains (?) and veinlets near base	36
Mudstone, yellowish-gray, calcareous; weathered rock appears "bouldery"	8
Sandstone, light-gray locally stained pale-orange; with calcareous cement and calcite-lined vugs	1
Chert, light-gray and locally black, massive	15
Chert, dark-gray, thick-bedded, contains a few thin beds of sandstone and siltstone	17½
Siltstone, white to dark reddish-gray, thick-bedded; some chert interbedded	13½
Siltstone, light-gray and pale yellowish-brown, cherty, fossiliferous; at top is 1½ feet cherty oolitic (phosphatic ?) sandstone	13½
Chert, pale-brown, thick-bedded, and siltstone grayish-yellow and pale-brown; chert is predominant in upper 5 feet, siltstone in lower 5½ feet	10½
Mudstone, pale-yellow, calcareous, cherty	14½
Sandstone, light brownish-gray, oolitic (phosphatic ?) argillaceous, calcareous	1
Siltstone, brownish-gray, calcareous, thick-bedded	8
Total thickness of member C	302
Member B:	
Phosphate rock, light-gray, pisolitic and coarsely oolitic, calcareous: contains ½ foot bed of limestone in upper 1½ feet	5½
Total thickness of member B	5½

Phosphoria formation—Continued

Member A:	Feet
Siltstone, yellowish-orange and light-gray, calcareous, with sporadic calcite veinlets and black dendrites; contains beds of yellowish-orange and pale-brown limestone	12½
Siltstone, yellowish-orange, calcareous; contains a few chert nodules and calcite stringers	3
Siltstone, grayish-yellow, calcareous, thick-bedded; contains a lens of siliceous pisolites and oolites at top	3½
Siltstone, shades of gray, brown, and pale-yellow, calcareous alternately thin- and thick-bedded, locally fossiliferous, cherty in lower 9½ feet	54
Mudstone, yellowish-orange, cherty, with interbedded limestone, yellowish-orange, cherty, argillaceous	8
Siltstone, grayish-yellow, calcareous, with interbedded chert; ½ foot limestone at base	11½
Siltstone, white and grayish-yellow, thin-bedded; contains dusky yellowish-orange limestone lenses in lower 15 feet	18
Sandstone, light-gray, calcareous	2
Siltstone, dusky-red, calcareous; contains small angular chert fragments in lower part	10½
Total thickness of member A	123
Total thicknes of Phosphoria formation	607

Quadrant formation not measured.

TRIASSIC ROCKS

Triassic rocks overlie the Phosphoria formation along the east flank of the Snowcrest Range. The Triassic sequence consists of 350 to 750 feet of interlayered thin- to medium-bedded chocolate-weathering fossiliferous limestones and siltstones that are here referred to the Dinwoody formation (Blackwelder, 1918, p. 425; Newell and Kummel, 1942, pp. 937–995) and of 200 to at least 300 feet of yellowish-brown weathering (and locally red-mottled) flaggy shale, siltstone, and sandstone with two intercalated units of gray-white limestone that may be a correlative of the Thaynes formation (Newell and Kummel, 1942, pp. 945–948; Boutwell, 1907, pp. 439–458) and possibly also of part of the Woodside shale. In the Melrose phosphate field and at McCarthy Mountain, about 30 and 20 miles respectively north of Dillon, rocks similar to this sequence previously had all been referred to as Woodside shale (Richards and Pardee, 1925, pp. 8–12, 28). The correlative (?) of the Thaynes formation, which is at least 300 feet thick at the south end of the Snowcrest Range (secs. 22 and 27, T. 13 S., R. 34 E.), thins to not more than 200 feet at the mouth of Ruby River Canyon, 35 miles to the north, and is absent in the Three Forks area, about 50 miles farther north (Berry, 1943, p. 6, columnar section). Probably, this northward thinning is the result of erosion after the early Triassic epoch, for Condit has shown that prior to the deposition of the Jurassic Ellis formation, the Triassic and older rocks of southwestern Montana had been tilted and eroded (Condit, 1919, pp. 120–121).

JURASSIC ROCKS

Jurassic rocks occur in the Centennial Mountains to the south of the area mapped (Condit, p. 114 and plate 10), in the Tendoy Mountains to the west (W. R. Lowell, oral communication), in the Madison and Gallatin Ranges a few tens of miles to the east (Gardner and others, 1946, pp. 63–68) and in the vicinity of Three Forks about 50 miles to the north (Gardner and others, 1946, pp. 12–20), but none were recognized in the area mapped. During the early part of the field work the writer considered the possibility that part or all of the few hundred feet of beds between the Dinwoody formation and the Kootenai formation might be of Jurassic age. Ralph Imlay of the United States Geological Survey later examined two well-exposed sections of these rocks. The fossils, although few, and the general stratigraphic sequence indicated to him that the rocks are of Triassic age, and they are so designated in this report.

CRETACEOUS ROCKS

In the northeastern part of the area mapped, sedimentary rocks of Cretaceous age underlie the Ruby River Valley, and a narrow belt to the southwest along the east flank of the Snowcrest Range. In this reconnaissance, only two units were distinguished: the Kootenai formation (Lower Cretaceous) below, and undivided Upper Cretaceous beds above.

The Kootenai formation is about 1,000 feet thick. It includes a variety of lithologic types, but in general the rocks grade upward from coarser-grained to finer-grained. A persistent unit of red shale, which generally is not more than 50 feet thick and is seen only in float, was mapped as the basal part of the formation, although it may be a correlative of the Morrison formation of Late Jurassic age. The red shale is overlain by a few hundred feet of coarse sandstone that contains abundant grains of dark chert, is conglomeratic near the base, and grades upward into buff and red shaly, clayey, and silty beds. Several hundred feet of red and green shale with a few beds of siltstone and sandstone make up the middle part of the formation, and two or three limestone units separated by shale form the upper part. The upper boundary of the formation was placed at the top of the uppermost limestone, which is commonly about 40 feet thick and crowded with the remains of fresh-water gastropods.

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The Kootenai formation in the Ruby River Valley is overlain by several thousand feet of somber-hued shales, siltstones, and sandstones, all of which have been mapped as undivided Upper Cretaceous rocks. The lower part of this sequence belongs to the Colorado group and is described as follows:

Generalized section along road in Ruby River Valley (secs. 17 and 20, T. 9 S., R. 3 W.); unit 7 is top of section

Upper part of Upper Cretaceous.
Disconformity (?) or conformity (?).
Lower part of Upper Cretaceous:

Colorado group:	*Approximate thickness (feet)*
7. Uppermost shale and sandstone beds not described	?
6. Lignite bed, overlain and underlain by black shale that contains *Cardium pauperculum* Meek, *Corbula* cf. *C. perundata* Meek and Hayden, *Anomia* cf. A. *micronema* Meek, *Brachydontes* aff. *B. multilinigera* Meek, *Ursirivus* (?) sp. (2 sp. ?), *Turbonilla* cf. *T. coalvillensis* Meek, *Eulimella* (?) sp., *Rhytophorus* (?) cf. *R. meeki* White, and *Mesostoma* (?) n. sp.[2]	10
5. Dark-gray, green, and black shales interbedded with dark-green and brown sandstones; in part calcareous	600
4. "Oyster reef" which contains *Ostrea soleniscus* Meek, *Cardium pauperculum* Meek, "*Barbatia*" *micronema* Meek (?), *Cyrena aequilateralis* Meek (?), *Brachydontes* sp., and *Aporrhais* (?) sp.[3]	3
3. Predominantly dark-gray shale; flaggy sandstone interbedded	100
2. Light-colored tuff, impure bentonite and bentonitic shale, and tuffaceous sandstone and siltstone (may be equivalent to the Aspen or Mowry shales or to part of the Frontier formation)	200
1. Interbedded black shale and "salt and pepper" sandstone; contains abundant small fragments of black chert	100

Reeside[4] states that the two faunal assemblages listed in units 4 and 6 are characteristic of the lower part of the Colorado group of earlier late Cretaceous age. On the basis of the mollusks and the lithologic sequence, he concludes that these beds contain equivalents of at least the Bear River and Aspen and the Wayan formations, though they could include much more. The rocks in unit 2 of the foregoing section are lithologically similar to those in the lower part of the Frontier formation south of Yellowstone National Park (Love and others, 1948, pp. 10–11, 42–43).

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[2] Letter and accompanying memorandum from John B. Reeside, Jr., to M. R. Klepper, dated Jan. 23, 1948.

[3] Idem.

[4] Idem.

The upper part of the Upper Cretaceous sequence, which appears to lie without discordance on the lower part, consists largely of calcareous and locally gritty sandstone, interbedded with dark-colored shales and a few thin seams of lignitic or semibituminous coal. The sequence is disturbed by minor folds and faults and is poorly exposed. Its thickness is not known but is certainly more than 1,000 feet and may exceed 2,500 feet. Plant remains from the hanging wall of the principal coal bed (sec. 28 (?), T. 11 S., R. 3 W.) include *Anemia* sp. *Gleichenia pulchella* Knowlton, *Saccoloma gardneri* (Lesquereux); and other fragments of dicotyledonous leaves. Roland W. Brown,[5] who made these identifications, considers the assemblage to be characteristic of the Mesaverde formation (Upper Cretaceous). The structure, stratigraphy, and paleontology of the Cretaceous rocks younger than the Kootenai formation must be studied in detail before these rocks can be subdivided into formations and correlated more precisely with Upper Cretaceous rocks elsewhere.

VOLCANIC DEBRIS IN CRETACEOUS ROCKS

Sedimentary rocks composed partly of volcanic debris were deposited recurrently during late Cretaceous and early Tertiary time. On the geologic map (pl. 16) these rocks are included with the undifferentiated Upper Cretaceous sedimentary rocks. The oldest rocks of this kind occur in the lower part of the Upper Cretaceous, about 100 feet above the top of the Kootenai formation. This unit is about 200 feet thick and comprises light-colored tuffaceous sandstone and siltstone, bentonite, and bentonitic shale. No fossils were found, but the lithology and stratigraphic position of the unit suggest that it may be equivalent to the lower part of the Frontier formation (Love and others, 1948, pp. 10–11, 42–43) or to the Mowry shale (Reeside, 1944; Rubey, 1929, pp. 153–154) and Aspen shale (Veatch, 1907, pp. 64–65).

Between this unit and the highest bed known to be of Colorado age are 600 to 700 feet of grayish-green sandstones and dark-gray shales. The sandstones contain dark mineral grains and fragments that may be calcic volcanic rock. These observations indicate that basic volcanic detritus was supplied to the area at times during the deposition of the Colorado sediments. The writer at first thought that these rocks might be approximately equivalent to the Livingston formation of central Montana, which contains a large amount of andesitic tuff, agglomerate, and breccia (Weed, 1893, pp. 21–27; Parsons, 1942, pp. 1175–1186). The rocks are now known to be pre-Livingston, for Colorado fossils have been found in shale and impure limestone beds (p. 68, units 4 and 6) near the base and top of the sequence of greenish-gray sandstone and dark-gray shale.

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[5] Memorandum dated October 23, 1947.

The rocks between those of known Colorado age and known Mesaverde age have not been examined; some of Mesaverde age probably contain admixed volcanic debris; and some of post-Mesaverde age contain abundant volcanic debris. The source of this debris is not known, but it almost certainly was outside the area of this report.

UPPER CRETACEOUS(?) AND TERTIARY ROCKS

More than half the area mapped is underlain by rocks younger than the Upper Cretaceous rocks equivalent to the Mesaverde formation, but time permitted only a superficial study of these younger rocks. On the map they are all included in a single unit. These post-Mesaverde rocks are herein divided into three groups, designated (in ascending order) group 1, group 2, and group 3. Probably, rocks of group 1 were deposited before the major movements of the late Cretaceous and early Tertiary Laramide orogeny, which affected the area, those of group 2 during and immediately after the major movements, and those of group 3 during the period of relative crustal stability that followed the orogeny.

Group 1 consists of light-gray and buff, dominantly calcareous sandstone, shale, and grit of nonmarine origin. Some beds are distinctly tuffaceous, and others probably contain small amounts of fine-grained volcanic debris. The thickness of the group is at least 3,000 feet and perhaps exceeds 5,000 feet. Rocks of this group are best exposed near Monida, in parts of Tps. 14 and 15 S., Rs. 6 and 7 W., where they underlie coarse clastic rocks of group 2 and on the divide between Ruby River and Long Creek, in parts of T. 12 S., Rs. 3 and 4 W., where they overlie coal-bearing strata of Mesaverde age. Neither the upper nor the lower contact of this group of rocks has been seen by the writer, but structural features near the contacts suggest that the rocks rest on the Mesaverde equivalent without discordance and are overlain with marked angular discordance by rocks of group 2.

Rocks of group 2 are predominantly coarse-textured fanglomerate and conglomerate, with intercalcated beds of limestone, sandstone, and shale. They overlie Paleozoic rocks unconformably in the western part of the Blacktail Mountains and form an almost continuous blanket around the western, southern, and southeastern flanks of the Snowcrest Range. There, beds of group 2 discordantly overlie rocks at least as young as the gastropod-bearing limestone that is designated as the top of the Kootenai formation, which is Lower Cretaceous. These predominantly coarse-textured deposits range from a few hundred to several thousand feet in thickness. They are considered to be the consolidated debris shed from nearby mountain masses that were elevated during late Cretaceous and early Tertiary time; they may have been deposited at different times in different localities.

Locally they are strongly folded and faulted, and to the west and northwest of the area mapped they are overthrust by older rocks (W. R. Lowell, oral communication).

No fossils have been found by which any of these coarse-textured rocks could be dated [6] but undoubtedly all the rocks of group 2 are younger than the Mesaverde correlatives in Ruby River valley and most, if not all, of them are younger than the rocks of group 1 near Monida. At least part of them underlie the middle Eocene rocks of group 3 in the valley of Sage Creek. The youngest fanglomerates and conglomerates may have been deposited at about the same time as the oldest rocks of group 3.

The central parts of the intermontane basins are occupied by rocks of group 3, which comprise mildly indurated light-colored claystone, siltstone, marl, sandstone, grit, and conglomerate. Most of these rocks are tuffaceous; some consist almost wholly of fine-grained volcanic debris. No attempt has been made to correlate the deposits in one basin with those in another, but it is known that in the basin through which Sage Creek flows, Eocene rocks (Sage Creek formation of Douglass, 1903, pp. 145–146), apparently of either lower Uinta or upper Bridger age, unconformably overlie lower Eocene (?) beds and are unconformably overlain by middle Oligocene rocks (Cook Ranch formation of Wood, 1934, pp. 249–257; 1941, chart preceding p. 1)[7]. Furthermore, in the basin through which Blacktail Creek flows, are exposed rocks of upper Oligocene (?) or lower Miocene (?) age (Blacktail Deer Creek beds of Douglass, 1902, pp. 237–245; Osborn, 1909, p. 106).

Consolidated sediments younger than early Miocene (?) have not been identified in the area.

[6] In 1948 the writer and W. R. Lowell examined a well-exposed section of rocks of group 2 along the east front of the Tendoy Mountains west of Kidd, Mont., a few miles west of the area covered by this reconnaissance. There the group consists of four units which are, from bottom to top: (1) irregularly thick-bedded fanglomerate and conglomerate that consists principally of fragments of Paleozoic limestone—approximately 2,500 feet thick; (2) indistinctly bedded limestone (in part concretionary) with a few conglomerate beds near base—approximately 800 feet thick; (3) interbedded tuffaceous and calcareous sandstone, siltstone, and mudstone, with a few conglomerate layers—approximately 600 feet thick; and (4) indistinctly bedded conglomerate and fanglomerate with a high proportion of quartzite fragments probably derived from the Belt series—approximately 2,000 feet thick and top not exposed. Fresh-water pelecypods and gastropods were collected from unit 3, but the collections have not been studied.

[7] During the summer of 1948, after this report had been written, Leo A. Thomas of the Geological Survey collected vertebrate remains near the south line of sec. 27 and in the SW¼ sec. 34, T. 12 S., R. 8 W., the former being the type locality of the Cook Ranch formation (Wood, H. E., 1934; Wood, A. E., 1933, pp. 134–135). C. L. Gazin of the U. S. National Museum identified the specimen from sec. 27 as *Pseudocynodictis sp.*, and that from sec. 34 as *Subhyracodon sp.*, both of which he considers to be from the Oligocene Cook Ranch horizon (Memorandum from C. L. Gazin to J. B. Reeside, Jr., Sept. 24, 1948). At the type locality the base of the Cook Ranch formation is not exposed, but overlying it with slight unconformity is indurated gravel of unknown age.

QUATERNARY DEPOSITS

Unconsolidated terrace deposits, alluvial fans, talus, slope wash, and valley-bottom sediments are considered to be of either Pleistocene or Recent age.

IGNEOUS ROCKS

INTRUSIVE ROCKS OF UNDETERMINED AGE

As previously stated (p. 59), small masses of granitic rock crop out along the west flank of the Snowcrest Range. They somewhat resemble and may be genetically related to granitic intrusive rocks of late Cretaceous and early Tertiary age that occur in the western and northern part of Beaverhead County (Billingsley, 1916, pp. 33, 46; Shenon, 1931, pp. 18–19). Commonly these rocks have been weathered to a granitic rubble that in reconnaissance could not be readily distinguished from the weathered pre-Cambrian gneisses into which they were intruded. Intrusive rocks of unknown age also cut the metamorphic rocks of the Ruby Range and the Blacktail Mountains. Many unmetamorphosed dikes, sills, and small irregular bodies of pegmatite and aplite cut the gneissic and schistose rocks in the southern part of the Ruby Range, and small masses of unmetamorphosed or slightly metamorphosed gabbroic and ultrabasic rocks have been intruded into intensely metamorphosed gneissic rocks in the southeastern part of the Ruby Range and on Jake Creek in the Blacktail Mountains. On the map these comparatively small bodies of younger intrusive rocks are not distinguished from the pre-Cambrian rocks that surround them.

TERTIARY VOLCANIC ROCKS

Several kinds of purely volcanic rocks, all considered to be of Tertiary age, occur within the area mapped. Silicic and intermediate flows and tuffs are exposed in the Blacktail Mountains (Tps. 10 and 11 S., Rs. 8 and 9 W.) and in and near the canyon of Sweetwater Creek (secs. 4, 5, 8, and 9, T. 9 S., R. 5 W.). They overlie pre-Cambrian and Paleozoic rocks and are overlain by Tertiary fluviatile deposits similar to the upper Oligocene (?) or lower Miocene (?) "Blacktail Deer Creek beds" and by younger Tertiary basalts. No evidence was found by which these volcanic rocks could be closely dated, but because of their relatively fresh appearance they are tentatively considered to be of early Tertiary rather than Cretaceous age.

The youngest rocks in the area are basalt flows, which range from a few feet to 50 feet in thickness. These flows overlie gravels that are disconformable upon the "Blacktail Deer Creek beds" and consequently are younger than early Miocene (?). The topographic position and degree of dissection of the flows suggest that they may have been extruded during the Pliocene or even later, and consequently may be equivalent to the Snake River basalt, which is widespread in Idaho.

GEOLOGIC STRUCTURE

GENERAL FEATURES

The geologic structures of southwestern Montana are the result of at least three periods of diastrophism. The most recent of these was in the late Cenozoic when block faults were formed (Pardee, 1947, p. 1215). Some of these faults are reflected by the present-day topographic features. The preceding diastrophism, which began during the latter part of the Cretaceous period and continued into the early part of the Tertiary, is indicated by the complexly folded and faulted (and locally intruded) Paleozoic and Mesozoic sedimentary rocks, and by the accumulation of coarse debris from the destruction by erosion of mountains that were formed during the disturbance. There was at least one period of important diastrophism in pre-Cambrian time, but record of that period will not be known in detail until the area is more thoroughly investigated.

STRUCTURAL PATTERN

The major folds of southwestern Montana trend a little east of north, are as much as 25 miles in breadth and 40 or 50 miles in length, and have vertical components of more than a mile. Among these are the domical area of the Ruby Range and Blacktail Mountains, in the center of which pre-Cambrian rocks are exposed; the syncline whose west limb forms the Snowcrest Range and whose east limb forms the Gravelly Range; and the large anticline along whose axis the Madison River now flows.

Superimposed on these broad regional folds, and somewhat obscuring them, are zones of more intense folding and faulting, particularly in the Willis and Dell quadrangles west of the area mapped and in the Madison Range east of the area mapped. Preexisting structures have been dislocated and modified by late Cenozoic block faults that are the most recent major structural features recognized and have strongly influenced the development of present-day topography of the region.

The area mapped comprises two raised blocks or ranges, the Ruby Range-Blacktail Mountains and the Snowcrest Range, which are surrounded by relatively depressed blocks, or basins. Cretaceous and older rocks, and in a few places early Tertiary sedimentary and volcanic rocks, form the mountains; Tertiary, and possibly latest Cretaceous rocks and Recent alluvium blanket the basins.

RUBY RANGE AND BLACKTAIL MOUNTAINS

The Ruby Range and the Blacktail Mountains form a structural dome whose core consists of highly metamorphosed pre-Cambrian rocks. The foliation of these pre-Cambrian rocks trends from northeast to about east and in general parallels the long axis of the Ruby Range-Blacktail Mountains mass. In the northwestern part of the Blacktail Mountains at the southern end of the Ruby Range-Blacktail Mountains mass, and also near the north end of the Ruby Range (Andrews and others, 1944), Paleozoic sedimentary rocks unconformably overlie the pre-Cambrian rocks and dip away from the center of the mountainous area. This suggests that near the end of the Mesozoic era the entire Ruby Range-Blacktail Mountains area was covered by Paleozoic and, possibly, by Mesozoic rocks. The present mountainous area is believed to have been outlined by doming during the Laramide revolution and rejuvenated by later Cenozoic folding, which culminated in block faulting. After the Laramide doming, erosion stripped away the cover of Paleozoic and Mesozoic rocks except near the edges of the uplifted area, and Tertiary sedimentary and volcanic rocks were deposited as an almost continuous girdle in the relatively depressed adjacent areas. The area was again domed, probably during the Pliocene. During or immediately following this doming, the Blacktail Mountains, which had been coextensive with the Ruby Range, appeared as a separate topographic unit as a result of uplift and tilting to the southwest along a northwest-trending range-front normal fault. This range-front fault has not been observed, but the steep, straight northeast face of the northern part of the mountains is best explained by inferring that such a fault exists and is covered by the apron of fan material that has accumulated in front of the steep face. Uplift of the mountain block was probably more than 2,000 feet at the north end, but not more than 1,000 feet south of Jake Creek.

SNOWCREST RANGE

The Snowcrest Range is essentially the east limb of a long anticline that for at least half of its extent has been overturned, and probably overthrust from the west (pl. 16, cross sections A–A′ and B–B′). The major structural features of the range are believed to have been formed during the Laramide orogeny, when the Paleozoic and Mesozoic sedimentary rocks were compressed into folds and broken by both normal and thrust faulting. Thrust faults of considerable displacement and of probable early Tertiary age have been recognized west of the area mapped (oral communications, W. R. Lowell and W. B. Myers) and in the Gardiner thrust in the Madison Range east of the area mapped (Peale 1896, geologic map; Roer C. Swanson, oral communication). Along the west margin of the Snowcrest Range gneissic rocks, probably of pre-Cambrian age, and undifferentiated early Paleozoic sedimentary rocks are in fault contact with younger Paleozoic rocks. The fault trace was not observed but the structure in the northern part of the range (pl. 16, cross section A–A′) suggests that pressure from the northwest overturned a large anticlinal fold and ruptured it along its axial plane, so that the west limb was thrust over the east limb.

The valley of the Ruby River has been carved in the relatively nonresistant Upper Cretaceous rocks that occupy the trough of the broad syncline east of the Snowcrest Range; the Gravelly Range, east of the area mapped, is composed of the more resistant Paleozoic rocks where they reappear on the east limb of this broad syclinal structure.

The present physiographic expression of the Snowcrest Range is presumed to be due to late Tertiary uplift and subsequent erosion. Such uplift may have been facilitated by normal faults marginal to the west front of the range, but reasonably conclusive evidence for faults of this type was not obtained.

BASINS

The mountainous parts of the area mapped are surrounded by relatively depressed basins, which the writer considers to be primarily of structural, rather than erosional, origin. The depression between the Snowcrest Range and the Gravelly Range is clearly a synclinal basin, and the very conspicuous Centennial Valley, whose west end is in the southeast corner of the area mapped, is probably in part synclinal (pl. 16, cross section B–B′) and in part down-faulted (along the north margin of the Centennial Mountains). Probably, the low area between the Snowcrest Range and the Ruby Range-Blacktail Mountains mass was downwarped. The rather broad valley of Red Rock River appears to occupy a downwarped and in part down-faulted area between the Blacktail Mountains and the Tendoy Mountains, and the relatively narrow valley of Blacktail Creek, which parallels the steep northeast front of the Blacktail Mountains, has been localized by a rather recent range-front fault.

EVOLUTION OF STRUCTURAL FEATURES

The Paleozoic and Mesozoic rocks of southwestern Montana have been folded into large anticlines and synclines, which are modified by overthrust faults, normal faults, and local zones of more intense folding. From Cambrian until late Cretaceous time only gentle warping or doming occurred. In the area studied these minor deformations are recorded only by absence of strata that are present elsewhere and not by recognizable angular unconformities or other obvious structural features. More intense deformation, which is considered to indicate the inception of the Laramide orogeny in or adjacent to the area, is believed to have begun in late Cretaceous time, for the equivalents of the Mesaverde formation and the overlying Upper Cretaceous (?) or Tertiary rocks (group 1) contain pebble beds and grits with abundant angular fragments that probably were derived from a local area of appreciable relief. The principal phase of the Laramide diastrophic activity occurred immediately before and during deposition of the thick fanglomerates and conglomerates of group 2, and probably consisted of at least two strong pulsations. The major fold structures are thought to have been formed during the first of these, and the lower fanglomerate and conglomerate unit of group 1 was probably deposited during and immediately subsequent to the latter part of this first pulsation. The overlying limestone and fine-grained clastic rocks were probably deposited during an interval of relative crustal stability between pulsations, and the upper fanglomerate and conglomerate unit during the second major pulsation, which made the small, more intensely folded structures and culminated with overthrust faulting. In the valley of Sage Creek middle Eocene beds rest with probable unconformity on coarse clastic rocks that are interpreted to be the products of this final Laramide pulsation.

The Laramide orogeny was followed by an interval of relative crustal stability during which the "Laramide" mountains were eroded to a surface of low relief and fluviatile and lacustrine deposits accumulated in intermontane basins that occupied about the same positions as the present day basins. The sequence of events during this interval probably conforms to that recognized by Pardee (1947, p. 1215) as typical in western Montana. However, the observations made during the present reconnaissance were not sufficiently detailed to demonstrate Pardee's generalization that the region had been worn to a surface of moderate or slight relief by Oligocene time, had then been gently warped so that the present-day mountains and basins began to form, and had again been eroded to a surface of slight relief (late Tertiary peneplain) by late Miocene or early Pliocene time. Late Tertiary uplift and block faulting, which according to Pardee began early in the Pliocene and continued into the early part of Pleistocene time, formed the ranges and basins that exist today, somewhat modified by Pleistocene and Recent erosion.

In summary, most of the major structural features observed in this area were formed during the Laramide orogeny that began during late Cretaceous time and ended before Middle Eocene time. The more conspicuous physiographic features are the result of late Tertiary uplift and block faulting.

ECONOMIC GEOLOGY

In the area mapped, talc, graphite, coal, and sand and gravel have been mined, and deposits of phosphate rock, oil shale, clay, building stone, copper, nickel, and iron are known to occur but have been little explored. During 1946 and 1947 the oil and gas possibilities of the southern part of the area were appraised by geologists of at least two petroleum companies; a seismic survey of an area south and southeast of Lima was made by one of them.

TALC

Replacement deposits of talc in pre-Cambrian dolomitic limestone of the Cherry Creek (?) group occur at several localities in the southwestern part of the Ruby Range. The principal deposit, the Smith-Dillon, is in Axes Canyon (sec. 23, T. 8 S., R. 8 W.) about 12 miles by road southeast of Dillon (Armstrong, 1944). The talc body is in dolomitic limestone at or near a contact with glassy quartzite. It is elliptical in plan with a maximum length of about 450 feet and a maximum width of at least 100 feet. Since 1941 the Tri-State Minerals Co. has been mining the deposit and shipping several hundred tons of talc a week. Select hand-sorted talc is massive, white steatite (?), and is used for talcum powder. Mine-run talc is used in the ceramic industry.

Similar, but smaller, replacement deposits of talc in dolomitic limestone have been prospected along the Sweetwater road (sec. 2, T. 8 S., R. 7 W.) about 11 miles east of Dillon.

GRAPHITE

One of the few deposits of Ceylon-type graphite in the United States is in the southern part of the Ruby Range on the ridge between Van Camp and Timber Creeks in secs. 29, 30, 31, and 32, T. 8 S., R. 7 W. (Winchell, 1914, pp. 105–110). The graphite occurs in pre-Cambrian gneiss and schist of the Cherry Creek (?) group and in quartz-feldspar pegmatite dikes that cut the metamorphic rocks. The deposit has been exploited intermittently since 1899, and about 2,200 tons of graphite has been produced. According to Armstrong (1946, p. 8), graphite, the only ore mineral, occurs in three distinct ways—as a vein filling, as a component mineral in pegmatite, and as a dissemination in gneiss. The most important mode of occurrence is as vein filling in fractures.

PHOSPHATE ROCK

In 1916, Condit, Finch, and Pardee (1927, pp. 198–204) traced the phosphate-bearing Phosphoria formation through the Gravelly Range east of the Snowcrest Range to T. 10 S., but it was not recognized in the southern part of the Snowcrest Range until 1944, when A. P. Butler (oral communication) observed characteristic outcrops along the West Fork of Blacktail Creek. During the present reconnaissance the formation was traced from T. 10 S., to the Lima Reservoir, a distance of about 25 miles. Throughout this distance it lies along the east limb of the anticline that forms the backbone of the Snowcrest Range. From Canyon Camp along the Ruby River (secs. 17 and 18, T. 9 S., R. 3 W.) to Little Basin Creek (sec. 7, T. 13 S., R. 6 W.) the formation crops out sporadically. South of Little Basin Creek it passes beneath a cover of Tertiary rocks, but reappears again in secs. 22 and 28, T. 13 S., R. 7 W. The total length of the belt underlain by the Phosphoria formation is about 32 miles.

The upper cherty part of the Phosphoria crops out in many places, but the phosphatic and shaly part of the formation are almost everywhere covered by talus of the Quadrant formation. Exposures of oolitic phosphate rock were seen at only four localities within the area: detailed sections have since been measured at two of these localities (pp. 62–66). In a few other localities loose chips of phosphatic shale and oolitic phosphate rock were found. The attitude of overlying and underlying rocks indicate that the phosphatic beds in the southern part of the range dip from 40° E. to vertical; in the northern part, where the beds are overturned, they dip from 35° W. to vertical.

Phosphate rock, possibly of commercial grade, occurs at about 75 feet above the base of the formation (as defined in this paper) and at 350 to 400 feet above the base. The lower phosphatic zone contains a unit from 4 to 6½ feet thick that consists largely of oolitic phosphate rock. The upper zone comprises interbedded phosphate rock and phosphatic shale. None of the units of phosphate rock in this upper zone exceeds 3 feet in thickness. A Geological Survey field party collected samples from the two zones at each locality but results of analyses are not yet available.

SILLIMANITE

In 1948 E. W. Heinrich, then of the Montana Bureau of Mines and Geology, discovered sillimanite-bearing rocks in the southwestern part of the Ruby Range (Heinrich, 1948, p. 20). One deposit that may be of economic significance occurs on the north side of Carter Creek 9.5 miles east-southeast of Dillon. In this deposit felted aggregates of sillimanite needles are scattered abundantly through a medium-grained biotite gneiss, which is cut by many small bodies of unmetamorphosed sillimanite-bearing pegmatite.

GRAVEL AND SAND

Extensive terraces of gravel and sand that occur along the Beaverhead and Red Rock Rivers furnish road metal, railroad ballast, and material for concrete. The supply, considered in terms of probable local demand, is virtually inexhaustible.

CLAY AND BUILDING STONE

Alluvial clay has been quarried on a small scale near Dillon and used in the local manufacture of bricks. Clayey beds or zones occur in the Tertiary and Cretaceous rocks of the area, but the suitability of these clays for industrial purposes has not been determined.

In the vicinity of Dillon sandstone of the Quadrant formation, Cretaceous (?) sandstone, and rhyolitic tuff of Tertiary age have been quarried on a small scale for building stone (Winchell, 1914, pp. 104–105). Part of the Quadrant formation is silica sandstone, which may be pure enough for use as glass sand. In the past it was used in large quantities and at present is used in small quantity for flux and converter linings at the Washoe smelter in Anaconda (Winchell, p. 104).

VOLCANIC ROCKS

Some of the Tertiary tuffaceous rocks in the area might be suitable for lightweight aggregate. Similar rocks in Frying Pan Basin northwest of Dillon are mined and moulded into lightweight blocks for local construction. Probably, the bentonitic beds in the lower part of the Upper Cretaceous rocks near Canyon Camp in Ruby River valley are too thin and too impure to be of economic value.

METALLIFEROUS DEPOSITS

Winchell (1914, p. 104) described several deposits of chalcopyrite and pyrrhotite and of magnetite in pre-Cambrian rocks near the south end of the Ruby Range. None of these deposits has been exploited in recent years, and, as far as is known, none has ever been productive. Local residents state that copper minerals have been found on the south slope of Olson Peak (sec. 19, T. 11 S., R. 4 W.) in the Snowcrest Range.

An ultramafic complex, 4½ miles long and as much as 1½ miles wide, occurs near the southern end of the Ruby Range (secs. 1 and 2, T. 9 S., R. 7 W. and secs. 35 and 36, T. 8 S., R. 7 W.) (Sinkler, 1942, pp. 136–152). According to Sinkler, annabergite, the nickel arsenate, occurs locally as encrustations on saxonite, one of the components of the ultramafic complex. She postulates that the annabergite is of hydrothermal origin and probably was deposited from solutions that contained arsenic and acquired nickel by liberating it from silicate minerals in the ultrabasic rocks they penetrated. A similar ultramafic body with low nickel content occurs on Jake Creek (sec. 17, T. 10 S., R. 7 W.) near the front of the Blacktail Mountains (Sinkler, p. 137).

COAL

A thin seam of lignitic or semibituminous coal on Basin Creek (sec. 28 (?), T. 11 S., R. 3 W.), a tributary of Ruby River, was formerly exploited on a small scale for local use. The seam is 2 to 3 feet thick and is interbedded with impure calcareous sandstones and arenaceous shales and siltstones of late Cretaceous (Mesaverde) age.

OIL SHALE

For more than 30 years it has been known that certain rocks in the Phosphoria formation and in the Tertiary deposits of southwestern Montana contain appreciable quantities of distillable hydrocarbons (Bowen, 1918, pp. 315–320; Condit, 1919, pp. 15–28; Winchester, 1923, pp. 78–91). Between 1915 and 1919 this knowledge led to a flurry of stock selling and the drilling of several dry wells in the Dillon area.

Samples of shale of the Phosphoria formation from seven localities west of the area described herein, and from one locality south of, and one east of the area, contain oil (Winchester, 1923, pp. 85–87). The highest content is in beds in Small Horn Canyon (sec. 14, T. 9 S., R. 9 W.) where a thickness of 5½ feet of black shale contains 21 gallons per ton, and the underlying 12 feet 7 inches of interbedded shale and phosphate rock contains 17 gallons per ton, a total of 18 feet 1 inch of rock with an average content of 18.2 gallons per ton. In 1919 the Dillon Oil Co. installed a small retort in Small Horn Canyon, but their attempt to recover oil in commercial quantity from these shales was unsuccessful (Winchester, p. 91).

Tertiary rocks that contain oil crop out along Keystone Creek, about 15 miles west of the area of this reconnaissance (Winchester, p. 89), but none were found within the area.

No samples from the area have been tested, but almost certainly some of the dark shale beds in the Phosphoria formation, some of the black shale and lignitic beds of Upper Cretaceous age, and some beds of the Jefferson (?) dolomite contain oil.

OIL AND GAS POSSIBILITIES

Petroleum companies showed little interest in southwestern Montana for more than 20 years after the negative results of the exploration for oil in the Dillon area during 1915–19 and the publication of Condit's opinion (1919, pp. 21–22) that probably there are no oil pools in this complexly folded, faulted, and intruded region. During the last few years, however, interest in the petroleum possibilities of southwestern Montana has been renewed. Although the present investigation was not specifically planned to evaluate the oil and gas possibilities of the region, certain geologic features were observed that have some bearing on the likelihood of finding petroleum, and these are briefly mentioned below.

SOURCE ROCKS

In the area mapped, potential pre-Tertiary source rocks (Jefferson? dolomite, Phosphoria formation, and Upper Cretaceous shales) are exposed only in the Snowcrest Range, but the same rock units crop out in the Centennial Mountains to the south, in the Tendoy Mountains to the west, at the north end of the Blacktail Mountains to the north, and in the Gravelly Range to the east; unquestionably they underlie parts of the basins that lie between the ranges. Nonmarine Tertiary rocks blanket about half of the area studies, but none were found that appeared to contain any appreciable quantity of organic matter. With few exceptions, the nonmarine Tertiary rocks in the northern Rocky Mountains have not yielded oil and gas in commercial quantities.

RESERVOIR ROCKS

In Montana and Wyoming oil and gas have been produced from a number of zones in the Mesozoic and Paleozoic rocks. The most productive of these are sandstones in the Kootenai formation and the Colorado group, the Quadrant and Tensleep formations, and the Madison limestone. Other formations that have yielded oil or gas in Montana (Perry, 1937, pp. 6–18; Gardner and others, 1945, chart 18; Sloss and Laird, 1945, chart 15) are: the Judith River formation of Late Cretaceous age (Baker-Glendive gas field), the Eagle sandstone of Late Cretaceous age (Bowes, Box Elder, Havre, Lake Basin, and the Dry Creek gas fields), the Ellis formation (Bannatyne oil field), the Amsden formation (Soap Creek and Gage cil fields), and the Big Snowy group (Devils Basin oil field). One hole drilled to the Jefferson dolomite on Whitlash dome encountered oil-saturated dolomite, and several in the Kevin-Sunburst field encountered large volumes of carbon dioxide gas under high pressure; none yielded oil in commercial quantity.

Most of the formations that have been productive elsewhere in Montana are present in and adjacent to the area mapped. As observed in outcrop, some of the sandstones of the Colorado group and the Kootenai formation seem to be suitable reservoir rocks. Other sandstones contain so much silt or clay, or are cemented by silica or calcite to such a degree that they probably would not be suitable. Rocks of Jurassic age are not present, and those of Triassic and Permian age do not appear to have the characteristics of favorable reservoir rocks. The Quadrant formation consists chiefly of massive beds of rather pure quartz sand, but the degree and character of cementation varies considerably from place to place. Locally, cementation is slight and many beds are friable; elsewhere the sand grains are welded by interstitial quartz into a tough vitreous quartzite;

less commonly, and probably only in certain horizons, the sand grains are cemented by dolomite. More detailed study is needed to determine whether the differential cementation is stratigraphically or structurally controlled, and whether it is partly due to differential weathering.

In parts of Montana, Alberta, and Wyoming, large quantities of oil have been produced from porous and permeable zones in the upper part of the Madison limestone (Mission Canyon limestone). The porous and permeable zones at different places appear to be the result of one or more of the following causes: solution by surface and ground waters during pre-Jurassic exposure of the Mission Canyon limestone to erosion; dolomitization by epigenetic replacement; presence of beds of sandstone or oolitic and granular limestone; or fracturing (Sloss and Hamblin, 1942, pp. 326–328). The Madison limestone in the area of this report is probably not sufficiently porous and permeable to be an important reservoir rock; it is not noticeably sandy or dolomitic, and it does not exhibit features that appear to be due to the action in pre-Jurassic time of ground or surface waters.

STRUCTURAL FEATURES

Condit (1919, pp. 21–22) pointed out that the sedimentary rocks in the Dillon-Dell area were so shattered by intense folding and faulting that any enclosed oil or gas would have found its way to the surface long ago. He also called attention to the intrusive igneous rocks in the area.

In a broad way, Condit's observations are probably applicable to most of southwestern Montana. In the mountainous areas, whether the rocks are intensely deformed, as in the Tendoy Mountains and Snowcrest Range, or only moderately deformed, as in the Centennial Mountain and the greater part of the Blacktail Mountains, most if not all the potential reservoir structures have been breached by erosion and flushed by circulating ground water. However, some of the intermontane basins may be underlain by moderately deformed and unbreached structures in Paleozoic and Mesozoic rocks. The Centennial Valley, for example, is considered to be essentially a synclinal trough, deepened by faulting. The rocks in the southern part of the Snowcrest Range dip southeastward beneath a blanket of Tertiary alluvium. The same sequence, dipping southward, is exposed along the north face of the Centennial Mountains. If, as appears reasonable, the Centennial Mountains is an up-faulted block, a favorable structural trap may exist where permeable beds beneath the valley floor about against the inferred range-front fault. Furthermore, there may be minor closed structures in the broad synclinal structure that underlies Centennial Valley.

Rocks and structures that might form reservoirs may occur east of the Tendoy Mountains in the vicinity of Lima, and west of the crest of the Blacktail Mountains east of Armstead. In the latter area gently westward-dipping Paleozoic sedimentary rocks are buried beneath the thick blanket of Tertiary volcanic and sedimentary rocks that forms the western half of the Blacktail Mountains. These same formations are exposed in complicated structures north and west of Armstead, and they may be involved in closed structures beneath the Tertiary cover east of Armstead. There may be minor closed structures in the Kootenai formation and older rocks in the synclinal basin between the Snowcrest Range and the Gravelly Range.

The older Tertiary rocks have been involved in folding, overthrusting, and normal faulting, and locally may contain structures that could serve as reservoirs. Although these rocks do not appear to contain significant quantities of indigenous organic matter, the possibility should not be overlooked that commercial quantities of oil and gas might leak in to them from underlying Paleozoic and Mesozoic rocks.

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