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SUMMARY OF THE GEOLOGY OF THE BEARTOOTH MOUNTAINS, MONTANA[1]

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[1] An abridgment of a thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at the University of Chicago, 1921.

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LOCATION AND EXTENT OF THE RANGE

The Beartooth Mountains are in southern Montana and northwestern Wyoming, where they form the front range of the Rocky Mountains. The range has the approximate form of a broad, much elongated, slightly curved oval which extends southeasterly from Yellowstone Valley above Livingston to the canyon of the Clark Fork of Yellowstone River, about 30 miles northwest of Cody, Wyoming (Fig. 1). It is about 80 miles long and has a maximum width of about 30 miles south of its central portion, northeast of the northeast corner of Yellowstone Park.

The boundary between the range and the Great Plains is sharply marked (Figs. 2 and 3) but the boundary on the southwest is much less definite. South of the state line the Clark Fork is taken commonly as the line of demarcation between the Beartooth Mountains and the Absaroka Range to the west. In Montana the two ranges merge more or less, which makes it difficult to draw a sharp natural boundary between them. For this discussion the boundary is taken mainly along the divide between the streams that flow south and west to Yellowstone River and those that pursue a northerly course across the greater portion of the Beartooth Mountains to the same river far beyond the front of the range. Inasmuch as this boundary roughly follows the structural limits of the range, it is less arbitrarily chosen than may appear from this statement.

The range lies wholly within the drainage system of Yellowstone River. With the exception of Soda Butte Creek and a few other small creeks that flow into the northeastern part of Yellowstone Park, all of the streams flow northeasterly from the plains-ward front of the range across the bordering plains for many miles before uniting with the trunk stream. The main streams are permanent, even in seasons of excessive drought, as they receive an abundant and constant water supply from numerous perpetual snow fields, several small glaciers, and a multitude of lakes that are scattered throughout the range.

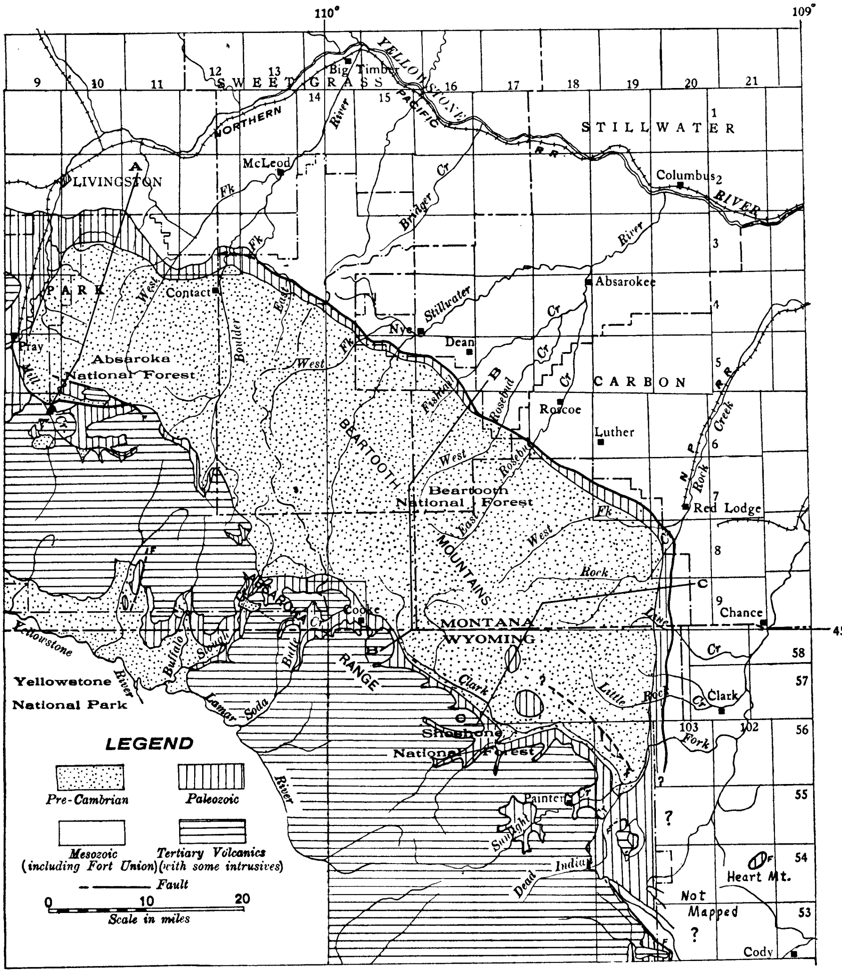

FIG. 1.—Sketch geologic map of the Beartooth Mountains and environs. Based in part on publications of the United States Geological Survey. Geology northwest of Cody after C. L. Dake. Geology west and south of Livingston somewhat generalized.

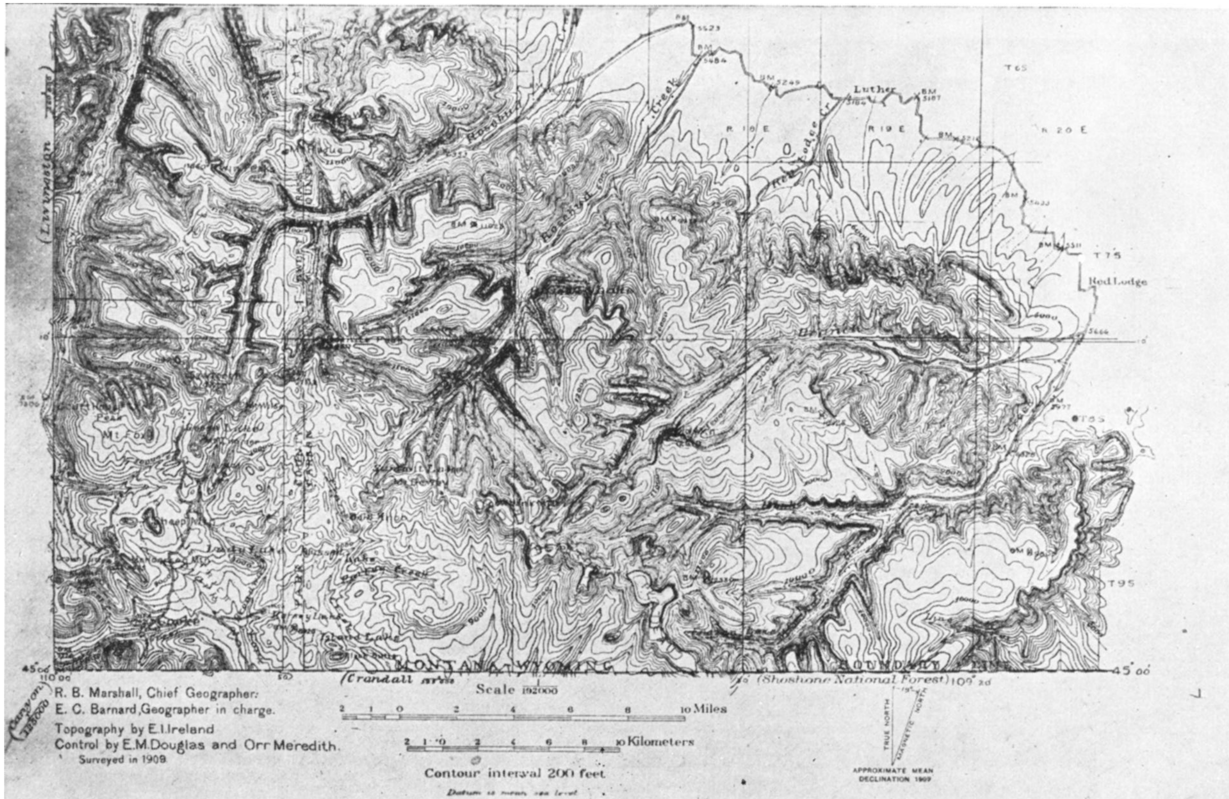

FIG. 2.—Topographic map of the central part of the Beartooth Range. Note the abrupt plains-ward front, extensive flattish areas of the sub-summit plateau, summit plateau remnants between 109°30′ and 109°40′, glaciated area on southwest slope, and the canyon-like valleys on the northeast slope.

SALIENT TOPOGRAPHIC FEATURES

The plains-ward front.—The Beartooth Range rises abruptly to a height of a few thousand feet above the Great Plains on the northeast. The 6,000-foot contour almost everywhere follows the base of the range, and the plains-ward crest has an elevation of 9,000 to 10,000 feet. In the southern part the frontal slope is uncommonly steep, but to the north it is neither so steep nor so uniform nor everywhere so sharply separated from the bordering plains.

The sub-summit plateau.—The remarkably even outline of the crest for considerable distances, especially in the southern half of the range, is an impressive feature (Fig. 3). It marks the plains-ward rim of a broad flattish plateau that extends along the eastern portion of the range for most of its length. This extensive surface is herewith designated, from its form and topographic position, the "sub-summit plateau." It consists of a series of gently undulating upland flats, each containing several square miles, that are the remnants of a once continuous erosional plain (Fig. 2). The largest tracts are about 10 miles wide and have an area of 10 to 20 square miles. Extensive portions of some of these plateau remnants are strikingly flat (Fig. 4).

In its longest dimension, parallel to the axis of the range, this plateau varies in altitude from slightly less than 10,000 feet, in the vicinity of Boulder River, to more than 11,000 feet in the central portion, then drops a few hundred feet toward its southern extremity. Its surface rises gradually toward the interior of the range, but becomes increasingly steep toward the main axial divide.

Sharp valleys 3,000 to 4,000 or more feet deep have been carved in this plateau by the several northeasterly flowing streams and their numerous tributaries. The dissection is least advanced in the southern half of the range and has progressed farthest in the northwestern portion, but even here the old surface is partially preserved in flattish tracts of considerable size. East Boulder and West Boulder plateaus, which are shown on the topographic map of the Livingston, Montana, quadrangle, are fairly typical remnants, but the best examples are in the south-central part of the range, just north of the Wyoming boundary (Figs. 2 and 4).

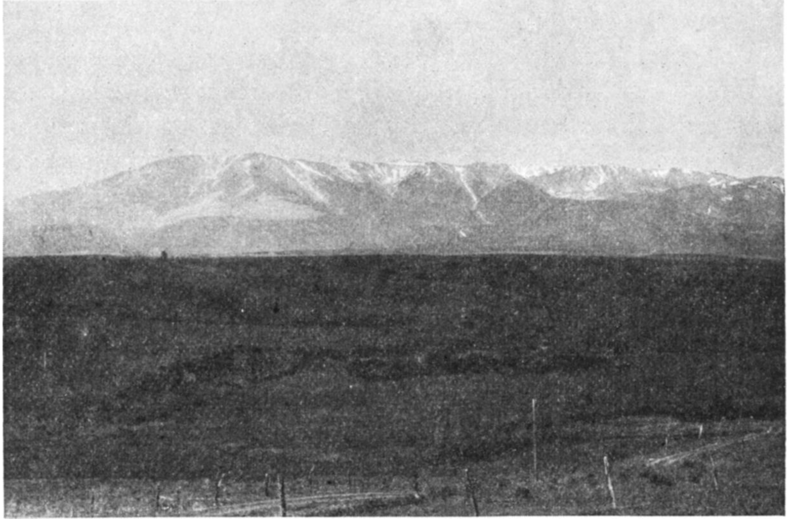

FIG. 3.—The plains-ward front of the Beartooth Range west of West Rosebud Creek. The elevation at the base is about 6,000 feet and at the summit about 10,000 feet. The even crest marks the rim of the sub-summit plateau, which is notched by cirques.

FIG. 4.—A portion of the sub-summit plateau showing its remarkable flatness over large areas. The altitude is about 10,000 feet. The rocks are pre-Cambrian crystallines. Silver Run Plateau, southwest of Red Lodge, in the foreground, with Line Creek Plateau to the south beyond Rock Creek.

The summit plateau.—The axial portion of the range is characterized by two distinctly opposing features: its extreme ruggedness, and the flattish summits of many of the dominant peaks (Fig. 5). The highest peaks and ridges of this rugged district in the south-central part of the range exhibit remarkably even-crested summits when viewed from any direction. The most extensive remnant of

FIG. 5.—Remnants of the summit peneplain along the main divide at the head of Rock Creek. Elevation of the even crests is about 12,400 feet. Looking southwest from Silver Run Plateau.

the summit plateau, which is called the Beartooth Plateau,[1] exists just north of the Wyoming boundary. It is a narrow, deeply notched plateau with an area of several square miles, which coincides with the axis of the range for about 12 miles (Fig. 2). Its rim almost everywhere overlooks very steep slopes or sheer precipices, most of which are from 1,000 to more than 1,500 feet high. The

[1] The name Beartooth Plateau has been used by some to mean the sub-summit plateau along the eastern front of the range, or the glaciated plateau on the southwestern slope. The writer follows the usage of the term on the published topographic map of the Beartooth National Forest, where the name is restricted to the summit plateau.

elevation of this plateau is approximately 12,000 to 12,400 feet, or about 1,500 to 2,000 feet above the general surface of the sub-summit plateau. As observed from an altitude of 12,200 feet in the vicinity of Granite Peak it appears to have a southwesterly dip of about 5° (Fig. 6).

FIG. 6.—The summit peneplain southeast of East Rosebud Valley. The elevation is about 12,400 feet. The rocks are pre-Cambrian crystallines. Looking southeast from the vicinity of Granite Peak.

STRATIGRAPHY[1]

The pre-Cambrian core.—The main mass of the range consists chiefly of pre-Cambrian granite and granite-gneiss, with subordinate amounts of basic gneisses and schists. A considerable mass of anorthosite-gneiss exists on the east side of Boulder Valley, and extends southeast for an unknown distance.[2] Numerous basic intrusions, mainly dikes and small stocks, partly of pre-Cambrian age and in part possibly much younger, invade this crystalline core

[1] The areal geology of the northwestern portion of the range is shown by the Livingston, Montana, folio (No. 1), and that of the southwestern slope south of the state line on the Crandall sheet of the Absaroka, Wyoming, folio (No. 52).

[2] C. H. Clapp, oral communication.

in many places. Coarse pegmatite dikes are fairly common in the granite and gneiss. A unique feature is a large dike of pyroxenite that extends from Boulder River, below Contact, southeast beyond the head of Little Rocky Creek, southwest of Dean, and contains a large tabular deposit of high-grade chromite.[1]

No sedimentary formations of pre-Cambrian age have been discovered anywhere in this region.

Sedimentary formations.—Sedimentary formations are restricted to the flanks of the range. The indurated strata range in age from middle Cambrian to late Cretaceous or Paleocene. All the Paleozoic systems, except the Silurian which is absent, are represented by extensive deposits of limestone and dolomite with subordinate amounts of more or less calcareous shale and sandstone. The entire sequence is present along the eastern and northern base of the range, but erosion has removed most of the upper Paleozoics on the southwest slope north of the Wyoming boundary. Mesozoic formations are present only along the plains-ward front of the range and in the adjacent plains. All the systems are present. They consist preponderantly of alternating sandstone and shale with some limestone, gypsum, and coal. The upper part of the sequence in the northern part of the area is composed mainly of volcanic materials (Livingston formation). In Carbon County a thick series (Fort Union) of sandstone, shale, and coal lies with apparent conformity upon the youngest beds of undoubted Mesozoic age. Farther south along the mountain front a conspicuous conglomerate may be of later age.

The maximum thickness of the sedimentary formations on the east side of the Beartooth Range is approximately 18,000 feet. This is exclusive of the Livingston tuffaceous sandstones and agglomerates which in places are more than 5,000 feet thick. The Paleozoic systems have a total thickness between 3,500 and 4,000 feet, the undoubted Mesozoic systems about 6,000 feet, and the strata included in the Fort Union formation approximately 8,500 feet.[2]

[1] L. G. Westgate, "Deposits of Chromite in Stillwater and Sweetgrass Counties, Montana," *U.S. Geol. Survey Bull. 725-A*, 1921, pp. 67–84.

[2] E. G. Woodruff, "The Red Lodge Coal Field, Montana," *U.S. Geol. Survey Bull. 341*, 1908, Pt. II, p. 92.

The thickness of the individual formations and their main characteristics are shown in Table I. Many of the thickness values have

TABLE I

FORMATIONS IN THE BEARTOOTH MOUNTAINS AND ADJACENT GREAT PLAINS

Age	Formation	Approximate Thickness	Dominant Characteristics
		Feet	
Quaternary.....	....	?	Glacial drift, stream gravels, talus, and landslides
Tertiary........	....	?	Andesitic breccias and lavas
Tertiary (?)....	Fort Union (Lance (?) in lower part)	8,500	Yellowish sandstone and shale with several beds of workable coal; contains leaves and fresh-water shells
Tertiary (?) and Cretaceous......	Livingston	3,000–5,000	Brownish and greenish andesitic sandstone and shale, with a thick member of andesitic agglomerate; lower beds are leaf-bearing
Cretaceous......	Montana group:		
	Bearpaw	125	Dark-gray clayey shale with scattered concretions and a few thin sandstones; marine invertebrate fossils
	Judith River	375	Soft, gray to yellowish sandstone and sandy shale with some lignitic beds; fresh- and brackish-water shells
	Claggett	435	Gray sandstone and sandy shale; marine and brackish-water invertebrates
	Eagle	200–300	Gray to white sandstone, thin- to massive-bedded, with sandy and carbonaceous shale; contains workable coal; marine fossils in lower part
	Colorado	2,000–3,700*	Dark-gray clayey shale with some intercalated sandstone and scattered calcareous concretions; marine fossils
Comanchean....	Kootenai	300–500	Buff coarse-grained to conglomeratic sandstone, and purple to maroon shale
Comanchean and Jurassic (?)	Morrison	150	Dark-gray to greenish-gray sandstone and shale
Jurassic........	Ellis	350–450	Greenish and reddish sandy shale, gray sandstone, and gray limestone; becomes sandy limestone to northwest; abundant marine fossils
Triassic........	Chugwater	0–700	Red sandstone and shale with beds of gypsum
Permian (?)....	Phosphoria	400	Gray quartzite and sandstone, chert, reddish shale, and impure limestone; marine fossils
Penn. and Miss..	Quadrant		
Mississippian....	Madison	1,500	Light- to dark-gray, blue-gray and brown limestone in thin to thick beds; chert nodules locally; abundant marine fossils
Devonian.......	Threeforks	100	Dark-gray, thin-bedded limestone alternating with dark shale; marine fossils locally
	Jefferson	425	Light- to dark-gray and brown fetid dolomite; commonly thin-bedded; marine fossils locally
Ordovician......	Bighorn	435	Light-gray to buff cliff-making dolomite alternating with thin beds; few marine fossils
Cambrian.......	Gallatin	400	Interbedded limestone and shale, flat-pebble conglomerate, glauconitic and oolitic beds; marine fossils, as trilobites
	Flathead	400	Shale, thin sandstone, and thin limestone; basal conglomerate locally
Pre-Cambrian... (Archean?).	....	....	Mainly granite, granite-gneiss, and mica schist; basic gneiss locally

* This thickness is doubtfully assigned to the Colorado near Livingston by W. R. Calvert, *U.S. Geol. Survey Bull. 471*, 1912, p. 387.

been obtained from the publications to which reference is made in the footnotes.[1]

[1] The data for the Montana group in this area have been obtained largely from C. A. Fisher, "Southern Extension of the Kootenai and Montana Coal-Bearing Formations in Northern Montana," *Econ. Geol.*, III (1908), pp. 93–96.

The Flathead formation (middle Cambrian) and the Gallatin formation (middle and upper Cambrian) cannot be readily subdivided in this part of the state into the several formations that constitute the Cambrian system in the Little Belt Mountains[1] and northwest along the Rocky Mountain Front. The Bighorn dolomite apparently marks in this range the northern-most extent of the Ordovician in Montana. Although the formation is a lithologic unit with no evidence of a break in it yet discovered on the northeast side of the range, "a conspicuous surface of disconformity, with a basal breccia" exists in it on the extreme southwest slope.[2] It may be noted further that the Devonian of Montana apparently does not extend many miles south of the Beartooth Range in Wyoming. Hence this range contains one of the most complete Paleozoic sections in the northern Rocky Mountains. The Madison limestone is the bold cliff-making limestone (Fig. 7) which is so conspicuous throughout the northern Rockies. The Quadrant formation in the northern part of the range is roughly equivalent to the Amsden and Tensleep formations in Clark Fork Canyon at the southern end of the range. D. D. Condit has recently differentiated the Phosphoria formation in this region, and has indicated its distribution along the east base of the range.[3]

A narrow belt of the Chugwater "Red Beds," presumably in the main of Triassic age, is present along the base of the range in northwestern Wyoming, but disappears a short distance north of the state line. The Chugwater and Quadrant formations are overlain respectively by the Sundance formation in Wyoming and the Ellis formation in Montana—two marine formations that are equivalent in the main and of middle to late Jurassic age.[4] They are composed chiefly of interbedded shale and limestone in proportions which vary from place to place. Between the mountain front and Clark Fork River in the plains, the Morrison and Kootenai

[1] W. H. Weed, "Geology of the Little Belt Mountains, Montana," *U.S. Geol. Survey Ann. Rept. XX*, 1900, Pt. 3, pp. 284–87.

[2] C. W. Tomlinson, "The Middle Paleozoic Stratigraphy of the Central Rocky Mountain Region," *Jour. Geol.*, XXV (1917), 35.

[3] *U.S. Geol. Survey*, Prof. Paper 120–F, Pl. IX, 1918.

[4] Charles Schuchert, *Bull. Geol. Soc. Am.*, XXIX (1918), 246.

(or the roughly equivalent Cloverly) formations, both in the main of Comanchean age, the Colorado shale, and the divisions of the Montana group, are exposed in several places. The Morrison and Cloverly formations crop out only in the southeastern part of the district, where they consist of varicolored clastics and thin limestones of non-marine origin. The Kootenai formation is present

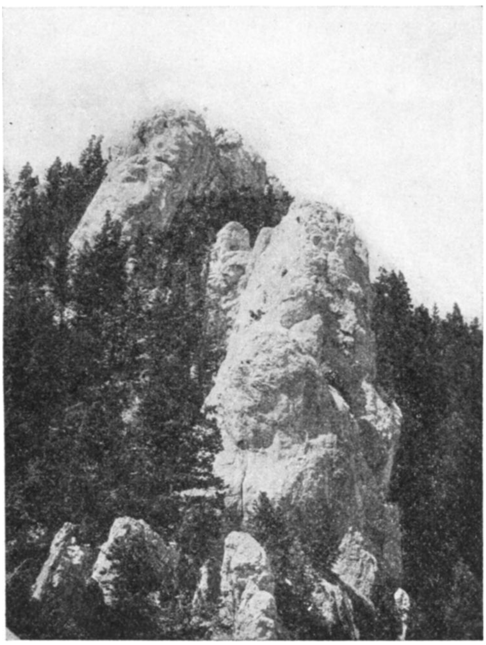

FIG. 7.—Massive Madison limestone that forms a conspicuous ridge west of Red Lodge. The beds are overturned slightly to the east (right). Gravel-capped Fort Union strata beyond east base of the ridge.

along the base of the range east of Livingston, where it corresponds approximately to the Dakota formation, as delineated on the Livingston areal map (Folio No. 1). The Colorado shale is the typical thick deposit of marine shale, but with more interbedded sandstone than is common farther north in Montana. A succession of non-marine sandstones and marine shales similar to that of the Lake Basin district[1] to the northeast, constitutes the Montana

[1] E. T. Hancock, "Geology and Oil and Gas Prospects of the Lake Basin Field, Montana," *U.S. Geol. Survey Bull. 691–D*, 1918, pp. 114–24.

group in Clark Fork Valley,[1] but the shales become distinctly more arenaceous and in part grade laterally into sandstone as the mountain front is approached. The Eagle formation contains workable coal in Clark Fork and Stillwater valleys.[2] Along the northern third of the range the Eagle is overlain by the thick tuffaceous beds of the Livingston formation, which apparently accumulated during the early Montana to Fort Union interval.[3] This formation consists of andesitic sandstones with a thick areally extensive lens of agglomerate as the middle portion.

The Lance formation has not been certainly identified in this region, and as typically developed on the Great Plains may be lacking. Detailed work in this part of the state will probably show that it is represented in the basal portion of the extraordinarily thick "Fort Union" section in Carbon County. Some of the tuffaceous sandstones in the upper part of the Livingston formation may be in part equivalent to the Lance.

The Fort Union formation occupies a broad area in the vicinity of Red Lodge and extends south along the mountain front toward the Wyoming line. It consists of a thick series of interbedded sandstone, shale, and clay, with numerous beds of coal in the middle portion. Several of these beds supply most of the coal produced in Carbon County. The entire formation is of continental origin.

Although the Fort Union formation in Montana is generally considered to be of early Eocene (Paleocene) age, there is a growing tendency to refer it with the Lance to the uppermost Cretaceous.[4] This is due in part to the apparent establishment of the Cretaceous age of the Lance by the discovery elsewhere of a member with a

[1] C. A. Fisher, *op. cit.*, pp. 77–99.

[2] Students of this region should note that the Laramie as shown on the Livingston areal map has been determined to be lower Montana, including the Eagle. See W. R. Calvert, *U.S. Geol. Survey Bull. 471*, 1912, pp. 386–89.

[3] R. W. Stone and W. R. Calvert, "Stratigraphic Relations of the Livingston Formation of Montana," *Econ. Geol.*, V (1910), 751–52.

[4] C. H. Clapp, "Cretaceous and Tertiary Continental Formations (of Central and Eastern Montana)," *Mont. Bur. of Mines and Metal. Bull. No. 4*, 1921, pp. 25–26.

W. D. Matthew, "Fossil Vertebrates and the Cretaceous-Tertiary Problem," *Am. Jour. Sci.*, 5th Ser., II (1921), 205–27.

Charles Schuchert, "Are the Lance and Fort Union Formations of Mesozoic Time?" *Science*, LIII (1921), 45–47.

marine Cretaceous fauna,[1] and the close relationship of the Lance and Fort Union formations. If the Lance is of Cretaceous age, the inclusion of the Fort Union in the Mesozoic is strongly supported by the lithologic similarity of the two formations, the homogeneity of the floras,[2] and the apparent lack of any pronounced hiatus in the Lance-Fort Union sequence. Moreover, upon the basis of recent studies of vertebrate remains in these and similar formations, the conclusion has been reached that the Fort Union belongs in the Cretaceous system.[3]

The Red Lodge district thus far has afforded no evidence bearing upon these phases of the problem. It is, however, a pertinent fact of considerable significance that the Fort Union of this region was involved in the first orogeny that deformed the underlying Mesozoic formations.

South of the Montana line within two miles of the mountain front is a line of hills formed of steeply tilted strata of a rather loosely cemented conglomerate which is composed mainly of well-rounded pebbles and cobbles of Paleozoic limestones. The age and relations of these beds have not been carefully determined, but from their position they seem to be either a part of the Fort Union or the marginal outcrops of the Wasatch of the Bighorn Basin. Although their lithology is more in accord with the published descriptions of the latter, their position and structure suggest that they may be a member of the Fort Union. They may possibly even be of intermediate age.

Another conglomerate, the Linley conglomerate, is present a short distance beyond the range, 10 miles northwest of Red Lodge, where it "lies with marked unconformity on tilted and eroded Fort Union beds."[4] It consists of about 300 feet (maximum) of sand and pebbles of igneous rocks from the crystalline core of the range,

[1] E. R. Lloyd and C. J. Hares, "The Cannonball Marine Member of the Lance Formation of North and South Dakota and Its Bearing on the Lance-Laramie Problem, *Jour. Geol.*, XXIII (1915), 253–57.

[2] F. H. Knowlton, "Are the Lance and Fort Union Formations of Mesozoic Time?" *Science*, LIII (1921), p. 307.

[3] W. D. Matthew, *op. cit.*

[4] W. R. Calvert, "Geology of the Upper Stillwater Basin, Stillwater and Carbon Counties, Montana," *U.S. Geol. Survey Bull. 641–G*, 1916, p. 203.

and a small amount of limestone. It is a local deposit, covering a few square miles, which is probably much younger than the conglomerate south of the state line.

Tertiary igneous rocks.—With the exception of the Livingston formation igneous materials of post-Cambrian age are not common in the Beartooth Mountains. Several dikes, sills, and stocks of Tertiary (?) age are present on the lower southwest slope in the Cooke mining district, and in the Haystack Peak area at the head of the main Boulder River.[1] On the east side of the range, south of Red Lodge, the Fort Union formation is invaded by a few narrow vertical dikes that are roughly parallel to the mountain front.[2] Some of the dikes and stocks within the pre-Cambrian core are probably of Tertiary age, but their extent remains to be determined.

The upper part of the imposing front of the adjacent Absaroka Range in northwestern Wyoming has been carved by the Clark Fork from more than 6,000 feet of volcanics that were ejected from the Crandall Basin volcano and associated vents during the Tertiary. The well-known landmarks of Pilot and Index peaks, which tower impressively above the southwest slope of the Beartooth Range, are sharply eroded from these formations. Although these volcanics do not now extend into the Beartooth Mountains, their great thickness and proximity indicate that their former eastward extent was much greater.

Terrace gravels.—Unconsolidated deposits of Tertiary and Quaternary age are widespread along the western margin of the Great Plains where they extend for many miles beyond the plainsward front of the Beartooth Mountains. The most common materials are stream gravels and bowlders of diverse constitution, which once probably formed an extensive piedmont plain. They have been worked over and over by the major streams and deposited in part at successively lower levels until now they mantle a series of broad terraces upon the truncated sedimentary formations along and between the principal valleys. Three or four of these terraces

[1] W. H. Emmons, "Geology of the Haystack Stock, Cowles, Park County, Montana," *Jour. Geol.*, XVI (1908), 193–229.

[2] N. H. Darton, "Coals of Carbon County, Montana," *U.S. Geol. Survey Bull. 316*, 1907, p. 186.

are commonly present, with the uppermost one several hundred feet above the present streams (Fig. 8).

Glacial drift.[1]—Glacial drift in the form of typical moraines and outwash gravels is present in most of the valleys on the east and northeast slopes of the range. This drift was deposited by fifteen systems of alpine glaciers, many of which contained numerous large tributaries. The outermost moraines commonly exist from 2 to 6 miles beyond the mountain front, but in a few valleys they are a short distance within it. A few of the lateral moraines below the canyon mouths are huge ridges that attain heights of 500 to 1,000 feet above the valley floors (Fig. 9). Drift of two distinct epochs, probably corresponding to early and late Wisconsin, is clearly recognized in several valleys. An impressive characteristic of the recent drift is the abundance of large bowlders strewn over its surface. In some valleys the later glaciers advanced beyond the earlier ones, whereas in others the older lateral moraines extend a mile or two beyond the younger terminal moraines.

FIG. 8.—Terraces along West Fork of Rock Creek, southwest of Red Lodge

A considerable portion of the southwest slope was occupied by a large ice sheet which left an abundance of striated and polished

[1] A paper on the glaciation of the range is being prepared by the writer.

surfaces, countless perched bowlders, and extensive morainal deposits. The area thus glaciated is about 350 square miles between the base of the axial divide on the northeast and the front of the Absaroka Range on the southwest. An extraordinary feature of this glacier was the formation of several distinct valley lobes which passed into valleys sharply trenched athwart the axial divide, then descended these valleys to the plains beyond the eastern base of the range, where conspicuous moraines were formed.

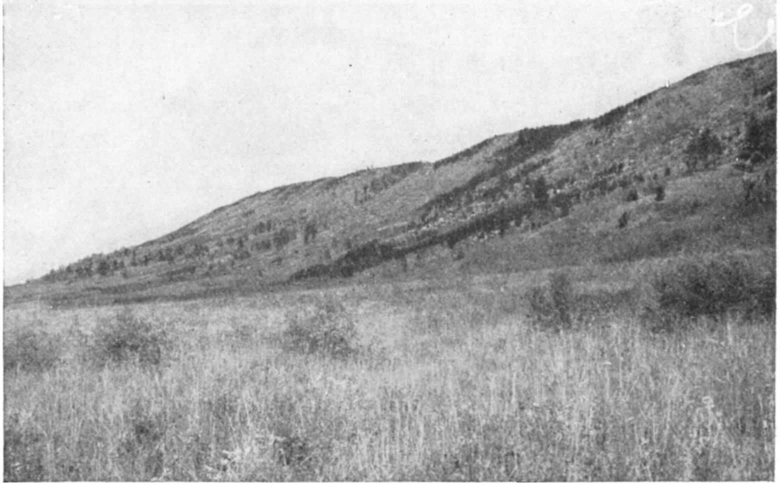

FIG. 9.—The recent lateral moraine on the southeast side of East Rosebud Creek. Its height is about 600 feet.

STRUCTURE

General form of the range.—The Beartooth Range is structurally a broad asymmetric anticline that is in part strongly overturned toward the Great Plains and broken along its northeast limb by a huge fault (Fig. 10). The Paleozoic formations on the southwest slope commonly have low southwesterly dips whereas along the northeast flank they exhibit a variation from high easterly dips to overturned beds that are more than 70° beyond the vertical. Numerous minor faults and folds exist along this side of the range and in the adjacent plains.

The Beartooth overthrust.—The plains-ward front of the range is bounded throughout almost its entire length by the Beartooth

fault, which is an overthrust of considerable magnitude. West of Red Lodge the overturned Madison limestone on the west has been brought against the upper part of the Fort Union formation on the east side of the fault trace. Farther northwest, in the vicinity of West Rosebud Creek, the relations of the faulted formations are obscured by the widespread mantle of terrace gravel and glacial drift, but it appears that the pre-Cambrian crystallines abut

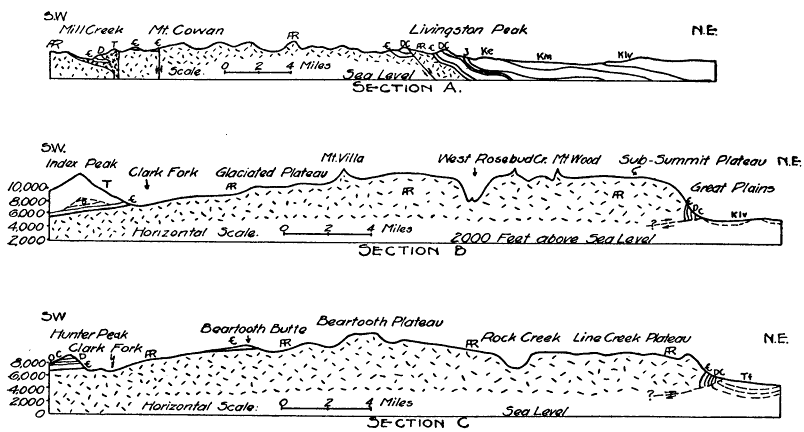

FIG. 10.—Geologic cross-sections of the Beartooth Mountains. Section A is a modification of section CDE of the Livingston folio. *AR*, Archean; *Ꞓ*, Cambrian and Ordovician; *D*, Devonian; *C*, Carboniferous; *J*, Jurassic and Comanchean; *Kc*, Colorado; *Km*, Montana; *Klv*, Livingston; *Tf*, Fort Union; *T*, Tertiary volcanics and intrusives.

against, or overlie, the upper part of the Livingston formation or the lower part of the Fort Union formation.

Along the southeastern front of the range, between the state line and Clark Fork Canyon, the Beartooth fault becomes a zone of thrust faults that in places cause the pre-Cambrian granite to rest upon the Chugwater "Red Beds" (Triassic).[1] "At one point the Chugwater is dipping west (overturned) at angles as low as 20°, and passes under the granite. At another point, the Dakota (Cloverly) was also seen dipping west at a very flat angle, and clearly upside down. The evidence of overturning rested not only

[1] C. L. Dake, "The Heart Mountain Overthrust and Associated Structures in Park County, Wyoming," *Jour. Geol.*, XXVI (1918), 52–53.

on the succession of beds, but on ripple-marks and cross-bedding, and is beyond dispute."[1]

The maximum thickness of the formations displaced by this fault is not less than 10,000 feet, and in places may be considerably more. The actual fault plane has nowhere been observed, but it dips westward at an angle apparently higher than is characteristic of most other Rocky Mountain overthrusts. The strata east of the fault are in some places sharply flexed whereas in others they

FIG. 11.—The Beartooth fault zone southeast of Stillwater Valley. Vertical Madison limestone along the range front, with gently east-dipping Livingston beds on valley slope. Looking southeast.

dip gently away from the fault zone (Fig. 11). At Red Lodge the Fort Union formation dips 18° toward the mountain front, but in the intervening distance of 4 miles it becomes horizontal, then dips gently in the opposite direction as the fault is approached.

The Beartooth overthrust appears to be the northward extension of the Heart Mountain overthrust of northwestern Wyoming, which has been determined recently by Hewett to have an eastward thrust of not less than 28 miles.[2] If not the direct continuation of the Heart Mountain fault it was very probably formed during the

[1] C. L. Dake, letter to the writer, Feb. 13, 1921.

[2] D. F. Hewett, "The Heart Mountain Overthrust, Wyoming," *Jour. Geol.*, XXVIII (1920), 536.

same orogenic epoch. Inasmuch as the fault plane is not exposed and remnants of overthrust beds, if ever present, have not been preserved beyond the eastern base of the range, the amount of horizontal displacement along the Beartooth front is indeterminable. In view of the enormous displacement at Heart Mountain beyond the southeastern end of this range, it is not improbable that the maximum displacement along the Beartooth fault plane was at least several miles, though this is not an absolute corollary.

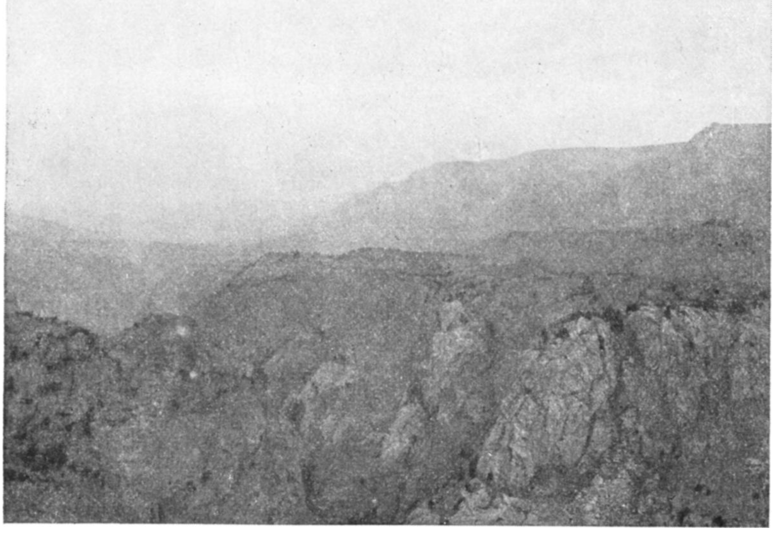

FIG. 12.—The Clark Fork fault (?) along the southwest side of the range. Pre-Cambrian granite in the foreground, overlain by horizontal Cambrian in the distance. Range in background is of pre-Cambrian granite.

The Clark Fork fault (?).—The extreme southwest flank of the range, along the northeast side of Clark Fork Canyon, appears to be bounded by a considerable fault of the gravity (or "normal") type. A rapid reconnaissance trip in stormy weather permitted only a cursory inspection of the geology of this area, but the bold escarpment that here rises abruptly to the western rim of the sub-summit plateau is strongly suggestive of a fault. The topographic evidence is well shown on the topographic maps,[1] although no fault

[1] Crandall, Wyoming, quadrangle and the advance sheet of Part of the Shoshone National Forest, Wyoming.

is indicated on the areal map of the Crandall quadrangle (Folio 52). Furthermore, the pre-Cambrian granite of which the escarpment is composed rises abruptly more than 2,000 feet above Cambrian strata at its base, which are apparently horizontal, or at most only slightly warped (Fig. 12). This escarpment trends northwest and disappears southwest of Beartooth Butte in the crystalline rocks of the sub-summit plateau. The maximum vertical displacement of this fault may be several thousand feet, as all the Paleozoic formations, and an unknown thickness of the pre-Cambrian rocks, have been eroded from the summit of the range.

HISTORY OF THE RANGE

Antecedent conditions.—The Paleozoic and Mesozoic eras were a time of gradual preparation for the birth of this Rocky Mountain front range. An erosional plain of low relief that had been developed upon the pre-Cambrian crystallines was flooded by the middle Cambrian sea. Repeated incursions in subsequent Paleozoic periods resulted in the deposition of a considerable body of sediments upon the site of the future range. The general region was upwarped somewhat during the closing stages of the Paleozoic era but was peneplaned before the transgression of the middle Jurassic sea.[1] Throughout the remainder of the Mesozoic era a huge mass of marine and continental sediments, with a large body of intercalated effusives, accumulated over the area. The ejection of the volcanics appears to have been a premonitory symptom of the orogenic revolution which was soon to involve this region. That not remote portions of the province were already being affected by notable uplift and erosion is attested by pebbles of Carboniferous limestones and presumably pre-Cambrian granite in the Fort Union formation near Cody, Wyoming.[2]

Early Teritiary orogeny.—The climacteric event in the growth of the Beartooth Range was the profound orogeny which resulted in the huge overturned anticline and the great overthrust fault along its northeastern flank. The precise date of this epochal deforma-

[1] D. D. Condit, "Relations of Late Paleozoic and Early Mesozoic Formations of Southwestern Montana and Adjacent Parts of Wyoming," *U.S. Geol. Survey*, Prof. Paper 120-F, 1918.

[2] D. F. Hewett, "The Shoshone River Section, Wyoming," *U.S. Geol. Survey Bull. 541*, 1914, pp. 105-6.

tion is unknown, but the combined evidence afforded by the Beartooth and Absaroka ranges clearly indicates that it took place long after the deposition of the Fort Union in the former, and long prior to the accumulation of the widespread "early basic breccias" in the latter.

The folding of the Fort Union formation during the first orogeny that affected the underlying Mesozoic strata has been previously pointed out in this paper. If the Beartooth overthrust was essentially contemporaneous with the Heart Mountain overthrust, and at present there is no reason to doubt this, it occurred not earlier than the middle Eocene and may not have taken place before the early Oligocene.[1] This conclusion by Hewett as to the age of the Heart Mountain fault is based upon these facts: (1) the overthrust beds in places rest upon the Bridger formation (middle Eocene), and (2) the "early basic breccias" (upper Miocene) "locally lie in channels cut 200 to 300 feet below the overthrust surface."[2] It is significant that the overthrust mass is tentatively estimated to have been about 15,000 feet thick near the mountain front. In view of the complete removal of this thickness prior to the ejection of the upper Miocene volcanics it is hardly probable that the faulting took place later than the Oligocene.

Epochs of Peneplanation.[3]—Prolonged erosion initiated by this uplift reduced the ancestral Beartooth Mountains to the surface of low relief that is partially preserved in the flattish summits along the crest of the present range. The conclusion that these summit tracts are remnants of an ancient peneplain rests not alone upon the fact of their accordant levels, but is substantiated by their flattishness over a considerable area of diverse rocks in the central part of the range.

The age of this summit peneplain can not be closely determined with certainty on the basis of the available evidence, but its limits can be fairly well established. Inasmuch as the Beartooth over-

[1] D. F. Hewett, "The Heart Mountain Overthrust, Wyoming," *Jour. Geol.*, XXVIII (1920), 537.

[2] *Ibid.*, p. 555.

[3] For a more detailed discussion of this topic see a forthcoming article by the writer, "Rocky Mountain Peneplains Northeast of Yellowstone National Park."

thrust is post-middle Eocene, the peneplanation of the deformed mass most probably was not accomplished before the Oligocene, and perhaps not until the Miocene. Several lines of evidence, which are discussed in the forthcoming paper, point to the conclusion that this peneplain is not older than the Miocene, and may possibly be of Pliocene age.

After the completion of the summit peneplain the range was uplifted about 2,000 feet, with slight longitudinal warping and gentle tilting of the surface toward the southwest. This elevation seems to have resulted from renewed movement along the overthrust fault surface. The new cycle of erosion thus initiated continued until a large portion of the range was again reduced to an old age lowland—the present sub-summit plateau. The central part of the range remained above this extensive plain as unreduced remnants of the earlier erosion surface.

The age of this sub-summit peneplain can not be closely determined until the place of the summit peneplain in the erosional history of the range has been more accurately determined. It is evident, however, that this surface was produced in the erosion cycle which was begun by the deformation that elevated the earlier peneplain, and was closed by the uplift that resulted in the excavation of the present canyon-like valleys to depths of a few thousand feet. If the summit peneplain is as old as the middle Miocene it appears not improbable that the sub-summit peneplain is as young as the Pliocene, but if the former is of Pliocene age it is probable that the latter is of late Pliocene or early Quaternary age. Moreover, although the younger peneplain must considerably antedate the existing deep valleys, the fact that flattish remnants as large as 10 to 20 square miles in vulnerable positions have been but slightly dissected by tributary valleys strongly suggests that it may have been completed and elevated as recently as the Quarternary. The boldness of the mountain front, its abrupt rise for thousands of feet above the plains, and the slight amount of dissection over large areas support this view.

Quarternary events.—This second epoch of peneplanation was terminated by a vertical uplift of several thousand feet, which

enabled the streams to carve out the present system of sharp valleys. The movement was probably due to stresses that forced the overthrust mass still farther forward and upward along the fault surface. Warping of the uplifted peneplain appears to have been slight, as the difference in altitude may be due in part to the original slope of the plain. There is some suggestion in the stream profiles that the central part of the range was elevated more than the lateral or terminal portions. Westward tilting at this time is suggested by the fact that the valleys on the northeast side of the axial divide are cut much farther below the surface of the sub-summit plateau than are those on the southwest slope.

Another conspicuous result of the pronounced regional uplift has been the development of the bold plains-ward front of the range by differential erosion. The denudation of the highly resistant massive granite and gneiss has been comparatively slight since the uplift, whereas the much weaker Mesozoic and Tertiary (?) sedimentary formations of the adjoining plains have been worn to much lower levels.

Several subsequent broad elevatory movements of less vertical extent have successively rejuvenated the streams so that they have produced the series of terraces that exist along the principal valleys beyond the mountain front. The most recent important change of level seems to have preceded the earlier glacial epoch, for in East Rosebud Valley remnants of the right lateral moraine of this stage descend the streamward face of the first conspicuous terrace above the late glacial outwash.

The last noteworthy event in the history of the Beartooth Mountains was widespread glaciation during at least two distinct epochs. The glaciers on the northeast side of the summit divide were confined to the valleys whereas the plateau on the southwest slope was covered by the Beartooth ice-cap. Apparently the sub-summit plateau on the northeast slope has not been glaciated anywhere except at the heads of the valleys that rise within its borders, but it experienced considerable nivation. Meager remnants of the former extensive alpine glaciers still exist at the heads of several valleys on the northeast side of the main divide.

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