CONTRIBUTIONS TO THE GEOGRAPHY OF THE UNITED STATES, 1922.

PENEPLAINS OF THE FRONT RANGE AND ROCKY MOUNTAIN NATIONAL PARK, COLORADO.

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PURPOSE OF THE PAPER.

The purpose of this paper is to call attention to some of the major surface features in the Rocky Mountain National Park and to point out their probable correlation with similar features in neighboring regions. The observations on which the paper is based were made in the summer of 1916, during an investigation in which other work demanded first consideration. This paper may therefore be considered a by-product. For the same reason many of the observations were not followed to conclusions, yet the data obtained seem to be sufficient to establish a certain order of events, the recognition of which may be of assistance in working out in detail the geologic and geographic history of the Rocky Mountain region.

TWO CYCLES OF EROSION PREVIOUSLY RECOGNIZED.

In an account of the general geology of the Georgetown quadrangle, Colo., Ball[1] describes three distinct types of land forms—"an old, mature mountainous upland; younger V-shaped valleys incised in this upland; and glacial cirques developed at the heads of some of the streams, passing downward into U-shaped valleys." Ball describes the mountainous upland as consisting of highlands of rounded or gently sloping tops which are remnants of an ancient peneplain or old surface of erosion. Most of these remnants in the Georgetown quadrangle lie above an altitude of 11,500 feet. On this old peneplain there were many monadnocks, some of which are now recognizable as the summits of the highest mountains. Similar surfaces of erosion occur elsewhere in the mountains, among them the well-known upland plain near Pikes Peak, recognized by Cross.[2]

[1] Spurr, J. E., and others, Economic geology of the Georgetown quadrangle (together with the Empire district), Colo. [General geology, by S. H. Ball]; U. S. Geol. Survey Prof. Paper 63, p. 31, 1906.

[2] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894.

Later Davis[3] accepted Ball's description and applied to the highlands the term "a two-cycle mountain mass." This term and other expressions in his paper indicate that Davis believes that only two main cycles of erosion are represented in the Rocky Mountains in Colorado—an older one resulting in the formation of a peneplain and a younger one during which the canyons and cirques were excavated. Hence the remnants of the highland plain found at many places in these mountains are referred to as parts of "the peneplain."

A POSSIBLE THIRD CYCLE.

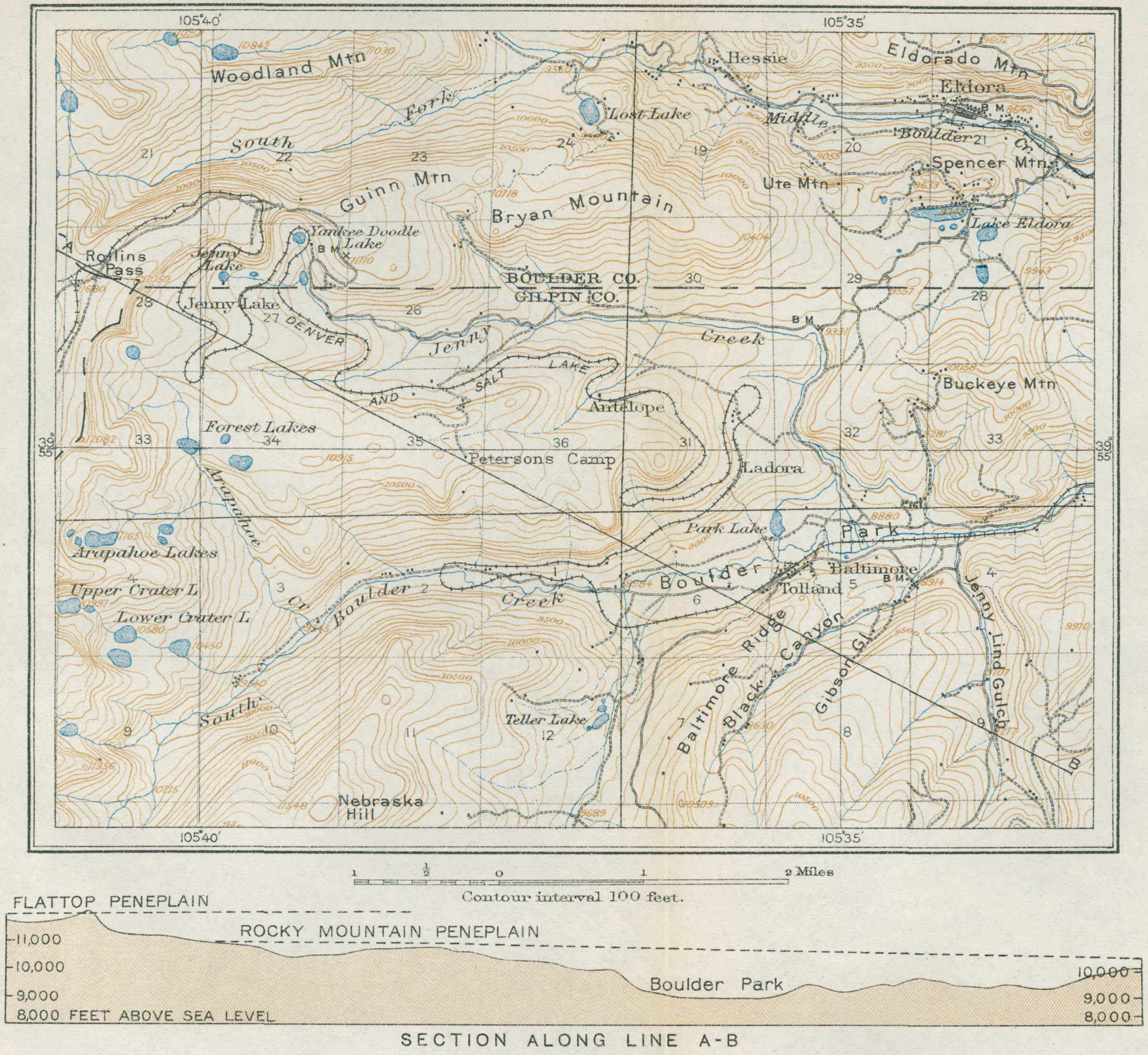
The dissected plateau near Pikes Peak which Cross described as practically the same as the floor of South Park was recognized by Richardson[4] in the Castle Rock quadrangle and by Finlay[5] in the Colorado Springs quadrangle. This plateau lies at altitudes between 9,000 and 9,500 feet and is extensively developed in the Front Range in Colorado. From localities at some distance from the mountains this plain appears to be an almost horizontal shelf that extends along the mountain front as far as the eye can reach. The area in which it is best developed and best preserved extends from Denver southward to Pikes Peak. In areas farther north, such as the mountains west of Golden, it is not so readily recognized, but it seems to be represented by surfaces much lower than the highland plain described by Ball as lying above 11,500 feet. Remnants of the lower plain may be recognized from some commanding eminence, such as Mount Lookout, near Golden, Colo., whose summit appears to be a part of the lower peneplain. This plain has become known somewhat widely as the Rocky Mountain peneplain, possibly because it is the most extensive land form in the Front Range. From Mount Lookout may be seen at nearly the same level numerous flat tops, benches, and smooth-floored reentrants (see Pl. I), which are remnants of the Rocky Mountain peneplain. But the best-known view of this peneplain is that which may be had from the side of Pikes Peak at an altitude of about 10,000 feet. From this point the observer looks to the north and west over the tops of the mountain ridges as over a level plain.

The reentrants seem to furnish indubitable proof of a distinct cycle of erosion. The older peneplaned surface was elevated, tilted, and dissected; the plain formed by the coalescing valleys has a slope notably different from that of the higher and older peneplain. A reentrant, possibly modified to some extent by glaciers, seen near Jenny Lake, Colo. (Pl. I), is a part of this new plain. This is one

[3] Davis, W. M., The Colorado Front Range: Assoc. Am. Geographers Annals, vol. 1, p. 42, 1911.

[4] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Castle Rock folio (No. 198), 1915.

[5] Finlay, G. I., U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (No. 203), 1916.



MAP AND PROFILE SECTION OF A PART OF CENTRAL CITY QUADRANGLE, COLO.

of the points of particular interest to tourists on the Denver & Salt Lake Railroad (Moffat road). This road winds over a surface of slight relief on the Rocky Mountain peneplain, enters the glacial cirque around Yankee Doodle Lake, and then ascends the steep slope leading to the high peneplain at Corona, which is described in this paper as the Flattop peneplain. Here a short walk brings the observer to the brink of the cliff, where he stands on the older peneplain, with the younger one in full view a thousand feet away.

Farther north there are old surfaces of considerable area, on which the rock is deeply disintegrated, such as that near Ward, at altitudes between 9,000 and 10,000 feet. These areas are parts of the Rocky Mountain peneplain. Still farther north, in the Rocky Mountain National Park, there are many remnants of a high plain, the Flattop peneplain, which corresponds to Ball's highland plain, and of a lower one, at an altitude of 10,000 feet or less (fig. 1), which corresponds to the Rocky Mountain peneplain. Both have been deeply dissected by the erosion of deep canyons during the present cycle.

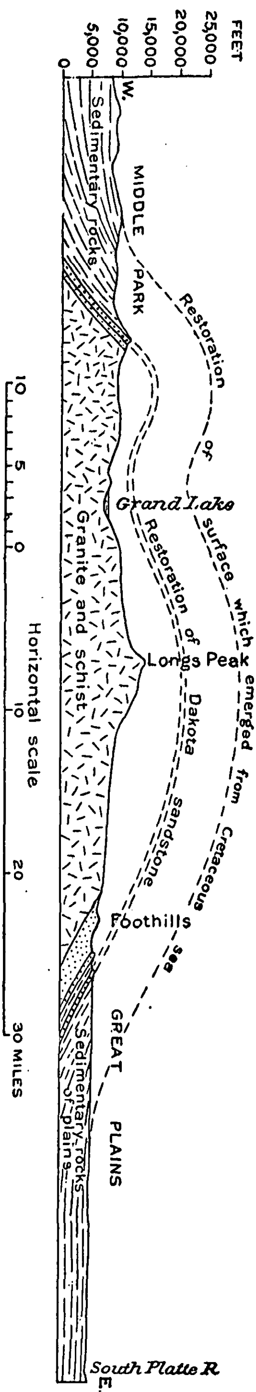


FIGURE 1.—East-west profile across the Rocky Mountains through Longs Peak and Grand Lake, Colo. The Dakota sandstone marks the position of an ancient floor resulting from erosion, which base-leveled the site of the mountains. On this floor were deposited sediments of Cretaceous age. The mountain region was arched at the end of the Cretaceous period, and the sedimentary rocks were eroded. Records of early Tertiary events in the mountain region were destroyed by later erosion. The first definite Tertiary event is recorded in the Flattop peneplain, a remnant of which is shown on Longs Peak. An uplift rejuvenated the streams, and the Rocky Mountain peneplain was formed. This plain appears to correspond in general to the surface of the Great Plains and is believed to have been completed in late Tertiary time. Renewed uplift of the mountains, possibly at the beginning of Quaternary time, initiated the canyon cycle of erosion.

Some geologists and geographers are disposed to regard the upland surfaces of both levels as parts of the same plain displaced by faulting; others see evidence here of two distinct peneplains which, together with the incised valleys and glacial cirques of the cycle not yet finished, make this a three-cycle rather than a two-cycle mountain mass.

CYCLES OF EROSION IN THE ROCKY MOUNTAIN NATIONAL PARK.

FLATTOP PENEPLAIN.

In the Rocky Mountain National Park near the crest of the highest range there are many flat or gently rounded surfaces that seem to be remnants of a peneplain. Most of them lie above timber line, which is here about 11,500 feet above the sea. One of the largest and most conspicuous of these remnants is on Flattop Mountain, whose name was suggested by its flat surface. (See Pl. II.) These remnants are so numerous and so close together that it is not difficult to reconstruct the old surface which they represent. Some of the gentler slopes are covered with residual soil, and the steeper ones with angular fragments of rock. A surface now connecting the several remnants would appear greatly warped and broken. Possibly the differences in altitude due to warping and faulting would in some places amount to a thousand feet or more. There are also peaks which were doubtless monadnocks on the old peneplain. Hallett Peak is plainly such a monadnock. (See Pl. II, *A*.) As viewed from the general level of the old peneplain this peak appears to be a dome rising about 500 feet, but from certain directions it appears to be a half dome, for the ancestor of Tyndall Glacier carried part of it away. Several smaller monadnocks are shown in Plate II, *B*. The nearly level top of Longs Peak may be a part of the Flattop peneplain warped up more than 2,000 feet, but it seems more likely that this mountain was a monadnock, although the nearly level surface of its summit, about 1,500 feet long and 1,000 feet wide, has been regarded as possibly a remnant of a peneplain still older than the Flattop peneplain. The rolling surface of the Flattop peneplain, which may be in part a product of recent warping, may be seen along the Continental Divide north of Longs Peak (Pl. III, *A*). Remnants of the same peneplain occur in many parts of the Rocky Mountain National Park on the highest mountains. Probably its most conspicuous remnant next to that on Flattop Mountain is on Hagues Peak (Pl. III, *B*).

In describing these highland surfaces as remnants of a peneplain I am not unmindful of the possibility that such surfaces may be formed in other ways,[6] but here the large number of the remnants at about the same altitude and their wide distribution favor the belief in their formation by peneplanation.

[6] Davis, W. M., Leveling without base-leveling: Science, vol. 21, pp. 825–828, 1905.

ROCKY MOUNTAIN PENEPLAIN.

On both sides of the high mountains the peaks rise to a fairly uniform altitude of about 10,000 feet. As viewed from a sufficient distance (see Pl. III) to obtain broad relations these peaks appear to stand at a general level 1,500 to 2,000 feet lower than the Flattop peneplain (see fig. 2), which seems to have resulted from a definite though uncompleted cycle of erosion. But the peneplain thus produced is not now rendered conspicuous by flat surfaces such as mark the higher peneplain, because of the intensive subaerial and subglacial erosion of a later cycle. Remnants of the older plain are preserved in spite of the long erosion that followed its uplift, because they lie near the heads of the streams and are affected but little by stream erosion.

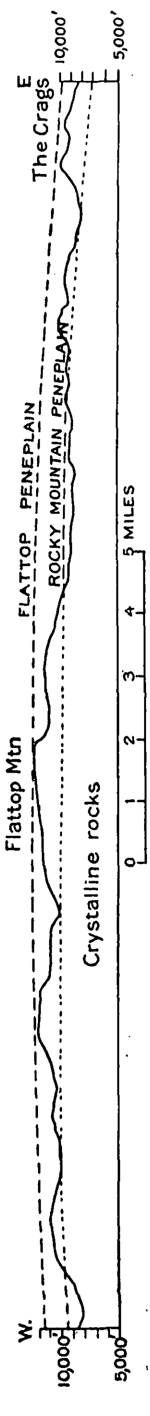


FIGURE 2.—Profile across the Front Range through Flattop Mountain from Colorado River (at the extreme left; formerly called Grand River) to The Crags, Colo., showing the relation of the Flattop peneplain to the Rocky Mountain peneplain.

This general level to which the mountains of intermediate height in the national park rise is here correlated with the Rocky Mountain peneplain, because it corresponds in position and apparently in age to the surface of the top of Mount Lookout.

CANYON CYCLE.

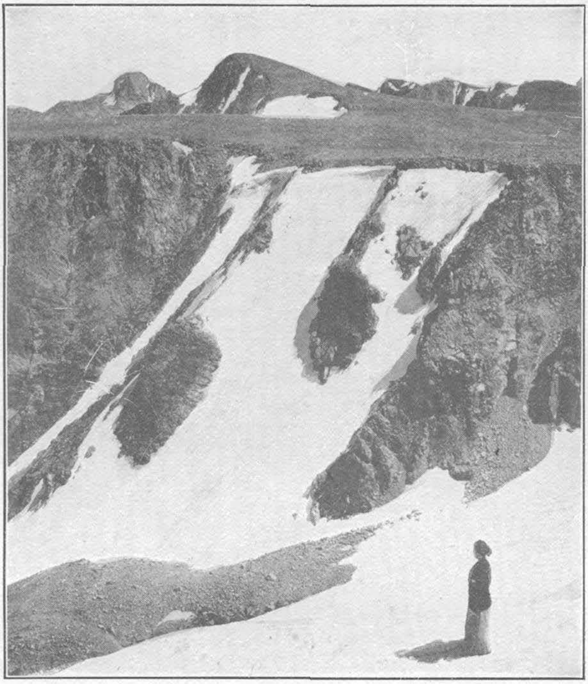
During the cycle of erosion not yet finished the Rocky Mountain peneplain has been deeply incised and throughout wide areas has been completely destroyed. This latest or canyon cycle is a composite one and will doubtless be subdivided when more detailed work is done, but for the present the preglacial canyon cutting and the ice action are grouped together under the name canyon cycle.

In the early part of this latest cycle the streams cut deep canyons, such as that of Thompson River (Pl. IV, *A*), through which the national park may be reached. Later in the cycle the heads of many of these canyons were glaciated and changed in form from the V-shape characteristic of stream work to the U-shape characteristic of glacial erosion. (See Pl. IV, *B*.)

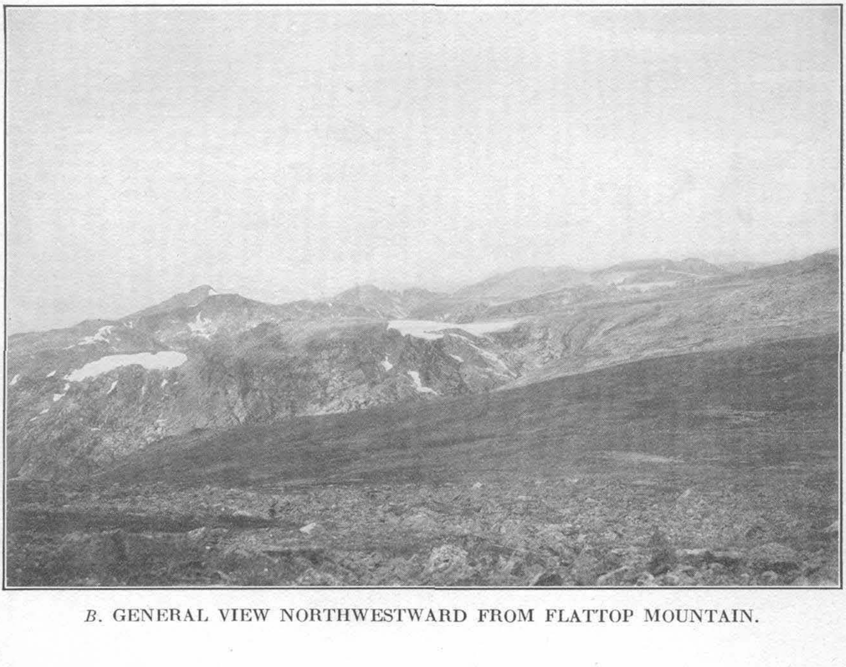
PLATE II.

A, Flattop Mountain, the type area of the Flattop peneplain. The gently inclined surface is at an altitude of about 12,500 feet. In the distance to the left is the flat summit of Longs Peak; in the middle ground is the rounded summit of Hallett Peak, a monadnock rising from the old peneplain; and in the distance to the right are tilted remnants of the same plain. Photograph by F. W. Byerly.

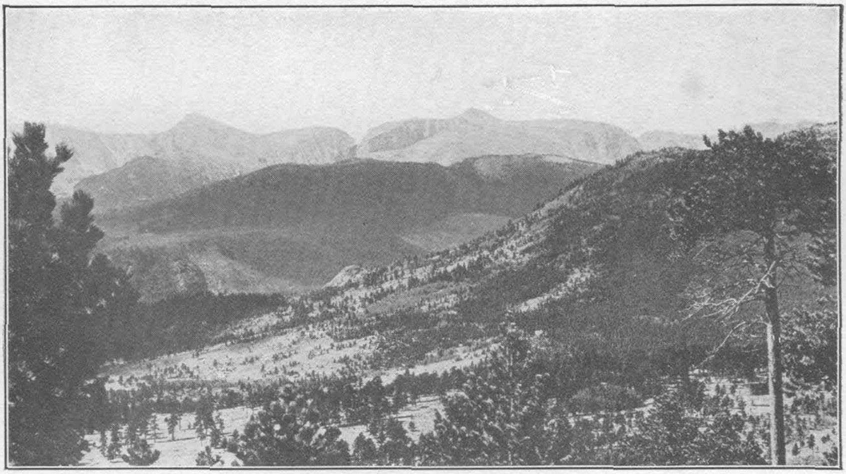
B, General view from Flattop Mountain (altitude 12,500 feet) northwest and across the peneplain to the Medicine Bow Mountains, in the distance at the left, the peaks of which rise to about the level of Flattop.



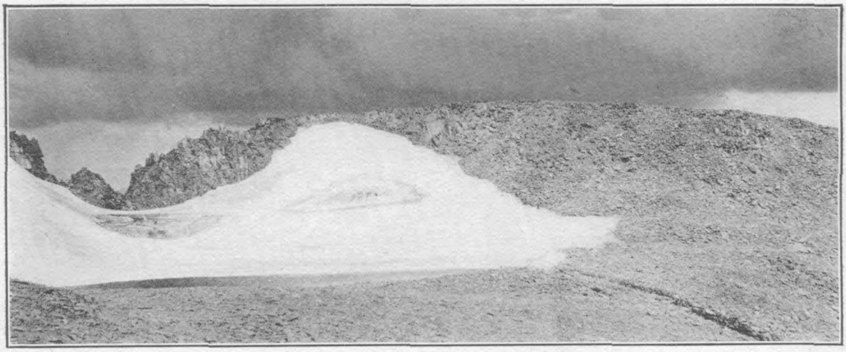
A. FLATTOP MOUNTAIN, COLO.



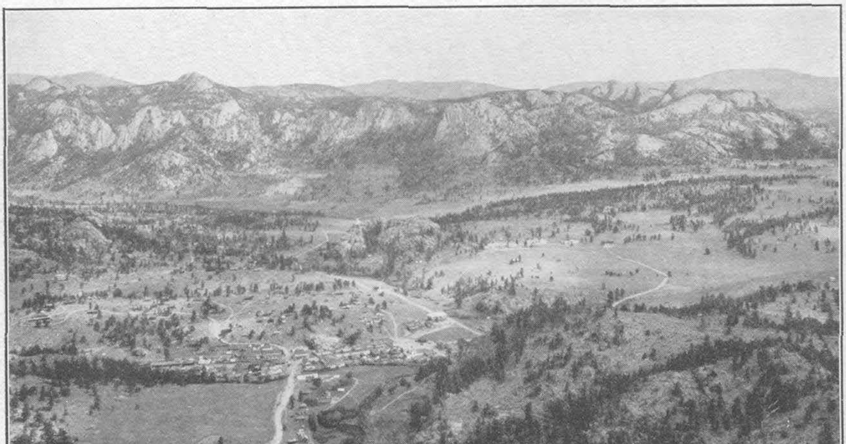
B. GENERAL VIEW NORTHWESTWARD FROM FLATTOP MOUNTAIN.



A. THE CONTINENTAL DIVIDE, COLO.



B. HALLETT GLACIER, COLO.



C. ESTES PARK, COLO.

PLATE III.

A, View of the Continental Divide from Deer Mountain, showing the Flattop peneplain and two monadnocks, Hallett Peak and Taylor Peak, on the sky line. A remnant of the Rocky Mountain peneplain in the middle ground, the glacial gorge of Thompson River, and the west end of the lateral moraine lying south of Moraine Park.

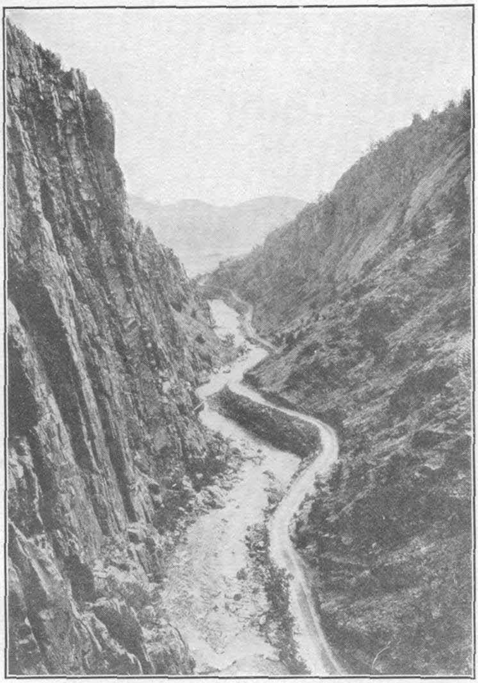
B, Hallett Glacier and a part of the Flattop peneplain at an altitude of 13,400 feet, north of Hagues Peak. In the dark parts of the glacier old crevassed ice is exposed.

C, View from Prospect Mountain northwestward across Estes Park to The Needles, showing the Rocky Mountain peneplain and a remnant of the higher or Flattop peneplain on the distant sky line. The park was eroded about 2,500 feet below the Rocky Mountain peneplain and shaped probably by the ice of the older or pre-Wisconsin stage of glaciation.

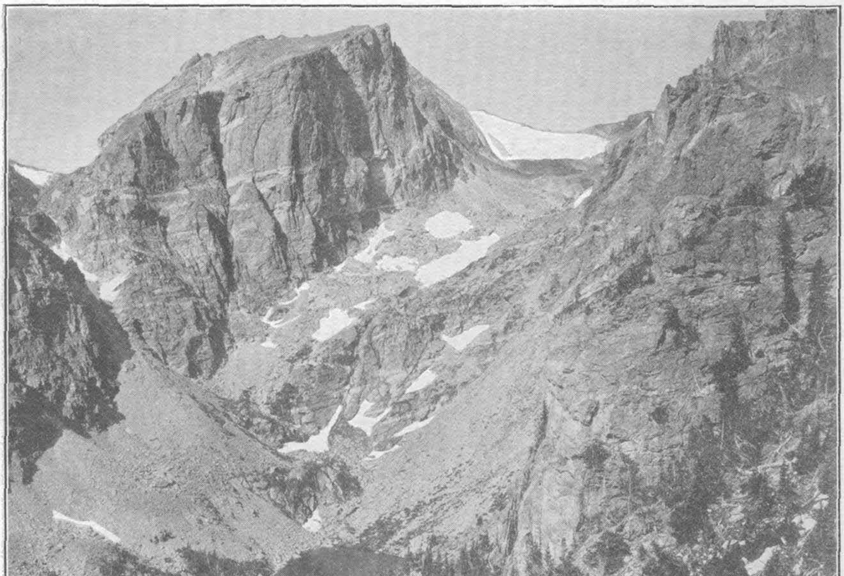
PLATE IV.

A, A V-shaped valley of the canyon cycle of erosion in the lower end of Thompson Canyon, cut in the upturned quartzite; looking downstream toward the Great Plains. In the distance is the "Red Beds" hogback of the foothills east of the mountains.

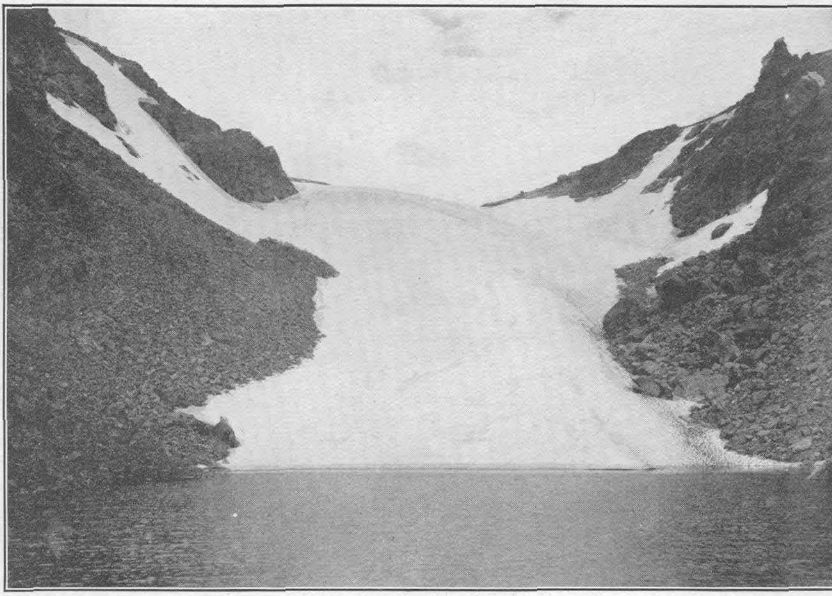
B, A V-shaped valley or glacial gorge cut in granite and schist by ice during the canyon cycle of erosion. Tyndall Glacier, at the head of the gorge, extends up to the Flattop peneplain at an altitude of 12,300 feet. The lake in the foreground is at an altitude of 10,200 feet and is 1¼ miles from the head of the glacier. The cliffs rise about 2,000 feet above the lake.



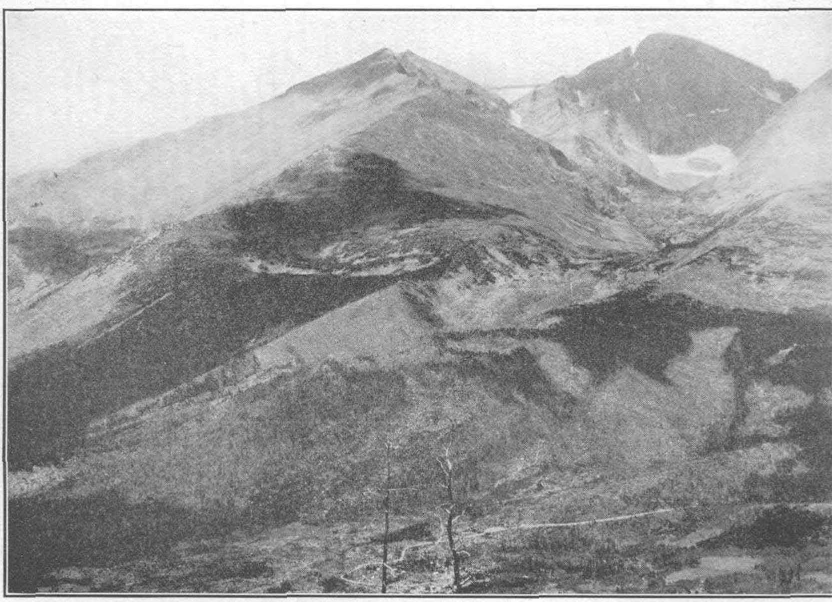
A. THOMPSON CANYON, COLO.



B. GORGE BELOW TYNDALL GLACIER, COLO.



A. ANDREWS GLACIER, COLO.



B. MILLS MORAINE, COLO.

PLATE V.

A, A view of Andrews Glacier from the lake in which the ice at its foot melts. Because of the great bend in the center the upper half of the glacier is not seen from the lake.

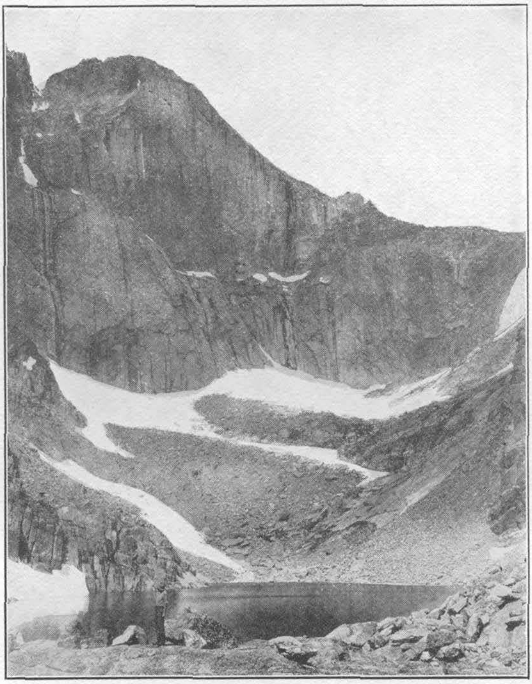
B, Mills moraine, as seen from Twin Sisters. The glacier originated in The Chasm (Pl. VI, *A*), on the east slope of Longs Peak, and was about 4 miles long. The rock débris carried out of The Chasm was dropped chiefly at the sides, building up the ridges shown in the photograph. The moraines range in altitude from 9,500 feet at their base to nearly 12,000 feet.

PLATE VI.

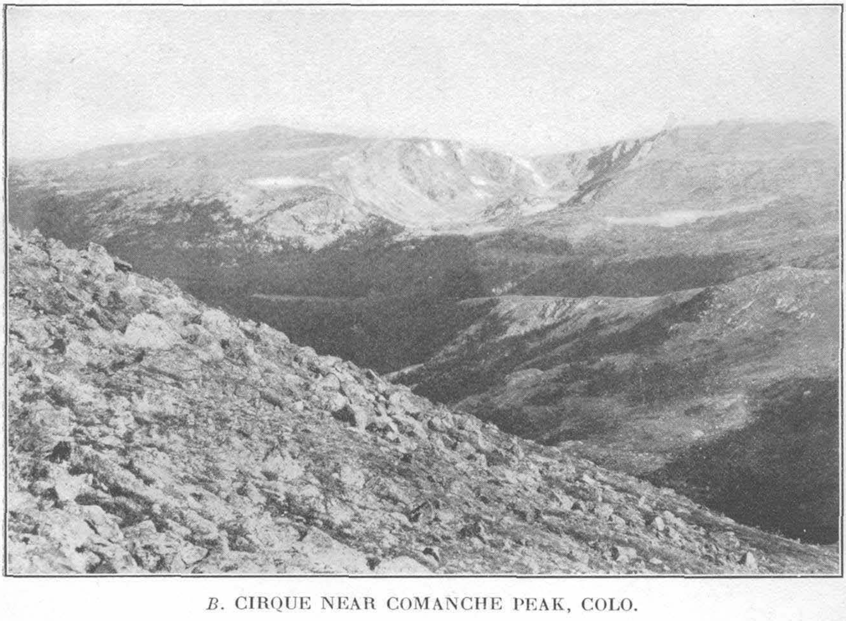
CIRQUES FORMED DURING THE WISCONSIN STAGE OF GLACIATION.

A, The Chasm, in the eastern face of Longs Peak, as seen from Chasm Lake. The precipitous face of the cirque rises about 2,400 feet above the lake.

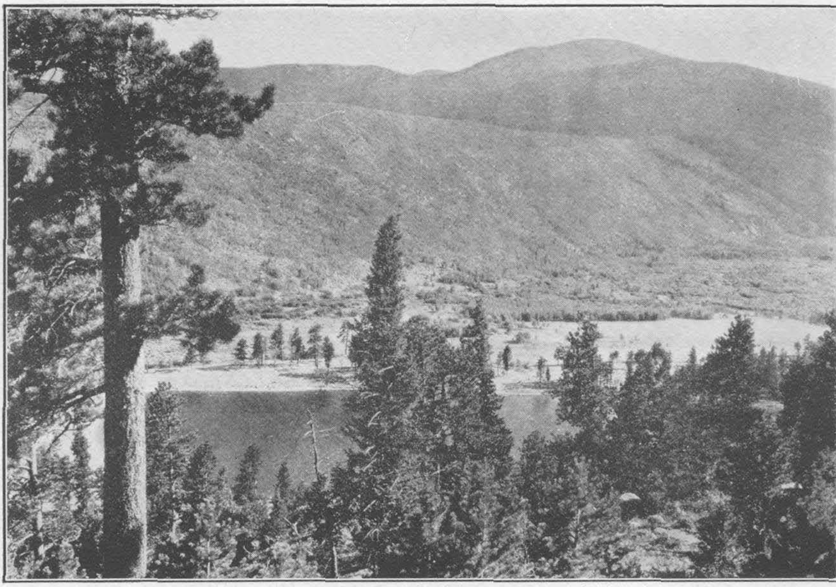
B, The cirque on the northern boundary of the Rocky Mountain National Park, 1 mile southwest of Comanche Peak, as seen from the saddle north of Hagues Peak, a distance of 5 miles. The cirque is 1 mile long, half a mile wide, and 1,000 feet deep. On both sides of the cirque is the Flattop peneplain, which has a maximum altitude here of more than 12,500 feet.



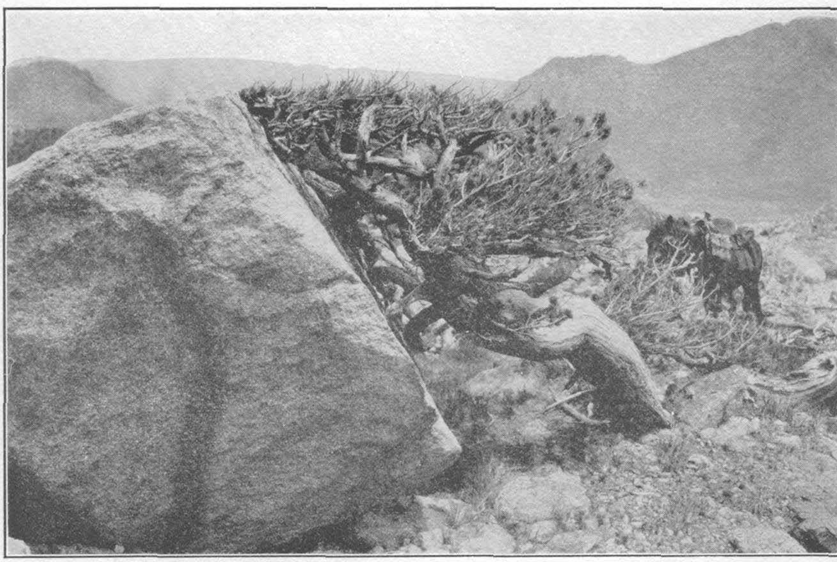
A. THE CHASM, LONGS PEAK, COLO.



B. CIRQUE NEAR COMANCHE PEAK, COLO.



A. MORAINE SOUTH OF COPELAND LAKE, COLO.



B. A TIMBER-LINE TREE ON LONGS PEAK, COLO.

PLATE VII.

A, View from Copeland moraine above Copeland Lake, across the St. Vrain to the lateral moraine south of the valley. The glacier which built these great moraines originated in Wild Basin south of Longs Peak and moved down the valley 10 miles or more.

B, A timber-line tree (limber pine) on Longs Peak. A result of the prevailing westerly wind, which sweeps the snow from the highland plains into the cirques of the eastern slopes. The intense dissection of the mountains east of Continental Divide near Longs Peak (see topographic map of Longs Peak quadrangle) is due largely to glaciers formed of snow swept by the west wind from the Flattop peneplain.

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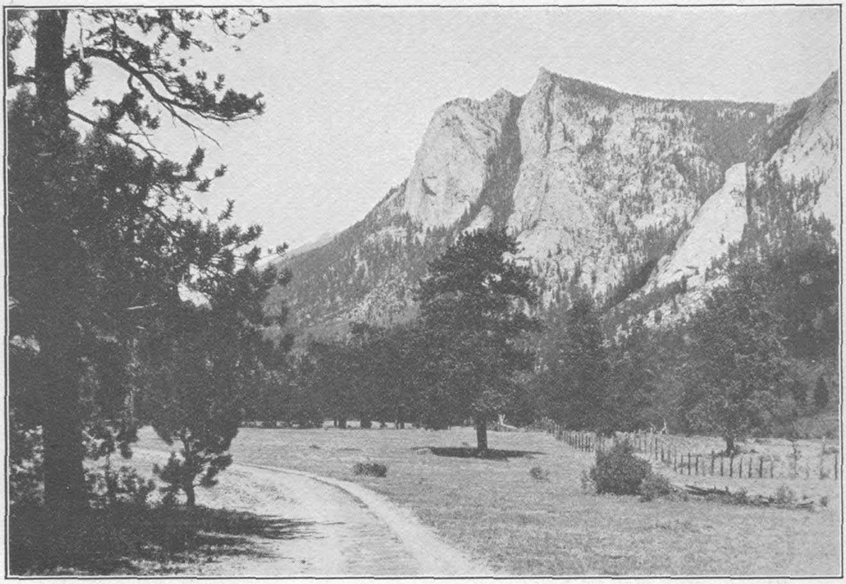
PLATE VIII.

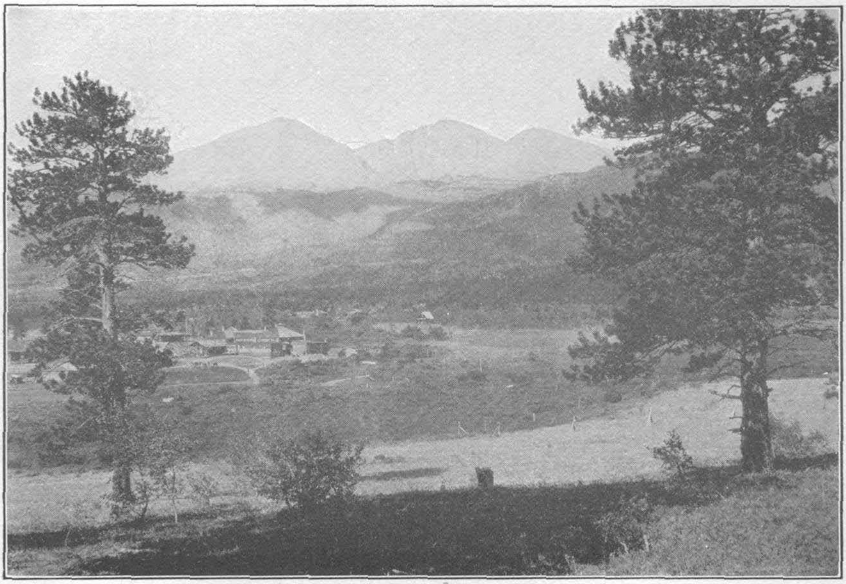
RESULTS OF PRE-WISCONSIN GLACIATION.

A, Black Canyon and The Needles. This canyon was not occupied by ice during the last stage of glaciation, but the broad, gently sloping floor and precipitous wall of granite rising 2,000 feet to the Rocky Mountain peneplain, which appears on the right, is suggestive of intensive ice action such as shaped the Yosemite Valley.

B, Longs Peak and Tahosa Valley. This valley is outside the area of Wisconsin glaciation, but its broad, smooth floor at an altitude of 9,000 feet, a mile or more in width, with mountains east of it rising to an altitude of 11,436 feet within a mile and mountains west of it rising to an altitude of 14,255 feet within 4 miles, suggests glacial action.



A. BLACK CANYON AND THE NEEDLES, COLO.



B. LONGS PEAK AND TAHOSA VALLEY, COLO.

At least two stages of glaciation are represented here—a later one, presumably corresponding in time to the Wisconsin stage, and an earlier one, corresponding in time to one of the older recognized stages. The results of the latest glaciation are conspicuously exhibited in the national park. Deep gorges (Pl. IV, *B*) and cirques were scooped out of the mountain sides by the ice, and morainal matter was heaped up to a depth of 1,000 feet or more. Many if not all of the gorges and cirques are stream-cut valleys that have been modified in form by the ice, but the excavation in some of them, such as The Chasm, on Longs Peak (Pl. V, *B*), was chiefly the work of a glacier, a fact shown by a comparison of the size of the cirque with the volume of morainal matter which obviously came from it. The ice at the Wisconsin stage modified the topography of both the Flattop peneplain and the Rocky Mountain peneplain. The gorge below Tyndall Glacier (Pl. IV, *B*) is cut into the higher plain, as is also the remarkably fine cirque near Comanche Peak (Pl. VI, *B*). The Rocky Mountain peneplain was affected to a less extent by the ice, for at the time it existed the glaciers on the eastern slope of the mountains occupied only the bottom parts of the valleys (Pl. III, *A*). Some of the moraines, such as the Mills moraine, were formed in part above the level of the Rocky Mountain peneplain (Pl. V, *B*), but most of them were built at lower levels (Pls. III, *A*, and VII, *A*).

Some of the cirques and gorges still contain large bodies of snow and ice. It is uncertain how many of these bodies should be called glaciers. The mass of ice on Hagues Peak (Pl. III, *B*) has been named Hallett Glacier, after Mr. W. L. Hallett, of Colorado Springs, who visited it in 1884 and noted the crevasses in the ice. For many years it was generally supposed that the Hallett was the only true glacier in the Longs Peak region, but now four other bodies of ice in this group of mountains are recognized as glaciers and named on the topographic map of the Longs Peak quadrangle—Sprague Glacier, an arm of which is shown in Plate II, *A;* Tyndall Glacier, shown in the distance in Plate IV, *B;* Andrews Glacier, the body of ice shown in Plate V, *A;* and Taylor Glacier.

The former presence in the Longs Peak region of glaciers older than those of the Wisconsin stage has not been demonstrated, but such features as U-shaped valleys, perched lakes, and peat-filled basins beyond the known limits of the Wisconsin ice go far toward such a demonstration. In the Black Canyon (Pl. VIII, *A*) the broad floor of the valley and the steep cliffs that rise precipitously 2,000 feet at its side suggest oversteepening of the walls by ice. In the character of the rock of the walls, which is massive granite, and in the form of the valley there is so striking a resemblance to Yosemite Valley as to suggest similar origin, yet Black Canyon did not contain a glacier during the Wisconsin stage. It is tributary to Estes Park (Pl. III, *C*), which presumably was filled with ice during this older stage of glaciation. Tahosa Valley (Pl. VIII, *B*) also may have been shaped, at least in part, by the older glaciers.

CORRELATION WITH PENEPLAINS OF OTHER AREAS.

The Flattop peneplain is probably to be correlated with the highland plain of the Georgetown quadrangle described by Ball. The canyon cycle is obviously the same everywhere along the Front Range, for the canyons are all of essentially the same degree of development. The intermediate cycle was not definitely recognized by Ball, and it is not easily discernible in the Georgetown quadrangle. However, from Golden southward to the Pikes Peak region the peneplain formed during the intermediate cycle appears as the great conspicuous upland called in this paper the Rocky Mountain peneplain.

A question has been raised as to the meaning of the intermediate highlands. There is little doubt that faulting and warping of relatively recent date has occurred in many parts of the mountains, and some of the surfaces here interpreted as remnants of the Rocky Mountain peneplain may possibly be displaced parts of the higher plain let down by faulting; but it is scarcely probable that the intermediate cycle of erosion can be explained away in this manner. Although my observations were hurried and limited to a small area I am disposed to believe that the Front Range is a three-cycle rather than a two-cycle mountain mass.

PHYSIOGRAPHIC HISTORY.

Although the physiographic history of the Rocky Mountains is imperfectly known, a probable chronologic order of events can be worked out which may be of value, at least in stimulating observation. A partial list of events, given in order from oldest to youngest, follows.

FIRST MOUNTAIN UPLIFT AND EARLY EROSION.

Reasons for believing that sedimentary deposits of Cretaceous age covered the site of the mountains in Colorado and that the mountains emerged from the sea at the end of the Cretaceous period have been given in an earlier publication.[7] As that publication is easily available these reasons need not be repeated here.

After the initial uplift the sedimentary rocks were eroded, at least in part, from the area later carved into mountains. Also during this early period of erosion andesite[8] was extruded in the mountain region, and this also was eroded away and waste from it was included in the early Tertiary beds (Denver formation).

[7] Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27–56, 1916.

[8] Cross, Whitman, Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, p. 315, 1896.

FLATTOP CYCLE.

Perhaps somewhat later, although this can not be asserted with confidence, flows of rhyolite and andesite were formed in the region north of Longs Peak. These flows were later broken up, and the blocks were transported, presumably by water, to the lowlands or broad valleys of that time, which had been eroded in the crystalline rocks of the mountain core. Here the débris of rhyolite and andesite was interbedded with volcanic ash, tuff, and flows of glassy lava, the composite mass occupying a wide area and resting on a floor of old crystalline rock. With the blocks of rhyolite were embedded rounded pebbles and boulders of granite, gneiss, and schist so large as to indicate that highlands of crystalline rock of considerable altitude existed near by at that time. A large mass of this composite material many hundreds of feet thick is preserved in Specimen Mountain, in the northern part of the Rocky Mountain National Park. As the base of the material is at nearly the same altitude as the Flattop peneplain, it may be that the broad valleys in which the material accumulated were due to erosion in the early part of the cycle which produced the Flattop peneplain and that the highlands which furnished the boulders of crystalline rock are represented now by such old monadnocks as Hallett Peak.

The formation of the Flattop peneplain was the third major event in the history of this region. Apparently the mountain region was elevated 2,000 feet or more, and the consequent erosion reduced the greater part of it nearly to a plain, leaving many monadnocks, such as Hallett Peak (Pl. III, *A*), Longs Peak, and Mount Evans. The bedded deposits of rhyolite and andesite débris which accumulated in the cycle were partly eroded away, and dikes of the same material were planed off even with the general surface. One large mass, that of Specimen Mountain, escaped erosion.

There is little evidence by which the date of this peneplain can be fixed, but the general succession of events indicates the improbability that it was formed before the end of the Eocene epoch, and the equal improbability that it is later than Pliocene.

ROCKY MOUNTAIN CYCLE.

Renewed uplift still further arched the great mountain anticline, lifting the center 1,500 to 2,000 feet. This uplift rejuvenated the streams, and the Rocky Mountain peneplain was formed. This is probably the most extensive physical feature of the mountain region in northern Colorado. Its formation required a long time. Many facts point to its being the mountain equivalent of the Great Plains, as is suggested by such profiles as those in Plate IV of the Denver

Basin monograph,[9] those of the Castle Rock folio,[10] and those of figure 3 of this paper. Doubtless the erosion that produced this peneplain furnished the material for the beds of late Tertiary age east of the mountains.

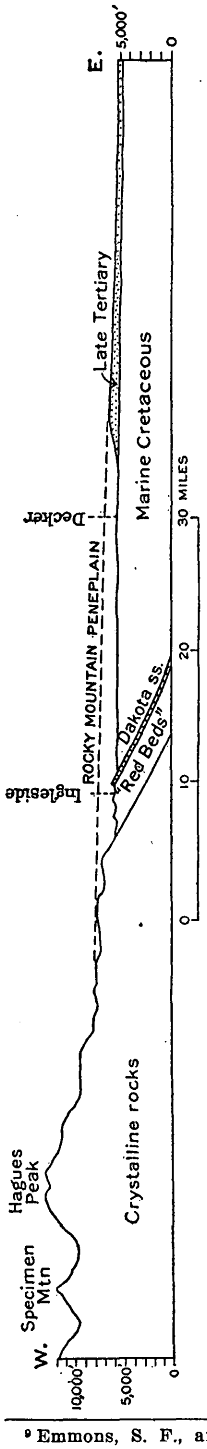


FIGURE 3.—Profile from the crest of the mountains at Hagues Peak northeastward to the Great Plains in northern Colorado. A remnant of the Flattop peneplain is preserved on Hagues Peak. Northeast of this peak the slope of both peneplains is greater than it is farther south, and the lower one descends to about 7,000 feet. This slope is such as to bring the restored Rocky Mountain peneplain down to the level of the Great Plains several miles east of the foothills. The space represented between this plain and the present surface shows the amount of degradation of the Great Plains during the canyon cycle.

Certain gravel beds observed near the tops of the mountains between Palmer Lake and Florissant may be due to the activity of some of the streams that helped to form this peneplain. These were observed many years ago by George H. Stone, who published in the Colorado Springs Gazette in 1900 a sketch map showing a large body of gravel on the highlands east of Florissant, near Divide station on the Colorado Midland Railway, between the headwaters of South Platte River and Fountain Creek. Smaller bodies of gravel which seem to mark the course of an old river lie between this locality and Palmer Lake. On Stone's map the site of the large body of gravel was called Hayden Lake, and the line of gravel beds between this body and Palmer Lake was called Hayden River. These gravel beds suggest the headwaters of one of the streams which in late Tertiary time furnished the pebbles of the gravel beds that still cover vast areas of the Great Plains in eastern Colorado.

CANYON CYCLE.

The Rocky Mountain cycle of erosion was terminated by renewed uplift accompanied by much warping of the surface and great displacement by faulting in many localities. South of Denver the Rocky Mountain peneplain seems to have been lifted without notable warping, the displacement being generally accomplished by slipping along fault planes in the foothill region. In north-

[9] Emmons, S. F., and others, Geology of the Denver Basin, in Colorado: U. S. Geol. Survey Mon. 27, 1896.

[10] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Castle Rock folio (No. 198), 1915.

ern Colorado the uplift seems to have partaken more of the nature of arching (see fig. 3), so that the older plain on Hagues Peak is about 5,000 feet higher than the younger plain in the foothill region.

There are some reasons for believing that this orographic disturbance marks the beginning of the Quaternary period. The surface gravel of the plain, which seems to have been spread out by streams in the later part of the Rocky Mountain cycle, contains fossil bones said to indicate Pliocene or Pleistocene time. If this dating of the last great uplift of the Rocky Mountains at the beginning of the Quaternary is correct, the canyon cycle of erosion is coextensive with Quaternary time. The work of cutting these canyons is comparable to that in the San Juan River region, where canyons 2,000 feet deep have been cut since the oldest Pleistocene glaciation of that region.[11] The dissection and degradation of the Great Plains near the mountains accomplished during the canyon cycle is no greater than the degradation in Montana since the early glaciation, now represented by the till which caps certain mesas having a maximum height of about 1,000 feet above the surrounding country.[12]

SUMMARY.

There is fairly satisfactory evidence in the Rocky Mountain National Park of three distinct cycles of erosion—one which resulted in the Flattop peneplain and was completed some time near the middle of the Tertiary period; one which resulted in the Rocky Mountain peneplain and was probably terminated at the end of the Tertiary; and the canyon cycle, not yet completed. A peneplain still older than the Flattop peneplain may be represented by the top of Longs Peak and other high mountains in Colorado, many of which have nearly the same altitude.

[11] Atwood, W. W., and Mather, K. F., The evidence of three distinct glacial epochs in the Pleistocene history of the San Juan Mountains, Colo.: Jour. Geology, vol. 20, p. 401, 1912.

[12] Alden, W. C., and Stebinger, Eugene, Pre-Wisconsin glacial drift in the region of Glacier National Park, Mont.: Geol. Soc. America Bull., vol. 24, pp. 529–572, 1913.