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# ROCKY MOUNTAIN PENEPLAINS NORTHEAST OF YELLOWSTONE PARK

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ABSTRACT

The Beartooth Mountains are truncated by two remarkably flattish surfaces. The summit plateau has an altitude of 12,000 or more feet over a large area in the most rugged portion of the range. The subsummit plateau extends the length of the range on both sides of the medial divide, at an elevation of about 9,500–11,000 feet. These plateaus are interpreted as remnants of two former peneplains. The summit peneplain can hardly be older than Oligocene, whereas the subsummit peneplain appears to be of Pliocene age.

## FOREWORD

The Beartooth Mountains are the front range of the Rocky Mountains northeast of Yellowstone Park. They extend from Livingston, Montana, on the northwest to Clark Fork of Yellowstone River, in northwestern Wyoming, on the southeast. The range rises abruptly 3,500–4,000 feet from the Great Plains and the Bighorn Basin to a sky line that is in many places remarkably even and continuous (Fig. 1). It is separated by the upper Clark Fork on the southwest from the Absaroka Range, which is closely related to it.

The Beartooth Range is a huge anticline with a core of pre-Cambrian granitoids and schists flanked by Paleozoic and Mesozoic sedimentary formations. It is generally overturned and overthrust toward the Great Plains, from which it is sharply separated by the

profound Beartooth fault of post-Middle Eocene age. The lower southwest slope beyond Clark Fork is buried beneath the huge pile of Upper Miocene volcanics which form the adjoining Absaroka Range.[1]

FIG. 1.—East front of the Beartooth Range near the Montana-Wyoming boundary. Note the abrupt rise from the Bighorn Basin to the even crest of the subsummit plateau. The Beartooth fault is at the base of the range. The elevation varies from less than 6,000 feet at the base of the range to 10,000 feet at its crest.

## THE SUMMIT PLATEAU

The most extensive and typical remnant of the summit plateau is along the main axial divide north of the Wyoming boundary (Fig. 2). Its noteworthy features are numerous tabular peaks and broad, flattish ridges, over an area of several square miles at altitudes of 12,000–12,400 feet, in the most rugged portion of the range.[2] Numer-

[1] A more detailed account of the stratigraphy and structure is given by the writer in "Summary of the Geology of the Beartooth Mountains, Montana," *Jour. Geol.*, Vol. XXXI (1923), pp. 441–65.

Reference should be made also to the Livingston, Montana, and Absaroka, Wyoming, folios, *U.S. Geol. Survey, Geol. Atlas, Folios 1 and 52.*

[2] Typical views are shown in *Jour. Geol.*, Vol. XXXI (1923), pp. 447–48.

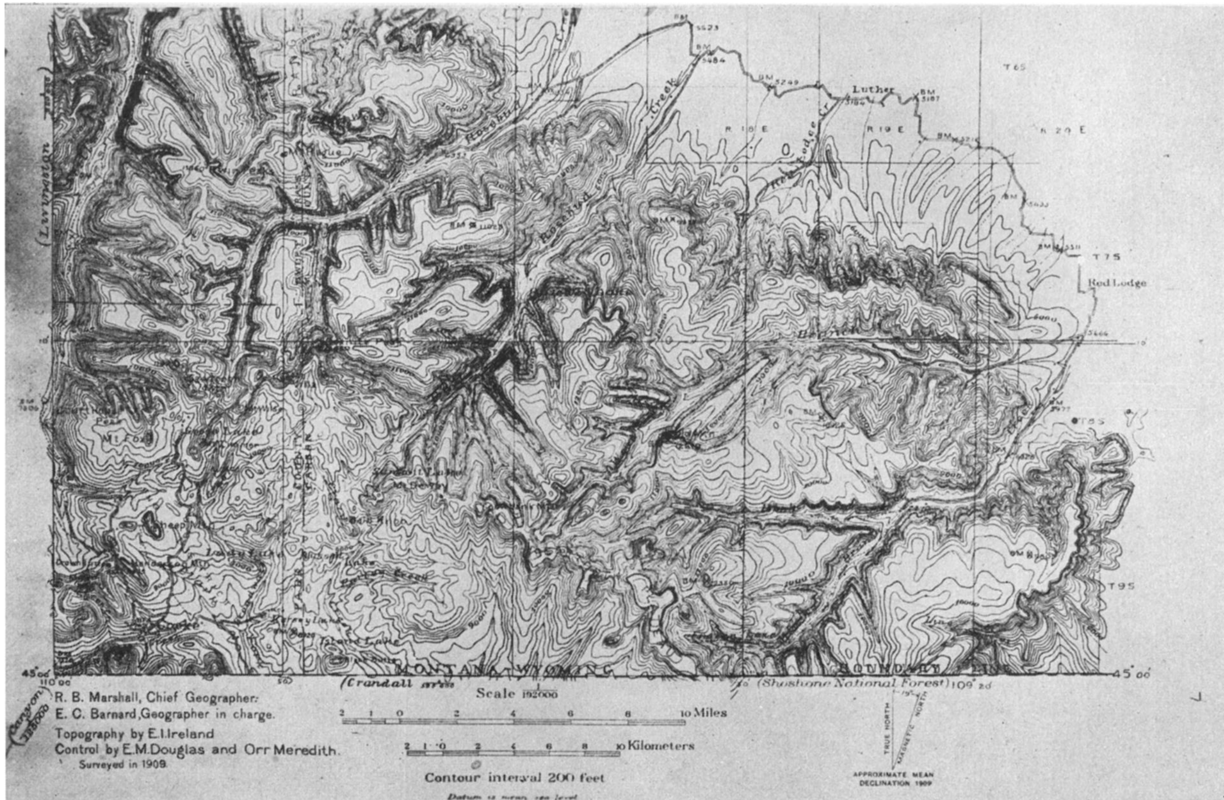


FIG. 2.—Topographic map of the central part of the Beartooth Range. Note the summit plateau remnants between 109° 30′ and 109° 40′ along the axial divide, extensive areas of the subsummit plateau on both sides of this divide, and the narrowness of the canyons which trench it. Granite Peak is just east of the intersection of 45° 10′ and 109° 50′.

ous vigorous streams and former glaciers have cut deeply into the margins of the plateau, but in spite of this severe erosion its low relief has been remarkably well preserved. A few isolated peaks farther northwest along the main divide indicate the former great extent of this surface. Granite Peak, which rises to an altitude of 12,850 feet in the central part of the range—and thus is the highest point in Montana—is a short, flattish ridge (Fig. 3), whose crest is

FIG. 3.—Granite Peak, the highest mountain in Montana, whose even crest is a remnant of the summit peneplain. Its elevation is 12,850 feet. Looking southwest from West Rosebud Plateau.

about 800 feet above the nearest part of the summit plateau, 6 miles to the southeast. Sawtooth Mountain, 5 miles farther west on the same divide, is a similar ridge at an altitude of slightly less than 12,000 feet. Mount Wood, 8 miles north of Granite Peak, probably reaches this summit level with an elevation of about 12,700 feet, but having been reduced to a sharp peak by the encroachment of several cirques, the former surface is not preserved.

Thus remnants of the summit plateau exist for about 20 miles along the axis of the range and for about 8 miles at right angles to it,

at altitudes ranging from approximately 12,000 to 12,850 feet. Accordance of summits is a common feature of individual ranges of the Rocky Mountains, but the noteworthy characteristic of the Beartooth summit surface is its flattishness at thousands of feet above base level over many square miles of deformed rocks of diverse constitution.[1]

FIG. 4.—A remnant of the subsummit peneplain northwest of Granite Peak. The elevation at the crest is about 11,400 feet and at the bottom of the canyon is about 9,000 feet. The base of Granite Peak is in the left foreground.

### THE SUBSUMMIT PLATEAU

Much of the Beartooth Range consists of a subsummit plateau, which is in general 1,500–2,000 feet below the summit plateau. The evenness of the plainsward margin of this subsummit plateau, except where indented by deep valleys or cirques, is impressive (Fig. 1). This rim has an altitude of about 9,500–11,000 feet, and is generally about 3,500 to more than 4,500 feet above the plains.

[1] For a brief description and sketches of a similar case in Central Asia, see W. M. Davis, "A Flat-topped Range in the Tian Shan," *Appalachia*, Vol. X (1904), pp. 277–84.

This plateau extends almost the entire length of the range on the eastern and northeastern side of the axial divide. It consists of very broad, gently undulating ridge crests 2,500–4,000 or more feet above the main streams (Figs. 2 and 4). Some of these flattish crests are 3–4 miles wide, and some are about 10 miles long. The largest flats have an area of 10–20 square miles. As described in another article:

> 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.

Silver Run and Line Creek plateaus, southeast of Red Lodge, are conspicuous remnants in this area (Figs. 5 and 6). Even in that rugged portion of the range northwest of Granite Peak known as the Granite Range, where numerous canyons are cut deeply into the plateau, the intervening ridge crests are remarkably flat (Figs. 2 and 4).

Thus a noteworthy characteristic of the subsummit plateau on the plainsward side of the range is its flattishness upon diverse pre-Cambrian rocks throughout an area that is about 70 miles long and 10 or more miles wide. An equally striking feature is the slight dissection of some of the larger remnants in spite of their occurrence at high altitudes between deep canyons with vigorous streams. The refilling of a dozen main narrow valleys and their short tributaries would restore in large measure this subsummit surface to its former gently undulatory shape.

The subsummit plateau on the southwestern slope of the range has been considerably modified by an ice-cap.[1] Instead of the typical grassy flats or broad *felsenmeers* on the northeastern side of the axial divide, the plateau here is characterized by rounded hills and ridges of bare rock interspersed with valleys and rock basins which contain scores of small lakes. Lake Plateau is typical of this area.[2] This glaciated plateau has a general elevation of about 10,000 feet north of

[1] For a description of this area see a forthcoming article by the writer, "Glaciation of the Beartooth Mountains."

[2] See the Livingston, Montana, topographic sheet of the U.S. Geol. Survey.

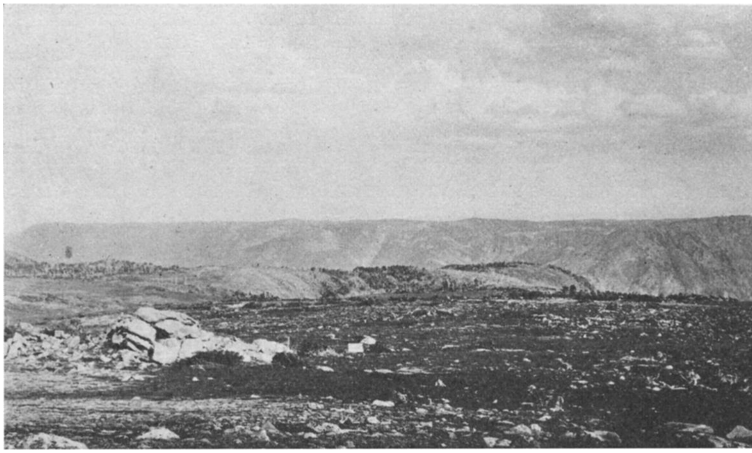

FIG. 5.—The subsummit peneplain southwest of Red Lodge. Part of Silver Run Plateau with Line Creek Plateau beyond Rock Creek. The elevation is about 10,000 feet. Looking southeast toward the plains.

FIG. 6.—Silver Run Plateau just east of the axial divide. Remnants of the summit plateau form monadnocks in the background. The massive peak has an elevation of 12,350 feet.

the Wyoming boundary, but it rises to 11,000 feet in places along the base of the axial divide, where it is about 1,500 feet below the summit plateau. In northern Wyoming this surface slopes rapidly toward Clark Fork.[1]

The higher portions of this glaciated area can be traced around the southern end of the summit plateau into the unglaciated subsummit plateau on the eastern side of the main divide. In the northwestern half of the range the divide between the subsummit and glaciated plateaus is hardly a mile wide. Northwest of Mount Douglas, west of Sawtooth Mountain, and southeast of Granite Peak the subsummit plateaus on opposite slopes are obviously parts of a formerly continuous surface (Fig. 2).[2] It is evident from these relations that the subsummit plateau formerly covered the greater part of the range.

## ARE THESE PLATEAUS REMNANTS OF PENEPLAINS?

Although flattish surfaces which truncate folded rocks are generally interpreted as peneplains, it is advisable to inquire briefly if the plateaus of the Beartooth Mountains may have some other origin. In addition to planation by running water, several causes of the accordance of summits in alpine mountains have been advocated,[3] but none of them seems applicable, except possibly in slight degree, to the Beartooth Mountains. These alternative explanations have been advanced chiefly to account for subequality in altitude of sharp peaks and narrow ridges "in an alpine range where there are no remnant plateaus directly referable to a common, uplifted and dissected peneplain."

It should be noted clearly that the Beartooth Mountains contain remnants of two broad plateaus which are separated by a considerable vertical interval. The slight difference in elevation of numerous tabular peaks and flattish ridges along the axial divide in-

[1] U.S. Geol. Survey, Crandall, Wyoming, topographic sheet.

[2] See also the Livingston, Montana, topographic sheet.

[3] N. S. Shaler, "Spacing of Rivers with Reference to the Hypothesis of Base-Leveling," *Bull. Geol. Soc. Amer.*, Vol. X (1899), pp. 263–76.

R. A. Daly, "The Accordance of Summit Levels among Alpine Mountains: The Fact and Its Significance," *Jour. Geol.*, Vol. XIII (1905), pp. 105–25; "Development of Accordance of Summit in Alpine Mountains," *Geol. Survey Can., Mem. 38* (1912), pp. 631–41.

dicates a formerly extensive, continuous summit surface without pronounced local relief. As this surface was developed upon folded rocks of diverse character it must have been an erosional plain. Similar features of the subsummit plateau in a much better degree of development and preservation force the same conclusion in regard to its origin.

The geographic relations of the range and the date of the orogeny debar marine erosion as a possible factor in the formation of these plains. It is also extremely improbable that the summit plateau represents the exhumed marine plain upon which the basal Cambrian sediments were deposited. Certain features weigh strongly against such an origin: (1) the extent of the remnants of the summit plain in the most vulnerable positions in the range; (2) the lack of sedimentary outliers; (3) the improbability that denudation of the axial portion of the folded range would stop at the contact of the sedimentary formations and the underlying beveled crystalline rocks. It is obvious that neither interpretation applies to the subsummit plateau. Although the accordance of alpine summits has been ascribed in part to alpine glaciation,[1] and erosion by ice-sheets has been advocated as a possible cause of planation,[2] it seems certain that the rôle of glaciers in the Beartooth Mountains has been mainly that of increasing the relief.

Inasmuch as these plateaus could not have resulted from marine planation or glaciation, they must have been formed mainly by the action of wind or running water. Wind erosion appears to be capable of reducing extensive areas to surfaces of low relief.[3] It is, perhaps, a more potent agent of planation under optimum conditions than is commonly realized. It is doubtful, however, that conditions have been adequately favorable to permit the leveling of the Beartooth Range by eolian erosion. Undoubtedly eolation has been at times an important factor in the modification of the topography and the

[1] R. A. Daly, *ibid.*

[2] F. E. Wright, "Ice-Cap Beveling," in "Some Effects of Glacial Action in Iceland," *Bull. Geol. Soc. Amer.*, Vol. XXI (1910), p. 723.

[3] S. Passarge, "Die Inselberglandschaften in tropischen Afrika," *Naturwiss. Wochenscher.*, Vol. III (1904), pp. 657–65.

W. M. Davis, "Geographic Cycle in an Arid Climate," *Jour. Geol.*, Vol. XIII (1905), pp. 381–407. "Leveling without Baseleveling," *Science*, N.S., Vol. XXI (1905), pp. 825–28.

transfer of materials, but it is considered to have been in this region a co-operative process of subsidiary importance rather than the dominant process of denudation. On the other hand, numerous examples of the extensive or almost complete planation of great masses by running water are exhibited in present topographies as well as in stratigraphic relations within the geologic column. Moreover, the existence of the central mountainous tract along the axis of the range, irrespective of the resistance of the rocks, as an unreduced erosion remnant upon the subsummit plateau, is substantial evidence of the origin of the latter through peneplanation. Hence it is concluded that both plateaus are remnants of old-age surfaces which were essentially peneplains.[1]

The view might be entertained that these plateaus are portions of a formerly continuous surface which has been deformed through faulting or warping. A fault boundary for the summit plateau, except locally, is precluded by the spurs that extend to the northeast beyond the inner margin of the subsummit plateau (Fig. 2). The precipitous descent in many places of more than 1,000 feet is due to glaciation at lower levels, and not to faulting. That the lower surface could not be a downwarped portion of the upper one is demonstrated by this interdigitate relationship as well as by the normal erosional slope which connects both plateaus on the northeast side of the axial divide (Figs. 2 and 6).

Thus the characteristics and relations of the summit and subsummit plateaus in the Beartooth Mountains warrant the acceptance with reasonable certainty of two epochs of extensive peneplanation in the Cenozoic history of the range.

## AGE OF THE PENEPLAINS

The age of these peneplains cannot be precisely determined at this time, but their development, uplift, and dissection must have occurred within certain fairly well-defined limits. In any attempt to solve this outstanding problem, several factors and lines of evidence need to be considered and evaluated carefully according to all of their interrelations. Let us first attack the problem by considering the summit peneplain.

[1] It is evident that the present surfaces are not the original plains, for they have been modified by many erosive processes.

*Summit peneplain.*—In a previous article it was stated:

> The peneplanation of the deformed mass most probably was not accomplished before the Oligocene, and perhaps not until the Miocene. Several lines of evidence . . . . point to the conclusion that the peneplain is not older than the Miocene, and may possibly be of Pliocene age.[1]

Since that article was published the writer has reached the conclusion that the summit peneplain can hardly be older than Oligocene or younger than early Miocene.[2] The bases of this determination follow.

Although the time required for the reduction of a region to approximate base level cannot be estimated with sufficient accuracy to permit its use in dating topographic features except in the most general manner, it is probable that the huge resistant mass of the range was not truncated until long after the major adjustments of the Beartooth overthrust had been made. This profound fault is essentially contemporaneous with the Heart Mountain overthrust, beyond the southeastern extremity of the Beartooth Range, which is post-Middle Eocene [3] Hence the assumption seems warranted, without unduly pressing the facts in the case, that the Beartooth summit peneplain was not completed prior to the Oligocene.

A record of events concurrent with the planation should exist in the environs of the Beartooth Mountains, unless obliterated by subsequent changes. Hence the Absaroka Range and the Great Plains should be sources of critical data.

It is unlikely that the Beartooth mass could have been planed down into the pre-Cambrian without the development of a similar surface on the much weaker rocks of the adjacent Absaroka Range. Two old erosion surfaces are available there for comparison: one at the base of the Upper Miocene "early basic breccia"; the other on the crests of a few summit ridges.

Deep dissection of the precipitous east front of the Absaroka

[1] "Summary of the Geology of the Beartooth Mountains, Montana," *Jour. Geol.*, Vol. XXXI (1923), p. 463.

[2] The modification results fro n critical reconsideration of all the available data; especially, the former provisional correlation of certain surfaces does not seem justified.

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

Range by numerous tributaries of Clark Fork affords a partial view of the topography upon which the volcanoes accumulated, and gives some measure of the amount of prior denudation in that area. These volcanics now rest on strata as old as Upper Cambrian, and presumably once extended far beyond Clark Fork on to the pre-Cambrian granite. Thus pre-Upper Miocene dissection amounted to several thousand feet. Furthermore, the exhumed surface along Clark Fork has in places a known relief of about 2,000 feet in less than 3 miles.[1] This topography on the southwest flank of the Beartooth Range signifies that either (1) the region was peneplaned, uplifted at least 2,000 feet, and in part deeply dissected before the Upper Miocene vulcanism; (2) much of the Beartooth Mountains had been worn down to an old-age plain whereas the southwestern portion had reached maturity only by this time; or (3) peneplanation and uplift occurred during some later epoch.

If only one peneplain existed in the Beartooth Mountains, it might be tentatively correlated with post-Miocene summit flats in the Absaroka Range, and thus would satisfy the last alternative. As will be apparent in discussion of the subsummit peneplain and younger features, this dating appears to be inadmissible. It is quite improbable that erosion of the huge obdurate mass of the Beartooth Range could have reached an old-age stage while weak shales and limestones on its lower flanks contained deep valleys. Hence the first alternative appears to be the most satisfactory interpretation. This indicates an Oligocene or early Miocene age for the summit peneplain. It may be that the old-age aspect of the region was retained until the episode of Middle Miocene deformation, which appears to have affected widely the northern Rocky Mountains. As a result of this uplift the topography beneath the volcanics is presumed to have been carved from the elevated plain.

This interpretation appears to have some corroboration in the diastrophic and gradational history of other front ranges to the north and the adjoining Great Plains. On this basis the planation, uplift, and renewed dissection of the Beartooth Mountains should

[1] Note the contact of this breccia with the underlying Paleozoics on the southwest slope of Hunter Peak, as shown on the areal geology sheet of the Crandall quadrangle, Absaroka, Wyoming, folio, *U.S. Geol. Survey, Geol. Atlas*, No. 52.

have occurred between Middle Eocene and late Miocene. Such denudation should be recorded somewhere in the sediments of the Great Plains, but unfortunately no known Tertiary deposits that postdate the Beartooth overthrust remain on the western plains of Montana. The Linley conglomerate, a local deposit of unknown age, about 10 miles northwest of Red Lodge, contains pebbles from the Paleozoic limestones and the pre-Cambrian crystalline core of the range. It lies unconformably on beveled Fort Union beds. This formation may afford some clue to the date of planation, but until diagnostic fossils are discovered, it may represent any post-Middle Eocene epoch.

The deformed Fort Union and underlying formations on the adjacent plains were truncated, and this erosional plain was covered by gravels which do not appear to be older than Pleistocene or late Tertiary. It is inherently probable that higher and older surfaces than those now preserved upon the plains were formed and covered with detritus from the range. Such alluvial deposits may have been essentially correlative with Oligocene strata which have been partially preserved at Cypress Hills, far out upon the plains of Southern Canada,[1] but this is conjectural.

Another possible source of pertinent data is along the Rocky Mountain front immediately north of the Beartooth Range. Over the Great Plains between the Little Belt and Beartooth mountains, erosion has planed across a folded terrane which includes the Livingston formation.[2] The upper part of this formation has been interpreted to be of Fort Union age.[3] Bozeman "lake beds" lie on pre-Cambrian granite at the south end of the Bridger Range, about 20 miles west of the northwestern end of the Beartooth Range. Little is

[1] Information in regard to these deposits is briefly summarized, and original references given, by Collier and Thom, "The Flaxville Gravel and Its Relation to Other Terrace Gravels of the Northern Great Plains," *U.S. Geol. Survey, Prof. Paper 108* (1918), p. 183.

[2] See the structure sections of the Little Belt Mountains folio, *U.S. Geol. Survey, Geol. Atlas*, No. 56.

[3] R. W. Stone and W. R. Calvert, "Stratigraphic Relations of the Livingston Formation, Montana," *Econ. Geol.*, Vol. V (1910), p. 752.

W. T. Thom, Jr., and C. E. Dobbin, "Stratigraphy of Cretaceous-Eocene Transition Beds in Eastern Montana and the Dakotas," *Bull. Geol. Soc. Amer.*, Vol. XXXV (1924), Fig. 2, p. 484.

known about the actual form of the surface beneath these sediments in the adjacent Gallatin Valley, but it cuts across formations ranging from Archean to Cretaceous. Vertebrate fossils show these beds to be Middle Miocene.[1] Similar sediments, designated Deep (Smith) River beds, occupy a broad basin southwest of the Little Belt Mountains. The southernmost occurrence is about 50 miles north of the Beartooth Range, along the east flank of the Big Belt Mountains. A considerable number of mammalian remains determine the lower beds (Fort Logan) to be Upper Oligocene or Lower Miocene.[2] These deposits overlap from the Livingston to the Spokane formation (Proterozoic) in a distance of 4 miles. The erosion surface which bevels the folded formations of the plains and the bordering portions of the front ranges appears to pass under these sediments; consequently, it would be of pre-Miocene age. It was presumably on this basis that Weed stated: "At the close of the Eocene [Oligocene?] period the entire quadrangle was reduced to a gently hilly country bordered by a broad level plain."[3]

No means exist of directly correlating this surface with erosion levels in the Beartooth Mountains, but it is highly significant that a much more extensive region, embracing both plains and mountains, was reduced to a gently undulating plain prior to the early Miocene. Thus the correlation of the summit peneplain with this surface seems justified, at least as a working hypothesis.

Determination of the age of summit peneplains in related districts of the northern Rocky Mountains may afford some clue to the solution of the local problem. As the result of extensive field study of the mountain ranges of central western Wyoming, and from a careful scrutiny of the evidence presented by geologists working elsewhere within the province, Blackwelder concludes that "the evidence from all points of view here considered, although it does

[1] Earl Douglass, "Fossil Mammalia of the White River Beds of Montana," *Trans. Amer. Phil. Soc.*, N.S., Vol. XX (1902), map on p. 241.

[2] W. B. Scott, "The Mammalia of the Deep River Beds," *ibid.*, Vol. XVIII (1896), p. 60.

W. D. Matthew, "Cenozoic Mammal Horizons of Western North America," *U.S. Geol. Survey Bull. 361* (1909), p. 112.

[3] W. H. Weed, "Geologic History," Little Belt Mountains folio, *U.S. Geol. Survey, Geol. Atlas 56* (1899), p. 7.

not establish the age of the [Wind River] peneplain, does strongly indicate that it was Pliocene."[1]

On the other hand, it is the conviction of several geologists working in northern Idaho and western Montana that the summit peneplain in that region is certainly pre-Miocene, and probably is Eocene.[2] The evidence presented by Umpleby and Atwood has been reviewed by Blackwelder[3] and Rich[4] who conclude that the published data permit, and in some instances favor, the alternative interpretation that certain summit peneplains are late Miocene or Pliocene. Recent detailed field studies in southeastern Idaho lead Mansfield to conclude that the Snowdrift peneplain of that region is pre-Middle Miocene, and possibly Oligocene or Eocene.[5]

The published data indicate that the summit peneplains of the northern Rocky Mountains are of two distinct ages. The earlier one apparently was formed during the epochs between the main orogeny and widespread Miocene re-elevation, whereas the later one was developed after this regional uplift. Thus the Beartooth summit peneplain may have a possible correlative in one of these pre-Middle Miocene surfaces.

On the other hand, as suggested by Atwood and emphasized by Mansfield, widely separated districts of the northern Rocky Mountains may have had a quite dissimilar physiographic history. Thus

[1] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *Jour. Geol.*, Vol. XXIII (1915), p. 206.

[2] J. B. Umpleby, "An Old Erosion Surface in Idaho; Its Age and Value as a Datum Plane," *Jour. Geol.*, Vol. XX (1912), pp. 139–47.

W. W. Atwood, "The Physiographic Conditions at Butte, Montana, and Bingham, Utah, When the Copper Ores in These Districts Were Enriched," *Econ. Geol.*, Vol. XI (1916), pp. 697–740; "Physiographic Conditions and Copper Enrichment," *ibid.*, Vol. XII (1917), pp. 545–47.

Waldemar Lindgren, "The Idaho Peneplain," *ibid.*, Vol. XIII (1918), pp. 486–88.

D. C. Livingston, "The Idaho Peneplain," *ibid.*, pp. 488–92.

J. T. Pardee, "Ore Deposits of the Northwestern Part of the Garnet Range, Montana," *U.S. Geol. Survey Bull. 660* (1918), pp. 162–64.

[3] Eliot Blackwelder, "An Old Erosion Surface in Idaho: A Criticism," *Jour. Geol.*, Vol. XX (1912), pp. 410–14; "Physiographic Conditions and Copper Enrichment," *Econ. Geol.*, Vol. XII (1917), pp. 541–50.

[4] J. L. Rich, "An Old Erosion Surface in Idaho: Is It Eocene?" *ibid.*, Vol. XIII (1918), pp. 120–36.

[5] G. R. Mansfield, "Tertiary Planation in Idaho," *Jour. Geol.*, Vol. XXXII (1924), pp. 472–87.

the age of erosion surfaces in far distant areas may have so little bearing upon the dating of peneplains in the Beartooth Mountains that it would be somewhat hazardous, in the present state of knowledge, to correlate them. It is to be expected, however, that major diastrophic and erosional events in a closely related group of mountain ranges would be reflected in each of the units. The Beartooth peneplains undoubtedly are more closely related to erosion surfaces in the Absaroka Range and the Rocky Mountain–Great Plains tract to the north than to those much more distant, although some of the latter may be approximately contemporaneous.

Summarizing the discussion of the Beartooth summit peneplain: Its age cannot be positively established within narrow limits, either from local evidence or by correlation with other peneplains in the province. It is evident, however, that the post-Middle Eocene orogeny almost certainly precludes its being as old as Eocene; rather, a post-Eocene age is indicated. The subsummit peneplain and younger erosional features apparently make a late Tertiary age inadmissible. Partial contemporaneity with the Oligocene plain on Cypress Hills of the northern Great Plains is tentatively suggested. This view is sustained in some measure by the erosional surface beneath the Upper Miocene volcanics of the Absaroka Range. Additional support is afforded by the occurrence of early to Middle Miocene basin deposits on Paleocene (?) to pre-Cambrian rocks at the southern ends of the Bridger and Big Belt ranges. Finally, a presumably correlative surface, which seems to pass under these sediments, exists in the peneplain of the northerly adjoining Great Plains. These seem, therefore, to be credible bases for considering the Beartooth summit peneplain to be Oligocene.

*Subsummit peneplain.*—Several lines of evidence which bear upon the age of the subsummit peneplain indicate it to be Pliocene. There is some suggestion that it may have been only slightly dissected in the late Pliocene or very early Quaternary.[1] Features that should be considered in dating this surface are: (1) character of the plateau remnants; (2) its relation to the summit peneplain; (3) possible cor-

[1] The writer dissents from the view of Alden (see *Bull. Geol. Soc. Amer.*, Vol. XXXV [1924], pp. 396, 399) that this surface may be as old as Oligocene. While there may be some justification for considering it to be late Miocene, the available evidence presented in this paper indicates that it is not older than Pliocene.

relatives among other Rocky Mountain erosion surfaces, especially in the adjoining Absaroka Range; (4) depth and extent of valleys eroded in it; and (5) possible correlatives on the Great Plains.

1. It may be re-emphasized here that the large area of the flattish remnants is the most striking feature of the subsummit peneplain, in spite of its position 4,000–5,000 or more feet above the Great Plains, and the vigorous streams of steep gradients that have trenched it (Fig. 2). This aspect, taken in connection with the abrupt rise of the mountain front for 3,000–4,000 or more feet above the plains, and its comparatively slight dissection (Fig. 1), suggests strongly that the elevation and transection of the subsummit peneplain occurred somewhat recently, rather than far back in the Tertiary. But such inferences must be checked by other evidence.

2. The subsummit peneplain was produced in the cycle of uplift and erosion that followed the formation of the summit peneplain. As indicated previously in this discussion, the latter must be post-Middle Eocene, and probably is Oligocene. After that date the range was elevated approximately 2,000 feet, and again very largely peneplaned. The first appropriate time of widespread uplift in the Rocky Mountains seems to be the Middle Miocene. Thus both the erosional history of the Beartooth Range and the diastrophic record of the province suggest that the subsummit peneplain is post-Middle Miocene, and probably Pliocene.

3. During late Miocene time there existed, on the extreme southwestern slope of the Beartooth Range, a volcano whose *ejecta* apparently formed a cone of great height and with a broad base. Through a restoration of this volcanic peak by comparing it with a modern one (Mount Etna) of similar type and structure, Iddings estimated that at least 10,000 feet of material was eroded from it before the level of the present mountain crests was reached.[1] It was further calculated that this peak probably had a basal radius of 20 or more miles.

Inspection of the maps of Crandall Basin reveals that erosion of the former volcanic peak resulted in a somewhat flattish plateau (Hurricane Mesa), which now has a maximum altitude of about 10,-

[1] J. P. Iddings, "The Dissected Volcano of Crandall Basin," *U.S. Geol. Survey, Mon. 32*, Part II (1899), p. 236.

600 feet, and that this erosion surface was developed across the broad core of coarse gabbro as well as upon the surrounding breccias.[1] Although this plateau may coincide in part with almost horizontal lavas, the removal of even a few thousand feet of volcanics and truncation of the Crandall cone and plug at this level indicate that Hurricane Mesa is a remnant of a former erosion surface of moderate or low relief. This surface doubtlessly was once quite extensive, but subsequent uplift of the region caused its destruction on the weaker breccias.

Other remnants of this erosion surface may exist farther south in the Absaroka Range on denuded Upper Miocene intrusions in Sunlight Mining Region, at Eagle Nest, and on the southwest spur of Wapiti Ridge, although the evidence is less conclusive than at Hurricane Mesa.[2] If these flattish ridge crests on intrusive masses and contiguous breccias should be due to peneplanation of the region, some of the mesas at accordant elevations on almost horizontal lavas may be of the same origin, but obviously this cannot be demonstrated.

The Beartooth summit plateau is the apparent continuation of Hurricane Mesa. Evidence presented in this article makes it very doubtful that both the summit and subsummit peneplains are post-Miocene. Hence the presumptive correlation of the surface on Hurricane Mesa is with the subsummit peneplain, making the latter post-Miocene in age.

In considering this correlation it should be noted that the subsummit plateau on the southwestern slope of the Beartooth Mountains has in places an altitude of about 11,000 feet as compared with 10,600 feet on Hurricane Mesa. Furthermore, it is improbable that the resistant mass of the Beartooth Range could have been planed at a lower level than is represented in Hurricane Mesa without much greater erosion of the Absaroka volcanics. Under the circumstances no other correlation seems possible. This implies that the Beartooth Range was tilted southwesterly between the two epochs of peneplanation, so that the earlier surface now passes below the horizon

[1] *Ibid.*, Plates XXXI and XXXII.

[2] See the areal geology maps in the Absaroka, Wyoming, folio, *U.S. Geol. Survey, Geol. Atlas*, No. 52.

of the later one and beneath the volcanics. Such tilting is not only inherently probable but is indicated by the southwesterly dip of the summit plateau, whose projected surface passes beneath the volcanics in the Absaroka Range.

Definite correlation with more distant peneplains is not attempted at this time, because of some uncertainty in regard to their age. It should be recalled, however, that many other planed surfaces in the province are considered to be late Miocene or Pliocene.[1]

4. Sharp canyons have been eroded several thousand feet below the subsummit plateau but they do not provide a reliable measure of the time that has elapsed since the uplift. There seems to be no reason per se why this canyon-cutting could not have been done mainly in the Quaternary, especially since glacial erosion was a large factor in the process.

Somewhat better evidence is given by Clark Fork Valley, along the southern and southwestern sides of the plateau. For several miles above the mouth of the canyon the river flows in a sharp inner canyon which is trenched in an older valley floor (Figs. 7, 8, and 9). The latter is about 1,000 feet above the stream, and lies 2,000–3,000 feet below the subsummit plateau. It is clear that Clark Fork halted in its down-cutting long enough to carve a valley of noteworthy width then, upon being rejuvenated, sharply incised its course.

The obvious interpretation of these features is to ascribe them to two episodes of vertical uplift of the range with the interposition of considerable time. On this assumption it follows that the old valley may be due to uplift in middle or late Pliocene, and the inner canyon to uplift near the close of the Pliocene or early in the Quaternary. This problem needs more thorough field study, but the time allotted for the erosion of these valleys seems ample, especially in view of certain other features to be described. Although the high-level valley is about 2 miles wide at its mouth (Fig. 7), and slightly more than 3 miles wide above the mouth of Russell Creek (Fig. 8), it is rather sharply constricted just below the great bend in Clark Fork. At this place, where apparently the entire left wall of the canyon is

[1] See C. L. Baker, *Bull. Geol. Soc. Amer.*, Vol. XXIII (1912), p. 73; Eliot Blackwelder, *op. cit.;* J. P. Buwalda, *Science,* Vol. LX (1924), pp. 572–73; R. T. Chamberlin, *Jour. Geol.*, Vol. XXVII (1919), p. 161; W. M. Davis, *Ann. Assoc. Amer. Geog.*, Vol. I(1911), p. 31.

pre-Cambrian gneiss and granite, the only bench occurs on the right (south) side at or near the contact of the almost horizontal Cambrian and the underlying crystallines. The wider portions of the valley floor are either cut in Paleozoic limestones and shales, or are along the contact of these strata with the pre-Cambrian (Fig. 9).[1] The much broader valley above Crandall Creek is due in considerable

FIG. 7.—Mouth of Clark Fork Canyon. The high-level valley on the south (right) wall is cut to the contact of Paleozoic limestones and shales with pre-Cambrian granite. The edge of the subsummit plateau is shown above the left wall of the canyon. Drift of Clark Fork glacier occupies the foreground.

part to profound glaciation. Furthermore, the abrupt rise of the pre-Cambrian for more than 2,000 feet above the almost horizontal early Paleozoics on the northeast side of Clark Fork demonstrates the existence of a fault which has influenced the excavation of this valley (Fig. 8). Although it was too dark to see the features clearly when the writer came to the lower part of the old valley, it appears that the Paleozoics on the south wall may have once abutted against

[1] See also *Bull. Geol. Soc. Amer.*, Vol. XXXV (1924), Plates XVII and XVIII (opposite pp. 405 and 407).

the opposite wall of pre-Cambrian granite. Owing to the lack of positive evidence the point may not be stressed at this time, but the writer has suspected that the lower canyon of Clark Fork may be controlled in part by faults. No decisive evidence of faulting was observed, however, at the mouth of the canyon. It is probable, moreover, that huge glaciers, during two or more stages of glacia-

FIG. 8.—Floor of Clark Fork high-level valley. It is on almost horizontal Cambrian beds. Pre-Cambrian granite rises beyond the Clark Fork fault to the subsummit plateau. It is about 2,500 feet above the old valley floor and 4,000 feet above the river at the foot of the steep slope.

tion, greatly widened this valley in the limestones and shales, and stripped them from their pre-Cambrian base.

Other valleys of the range do not have similar high-level floors, but this is probably due to the fact that, except for a narrow zone at the canyon mouths, they are eroded in pre-Cambrian crystallines. Stillwater Valley furnishes suggestions of halts in its down-cutting, but these breaks in the profile may be the result of stages of glaciation or other factors.

From this discussion it is evident that less time was needed for

the erosion of the Clark Fork high-level valley than appears at first thought to be demanded. This valley, in its pre-glacial form, was excavated rapidly under especially favorable conditions, during an uplift which seems to have been comparatively rapid. The narrowness of all the canyons in proportion to their great depth, and the fact that the broad, flattish uplands extend to the margins of these canyons, indicate the great supremacy of uplift and down-cutting over lateral erosion. Hence it seems reasonable to conclude that the subsummit peneplain might have retained its essential character

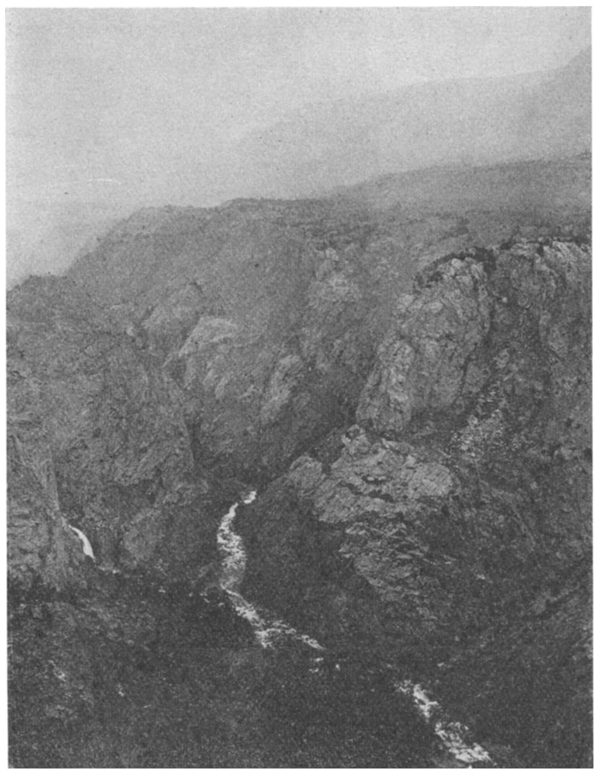

FIG. 9.—Inner canyon of Clark Fork. It is cut about 1,000 feet below the high-level valley floor, which is at the contact of horizontal Cambrian beds (right background) and pre-Cambrian granite. The pre-Cambrian mass of the range is in the rear beyond the Clark Fork fault.

until rapid late Pliocene uplift induced its dissection. Furthermore, there are hints in the steepening of the slope of the subsummit plateau toward its plainsward edge, and in the occurrence of large bowlders at high levels far beyond the range, that widespread nivation or very early glaciation may have affected the rising plateau. Should this surmise be true, it is possible that the subsummit surface may have been in general but slightly dissected by relatively shallow valleys at the dawn of the Quaternary. This must, however, remain in the field of conjecture for the present.

5. The great denudation which resulted in the Beartooth subsummit peneplain must have been recorded also far out on the Great Plains. Although the region has since undergone considerable uplift and dissection, this record may have escaped destruction in some places. Favorable sites for its preservation are on the broad high divides in the Yellowstone drainage system, where remnants of the old erosional surface and overlying deposits might occur.

An opportunity has not been available for extending these studies beyond the Beartooth Range, except for casual observations made during a rapid reconnaissance survey of the western plains and the front ranges for the Montana Bureau of Mines. The highest flattish divides along Yellowstone River far out on the plains and its main tributaries from the range are commonly covered by thick deposits of gravel,[1] which lie upon a broad erosional plain. The age of these gravels is unknown, but they appear to be late Tertiary or possibly early Quaternary. Their time relation to the erosion of the Beartooth Mountains is uncertain, but they may have been derived from the range as it was uplifted after the formation of the subsummit peneplain. Or, possibly, they may have been in part let down from earlier deposits made at higher levels during erosion of the range.[2]

[1] G. S. Rogers, "Geology and Coal Resources of the Area Southwest of Custer, Yellowstone and Bighorn Counties, Montana," *U.S. Geol. Survey Bull. 541–H* (1914), p. 31.

E. T. Hancock, "Geology and Oil and Gas Prospects of the Huntley Field, Montana," *ibid., Bull. 711* (1920), p. 128.

W. R. Calvert, "Geology of the Upper Stillwater Basin, Stillwater and Carbon Counties, Montana," *ibid., Bull. 641* (1916), Plate XXI (opposite p. 202).

[2] The relation of these terraces and their gravels to erosion of the mountains presents an interesting problem, but lack of space prevents its discussion here.

The Flaxville plain of northeastern Montana, whose gravels contain remains of Pliocene vertebrates,[1] may be part of an extensive erosional surface which was formed over the Montana plains during a portion of the cycle that resulted in the Beartooth subsummit peneplain, but again this is at present conjectural.[2] Former erosion levels exist in some other front ranges to the north, but their age has not been determined, although there are suggestions of comparatively recent uplift and dissection of extensive erosional surfaces.[3]

In review, these points bear on the age of the subsummit peneplain: (1) Middle (?) Miocene uplift caused dissection of the summit peneplain; (2) an Upper Miocene volcano and its lavas as well as certain intrusions were truncated; (3) the Clark Fork high-level valley was formed during uplift of the subsummit peneplain; (4) this valley was eroded rapidly by streams, and possibly by early Pleistocene glaciers, and owes its form in part to recent glaciation; (5) the sharpness of all the canyons, the abruptness of the mountain front below the plainsward margin of the subsummit plateau, and the slight dissection of the latter suggest comparatively recent rapid uplift of the range. Hence the subsummit peneplain is considered to be of Pliocene age; possibly it retained its essential characteristics until late in the period.

The events following peneplanation, as now interpreted, may be briefly summarized. Late Pliocene uplift renewed stream erosion, with Clark Fork making its high-level valley. These young valleys may have contained pre-Wisconsin glaciers, of which there are some

[1] A. J. Collier and W. T. Thom, Jr., "The Flaxville Gravel and Its Relation to Other Terrace Gravels of the Northern Great Plains," *U.S. Geol. Survey, Prof. Paper 108* (1918), pp. 179–84.

[2] For a brief statement of a different view, see W. C. Alden, "Physiographic Development of the Northern Great Plains," *Bull. Geol. Soc. Amer.*, Vol. XXXV (1924), pp. 385–424 (see pp. 396, 399, and 404).

Dr. Alden states that it is "unlikely that the Beartooth subsummit plateau is younger than Miocene, even if it is not so old as Oligocene" (p. 399). He bases this conclusion apparently on somewhat uncertain correlation of the Flaxville Plain with the uppermost terrace beyond the Beartooth Mountains and with the Clark Fork high-level valley. In view of the lack of evidence in proof of the Miocene age of the subsummit peneplain or of adequate disproof of its Pliocene age, as well as the evidence discussed in the present paper, it appears that this interpretation is not valid.

[3] Note the accordance of summits on some of the parallel ridges eroded from the thrust-fault blocks of the front range in the Saypo and Coopers Lake quadrangles.

suggestions. Later uplifts caused erosion of the inner Clark Fork Canyon and continued deepening of the other canyons. Prior to the advance of early Wisconsin glaciers, a series of terraces was developed beyond the mountain front. The uppermost terrace (Roscoe) may be late Tertiary or early Quaternary. An extensive intermediate terrace (Red Lodge) considerably antedates the Wisconsin epoch. A lower terrace (Rosebud) is also probably pre-Wisconsin. The last notable event was profound glaciation during the two Wisconsin stages. Whether uplift intervened between these stages or followed the later one has not been certainly determined.

## SUMMARY

The salient points in the preceding discussion are:

1. The Beartooth Range contains two extensive erosion surfaces which are most probably peneplains. The summit peneplain is more than 12,000 feet above sea-level, and the subsummit peneplain is commonly about 2,000 feet lower.

2. An analysis of several lines of evidence leads to the conclusion that the summit peneplain is most probably Oligocene.

3. The subsummit peneplain is interpreted to be Pliocene. It may have been but slightly dissected late in the period, or, possibly, even in early Quaternary time.

4. The range was uplifted several times. These episodes were: (*a*) the climacteric orogeny which produced the ancestral range and the Beartooth overthrust in post-Middle Eocene time; (*b*) Middle (?) Miocene vertical uplift of about 2,000 feet; (*c*) late (?) Pliocene or early Quaternary (?) vertical uplift of a few thousand feet; and (*d*) Quaternary uplift, possibly at more than one time.