GLACIATION ON THE EAST SIDE OF THE COLORADO FRONT RANGE BETWEEN JAMES PEAK AND LONGS PEAK

BY

WILLIAM D. THORNBURY

B.A., Indiana University, 1925

A THESIS

SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL OF THE UNIVERSITY OF COLORADO IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE MASTER OF ARTS

DEPARTMENT OF GEOLOGY

UNIVERSITY OF COLORADO

1928

This Thesis for the M.A. Degree, by

William D Thornbury

not proof read, has been approved for the

Department of

Geology

By

J. E. Worcester

June 6, 1928

C O N T E N T S

ILLUSTRATIONS

INTRODUCTION

ABSTRACT

The portion of the Front Range of Colorado between James Peak and Longs Peak was extensively glaciated during the Pleistocene period by valley glaciers which extended from near the continental divide down the valleys of South Boulder Creek, Middle Boulder Creek, North Boulder Creek, South St. Vrain Creek, Middle St. Vrain Creek, and North St. Vrain Creek for an average distance of twelve miles. The glaciers were valley glaciers except in the region northwest of Ward, where the South St. Vrain glacier and the Middle St. Vrain glacier coalesced to form a piedmont glacier which covered between five and six square miles. Evidence is presented to prove the existence of two periods of glaciation. This evidence consists of (a) difference in the degree of weathering of the morainal material of the two periods, (b) the presence of morainal material at different topographic levels and, (c) the development of such topographic features as tandem cirques, 'hanging cirques', and the existence of one glaciated valley within another, land forms which can only rationally be explained as the result of two periods of glaciation.

LOCATION

The area which is to be described in this

in this paper. It includes parts of the Central City, Blackhawk, Boulder, Rocky Mountain National Park, and Mt. Olympus quadrangles.

The area is rather centrally located in Colorado. It is very near the center of the state in an east and west direction, but is a little north of the center in a north and south line. It is located in a region where the Front Range of Colorado reaches its maximum ruggedness and elevation. Longs Peak, which is at the northern edge of the area and whose elevation is 14,255 feet above sea level, is one of the highest peaks in Colorado. James Peak at the southern edge of the area is very nearly a thousand feet lower than Longs Peak.

ACKNOWLEDGEMENTS

The writer wishes to express his indebtedness to Dean P. G. Worcester for the assignment of a very interesting problem and for the advice and assistance which he offered as the work progressed toward completion. To Dr. R. D. George he is also indebted for the opportunity to undertake the work. To Mr. W. H. Thoman he is also grateful for the care and pains with which he prepared the outline map of the area.

HISTORICAL DISCUSSION

Several articles have been published in which a description of some of the existing glaciers of the Front

Range has been given, but so far as the writer was able to ascertain no attempt has been made to describe in a systematic way the glacial geology of the east side of the Front Range of Colorado. The nearest approach to this is an article by Professor Junius Henderson[1] of the University of Colorado in which he describes the extinct and existing glaciers of Colorado in a rather general way. About all that was attempted in his article was to point out the areas in Colorado in which glaciers have existed and those in which they still exist and to show the general effect of the glaciers upon the topography of the state. Bastin and Hill[2] have described in some detail the effects of glaciation in the region just south of the one under discussion, but their paper is primarily one dealing with the economic resources of the area and treats upon the subject very briefly.

As a means of contrasting the extent of our present knowledge of the extent of glaciation in the Front Range with that of fifty years ago, the following extract is taken from an article by J. W. Foster[3] in the American

1. Henderson, Junius, Extinct and existing glaciers of Colorado: Colorado University Studies, vol. 8, pp.33-76, 1911.

2. Bastin, E. S. and Hill, J. M., Economic geology of Gilpin county and adjacent parts of Clear Creek and Boulder Counties, Colorado: U.S.G.S. Prof. Paper 94, pp. 57-60, 1917

3. Foster, J. W., The Mountains of Colorado: Am. Naturalist, vol. 11, pp. 65-75, 1872.

Naturalist in 1872: "All evidence of glaciation is lacking upon the plains. Entering the mountains, the cliffs are jagged, nowhere exhibiting those smooth outlines seen in the Alps and called by De Saussure roche moutonnees. The enclosing banks of the streams are made up of large egg-shaped pebbles and occasional boulders of two to three feet in diameter. None of these materials, so far as I have observed, are striated, while the true drift pebbles are almost invariably marked by such signs."

With part of the content of this quotation most any one would agree, but he would be forced to disagree with the contention that there are no signs of glaciation in the mountains.

It has been estimated[4] that from ten to twenty percent of the area of Colorado was at one time covered by glaciers, but the latter estimate seems far too liberal. It is possible that ten percent of the state may have been glaciated but that is surely a liberal enough estimate. The statement has been made[5] that seventy-five percent of the present mountain valleys which head near the crest of the range had glaciers in them. It seems very

4. Henderson, Junius, op. cit.

5. Worcester, P. G., Unpublished Dr's. thesis on the physiography of Colorado.

probable that this statement is true. In the area under discussion it is an underestimate, for every major valley between James Peak and Longs Peak, which extends back to the range has had a glacier in it.

According to Henderson[6]. twenty-two of the sixty-three counties in Colorado have some indications of former glaciation in them. It is probable that three or four more counties should be added to this number.

Although there is some dispute as to what constitutes a true glacier, if we use the term in the broadest sense of the word we find that there are thirteen living glaciers in Colorado today. Except for two small glaciers upon the north side of Mt. Blanca in the Sangre de Cristo Range, they all occur north of the southern boundary of the area under discussion. The eleven glaciers which have been described in North-central Colorado are all within the area included in the Rocky Mountain National Park quadrangle, but only five of the eleven are within the Rocky Mountain National Park quadrangle. The eleven glaciers of north-central Colorado are the Hallett, Sprague, Tyndall, Andrew, Taylor, the two St. Vrains, Arapahoe, Isabel, the Fair, and the North Arapahoe or Henderson. All of these glaciers except the Fair are on the east side of the continental divide. It is not improbable that other

6. Henderson, Junius, Extinct glaciers of Colorado: University of Colorado Studies, vol. 3, 1906.

glaciers exist within the state, but they have not been examined and described.

The greater abundance of glaciers upon the east side of the continental divide is probably attributable to the prevalence of strong westerly winds which blow considerable amounts of snow over on to the east side of the divide and thus cause larger snow-fields to form there. Differences in exposure may have something to do with the greater accumulation of snow on the eastern side of the range. The western side of the divide receives the afternoon sun's rays and they are usually more effective in the melting of snow than are the morning rays and thus melting would be more rapid on the western side.

The ancient glaciers were not confined to this part of the state by any means. Evidence of former glaciation is found all along the Front Range and the southern continuation of this range, the Wet Mountains and Sangre de Cristo Range. In the Georgetown area there is abundant evidence of extensive glaciation, and the same is true of the Pikes Peak region, except that the glaciers here were not so numerous or as extensive as they were farther north. This was partly due to the milder climate in the Pikes Peak region, and partly due to the topographic conditions. Pikes Peak is somewhat isolated from the main range and there is not the height

and mass of mountains there to cause as much precipitation as would occur farther north.

The Park, Mosquito, and Sawatch ranges all bear evidence of former extensive mountain glaciation. The region about Leadville has numerous terminal and lateral moraines on both the east and west sides of the Arkansas Valley. The glaciers on the west side of the valley were more extensive than those on the east side of the valley. It is probable that at least a third of the area was covered by glaciers.

The west side of the Front Range also bears evidence of having been glaciated, but the glaciers were not so numerous or as long as were those on the east side of the continental divide.

The Sangre de Cristo Range had numerous glaciers in it and, as was mentioned above, there remain today two small remnants of the once more numerous and extensive glaciers of this range[7].

The Spanish Peaks were also glaciated and retain today on the north side two large fields of neve, which have been erroneously reported as glaciers.

The San Juan Mountains and the surrounding territory were probably more extensively glaciated than any other region in Colorado. Evidence[8] has been presented.

7. Siebenthal, C. E., Notes on glaciation in the Sangre de Cristo Range, Colorado: Jour. Geology, vol. 15, pp. 15-22, 1907.

in support of the belief in three periods of glaciation in this region. The largest glacier in the area was the one which occupied the valley of the Las Animas river. The collecting ground for this glacier covered several hundred square miles and it attained a length of fifty miles. Glaciers comparable in magnitude with the one in Las Animas Valley existed in the valleys of the Upper Rio Grande, San Miguel, and Uncompaghre rivers. The glacier which moved northwest down the valley of the Uncompaghre built up a terminal moraine just northeast of the village of Ridgway which is over four hundred feet high. Every tributary valley in the region was glaciated.

Other areas in which evidence of former glaciation is present are the Elk Mountains, the La Plata Mountains, the White River Plateau, and South Park.

8. Atwood, W. W. and Mather, K. F., The Evidence of Three distinct glacial epochs in the Pleistocene history of the San Juan Mountains, Colorado: Jour. Geology, vol. 20, pp. 385-409, 1912.

G E O G R A P H Y

RELIEF

The region under discussion is an elevated dissected plateau, above which rises the higher peaks of the area. The Continental Divide follows the crest of the Front Range and averages about 13,000 feet in elevation. The highest mountain in the region is Longs Peak, the top of which is 14,255 feet above sea level. Arapahoe Peak is second in height with an elevation of 13,506 feet.

Although there are numerous peaks along the crest of the Range, the relief is not as great as might be expected. Near the heads of the valleys the topography is rather rugged and the valleys are canyon-like and steep walled, but the greater part of the region consists of the undulating remnants of two former peneplains. The older and higher of these is known as the Flattop peneplain and the younger and lower is called the Rocky Mountain peneplain. Such spurs as Bryan Mountain, Chittenden Mountain, and Woodland Mountain are remnants of the Flattop peneplain. Caribou Flats, Sherwood Flats, and Tennessee Mountain are examples of portions of the Rocky Mountain peneplain.

In the main, glaciation has been more effective than any other agency in increasing the relief of the region. If the effects of glaciation could be removed

the area would present the appearance of a moderately rolling upland. Rock structure has had very little influence upon the development of the topographic features. Although the rocks differ as to type, they do not differ a great deal in hardness and there is no marked control of relief by rock structure.

DRAINAGE

The region is very well drained by six major streams and a great number of tributaries. From the south to the north, the main streams are South Boulder, Middle Boulder, North Boulder, South St. Vrain, Middle St. Vrain, and North St. Vrain.

South Boulder Creek is fed by several tributaries among which are Arapahoe Creek, the stream in Mammoth Gulch, and Jenny Creek. Middle Boulder Creek is formed by the junction of the North and South Forks at the little village of Hessie. North Beaver Creek empties into Middle Boulder on the east edge of the town of Nederland. About six miles below Nederland North Boulder Creek joins with Middle Boulder Creek and the resulting stream is known as Boulder Creek. Boulder Creek joins with South Boulder Creek on the plains near the village of Valmont. The South St. Vrain and Middle St. Vrain join before reaching the plains and form a stream called the South St. Vrain until the town of

Lyons is reached, where the North St. Vrain joins the South St. Vrain to form the St. Vrain. The St. Vrain and Boulder Creek join five miles southeast of Longmont and the combined stream enters the South Platte about thirteen miles southeast of Loveland. The South Platte ultimately enters the Missouri and thus the water from the region reaches the Mississippi and finally the Gulf of Mexico.

The gradient of most of the streams is steep. Seldom is it less than 100 feet to the mile and in many places it is as much as 500 or 600 feet to the mile. The headward portions of the streams usually have a very steep gradient. The Narrows in Boulder Canyon is a good example of this characteristic. Similar features are found in other stream valleys of the region.

The stream flow is fairly regular throughout the year, but there isusually considerable more water in the streams during the summer months than at any other time because of the summer melting of the snow in the mountains. Along several of the streams the flow is regulated by the construction of dams. Such is the case along the Middle Boulder Creek, North Boulder Creek, and the Middle St. Vrain Creek. The water thus stored is used either for city water supply or for irrigation purposes.

CLIMATE

As a result of the very considerable range in

elevation, the climate varies in different parts of the region. The mean annual temperature at a point near Longs Peak at an elevation of 8,700 feet is 38 degrees Fahrenheit. The mean monthly temperatures at this point vary from 22.5 degrees in February to 55 degrees in August. At Sugarloaf, which is just off the east edge of the map and near the center of the area in a north and south line, the mean annual temperature is 43 degrees. The station near Longs Peak has a mean annual snowfall of 146 inches and a mean annual precipitation of 20.72 inches. The highest temperature ever recorded at this station was 86 and the lowest temperature ever recorded was -31 degrees.

With increase in altitude there is a decrease in mean annual temperature and an increase of mean annual precipitation up to a certain limit. It is probable that the maximum precipitation is reached at an elevation around 12,000 feet. Except during the summer months and early fall, most of the precipitation in the mountains is in the form of snow. During the summer months daily afternoon showers are common and sometimes destructive storms occur.

Except at the very eastern edge of the region, there is hardly a month in the year free from slight frosts. In the plateau area the growing season ranges from sixty days at an elevation of 8,500 feet to thirty

days at an elevation of 10,000 feet. The first snows usually fall in Steptember but the snow does not remain on the ground, except near the divide, until about Christmas. The relative humidity is low and evaporation is usually fairly rapid.

There is a great deal of local variation in climatic conditions and places at about the same elevation may differ widely as to the severity of the weather because of topographic conditions and exposure. As a rule the winters are rather severe above an elevation of 10,000 feet, but there are probable exceptions to this statement. The number of sunny days at such places as Ward very likely exceeds the number of similar days at such places as Boulder, which has an elevation of 4,000 feet less than that of Ward.

VEGETATION

Most of the area lies within the boundaries of the Colorado National Forest. The entire region was once heavily forested, but fires and lumbering have destroyed a large part of the timber, particularly in the southern half of the area. The most common trees are yellow pine (Pinus ponderosa), Douglas spruce (Pseudotsuga mucronata), lodgepole pine (Pinus murrayana), silver spruce (Picea paryana), and the quaking aspen (Populus tremuloides).

INHABITANTS AND INDUSTRIES

The inhabitants of the region are nearly all dependent upon either mining or tourists for their livelihood. There are no large towns within the area; Nederland with a population of 500 is the largest one. The mining of tungsten near Nederland and tourists furnish most of the income here. Tolland with a population of 250 people is a summer resort and shipping point for the ranchmen and miners of the upper part of the valley of South Boulder Creek. Ward has a population of 200 and was once a mining town of considerable importance. There are still several mines operating near there. Allenspark, Eldora, and Peaceful Valley depend in the main upon summer tourists for their support. Besides these towns there are numerous scattered camps and cabins, as at Glacier Lake, Stapps Lake, Brainard Lake, and other places throughout the area.

ROUTES OF TRAVEL

There is only one railroad within the area and that is the Denver and Salt Lake Railway, or the Moffat Road, as it is commonly called. This road extends up the valley of South Boulder Creek. There was formerly a railroad running to Ward, Cardinal, and Nederland from Boulder; but the decline of the mining industry resulted

in the junking of this road. However, there are good auto roads connecting all of the towns and daily stages run between Boulder and Nederland and Boulder and Ward.

PHYSIOGRAPHIC HISTORY

GENERAL GEOLOGY OF AREA

The region lies in the very heart of the Front Range of Colorado. The Front Range is formed by the union of the Laramie and Medicine Bow Ranges of Wyoming and may be considered as a broad anticlinal fold in which large areas of pre-Cambrian rocks are exposed between uptilted Paleozoic and Mesozoic beds on the east and west.

The pre-Cambrian rocks include very old sedimentary and intrusive rocks which have been greatly metamorphosed and younger igneous rocks which do not show the signs of nearly so much metamorphism. They are in the main granites, gneisses, schists, and locally quartzites. There are no unaltered sedimentary rocks within the area under discussion.

PRE-PLEISTOCENE HISTORY

It is probable that during most of the Cretaceous period the greater part of the area now occupied by the Front Range, if not all of it, was covered by a great inland sea. The physiographic history of the region, in so far as it has any bearing upon the present topographic features, may be said to date from the uplift of the

present Rocky Mountains, which probably began in late Cretaceous times and continued into Quaternary times.

The igneous and metamorphic rocks which now constitute the core of the Front Range were probably covered with several thousand feet of sediments which had been deposited during the Cretaceous period. Following the uplift of the region, removal of these sediments was begun and by early Oligocene times a great peneplain had been developed throughout the area. This is known as the Flattop peneplain because of the preservation of a considerable remnant of this peneplain upon Flattop Mountain.

Uplift of this peneplain occured during the general Miocene uplift which affected the western United States and erosion set to work again to reduce the area to base level. This was accomplished by about early Pliocene times and a second peneplain known as the Rocky Mountain peneplain came into existence. This peneplain was uplifted late in the Pliocene period and erosion again set about baseleveling the region. No general peneplanation was effected after the development of the Rocky Mountain peneplain, but local baseleveling did occur several times upon the plains and in the edge of the foothills. While this was going on there occurred in the mountains extensive mountain glaciation, and it is with this phase of the

physiographic history of the region that this paper particularly deals.

PLEISTOCENE GEOLOGY

CHARACTER OF GLACIATION

No part of Colorado was ever covered by a continental glacier. The southernmost limit of continental glaciation in the Rocky Mountains was in northern Montana and there is no evidence to indicate that continental glaciers ever existed in either Wyoming or Colorado.

Throughout Montana and parts of Wyoming, there is evidence of the existence of numerous glaciers which extended down from the mountains onto the plains and coalesced to form piedmont glaciers. In one place only in the area under discussion is there evidence that such a condition existed. This is in the area between the valleys of South and Middle St. Vrains Creeks. In this locality the two valley glaciers unquestionably united to form a piedmont glacier covering between five and six square miles.

There were seven or eight separate glaciers in this region, in addition to several tributary glaciers of considerable size. Prominent glaciers have occupied the valleys of South Boulder, Middle Boulder, North Boulder, South St. Vrain, Middle St. Vrain, North St. Vrain, Tahoosa, and Jenny Creeks. The glacier in Jenny Creek joined with the one in Middle Boulder Creek, but as

it was over five miles long, it may be considered a distinct glacier. The same might be done with the glacier which came down Mammoth Gulch and joined with the main glacier in the valley of South Boulder Creek.

GLACIERS OF THE AREA

South Boulder Creek: The valley of South Boulder Creek has all the evidence of a typical glaciated valley. Evidence of glaciation may be seen from a short distance above Rollinsville to the head of the valley. From Tolland upward there is an abundance of glacial boulders along the sides and on the floor of the valley. South Boulder Creek has its origin on the north face of James Peak and is fed by streams from Crater Lakes and Arapahoe Lakes. These lakes are typical glacial lakes formed by morainal damming at the lower end of tandem cirques.

Arapahoe Creek joins South Boulder Creek near East Portal and below this point in the valley South Boulder Creek has a very pronounced U-shape. Arapahoe Creek enters South Boulder Creek over the edge of a hanging valley which has a drop of about six hundred feet in a little over a quarter of a mile. The morainal material along the sides of the valley is not very abundant, but it can be observed in a number of places. The thickness of the timber here obscures the material to some extent.

Mammoth Gulch enters South Boulder Creek from the South about one mile west of Tolland. There is differences of a little over five hundred feet between the floor of South Boulder and the level of the mouth of Mammoth Gulch. The hanging valley in this case is even better developed than the one where Arapahoe Creek enters South Boulder Creek.

The size of Mammoth Gulch is disproportionately large as compared with the size of the stream which flows in it. The difference between the level of its mouth and the valley of South Boulder Creek may in part be due to the difference in the size of the two streams, but it seems that the major cause of the lack of adjustment between the two valleys is glaciation. South Boulder Glacier eroded its valley to a depth considerably below that of the glacier in Mammoth Gulch. The hanging valley thus was formed.

There is another marked difference between the valley of South Boulder Creek and its tributary valley. In South Boulder Creek valley the effects of glaciation are largely of an erosional character whereas in Mammoth Gulch the most characteristic glacial features are the result of deposition. Morainal material is very abundant throughout Mammoth Gulch. Lateral moraines are found on both sides of the valley and they extend from 300 to 400 feet above the valley floor. The material is more

abundant on the north side of the valley than on the south side. This is probably due to the fact that Mammoth Gulch swings around from an east-west direction to a north-south direction and in doing so the north side of the valley would be on the inside of the curve. Deposition would be more common on this side of the valley; just as a river in making a bend will deposit material upon the inside of the curve and erode on the outside of the curve.

The glacier which extended down Mammoth Gulch formed upon the east face of James Peak not over a fourth of a mile southeast of the point of origin of the glacier in South Boulder Creek. In the old cirque in the front of the peak James Lake now exists. Below it upon one of the benches which are so common in the upper parts of glaciated valleys lies Echo Lake.

There is a very strong suggestion of the presence of two lateral moraines along the sides of Mammoth Gulch, but it can not be said with certainty that they are there. There are two benches along the valley sides but they may have been developed during the same period of glaciation. Discussion of this will be left for the section dealing with the periods of glaciation.

Another characteristic of Mammoth Gulch is the presence along the sides of the valley of wide spoon-shaped depressions that resemble very much old glacial

cirques. They differ from typical cirques in that the walls are not nearly so precipitous as the walls of a cirque usually are. They are not strewn with boulders but usually are covered with a considerable depth of soil. They are favorite grazing grounds for the sheep that pasture in this valley during the summer and fall months. These depressions occur on both sides of the valley and at approximately the same elevation on opposite sides. They are found at lower elevations farther down the valley. They occur just above the highest morainal material and in one place there is a crescentic deposit of glacial material just at the lower edge of the basin which resembles very much a small terminal moraine. It is thought that these features bear a very definite relationship to the periods of glaciation which have occurred in this region. This relationship will be pointed out later.

No semblance of a present day glacier is to be found upon James Peak. There are three small snow banks which last through the summer but they do not even approach the neve stage.

A second tributary to South Boulder Creek is Jenny Creek, which flows parallel with South Boulder Creek for about five miles and then makes a right-angled turn to the south and empties into South Boulder. The valley of this creek offers a very marked topographic contrast to those of South Boulder Creek and Mammoth Gulch. It does not present the easily discernible evidence of having been

glaciated that the two other valleys possess. About the only suggestion of glaciation is the presence of four small lakes near the head of the valley, but it is more smooth and much less rugged than the ordinary head of a valley which has recently had a glacier in it.

There is not the morainal material along the sides of the valley that is found elsewhere in the glaciated valleys of the region. No definite lateral moraines are present and from first observation one would be inclined to say that there was no morainal material along the valley sides or on the valley floor. There is present considerable thoroughly weathered material which is angular or subangular in shape. It does not on the surface resemble glacial debris at all, but there are a few places along the valley where exposures of considerable depth are found and these disclose the true nature of the material. It is really glacial material which is deeply weathered at the surface and covered with considerable soil. But in no place in the valley is there fresh glacial material to compare with the abundant lateral moraines of Mammoth Gulch. It seems that we have here evidence that Jenny Creek did not have a glacier in it at the time that the greater part of the glacial debris of South Boulder Creek and Mammoth Gulch was deposited. The significance of this will be discussed more fully under the section dealing with the periods of

glaciation.

Another interesting topographic feature of South Boulder Creek valley is what is known as Boulder Park. There is a very decided widening of the valley of South Boulder Creek in the part known as Boulder Park. The Park

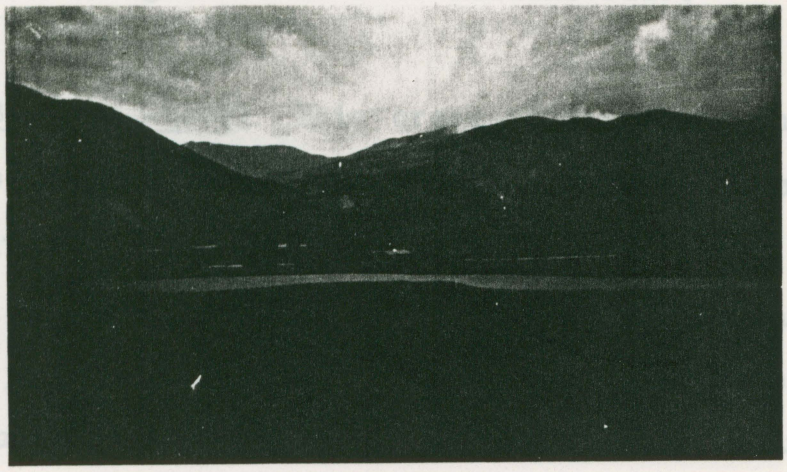


Figure 2. Boulder Park, looking northwest.

is about two and three-fourths of a mile long and it averages nearly a mile in width. The widening of the valley along this part is probably due in part at least to the juncture of the tributary glacier in Mammoth Gulch with the main glacier in South Boulder Creek valley. The increased volume of ice was accomodated by widening of the

valley. The levelness of the floor of Boulder Park is due to the filling of an old lake which formed at this point. A remnant of this once more extensive lake is the lake across from Tolland known as Park Lake. Except for this small lake the entire floor of Boulder Park is an old lake filled bed. The lake was probably caused by the deposition of a terminal moraine across the valley below the lower end of Boulder Park. A smaller lake bed of similar origin occurs near Rollinsville.

Middle Boulder Creek: This creek is formed by the union of three branches, South Fork, Jasper Creek, which has two important branches, and North Fork. South Fork and Jasper Creek flow on the south and north sides of Woodland Mountain respectively and join just east of the eastern end of this mountain. About a mile farther downstream and just west of Hessie the North Fork joins the main stream and forms Middle Boulder Creek proper. All three forks of Middle Boulder Creek have been glaciated.

There is a great abundance of glacial material along both sides of the valley of South Fork, but only on the north side of the valley are lateral moraines found at two distinct levels. The two levels stand out clearly and the morainal material composing them shows a decided difference in the amount of weathering which has affected the glacial boulders. The upper lateral moraine

is about six hundred feet above the valley floor and extends up to the top of Woodland Mountain. One unusual feature that was found associated with this moraine is a small lake in a depression on the moraine. Figure 3 is a view of this lake. It is one of the few lakes in the

Figure 3. Lake on upper moraine in South Fork of Middle Boulder Creek.

region that is found developed along the side of a valley and back of the older and higher lateral moraine. This lake is over 400 feet above the valley floor.

The glacier in the South Fork of Middle Boulder originated in a compound cirque on the east side of the

continental divide just north of Corona where the Denver and Salt Lake Railway formerly passed over the divide. In addition to the old cirques at the head of the valley there are a number of cirque-like depressions similar to those described in Mammoth Gulch along the side of the valley and above the highest morainal material found along the valley sides.

About a mile above the point where Jasper Creek unites with South Fork is an important tributary of Jasper Creek which enters the valley of Jasper Creek over a very prominent hanging valley. There is a drop of approximately 500 feet in a quarter of a mile. There are two lakes near the head of this tributary and morainal material along the valley which seem to agree in height with the upper moraine of the South Fork Valley.

There is an abundance of glacial boulders all along the valley of Jasper Creek. Jasper Lake near the upper part of the valley is partly due to morainal damming and partly due to glacial gouging. There were two important branches to the Jasper Creek glacier. One came down from the region of Devil's Thumb and the other branch came from above Jasper Lake. At the point where the two joined the glacier must have been over a mile wide, if the present width of the valley there may be used as a measure of the width of the glacier which formerly occupied it.

The North Fork of Middle Boulder resembles very

much the other two branches as far as the effects of glaciation are concerned. The morainal material is not quite so abundant as in the other two valleys, nor is there as conclusive evidence of the presence of morainal material of two ages as in the other two forks; but there is no doubt that the valley has been glaciated.

Below the point where the North Fork joins the main valley of Middle Boulder the depth of the valley increases considerably. There is a pronounced 'step' in the valley just above the point where the two join. Middle Boulder offers several examples of the same thing. Wherever two valleys of any size join they usually do so over a pronounced fall. This is the case where the South Fork and Jasper Creek join and at two places up Jasper Creek where good sized tributaries enter it. It is also true in two places up the North Fork. There is also usually a slight widening of the valley at these points, but it seems that most of the increased volume of ice is accomodated through valley deepening rather than by valley widening. This is offered as an explanation of most of the so-called 'steps' which are too far down the valley to be considered as tandem cirques. It has already been pointed out that there is a widening and deepening of South Boulder Creek valley at the point where Mammoth Gulch enters it. Other cases of the same thing will be noted later.

Below the site of Eldora there exists another lake

flat, locally known as 'Sulphide Flats', which is similar to the one described in the valley of South Boulder Creek near Tolland. This lake was not as large as the one in South Boulder Creek valley. It was about two miles long and less than a half mile wide. The lower end reached to within a half mile of Nederland. A tiny lake still survives the filling which has taken place since the retreat of the last glacier.

Lake Eldora lies about 700 feet above the valley floor of Middle Boulder Creek. Morainal material is very abundant about the lake and the lake is clearly due to morainal damming. There is a terminal moraine at the east end of the lake which apparently belongs to the first period of glaciation. The degree of weathering of the material and its topographic relationships indicate that this is the case. If this assumption be true, the 700 feet difference in elevation between Lake Eldora and the floor of Middle Boulder Creek valley represents approximately the amount of erosion that was accomplished by stream erosion during the interglacial period, glacial erosion during the second period of glaciation, and post-glacial stream erosion.

Reference has already been made to the fact that Jenny Creek valley did not have a glacier in it during the more recent period of glaciation. The area about Eldora Lake offers confirmatory evidence of this contention and

also evidence that the glacier which occupied Jenny Creek valley during the first period of glaciation joined with the Middle Boulder Creek glacier rather than with the South Boulder Creek glacier. Jenny Creek at the present time makes an abrupt and nearly right-angled turn in order to flow into South Boulder Creek. There is a col only 200 feet high separating Jenny Creek from Middle Boulder and if the course of the stream were projected from the point where it turns to flow toward South Boulder Creek in the same general direction that the stream has been flowing in the five miles above this point it would intersect the Middle Boulder Creek valley just below Lake Eldora. Unless this is assumed to be the proper explanation, there is much difficulty encountered in explaining the formation of the terminal moraine in front of Eldora Lake.

The Middle Boulder Creek glacier very probably split near its lower end, for there is very good evidence to indicate that one branch went between the east end of Eldorado Mountain and the hill which lies between Middle Boulder Creek and North Beaver Creek. The old roadbed of the Denver, Boulder and Western Railroad between Cardinal and Eldora follows through the sag cut out by the glacier and good exposures of the glacial boulders which were deposited are seen along the old roadbed.

It is difficult to say with certainty the exact limits of the glaciers which occupied Middle Boulder Creek valley. The second ice advance extended a short distance.

below Nederland, but the extent of the first advance can not be so easily determined. It seems very probable that this glacier advanced farther down the valley than the second glacier did. For two or three miles below Nederland the upper part of the valley is remarkably open and suggests

Figure 4. View of 'Sulphide Flats' and two lateral moraines.

that the first glacier may have produced this open valley. The present valley of Middle Boulder Creek is cut down into this higher and more open valley. The shape of the valley could have been produced by the glacier extending down this far or it may be that the present valley is cut down into a

mature valley which had been developed by stream erosion. It seems more probable that the latter explanation is correct and that the glacier of the first period extended only a half or three quarters of a mile farther down the valley than the glacier of the second period. If it were assumed that open shape of the upper part of the valley in this part of Middle Boulder Creek was produced by glaciation, the farthest extent of the glacier would be somewhere in the neighborhood of Castle Rock, but when this is compared with the limits of the other glaciers of the region it seems that this is too far east.

North Boulder Creek: The greater amount of the water in North Boulder Creek comes from Arapahoe Glacier and Albion Valley. The upper part of North Boulder Creek valley is perhaps better known than any other valley in the region because of the presence in its upper course of the largest existing glacier in Colorado. This is the Arapahoe Glacier. The stream from Albion Valley joins with the one from Arapahoe Glacier at Silver Lake, a lake from which Boulder gets its water supply. There are three or four smaller tributaries farther down stream which add some water to the total volume of North Boulder Creek.

Arapahoe Glacier is by far the best known glacier in Colorado. When first discovered in 1900 there was some doubt expressed by geologists as to the probability of its

being a true glacier. Observations which have been made yearly about the first of September by Professor Junius Henderson of the University of Colorado have established beyond all doubt the fact that it is as typical a valley glacier as any of the larger alpine glaciers of Switzerland. It can be seen from the brow of University Hill in

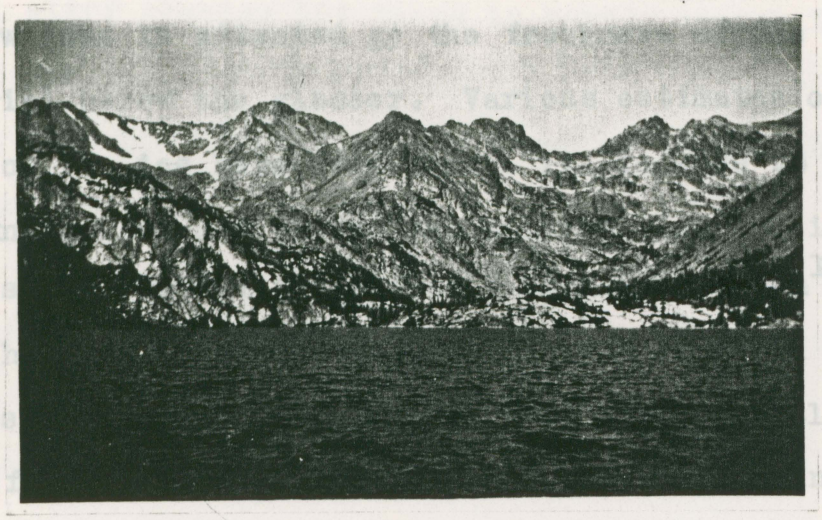


Figure 5. Arapahoe Glacier and upper part of valley of North Boulder Creek.

Boulder, but the true nature of the glacier was overlooked for a long time. During the most of the year it is covered with snow, but it is possible to get a good view of its surface during the latter part of August or early in Sep-

tember. When viewed by the writer shortly after the first of September its surface was relatively free from snow and the true glacial nature of the ice body could be easily seen. The glacier covers about one-half of a square mile. It is slightly over a half mile long and at least as wide as it is long. Measurements that were made by Professor Henderson[9] indicate that it is retreating at a rate varying from eleven to twenty-seven feet a year. That it not so long ago extended considerably farther down the valley than it now does is attested gy the freshness of the morainal material below the glacier. Various estimates of the thickness of the ice have been made. It is safe to say that the thickness does not exceed one hundred feet and is not less than sixty feet at the center. Prof. Henderson[10] states that he has found crevasses which run in depth from thirty to possibly sixty feet, although he never actually measured any of the latter depth. A prominent bergschrund is exposed by the summer melting of the snow. There is a very large terminal moraine in front of the glacier, back of which a small lake has formed. There are a number of small lakes just below the glacier and farther down the valley are Triple Lakes, Goose Lake, Island Lake, and Silver Lake.

9. Henderson, Junius, Extinct and existing glaciers of Colorado: Colorado University Studies, vol. 8, pp. 61-62, 1911.

10. Henderson, Junius, Idem. p. 61.

These are all due to either glacial gouging or damming.

The stream from Albion Valley joins North Boulder Creek at Silver Lake. Albion Valley is separated from the valley in which Arapahoe Glacier lies by Mt. Albion, the top of which has an elevation of 12,596 feet. Albion Valley has been as extensively glaciated as Arapahoe Valley, and there exists at its head a snowfield which persists through the summer. This snowfield resembles a small cliff glacier but there is hardly enough ice to call it a glacier. There is a small glacier in the valley of North Arapahoe Creek which is known as the North Arapahoe or Henderson Glacier.

The glacier in North Arapahoe Valley joined with themain Arapahoe Glacier at about the place in the valley where Triple Lakes now are and farther down the valley in the locality of Silver Lake the Albion branch joined the main glacier. Still farther down the valley a third tributary from the valley in which Rainbow Lakes lie joined the principal ice stream to form the North Boulder Creek Glacier proper. It seems very probable that there was a glacier in the valley in which Rainbow Lakes occur only during the first period of glaciation. The maximum width of the North Boulder Creek Glacier was attained just above the Arapahoe Falls. At this point the glacier must have been at least a mile and a half wide.

It is difficult to say with certainty whether or not a glacier ever existed in Caribou Park and the valley of Caribou Creek. Caribou Park is a rather broad open basin in which there are few if any undoubted glacial deposits. It is quite certain that no glacier formed in this valley during the second period of glaciation, but there is a strong prob-

Figure 6. Old cirque and rock debris on east side of Bald Mountain, looking northwest.

ability that this valley was glaciated during the first period. Near the head of the valley which comes down from Bald Mountain there are enormous deposits of very large boulders just below a cirque-like depression in the side of the mountain. Figure 6 is a view of this old cirque

and boulder field. The relationship of the two suggests that these boulders are part of the morainal material which accumulated below this cirque and which was subsequently spread out over the valley floor by the post-glacial streams. The boulders show very little sign of the rounding that is usually associated with glacial boulders, but if it is remembered how near these boulders are to their source this is easily understood. An examination of the morainal material in the terminal moraines of any of the existing glaciers in the region will show a similar lack of rounded form and a great predominance of angular boulders. Caribou Park has an elevation of 10,000 feet above sea-level. The cirque-like depression on the side of Bald Mountain is fully 1,000 feet above the floor of the Park. This is high enough for a glacier to form under average conditions. The cirques above Rainbow Lakes are at an elevation of 10,300 feet and probably were formed at the same time as the one on Bald Mountain. A glacier is known to have formed there and as the topography and exposure is similar to that on the front of Bald Mountain, there seems to be no apparent reason why a small glacier could not have formed upon the face of Bald Mountain. It is probable then that during the first period of glaciation that a small glacier existed in Caribou Park and perhaps extended down and joined with the North Boulder Creek Glacier. During the second period of glaciation no true glacier existed in Caribou Park, but it is very likely that extensive fields of snow and

neve occupied the area.

The old railroad bed of the Denver, Boulder and Western Railway follows roughly the eastern edge of the outermost terminal moraine of the North Boulder Creek Glacier. The settlement of Bluebird is located close to the edge of this terminal moraine. There is an enormous accumulation of morainal material along this part of the valley, and the falls in North Boulder Creek just above this point are due in part at least to this accumulation of morainal material.

The effects of glaciation do not end here by any means. Beyond the terminal moraine is a large fan-shaped deposit of glacio-fluviatile material which was carried out and deposited by North Boulder Creek as it cleared out the morainal material along its course. The slope of this deposit is very steep just beyond the terminal moraine but it gradually flattens out down the valley. The material consists of a mixture of boulders and pebbles of different sizes with very little evidence of stratification. The size of the boulders gradually decreases downstream, but boulders over a foot in diameter are not uncommon two miles down the valley. The material can be traced a little ways below the point where the Nederland-Ward road crosses North Boulder Creek. Tucker's Ranch is located in part upon this outwash material. This is the largest deposit of its kind

that can be found in the region.

The material above Arapahoe Falls consists of a great mass of intersecting lateral and terminal moraines. Very little evidence can be found here to indicate whether the material belongs to one or more than one period of glaciation. The boulders show all degrees of weathering and if the material was brought there by more than one advance of the ice it is so intimately intermingled that no determination of the relative ages of the boulders can be made. Figure 3 is a view of a small lake back of one of the terminal moraines in this part of the valley. The lake is just back of the outermost moraine and from it one can look directly down on the outwash material described above.

South and Middle St. Vrain Creek: The conditions in these two valleys are such as to make it advisable to discuss the two together. As was mentioned before the evidence seems to indicate that beginning about one mile north of Ward is an area in which a piedmont glacier was formed. The two valleys had separate glaciers in their upper portion, but the South St. Vrain Glacier joined with the Middle St. Vrain Glacier at the foot of Mt. Audubon and formed a piedmont glacier which covered between five and six square miles. A short branch of the South St. Vrain Glacier extended a little less than a mile down California Gulch.

South St. Vrain Creek is formed by the union of two tributaries, one of which flows down the valley between Navajo Peak and Apache Peak and the other the valley on the south side of Mt. Audubon. The two tributaries unite at Brainard Lake. At the head of the south fork lies Isabel Glacier. This is a small cliff glacier. A terminal moraine

Figure 7. Lower part of Isabel Glacier and moraine at its foot.

perhaps 35 feet high and consisting of angular boulders of different sizes exists at its lower end. The lower part of the glacier consists of true ice which merges upward into neve. A distinct bergschrund is descernible around its upper margin. Figure 7 is a view of the lower end of

Isabel Glacier and the terminal moraine. There are several lakes in the valley below the Isabel Glacier, but the two larger are Isabel Lake and Long Lake. Long Lake is the larger of the two and is about a half mile long and a quarter of a mile wide. It is largely the result of morainal damming at its lower end. Isabel Lake is largely the result of glacial scooping.

Brainard Lake lies at the junction of the two forks of the South St. Vrain. Although the basin in which the lake lies is natural, a dam across the valley has increased considerably its size. The valley of the South St. Vrain below Brainard Lake is much more open and is considerably wider than are the valleys about this point. The presence of morainal material below Brainard Lake is also more pronounced. There are vast quantities of glacial deposits along the valley, largely in the form of lateral moraines, but some terminal moraines are scattered along the valley. Above Brainard Lake the valleys show more the effects of glacial erosion than of glacial deposition.

The best example of an old glacial cirque to be found in this region exists on the east face of Mt. Audubon. It is very nearly a perfect amphitheatre and is one of the most outstanding topographical features of the region. The bottom of the cirque is at an elevation of 11,200 feet above sea level. A view of the bottom of the cirque is shown in

Figure 8. Its bottom is remarkably free from boulders, but there are a few scattered around which are usually covered with growths of mosses or lichens. A small stream flows out of the cirque over a five hundred foot drop into a small lake in the valley below.

It appears that the cirque described above was formed during the first period of glaciation and that the morainal

Figure 8. Lower part of cirque on east face of Mt. Audubon and part of South St. Vrain Creek valley.

boulders which are found on the east slope of Mt. Audubon above an elevation of 11,000 feet were deposited there during this period of glaciation. The degree of weathering of the boulders and the prevalence of mosses and lichens upon them indicate that they were not deposited very

recently. Then too, they are distinctly above the main morainal deposits in the valley below.

Redrock Lake lies about one and three-fourths of a mile below Brainard Lake and is in a depression in the lateral moraine on the south side of the valley. It is about 300 feet above the valley floor and is at an elevation of 10,150 feet above sea level. This elevation probably represents about the upper surface of the ice in this part of South St. Vrain Valley.

Three-fourths of a mile slightly northwest of Ward is another small lake known as Duck Lake. This lake lies between a lateral moraine and the side of the old valley. It is on the north side of the hill which split the South St. Vrain Glacier resulting in a short branch extending down California Gulch. The glacier passed on both sides of the hill but did not reach up to the top of the hill. The part of the valley of the South St. Vrain near Duck Lake is covered with a very great deal of morainal material in the form of terminal and lateral moraines, and the topography is the typical hummocky topography developed under such conditions.

The Middle St. Vrain Creek valley does not join the South St. Vrain Creek valley within the limits of the glaciated area. The two valleys gradually converge and come together about five miles beyond the easternmost extension of the glacier which formerly occupied the two valleys, but there is evidence to indicate that the two glaciers must

have joined at a considerable distance above the place where the streams now meet. During the first period of glaciation the two glaciers joined. During the interglacial interval the Middle St. Vrain Creek developed a valley which was deep enough that when the ice advanced a second time it did not spread beyond the limits of its valley.

The Middle St. Vrain Valley shows particularly well the effects of the two periods of glaciation. There are two distinct valleys along this stream. The first period of glaciation developed a broad U-shaped valley whose sides extend up to an elevation of approximately 10,000 feet above sea level. Within this valley is a much narrower U-shaped valley which was formed by the second advance of the ice. The top of the inner valley is 500 feet below that of the outer valley. Beaver Creek, Stapps Lake, and the Beaver Reservoir are all at the level of the older valley and a study of the topographic map of the region will show that Beaver Creek flows at an elevation which is roughly 500 feet above that of the Middle St. Vrain. It is probable that the glacier which existed in the high valley during the early period of glaciation joined with the glacier in the South St. Vrain Valley in about the neighborhood of the Beaver Reservoir and at the east end of the spur projecting eastward from Mt. Audubon. Below this point the two valley glaciers formed a small piedmont glacier. It is interesting to note that this

piedmont glacier extended out upon the surface of the Rocky Mountain peneplain which had been developed in the preceding Pliocene period.

At the head of the Middle St. Vrain Valley about eleven miles from Peaceful Valley are the two St. Vrain glaciers. The St. Vrain glaciers are intermediate in size between Arapahoe Glacier and Isabel Glacier but have more the characteristics of cliff than valley glaciers.

The upper part of the inner Middle St. Vrain Creek valley is an excellent example of a glaciated valley and it is very noticeable that erosion has been more effective on the outside of the valley curve and deposition characteristic of the inside of the curve. The north side of the valley shows very markedly the effects of erosion with very little deposition; whereas the south side of the valley has a considerable amount of morainal material along it. There are three or four small lakes along the valley side which occur on the level developed by the first advance of the glacier. Red Deer Lake is an example of such a lake. They are similar in origin to Redrock Lake and Duck Lake in the valley of the South St. Vrain, being formed back of lateral moraines.

The lowermost extent of the last glacier to occupy the Middle St. Vrain Valley was in the neighborhood of Peaceful Valley. Glacial boulders can be found farther down the stream, but they may have been carried there by the stream.

The South and Middle St. Vrain Valleys differ from those previously studied in that there is a pronounced scarcity of glacio-fluviatile material in both valleys. There is no evidence of the existence of a lake such as existed in South and Middle Boulder Creek valleys or of a great accumulation of outwash material such as is found in the valley of North Boulder Creek.

North St. Vrain Creek: The upper part of the valley of the North St. Vrain is known as Wild Basin. This basin includes all the valleys between Ogallalla Peak and Longs Peak. The streams of this basin are Ouzel Creek, Cony Creek, Hunters Creek, a small stream which flows out of Sandbeach Lake, and the headwaters of the North St. Vrain proper which flows out of Thunder Lake. All of these valleys together form a very rugged and irregular drainage basin converging into the valley of the North St. Vrain. The topography is of different sorts. Steep walls enclose the basin but within are areas which are park-like in nature. These areas are largely old cirque floors which have been widened by the glaciers which occupied them. Rapids and waterfalls are very common and every tributary has a series of lakes along its course. In places large areas of bare rock exist which have been polished by the glaciers which moved over them. In other parts of the basin the forest growth is too dense to see any rock exposures at all. Some of the

most rugged scenery of the entire region is to be found in Wild Basin.

Each of the tributaries of the North St. Vrain had a glacier in it which has left its impress upon the topography largely due to the erosional effects rather than from any glacial deposits. Rounded and polished surfaces are far more common in the upper part of the valley, just as glacial deposits predominate farther down the valley. Thunder Lake lies in a broad open area covering twelve or fifteen acres and is the result of glacial erosion. Sandbeach Creek and Hunters Creek enter the North St. Vrain Valley over a series of rapids and waterfalls caused by a lateral moraine along the side of the valley.

The best developed lateral moraines of the entire region between James Peak and Longs Peak occur in the valley of the North St. Vrain. The moraine on the north side of the valley is called the Copeland Moraine. This lateral moraine is at least two miles long. There is an equally well developed lateral moraine on the south side of the valley. These moraines are 400 feet high and even the novice might be expected to suspect their mode of origin, but it is interesting to note that the keeper of Copeland Lodge, a summer resort at the east end of the Copeland Moraine, was unaware of the origin of the ridge above the lodge.

The North St. Vrain Glacier extended to about a mile

below the Point where the road from Ward to Estes Park crosses the stream and the terminal moraine left by the glacier is still preserved and there are a series of rapids in North St. Vrain Creek where it plunges over this moraine. Back of the moraine and extending up the valley to about the point where Hunters Creek enters the main stream is a filled valley similar to those described in the valleys of South and Middle Boulder Creeks. Copeland Lake is the remnant of a much larger lake whose basin has been nearly filled by the material carried into it by the streams from above.

Tahoosa Valley: Although no detailed study was made of this valley, some observations were made in Tahoosa Valley in order to determine whether or not a glacier occupied this valley. Chasm Lake lies in an old cirque on the east face of Longs Peak. From this cirque a small glacier extended down the valley of Roaring Fork and at an elevation around 9,000 feet joined with the glacier which existed in Tahoosa Valley. Terminal moraines are present upon the sides of Tahoosa Valley which were deposited by the glacier which extended down the valley of Roaring Fork. The glacial material in Tahoosa Valley is decidedly more weathered than that at the mouth of Roaring Fork Valley; so the evidence seems to indicate that Tahoosa was glaciated during the first ice advance. However, the presence of fresher material above

the point where the valley of Roaring Fork joins with Tahoosa Valley would seem to indicate that a short glacier extended down from the cirque on Longs Peak during the last glacial period, but that it reached no farther than the edge of Tahoosa Valley. Whether or not the Tahoosa Glacier connected with the North St. Vrain Glacier was not determined definitely, because of lack of time, but it seems very probable that the two did connect just east of Deer Ridge.

INFLUENCE OF GLACIATION UPON TOPOGRAPHY

That we are living now in the closing stage of the last period of mountain glaciation which occurred in this region is shown by the fact that Arapahoe Glacier is still retreating slowly. It is entirely possible that within a very short time geologically all of the existing glaciers of this region will disappear.

The two periods of glaciation which can be distinguished in the mountains must have been due almost entirely to climatic changes. The first period of glaciation may have been partially due to the general uplift which affected this region following the formation of the Rocky Mountain peneplain but the second advance of the ice can hardly be explained in this way; for no uplift sufficient to produce glacial conditions has taken place since the Pliocene uplift. Therefore, we must conclude that the advance and retreat of the glaciers were due to important climatic changes throughout the Rocky Mountain region. These changes did not occur suddenly but were very gradual, just as Arapahoe Glacier is now slowly retreating as a result of a rise in the mean annual temperature of the region. It does not require as great a change in climatic conditions to produce glaciation in such a region as the Rocky Mountains as is commonly thought. The mean annual temperature is low enough now that glaciers may exist in the heads of the most protected valleys. A drop of only a few degrees in the mean annual

temperature would undoubtedly cause the existing glaciers to advance rather than retreat and would cause new glaciers to form in valleys now unoccupied by glaciers. So it seems safe to conclude that the climate of the Rocky Mountain Region during the two periods of pronounced glaciation was not so very much colder than it now is.

The influence of glaciation upon topographic forms may be either the result of glacial erosion or glacial deposition. The erosional effects are much more prominent in the upper parts of the valley and the depositional modifications can be seen more commonly in the lower parts of the valley.

The farther one goes up a glaciated valley, the scarcer glacial material becomes. This is the result of the fact that the head of the valley supplies the material which is deposited farther down the valley. Glacial boulders are not lacking in the upper part of the valley, but there are seldom any accumulations comparable in size to those found near the lower end of the glacier. Part of this scarcity of material is due no doubt to stream erosion following the retreat of the glacier; for the gradient of a stream is much steeper in the upper part of the valley and erosion will naturally be more effective in removing the glacial material left there by the glacier.

Glacial cirques are by far the most common topographic features found in the upper parts of the valleys

which are the direct result of glacial erosion alone. They are found at the very heads of the valleys and also in some cases at a considerable distance below the head of the valley. The cirques are very often compound as at the head of South Boulder Creek or the North St. Vrain Creek. Tandem cirques are also prominent in nearly every large valley.

Figure 9. Mt. Neva and upper part of valley of the North Fork of Middle Boulder Creek.

This term is applied to two or more cirques occuring at different levels in the same valley. It is usually considered that they are the result of more than one period of glaciation. Most of the lakes in this region which are at an altitude above 10,000 feet occur either on the floor of the cirque at the head of a valley or in tandem

cirques along the valley.

Another characteristic feature of mountain topography resulting from glacial erosion is the development of serrate ridges along the divides. As the cirques of adjoining valleys cut their way back into divides they gradually cut down the intervening spurs and ridges and in time develop a series of jagged peaks which stand out in marked contrast with the rounded slopes of the unglaciated peaks. Sawtooth Mountain near the head of the Middle St. Vrain Valley, James Peak at the head of South Boulder Creek Valley and Mt. Neva at the head of North Fork of Middle Boulder Creek valley are good examples of this type of topographic features.

Rapids and waterfalls in the upper parts of the valleys are in the majority of cases due either to unequal glacial erosion upon beds of different hardness or to the descent of the stream from one cirque bottom to that of another. In a few instances these waterfalls are caused by the stream's descent over a moraine. This is the case in the valley of the North St. Vrain below Copeland Lake and in Boulder Creek Valley below Silver Lake.

The formation of truncated spurs is another result of glacial erosion. The glacier in moving down the valley does not take as crooked a course as a stream does and consequently may cut off the ends of the spurs which projected out into the valley.

The principal modification of the valley in its

lower part is the change from the V-shaped valley produced by stream erosion to the U-shaped valley resulting from glacial erosion. Every valley in the region which has been glaciated exhibits this characteristic. The sides are oversteepened and the floor is usually widened considerably. Hanging valleys are common where tributaries enter the main valley.

Glacial deposition takes the form of ground moraine, lateral moraines, and terminal moraines. Such features as kames and eskers are lacking. It is entirely possible that they may have been deposited, but subsequent stream erosion has removed all trace of them. As a whole lateral moraines are the most common type of moraine found in the valleys. Terminal moraines are much more likely to be removed by stream erosion because they lie athwart the stream's course. Every valley has a number of lateral moraines along its sides. They may extend unbroken for two or three miles or they may be broken up into a number of short ridges only a few hundred feet long. Copeland moraine in the valley of the North St. Vrain Creek is perhaps the most distinctive lateral moraine in the region. It is 400 feet high and two miles long.

Lakes are in many cases the result of damming by lateral or terminal moraines. A number of lakes which have been formed in this way have been mentioned. Redrock

Lake, Duck Lake, and Red Deer Lake are excellent examples of lakes formed back of lateral moraines. Longs Lake, Silver Lake and Eldora Lake are examples of lakes formed back of terminal moraines.

The once more extensive lakes which existed in the valleys of South Boulder, Middle Boulder, and North St. Vrain Creeks were the result of the deposition across the valley of a terminal moraine. In each case the lake basin has been nearly filled and the streams are already at work removing the material which was only a short time ago deposited in the lake. These old lake beds belong to the class of deposits known as glacio-fluviatile deposits. The material was derived largely from the glacial material dropped farther up the valley, but it was carried to its present position by the streams and deposited upon the floor of the lake and hence possesses the stratification common to lake deposits. The outwash deposits in North Boulder Creek valley have been mentioned before. They differ from the lake deposits in that the stratification is much less pronounced and the material is much more heterogeneous. Boulders two feet in diameter are mingled with small pebbles, gravel, and sand. The deposit is similar to an ordinary alluvial fan except that the material is glacial material rather than purely alluvial material. The steep graident of North Boulder Creek below Arapahoe Falls is in the main responsible for

the deposition of this material. The swift velocity of the stream along here enables it to carry or move very large material, but when it reaches the flat below the check in its velocity causes deposition of part of the material. It is probable that most of the material in this 'fan' was carried down the valley by the floods which must have accompanied the withdrawal of the glacier and the change to warmer climatic conditions.

There were very few important drainage changes resulting from the glaciation of the region. Two possible modifications have already been mentioned. These were in the case of Jenny Creek and North Beaver Creek. It seems certain that Jenny Creek formerly emptied into Middle Boulder Creek near the present site of Lake Eldora rather than into South Boulder Creek as it now does. Evidence also points to the conclusion that North Beaver Creek once flowed west of the hill which lies between its present course and the valley of Middle Boulder Creek. A short branch of the Middle Boulder Creek Glacier followed up the old valley of North Beaver Creek and by damming it forced it to cut a new valley through the ridge extending south from Sherwood Flats. The presence of glacial material up this old valley and the narrowness of North Beaver Creek's valley where it flows through this ridge as compared with its open character above and below this point are both indicative that this change in drainage has occurred. So

far as it was possible to determine these two cases were the only ones where drainage modifications resulted from the effects of glaciation.

EVIDENCE OF MORE THAN ONE PERIOD OF GLACIATION

In a number of places in this paper it has been tacitly assumed that there is evidence for more than one period of glaciation. It now remains to bring together the various bits of field evidence in support of such an assumption.

The usual criteria offered for the existence of more than one period of mountain glaciation are (a) differences in degree of weathering of morainal material and (b) the occurence of moraines at different topographic levels. Although these criteria will be used in this paper, it is hoped that it can be shown by means of the topographic features developed that they can only be explained as the result of more than one period of glaciation.

In the following discussion it is attempted to prove that there is evidence of two distinct periods of glaciation in the region. It is entirely possible and in fact probable that there were as many periods of glaciation in the mountains of Colorado as there were in the interior of the continent of North America, but the evidence of one period may be entirely obliterated by the one following it and thus leave no evidence of its existence. This is particularly true if the interglacial period has not lowered the valley floor enough that the

surface of the next glacier to advance down the valley is below the level of the morainal material deposited by the first glacier and thus the second advance of the ice may remove the evidence of the first. If evidence is found of two undoubted periods of glaciation, we may thus be fairly well sure that they were separated from each other by a fairly long time interval.

It has already been mentioned that the glacial deposits in the valley of Jenny Creek are much more weathered than the lower moraines found in Mammoth Gulch, South Boulder Creek Valley, and Middle Boulder Creek valley. None of the fresh glacial material which occurs in such abundance in these valleys is found along Jenny Creek. The only explanation of this fact is that Jenny Creek valley had a glacier in it during the first period of glaciation but did not have one in it during the later. There is also evidence of moraines of different ages in Mammoth Gulch. The younger and lower moraine extends from the valley floor up to 300 to 350 feet above it and then about 150 feet above the top of this moraine occurs another lateral moraine which is composed of decidedly more weathered material than that in the one below.

Along the road from Nederland to Rollinsville are a number of lakes of which Manchester Lake and the Los Lagos Lakes are the largest. There are two or three smaller lakes in the same vicinity. It seems very probable

that these lake basins are the result of the first period of glaciation. The material around these lakes is very similar to that found up Jenny Creek valley and around Eldora Lake. They could not have been formed by the last period of glaciation as they are too high above the floor of South Boulder Creek for the glacier to have reached up to where they are located.

Middle Boulder Creek valley and its three branches offer similar evidence to that of South Boulder Creek of the existence of two lateral moraines at different levels and composed of boulders exhibiting different degrees of weathering. On the south side of the valley of Middle Boulder Creek near Eldora these two moraines may be seen. Eldora Lake is formed back of a terminal moraine deposited by the older glacier. The South Fork of Middle Boulder Creek likewise has moraines of two ages in it. There is morainal material extending to the top of Woodland Mountain but the material near the top of the mountain is clearly older material than that lower down in the valley. There is a small lake near the top of the mountain which lies in a depression in the upper lateral moraine. The two moraines are not so well developed up Jasper Fork but they can be distinguished without much difficulty up the North Fork of Middle Boulder Creek.

The Arapahoe and Albion valleys of North Boulder Creek both contain lateral moraines at two distinct levels

and composed of materials showing different degrees of weathering. Mr. C. A. Morey has described these two valleys in considerable detail in his thesis for the master's degree at the University of Colorado. He examined nearly five hundred boulders from the two moraines and in nearly all cases he found that the boulders from what he considered the older moraine showed the higher degree of weathering.

The conditions in Caribou Park have already been discussed and it appears very probable that there was a glacier in this park during the first period of glaciation but not during the second, but no very definite morainal deposits are to be found except below the cirque on Bald Mountain. The cirque in which Rainbow Lakes lie was formed during the first period of glaciation.

South St. Vrain Creek valley does not have any very conclusive evidence of moraines of more than one age in it. The Middle St. Vrain in particular has in it very good evidence of two moraines at different levels. Red Deer Lake is formed upon material belonging to the first period of glaciation. Figure 10 shows a view taken from approximately the top of the younger moraine looking down into the glaciated valley formed during the more recent advance of the ice. The older moraine is above the place from which this picture was taken.

The two lines of evidence offered already are usually considered sufficient proof of more than one period

of glaciation and usually they are enough upon which to base such a conclusion, but it seems to the writer that a third line of evidence can be presented which will add to the sureness with which one may draw his conclusions. This additional proof is to be obtained from a study of the physiographic features developed by the different periods of glaciation. Such features as tandem cirques, 'hanging cirques', and entrenched glacial gorges come in this category.

The term tandem cirque as ordinarily used refers to two or more cirques occurring at different levels along the valley. As the term tandem implies, they are arranged along the length of the valley in a sort of end to front arrangement. The older of the two cirques is found at a lower elevation and farther down the valley than the one more recently formed. The stream which flows in the valley in which they lie empties from one into the other over a waterfalls or rapids. During the first period of glaciation the lower cirque served as the head and collecting basin for the glacier in the valley. During the second period of glaciation the collecting ground was higher up the valley and a new cirque formed at this level, but the old cirque was not destroyed by the glacier as it moved down the valley. After the retreat of the ice the debris deposited there is likely to be cleaned out and a rock-bound lake formed in the bottom of the cirques. As good

an example as any of this type of lakes are the Upper and Lower Crater Lakes near the head of South Boulder Creek valley. These lakes exist in tandem cirques. The lower lake is in the basin formed during the first period of glaciation and the upper lake is in the cirque developed by the last glacier. There is a difference in elevation of 417 feet between the two lakes. There are numerous other examples of the same kind of lakes throughout the region.

Care must be taken not to confuse the tandem cirques with the so-called 'steps' that are common along most of the valleys. The tandem cirques occur only near the head of the valley; whereas the 'steps' are found farther down the valley. A possible explanation of these 'steps' has been offered and that is that they are the result of deepening of the valley where a tributary joins the main valley or where two forks of the stream join. As a result of the increased ice volume the valley was partially widened and partially deepened to accomodate it. There are other possible explanations of these features, such as difference in rock hardness or the persistence of irregularities in the valley floor which were there before the glacier came down the valley.

The term 'hanging cirque' has been applied to the cirque-like basins which are found along the sides of the valley at an elevation discordant with that of the valley

floor. Usually there are about an equal number of them on each side of the valley. That these were collecting grounds for snow and neve is attested by their amphitheatre shape. It is believed that they were formed during the first glacial period rather than the second. The reason for thinking this is that in nearly all cases the material in these depressions shows no signs of having been deposited there recently but is usually highly weathered and mixed or covered with a considerable quantity of soil. If they were formed during the last ice advance, it would seem that in some places they would be found occurring at the same level as the lateral moraines deposited during that time. But in no place is this true. They range from 200 to 400 feet above the lateral moraines.

It is believed that the first period of glaciation covered more area than the second one and that the glaciers were much broader and had many more tributaries than did those of the later period. It is probably true that these ' hanging cirques' were filled with snow during the second ice advance, but there is little evidence to indicate that much erosion took place in them. The cirque on the east face of Mt. Audubon has already been mentioned as the best example of one of the 'hanging cirques' to be found in the region. They are common along nearly every large valley in the region which has been glaciated, but they are usually much less conspicious than the one on Mt. Audubon.

There is still further evidence along the valley of the Middle St. Vrain that the present topographic features there are the result of two ice advances. The Middle St. Vrain flows in a narrow U-shaped valley which was produced by the last advance of the Middle St. Vrain Glacier. This

Figure 10. Inner gorge of the Middle St. Vrain Creek.

valley is cut within a broader and older valley which was formed by the first advance of the glacier. The older valley floor is 500 feet above the present valley floor and is roughly three times as wide as the inner glacial gorge. Figure 10 is a view of this inner gorge. Stapp Lake and the Beaver Reservoir lie in this upper glacial valley. There can be no doubt that the conditions here were produced by two periods of glaciation. The first

glacier was a much larger glacier than the more recent one and joined with the South St. Vrain Glacier to form a piedmont glacier which covered a considerable area north of Ward. The glacier of the later period was restricted completely within the valley walls.

There are four lines of evidence supporting the contention that two distinct periods of glaciation are represented in this region. These lines of evidence are (a) difference in the degree of weathering of the morainal material, (b) the presence of lateral and terminal moraines at different levels, (c) the existence of tandem cirques and 'hanging cirques', and (d) the presence of one glacial gorge within one of older age. Thus we may safely conclude that the region has been glaciated at least twice and possibly more times than that, but conclusive evidence of only two periods of glaciation is available.

Post-glacial Erosion.

The amount of stream erosion which has taken place since the withdrawal of the glaciers is not very much and this indicates the recency of the last ice advance. The valleys which have been cut into the glacial material deposited along the valley floors do not average over twenty feet in depth. In the lower parts of the stream where considerable deposition has occurred, as in the lower part of Sulphide Flats in Middle Boulder Creek valley, the

depth may exceed that because of the ease with which the material is removed. In the lower part of the South St. Vrain the amount of erosion exceeds this amount, but this is again in an area of great morainal deposition. In the upper parts of the valleys, as in the upper part of Mammoth Gulch and in the South Fork of Middle Boulder Creek, the depth of the valleys is probably on an average less than ten feet. The difference is largely due to the fact that in the upper parts of the valleys the streams are flowing upon bedrock.

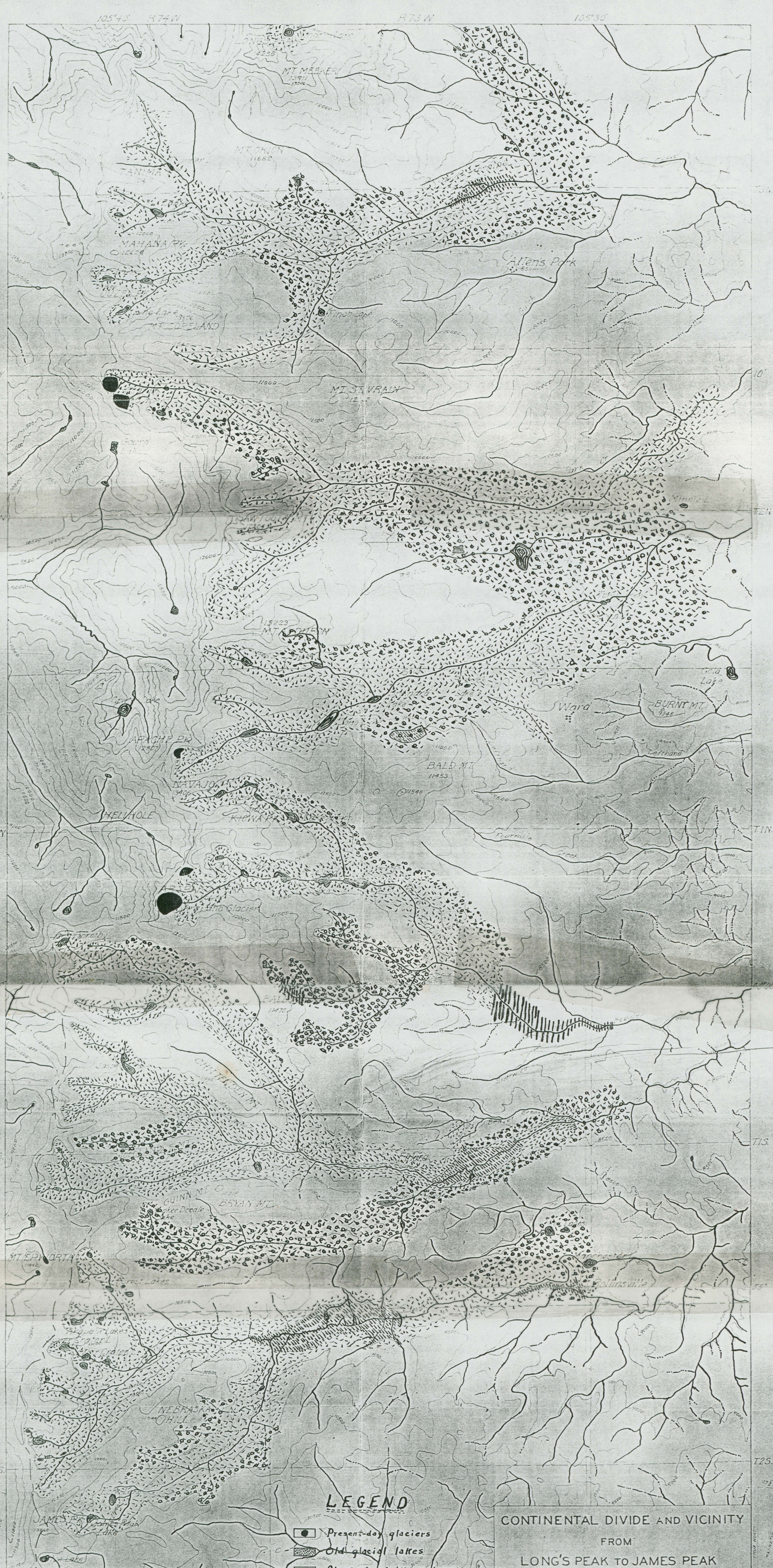
Age of Glaciation.

It seems very probable that the last period of mountain glaciation coincided roughly at least with what is called the Wisconsin stage farther east in the interior of the continent. There is no particular evidence to prove that this was the case, nor does there seem to be any reason for assuming that the advance of the continental ice sheet was not accompanied by an extension of mountain glaciers in the western part of the United States.

It is much more difficult to arrive at any conclusion regarding the time of the older period of glaciation. As has been said before, probably all of the periods of continental glaciation had their counterpart in the western mountains. As to which of these periods the older morainal material represents, it cannot be said. This much can be said: The difference in the degree of weathering of the

material deposited by the two ice advances seems to indicate that the time between the two was very long. It was probably far longer than the time that has elapsed since the last period of glaciation, but whether or not the older morainal material was deposited at the beginning or near the middle of the Pleistocene period can not be determined from the information available.

Pocket



CONTINENTAL DIVIDE AND VICINITY
FROM
LONG'S PEAK TO JAMES PEAK
SCALE 1/62500
0 1 2 3 MILES
LEGEND
Present-day glaciers
Old glacial lakes
Glacio-fluviatile outwash
Glaciers of first period
Glaciers of second period
R74W
R73W
T.1N.
T.1S.
T.2S.
Allens Park
MT. ST. VRAIN
Ward
BURNT MT.
BALD MT.
NAVAJO
BRYAN MT.
Rollinsville