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GLACIATION IN THE ARAPAHOE AND ALBION VALLEYS

COLORADO

BY

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GLACIATION IN THE ARAPAHOE AND ALBION VALLEYS

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PART I

GLACIATION IN THE ARAPAHOE AND ALBION VALLEYS

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PART I

INTRODUCTION

This paper is the result of two months of field work in the Arapahoe and Albion valleys, Colorado. The purpose was to study the glaciation in the region, past and present and to determine, if possible, the extent and the effects of this glaciation. An attempt was also made to gather evidence with reference to the possibility of two advances of the ice. The data gathered are of two kinds, namely, (1) topographic, and (2) condition of the drift. The topographic map was first made and the geological data were then gathered. In addition to the map the discussion is illustrated by photographs and diagramatic drawings.

Thanks are due to Dean W.E.McCourt, Professor A.B.Sperry, and Professor Russel Gibson for suggestions in the field and to Dr.R.D.George for criticism of the manuscript.

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ILLUSTRATIONS

CONTINENTAL GLACIERS

At Cobalt, Ontario, evidence of glaciation has been found as far back as Lower Huronian time.[1] In Norway, China, and Australia glacial deposits have been found as far back as Cambrian time. In Pleistocene time the larger part of Europe was covered with ice as well as parts of Asia and Africa[2]. In North America the ice covered, during Pleistocene time, nearly all of Canada, a small part of Alaska, and a considerable portion of the northcentral parts of the United States. There were three separate centers of dispersal in North America, namely, the Cordilleran, covering the western coast portion of Canada and a small part of Alaska; the Keewatin, covering the central portion of Canada and extending south into the United States; and the Labrador ice sheet, covering the eastern portion of Canada, and extending southwest into the United States. This glacier is known as a continental glacier. From examination of the drift and from the fossils found in it it is possible to divide the glaciation during the Pleistocene into the following time periods[3]:

Post-glacial period
5th.-Wisconsin glacial period
4th.-Peorian interglacial period
4th.-Iowan glacial period

[1] Coleman, A.P., The lower Huronian ice age: Jour. of Geology, vol. 16, p. 149, 1908.
[2] Chamberlain and Salisbury, College Geology, p. 492, 1909.
[3] Chamberlain and Salisbury, College Geology, p. 874, 1909.

3d.-Sangamon interglacial period
3d.-Illinoian glacial period
2d.-Yarmouth interglacial period
2d.-Kansan glacial period
1st.-Aftonian interglacial period
1st.-Sub-Aftonian glacial period

MOUNTAIN GLACIERS

Another important type of glacier is that known as a valley or Alpine glacier. These glaciers are very numerous in the Alps. In North America they are found on the high peaks of the Cascade Range, in the mountains of British Columbia, in Alaska, the Canadian Rockies, and in the Rocky Mountains. In the Rocky Mountains of Colorado glaciers formerly existed in the Northern Front Range and Medecine Bow district, the Pike's Peak district, the Leadville district, the San Juan region, in the Grand Mesa and White River Plateau regions, and in the Sangre De Cristo Range. Topography characteristic of glaciated regions, such as cirques, roches moutonnees, serrated ridges, U-valleys, rock-basin lakes, and glacial striae may be seen in these regions as well as large amounts of drift in the form of moraines. Some regions of Colorado contain existing glaciers. Chief among these glaciers are Arapahoe, Isabel, and Fair. The so-called Hallet, Tyndall, and Sprague glaciers are probably only névé fields. The largest of these glaciers, the Arapahoe Glacier, will be described in a later part of this paper.

Causes

Processes fundamental in the formation of a glacier are (1) accumulation of snow by

(a) direct snowfall
(b) avalanches
(c) wind-blown snow

(2) change of snow to ice
(3) movement.

In this region the snow which falls in the winter is not all melted during the following summer. Thus, in the course of time, a certain amount will have accumulated. Small avalanches from the peaks above also add to the amount while some is blown in from the high peaks and falls on to the accumulating mass of snow below. There are many theories regarding the process by which the snow changes to ice. Chamberlain and Salisbury[1] believe that moisture in freezing crystallizes, that the crystals in their subsequent passage through different strata of air become somewhat altered in shape, and after they have fallen their sharper points melt more rapidly than their centers. After a time the snow thus becomes granular, passing into névé and as pressure is increased by additional weight of snow the granules gradually pass into solid ice.

Several factors aid in producing motion in a glacier. Among these is the thickness of the ice. The greater the thickness of ice the greater the weight on

[1] Chamberlain and Salisbury, College Geology, pp. 275-278, 1909.

the slope and therefore the easier to overcome the friction. The amount of material which a valley glacier picks up along the bottom also affects its movement since this material tends to hinder motion due to the resulting friction. The angle of slope due to the valley floor is a factor in motion as well as the topography of the slope. Alternate freezing and thawing may bring about movement for as a granule or crystal is subjected to pressure it will partially melt and upon release of the pressure the melted portion of the crystal will at once refreeze. This melted portion, in order to escape the pressure, fills any interstitial space between other granules and at once freezes there. This process results in a slight movement of the granule. The sum of such movements in different granules or crystals of ice results in the slow movement of the ice.

Movement may also result from slipping along the gliding planes of the ice crystals. A crystal of ice is made up of a series of plates at right angles to the principal axis of the crystal.[1] These plates may slip on one another as cards in a pack would slip upon application of pressure at an angle. Crystals of snow in falling do not lie in a parallel position. These plates, therefore, would not slip unless the individual crystals were all

[1] Chamberlain and Salisbury, College Geology, p. 278, 1909.

aligned in the same direction which would be impossible since snow crystals lie in any direction in which they happen to fall. However in the lower parts of a glacier the crystals approach a parallel position probably due to vertical pressure and shearing of the ice. It is possible then that the plates may slip or glide upon each other and motion of the mass will result.

Water may assist in the movement of the ice. In the lower parts of a glacier the temperature is near the melting point. As a result the ice is in contact with considerable water. Thus the crystals are lubricated and movement may take place more readily. Water greatly lessens the friction between boulders carried at the bottom of the ice and the valley floor over which the ice moves.

Pressure has much to do with the movement of the ice since the greatly increased weight of ice as it accumulates brings about a more or less plastic condition in the lower layers and such a condition aids movement.

Work

Erosion

Motion starts and work begins when a part of the ice field breaks away from the rest leaving a large crack or bergschrund. Water seeps into this crack, eventually reaches the bottom of the ice field, and by alternate freezing and thawing plucks the rock underneath, thus forming a cirque. The collecting field of the snow which changes to ice may be in the form of a large amphitheatre in which there are several cirques. Between these cirques the peaks and ridges are jagged and sharp pointed and are known as serrate ridges. Continued erosion by alternate freezing and thawing in the crevasses of a glacier may result in the valley being cut in cascade form. This process is aided to some extent by erosion along the bottom as the ice moves. Internal drainage, accompanied by freezing and thawing, loosens much material which is carried off by the ice. Some of this material is very coarse and its passage over the region under the ice results in much abrasion. Scratches or striae are thus formed, and even rocks may be worn smooth to form roches moutonnees. Continued carrying away of material from the sides of a valley results in a U-valley, while erosion along the bottom often results in rock-basins being formed which may fill with water and are known as rock-basin lakes. Drainage from the area around depressions in the drift often results in small lakes which occupy these depressions.

In a glaciated valley the ice may deepen the valley more rapidly than the tributary valleys can be lowered. Such a tributary valley will then be above the main valley and is known as a hanging valley. Many such hanging valleys are formed by glaciers.

Deposition

While there is some material carried within the glacier most of it is carried upon or under the ice. Much of the debris upon the surface results from dust and from rock falls from the cliffs along the sides. At the same time the ice gathers much material from the sides of the valley and from the valley floors over which it moves. At the terminus of the glacier both superglacial and subglacial material as well as that within the ice is deposited together and in this manner the terminal moraine is formed. Often much of the material is deposited along the sides of the ice and forms a lateral moraine. If two glaciers in adjoining valleys, upon confluence, deposit lateral moraines together a medial moraine is formed. Drift deposited in the depressions beneath the ice as it advances and that which is deposited on the valley floor as the ice melts back is known as ground moraine.

GLACIATION IN THE ARAPAHOE AND ALBION VALLEYS

COLORADO

PART II

LOCATION AND AREA OF THE REGION

The area under consideration is located in the Colorado National Forest, Latitude 40° to 40° 5' N., Longitude 105° 30' to 105° 45' W., Township 1 North, Range 74 West to Range 73 West.

This area is roughly Y-shaped. The Albion Valley and the Arapahoe Valley, both of which contained glaciers, are approximately parallel in their upper parts with Mt. Albion and Mt. Kiowa between. At the eastern extremity of Mt. Albion these valleys are joined (Fig. 1).

Fig. 1. Albion and Arapahoe Valleys. Mt. Albion and Mt. Kiowa between. From Silver and Gold Trail.

TOPOGRAPHY

The valley formed by the junction of the Arapahoe and Albion valleys extends due east for about two miles from which point it curves toward the south east, approximately S.55°E. At the edge of this valley on the north and northeast lies a large lateral moraine. At the head of the Arapahoe Valley (Fig.2) rises South Arapahoe Peak, about 13,300 feet, and North Arapahoe Peak, 13,506 feet in elevation. Mt.Albion, 12,569 feet, and Mt.Kiowa,

Fig.2. Arapahoe Valley from Silver Lake, showing Arapahoe Glacier and cirque at the left. Mt.Albion is at the extreme right.

13,101 feet in elevation rise between the valleys. Mt.Arikaree, 13,147 feet in elevation, on the south side, and Mt.Navajo, 13,406 feet in elevation, on the north side, stand at the head of the Albion Valley. The ridge

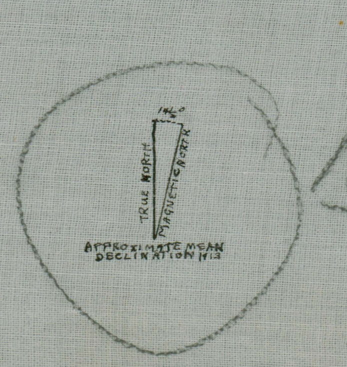
Glaciers of the Arapahoe and Albion Valleys Colorado

Topographic and Glacial Map
of the
Arapahoe and Albion
Valleys
Colorado

Legend
- Outcrops
- Contours
- Stream
- Lake
- Glacier
- Roads
- Trail
- Moraine First Advance
- Moraine Second Advance
- Ridges Lateral
- Ridges Terminal
- Outwash
- Rock Ridges
- Snow Sap
- Lake Terrace
- Delta
- Main Ridge
- Alluvium

Topography and Geology by C.R. Morey

Scale – 4 inches = 1 mile
Contour interval = 50 feet



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extending from Mt.Navajo eastward and known as Bald Mountain,11,453 feet in elevation,is the northern boundary of the Albion Valley while the southern boundary of the Arapahoe Valley is marked by a ridge,also known as Bald Mountain,12,758 feet in elevation,extending eastward from South Arapahoe Peak.

THE ARAPAHOE GLACIER

The only valley glacier existing in this region is the Arapahoe Glacier. Processes in the formation of this glacier have been active over a long period of time. This is shown by the very large cirque which has been formed at the head of the glacier. Each summer numerous crevasses open and the bergschrund opens to a width of 15 feet at times. There is much drift carried by the ice which is piled up at the terminus in a huge terminal moraine. According to Henderson[1] the glacier is slowly shrinking and will in a comparatively short time, geologically speaking, become extinct.

The altitude of this area bordering the Arapahoe Glacier and consequently the cool temperature resulting therefrom,especially during Pleistocene time,necessitate the precipitation of moisture as snow. This occurs at various times throughout the year. Not only does the snow accumulate by direct snowfall in this region but

[1]Henderson,Junius,Extinct and existing glaciers of Colorado:Univ.of Colorado Studies,vol.8,pp.62-63,1910.

much piles up by small avalanches which slide down the valley slopes and much drifts in wind-blown from the peaks which are almost always bare. During the summer much of this snow melts but not all of it. In the course of time, therefore, a large amount accumulated, left over from summer to summer. This accumulated snow gradually changed to ice. According to Hendreson[1], who made careful measurements of the rate of flow of the relative parts of the glacier, the average distance over which the glacier moved during the year 1904 was approximately 27 feet. At the present time, July 11, 1927, there is a large amount of snow covering the ice of the glacier except in one place. Thus no definite data could be obtained as to the thickness of the ice. Only one crevasse was found to be open. This crevasse, at the widest place, was not over 15 inches in width. Ice, however, could be seen down to a depth of approximately 18 feet. At the east end of this crevasse the bottom of the glacier bed could be seen. An idea of the thickness at this point could thus be had. Judging from the position of the contours on the ice the thickness could not be over 90 feet at the deepest place. Henderson estimated the thickness in 1904 at not over 100 feet. The glacier itself is very small, covering an area of not over 500,000 square feet. Its dimension is greater north and south than it is east and west. The angle of the slope over

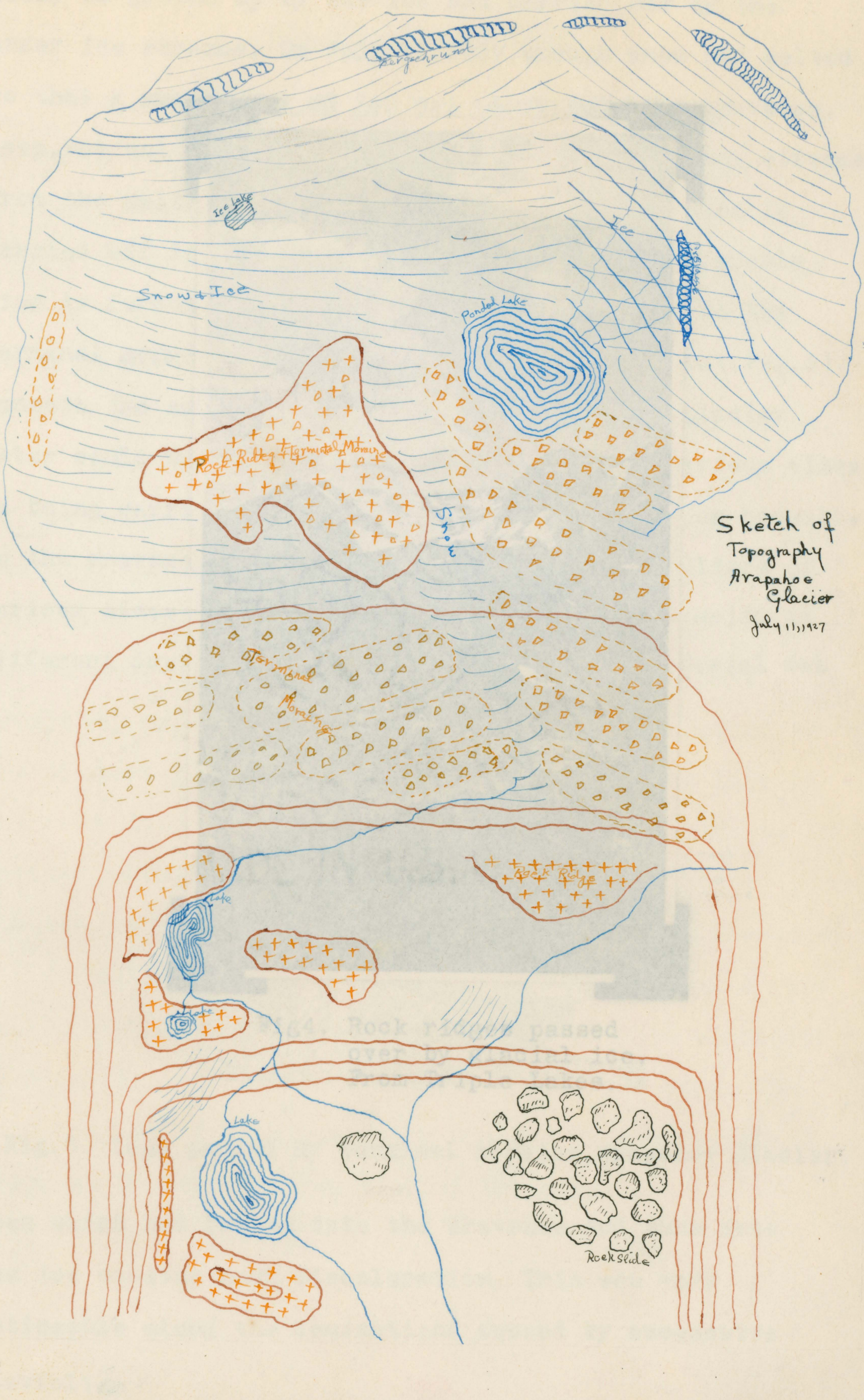
[1] Henderson, Junius, Extinct and existing glaciers of Colorado: Univ. of Colorado Studies, vol. 8, p. 53, 1910.

which the ice flows could not be determined. It is ,however, greatest on the west side of the glacier. On the east side the slope is toward the center due to the great ridge of terminal moraine against which it lies(Fig.3).This sloping towards the center is also partly due to the greater depth

Fig.3. Terminal moraine,Arapahoe Glacier. Ice in foreground,U-valley,rock-basin lakes,and lateral moraine in the distance.

of the cirque on the west side caused by weathering of the country rock at the bottom of the bergschrund. Great masses of terminal moraine lie in ridges along the east side of the glacier and more drift is constantly being added(See sketch,page 19). This drift varies from huge masses of rock over which the ice rode,and large boulders 30 feet in diameter,to those approximately a foot in diameter(Fig.4). With these boulders are mixed many much smaller as well as a large amount of very fine material. Enough rock flour to make the water of the small lakes

Plate I



Sketch of Topography Arapahoe Glacier July 11, 1927

Fig4. Rock ridges passed
over by glacial ice.
From Triple Lakes.

milky is ground up by the ice and carried off by the under ice streams. On July 11,1927,enough snow had melted so that a small area of ice was uncovered. One crevasse, deep,but not large,was seen. Over the ice run many streams from the melting snow and ice above. So much water is carried off in this manner that a lake of considerable size is formed at the foot of the glacier next to the terminal moraine for a distance of about 100 feet(Fig.5). Beneath the surface of the ice but within the glacier water could be heard running. Much debris of various sizes is being carried by the ice,either upon,within,or beneath. In the crevasse,open near the east end,many boulders of various sizes could be seen lying as englacial drift at different depths in the ice. Also much fine material was

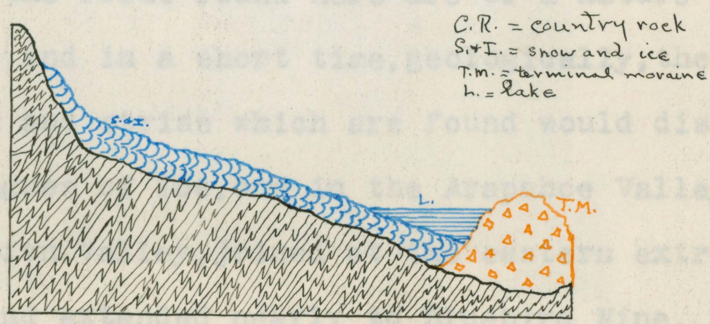


Fig.5. Lake ponded by terminal moraine,Arapahoe Glacier.

seen which had fallen into the crevasse and sunk into the ice causing much discoloration. This was very noticeable along the laminations caused by successive snowfalls.

GLACIERS OF THE PAST

That there was a glacier in the Albion Valley is shown by the very large U-shaped valley containing a series of small rock-basin lakes. Also a very large number of roches moutonnees are to be seen near Lake Albion and an even greater number just east of the third Green Lake. Great numbers of erratics may be seen around this same lake. One large cirque occupies the head of this valley.

Between the ~~north~~ south slope of Mt. Albion and the cirque of the Arapahoe Glacier lies a large amphitheatre which contains many small cirques separated by many jagged or serrate ridges. Some excellent examples of hanging valleys may be seen here(Fig.6). That the glaciers formerly occupying these valleys have only recently retreated is the opinion of Henderson. His evidence for this lies in the fact that the rocks found here are of a nature to weather easily and in a short time, geologically, the glacial polish and striae which are found would disappear.

Two tongues of ice, one in the Arapahoe Valley, and one in the Albion Valley, joined at the eastern extremity of Mt. Albion and extended nearly to Bluebird Mine. The only remnant of this ice which remains is the present Arapahoe Glacier(See map overlay in pocket).

Fig.6. North Arapahoe Valley from Triple Lakes. Serrate ridges at upper left. Hanging valley in foreground

Work

Erosion

In many places glacial striae may be found on the rocks over which a glacier passes. This is one of the best evidences for glaciation. In this region very few of these scratches or striae are to be found since weathering has removed the traces in nearly every case. A few, however, may be seen on the north side of the Arapahoe Valley near the trail at the beginning of the first bench at an altitude of about 11,000 feet.

Another evidence of glacial action is to be found in the roches moutonnees or rounded knolls of rock. These are prominent in the Arapahoe Valley between Goose and Triple lakes. They are especially abundant around the Green Lakes in the Albion Valley. Here they lie parallel to the direction of the ice flow, are much rounded and weathered, are more steeply sloping, and are worn most on the west side. They vary in size from those about 500 square feet in area to those whose surfaces contain only a few square feet (Fig.7). Before glaciation both the Arapahoe and Albion valleys were young and consequently V-shaped. As the ice accumulated and filled the valleys much of the loose debris along the sides of the valleys was carried along. Many rock slides from the sides of the valley resulted. This removal of material, both coarse and

Fig.7.Roches moutonnees in the Arapahoe Valley. Looking north from Goose Lake.

Fig.8. Glaciated U-valley.Arapahoe looking east from first bench Lateral moraine in distance.

fine, from the sides of the valleys by the snugly fitting ice gradually changed their shape to that of U-valleys (Fig.8).

Many excellent examples of cirques may be seen in the region, especially in the Arapahoe Valley. The largest and best developed cirque is that at the head of the Arapahoe Glacier. This cirque forms a large semicircle between North and South Peaks. Late in August or early in September, according to Fenneman,[1] the bergschrund is opened around the cirque, sometimes to a width of 15 feet and to a depth of over 50 feet. On July 11, 1927, it was just beginning to open in four places around the cirque. In August, 1925, the bergschrund was open much more and several crevasses were seen in the ice. The conditions in July, 1926, were about the same as in July of this year (1927). The alternate thawing and freezing in this bergschrund has, of course, sapped the country rock and as a result the large cirque was formed.

The ice, by abrasion, scooped out many depressions, some of which became filled with water, forming lakes of various sizes (Fig.9). These are known as rock-basin lakes.

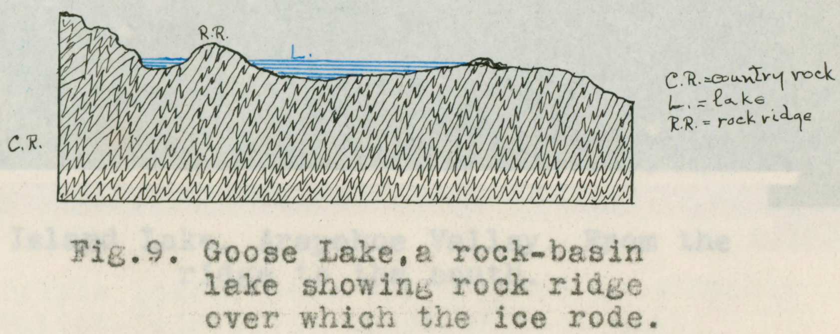


Fig.9. Goose Lake, a rock-basin lake showing rock ridge over which the ice rode.

[1] Fenneman, N.M., The Arapahoe Glacier in 1902: Jour. of Geology, vol.10, p.847, 1902.

By damming they have been greatly enlarged and furnish the water for the city of Boulder. In the Albion Valley the chief lakes of this type are the Green Lakes and Lake Albion, while in the Arapahoe Valley the chief lakes are Island, Goose, and Triple lakes. Goose Lake is an excellent example of a lake almost divided into two parts by a high rock ridge over which the ice rode but which it was unable to cut down to the level of the surrounding rocks (Figs. 9, 10, 11, 12). There has been much weathering of the country rock over which the glaciers passed in the region of the rock-basin lakes. Great masses of rock are split off or exfoliated from the country rock in many places. This is due chiefly to the work of frost.

Fig. 10. Island Lake. Arapahoe Valley. From the ridge to the south.

Fig.11. Goose Lake. Arapahoe Valley. From the ridge to the south.

Fig.12. Triple Lakes. Rock-basin lakes in Arapahoe Valley from first bench, looking east.

A longitudinal section of both valleys shows a series of steps or cascades(Fig.13). The general belief among geologists,according to Henderson[1],is that these

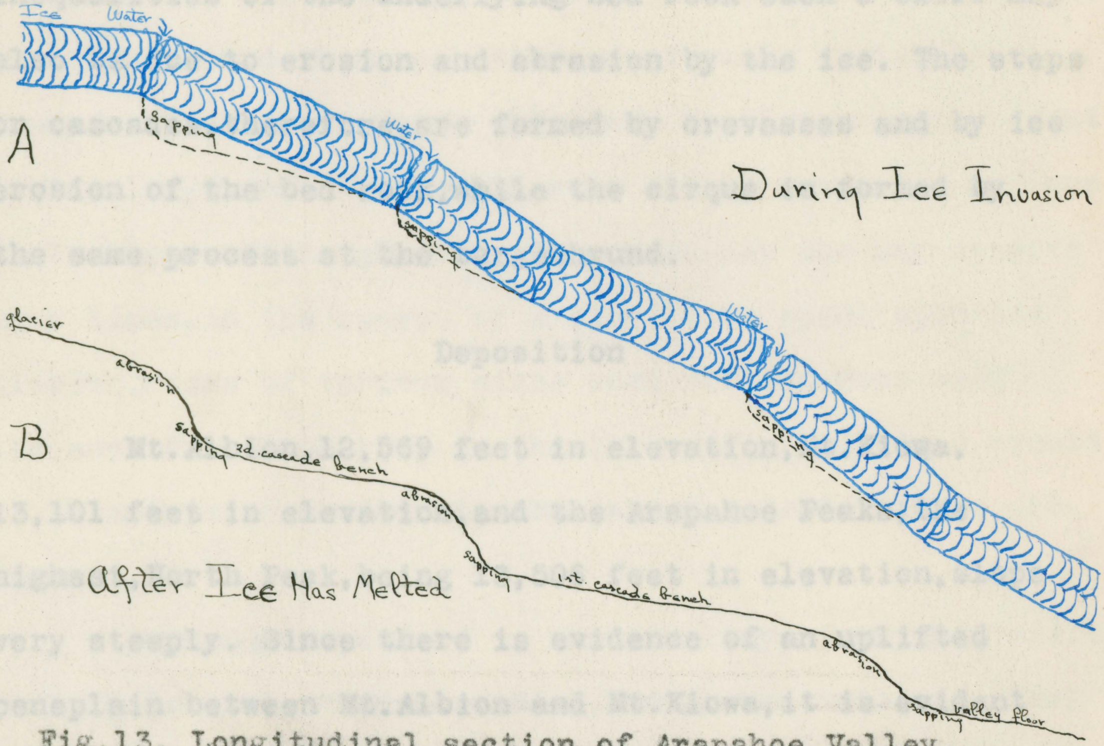


Fig.13. Longitudinal section of Arapahoe Valley showing benches formed by sapping and abrasion.

cascades are formed by continuous sapping at the bottom of the ice where there is a crevasse. When a glacier moves over an uneven surface from a higher to a lower grade the ice cracks and a crevasse forms. This crack may extend to the bottom of the ice. The ice will protect the valley bottom over which it flows from weathering by frost but at

[1]Henderson,Junius,Extinct and existing glaciers of Colorado:Univ.of Colorado Studies,vol.8,p.45,1910.

the crevasse this kind of weathering may take place with the result that the debris formed from the rock may be carried off by the water flowing under the ice. In time a cliff will be formed as a result and it will slowly recede upstream forming a cascade. Due to structural inequalities of the underlying bed rock such a cliff may also be due to erosion and abrasion by the ice. The steps or cascades, therefore, are formed by crevasses and by ice erosion of the bed rock, while the cirque is formed by the same process at the bergschrund.

Deposition

Mt. Albion, 12,569 feet in elevation, Mt. Kiowa, 13,101 feet in elevation, and the Arapahoe Peaks, the highest, North Peak, being 13,506 feet in elevation, slope very steeply. Since there is evidence of an uplifted peneplain between Mt. Albion and Mt. Kiowa, it is evident that there were V-shaped valleys present before the glaciation began. These were youthful valleys. During the Pleistocene the large valley glaciers which were formed fitted snugly to the slopes. Large amounts of rock debris, therefore, fell on the accumulating ice because of the alternating freezing and thawing and because of the grinding off of large amounts of material by friction against the slopes as the ice moved downward. This material was carried along by the ice. Some of it was carried as superglacial material, some as englacial. Much that started as superglacial became englacial as it proceeded down with the ice due to melting of the ice upon which it was carried and due to subsequent snowfalls upon the ice. Some material,of course,was carried as subglacial drift. In addition to the above ways in which the ice gathered material there was a considerable amount gathered from rock slides and small avalanches. One of the striking facts which may be observed at present is the large number of small rock slides which one may see at the head of the glacier. On a warm day one may observe many times,in the course of a short time spent upon the glacier,rocks of various sizes come rolling down upon the snow from higher up on the cirque(Fig.14). As a result of this type of weathering the jagged serrate ridges are formed.

Moraines deposited in these valleys from this drift include lateral,terminal,medial,and ground moraines. They are composed for the most part of unstratified drift varying in size from huge boulders 35 feet in diameter to fine clay and gravel(Fig.15,page 33).

The north and south lateral moraines,respectively, of the Arapahoe and Albion valleys became medial at the junction of the two valleys at the east end of Mt.Albion. Here the drift is similar to that of the other moraines, being composed of various sized boulders mixed with fine material,the entire mass unassorted. In some places large outcrops of rock were ridden over by the ice and protrude

Fig.14 Small rock slides and debris of various sizes on the ice. Arapahoe Glacier.

up through the drift(Fig.16,page 34).

The most significant moraines are lateral. A study of the valley shapes and drainage of the area shows considerable evidence for a change in the direction of the glaciers as they moved down the valley. This change took place about four miles from the head of the valleys. The original direction is nearly east-west. At the curve the direction changes to S.55°E. Along the north and east sides of the valley large amounts of drift were piled up as lateral moraines. Likewise on the south and west borders of the valley the same condition, though to a lesser extent, may be noted(Figs.17,18,19,20,21).

Fig.15. Glacial boulder west of University Camp. Shows signs of weathering since deposition.

Fig.16. Medial moraine showing nature of drift.
From Silver and Gold Trail.

Fig.17. West lateral moraine from Arapahoe Trail.

Fig.18. East lateral moraine looking east from
Arapahoe Trail. The largest lateral.

Fig.19. Continuation south, of Fig.18. Shows
lateral moraine ending lobe-fashion
at Maxwell road. From Arapahoe Trail.

Fig.20. East lateral moraine looking west from Maxwell road near University Camp.

Fig.21. Continuation north of Fig.20. From Maxwell road near University Camp.

Upon the north and east sides the moraine has the appearance of a high ridge of drift, steep-sided, with rock slides and talus heaps at various points and much coarse material scattered along its base(Fig.22, page 38). This moraine is nearly three miles in length and varies from 50 to nearly 400 feet in height. The top is wide, in some places the width exceeding 1500 feet, and consists in innumerable small ridges, knolls, and kettles. These ridges are in no certain order and lie in all directions. Many of the kettles contain water(See Figs.23,24, page 39, and Fig.25, page 40). Some of these ridges are of considerable size, however, and are deposited along the lower inside edge of the lateral moraine. Their position and form indicates that they are probably terminal in nature. They are located along the Silver Lake road near its junction with the Maxwell road. Much terminal drift lies at the end of the glacier. It is deposited in parallel ridges which are very close together. Some of these ridges are deposited in a north-south direction while others are deposited in a southeast-northwest direction. From a distance all of these deposits appear to lie in a north-south direction across the valley. The separate parallel ridges of terminal drift are possibly due to deposition resulting from the retreat of the ice on successive years(See sketch, page 19). On the west side of the valley is a lateral moraine very similar to the lateral moraine on the east side of the valley. It is not as high, however, but is

Fig.22. Lateral drift ridge on east lateral moraine shown in Fig.18. Silver and Gold Trail.

Fig.23. Kettle lake in terminal moraine.
Maxwell road near Silver Lake road.

Fig.24. Kettle lake in lateral moraine.
Albion road at timberline.

curved in a similar manner and extends in the same general direction. Upon each of these lateral moraines is a ridge of drift varying from 20 to 50 feethin height, very evenly deposited, and extendiꞑng the entire length of the lateral. These ridges are typical "perched" moraines and are probably due to a later advance of the ice.

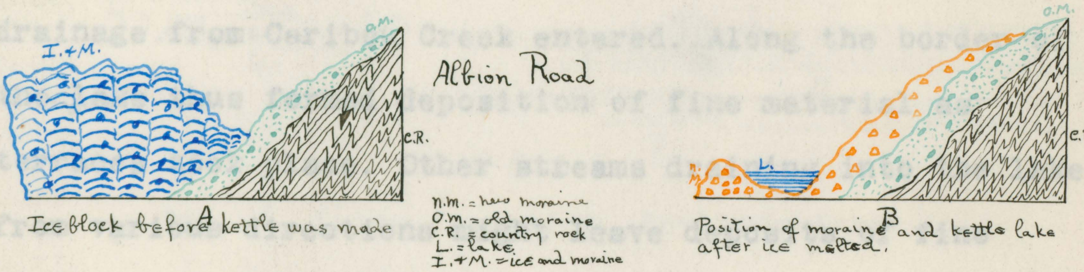


Fig.25. Possible way in which a kettle lake is formed.

One of the results of morainal deposition is to be seen in the area known as Devlin's Park. This region is bounded on the southeast by the main deposits of the west lateral moraine. The moraine at this point extends ridge-fashion south until it strikes the main rock outcrops to the south. About 300 feet before it comes into contact with these rocks it is cut through by Caribou Creek which occupies a deep valley at this place. West of this morainal deposit is a large level area about one square mile in extent, bordered on the south by a terrace, and on the north by a huge, more or less bar-shaped, ridge of sand and gravel. On the northwest and west sides of this area are small terraces. All of the terraces are approximately at the same level. It is suggested that this area was at one time covered with water held in at its east boundary by the ice of the glacier. The ice was succeeded by drift deposits which continued to hold back the waters of the lake thus ponded. The water was ponded back toward the southwest from which direction the drainage from Caribou Creek entered. Along the border of the lake thus formed deposition of fine material as terraces took place. Other streams draining into the lake from various directions might leave deposits of fine material as delta deposits. Since the moraine ridge which held back the water pitches toward the southeast the natural outlet for the lake would be in that direction. Hence in time the moraine was cut down by stream erosion. Eventually the lake was drained, the terraces remaining as stream deposits and probably to some extent as wave-built terraces. The peculiar ridge at the northeast side of the park may be accounted for by deposition as a small delta from streams draining from the moraine to the east. The material of this ridge is made up of fine gravel and coarse sand. It lies parallel with the main lateral ridge of morainal material and within 20 feet of it for a distance of several hundred feet. Streams draining from the moraine to the west could have deposited this material as a delta in the lake. Later as the lake drained, erosion would cut down between the delta and the moraine leaving the present ravine between them(Fig.26).

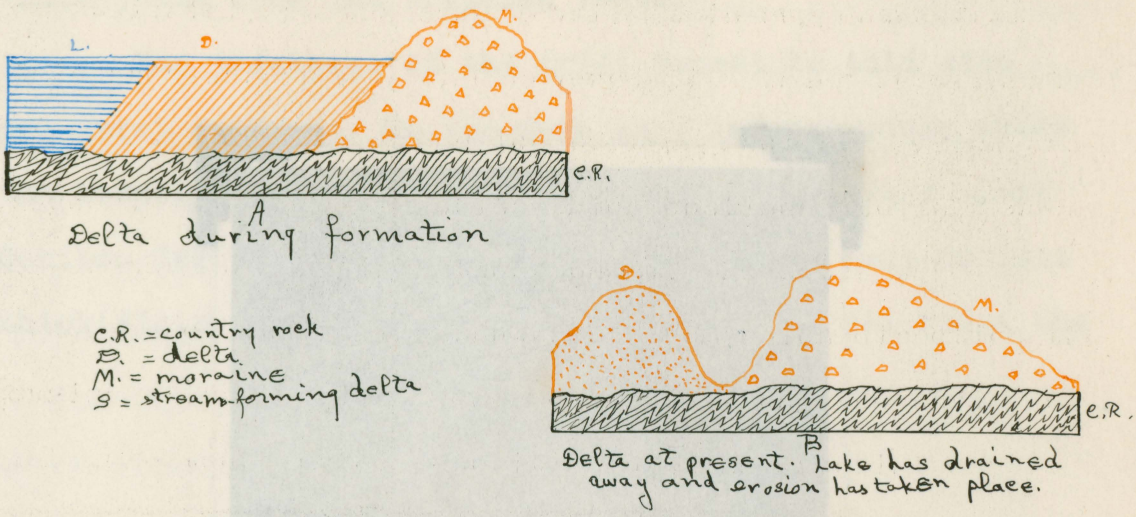


Fig.26. Delta formation. Devlin's Park.

Ground moraine lies in the valley between the lateral moraines. The boulders are small for the most part although a few large ones are scattered about(Fig.27). Some of this material has been transported by the ice as much as eight miles. The drift is much weathered both on the ridges and on the east lateral slope. The boulders are composed chiefly of granites,gneisses,schists,and felsite porphyries,with a few scattered hornblendėtes and diorites. The porphyry,which is found scattered in considerable abundance over the east side of the area, comes from porphyry dikes which have been located in place only in the Albion Valley. The gneiss comes mainly from the upper Green Lakes region. The schist and various kinds of granite come from the walls of the Albion Valley.

Fig.27. Glacial boulder.
Silver Lake Valley.
Shows pitting and
rounding.

The schists and granites, together with considerable amounts of gneiss which are found mostly in the Arapahoe Valley, come from the Arapahoe Peaks.

The thickness of the drift cannot be told with any great accuracy. On the main east lateral ridge where the Maxwell road cuts across, and at Devlin's Park where Caribou Creek cuts through, the drift is at least 50 feet thick (Fig.28). On the slope of the east lateral ridge the

Fig.28. Moraine, Caribou Creek.
Cross section.

drift is much thinner as is shown by cuts on the Maxwell road (Fig.29), and on the Albion road near Hill's Mill where the country rock is no more than a foot below the surface of the drift. Not only is the drift scattered over

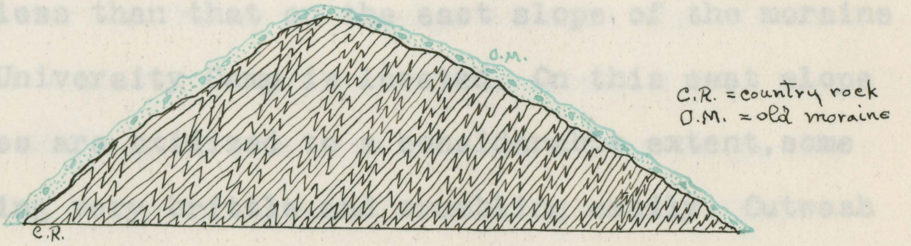


Fig.29. Country rock exposed at cut, Maxwell road, showing thin covering of old moraine on a small rock ridge spur of the east lateral moraine.

the area in boulders of varying sizes, but especially in the Green Lakes region are there great numbers of erratics occurring mainly as balanced rocks. Some very large granite boulders are balanced on "sheep-backs" or roches moutonnees made up of schists. The drift is much more sparsely distributed in the region of Hill's Mill and east of University Camp. The material is washed out or leached, weathered and decomposed, and is spread out in many places in fan-like lobes. The edge of the drift may be traced a short distance east of these places and further south beyond the Maxwell road. The boulders are much rounded, the angularity decreasing gradually from the Albion road at timberline to the drift east of University Camp. This is due not only to greater distance of transportation of the boulders but to excessive weathering. The degree to which these boulders are weathered seems to depend somewhat on their location. On top of the highest ridge of the lateral moraine on each side of the valley, and between these ridges, the weathering of the drift boulders appears to be much less than that on the east slope of the moraine where the University Camp is located. On this east slope the granites are oxidized to a considerable extent, some of them being very brittle and crumbling easily. Outwash is abundant around Hill's Mill and all along the edge of the moraine near Bluebird Mine. Its thickness is not great but it is spread over much territory.

PERIOD OF GLACIATION

Two Advances of the Ice

Evidence

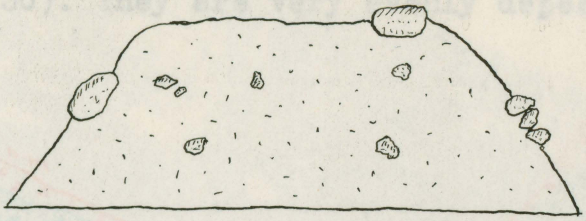
Henderson[1] believes that glaciation in Colorado took place in Pleistocene time, Wisconsin period, but he states that there is little evidence from which to determine the age. However he recognizes two epochs. Bastin and Hill[2] date the time of the earlier glaciation as pre-Wisconsin and that of the later as Wisconsin. A study of the area of the Arapahoe and Albion valleys reveals abundant evidence for two advances of the ice. This evidence is of two sorts, namely, (1) topographic, and (2) condition of the drift. As shown on the map there is a distinct lateral moraine extending from high in the Albion Valley southeast and curving toward the south and which has been called in this paper the east lateral moraine. Bordering the eastern edge of this moraine is a distinct and well marked ridge approximately fifty feet higher than the top of the main moraine. This ridge can be traced almost continuously from north of the Albion

[1]Henderson, Junius, Extinct and existing glaciers of Colorado: Univ. of Colorado Studies, vol. 8, p. 52, 1910.

[2]Bastin and Hill: U.S. Geol. Survey Prof. Paper 94, p. 58, 1917.

road, which crosses it about two miles west of Hill's Mill, south and southeast until it is crossed by the Maxwell road about 1,000 feet east of Arapahoe Falls. At this point it is much lower and breaks up into several ridges, continuations of which extend for approximately 1500 feet southeast of the road, running out lobe-fashion. At one point, above the Maxwell road, about 800 feet north of the road, this ridge curves into a rough half S-shape. This peculiar change in the direction of the ridge may be due to a large block of ice breaking off from the main mass of the ice at this point and depositing its load as it melted while the main mass moved on. Farther down the valley Beyond Arapahoe Falls on the east side of North Boulder Creek a much lower ridge begins, extending, with some interruptions and irregularities in direction, as far southeast as a point about 1,000 feet from Bluebird Mine (Plate II, page 48). To the north of this low ridge and throughout most of its distance, and parallel to it, extend similar but higher ridges. Examination of the drift of these parallel ridges shows it to be weathered to about the same degree as the older drift of the east slope of the main lateral ridge near University Camp. It was probably deposited by the ice upon its first advance. On the west side of the valley on top of the west lateral moraine is another ridge very similar to the ridge on top of the east lateral moraine. It starts directly east of Bald Mountain and runs south for a short distance and then southeast ending opposite Devlin's

Plate II.



A. Cross section of the
railroad cut near Bluebird
Mine

Material is morainal
drift and outwash.

B. Cross section of the
railroad cut 275 feet
farther north than in A.

Ridges disappear as outwash.

Material of old moraine near Bluebird Mine.

Park. There is a very distinct curve in this ridge just at the point where the Arapahoe Trail crosses it.

These ridges appear to be superimposed upon the main lateral moraines. In other words they are "perched" moraines(Fig.30). They are very evenly deposited as compared

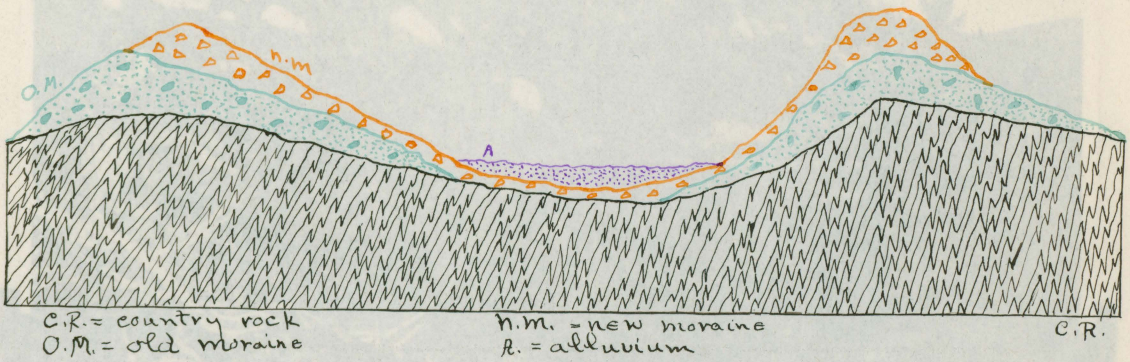


Fig.30. "Perched" moraines. Two advances of the ice.

with the rest of the drift. Their position is always on the highest parts of the drift accumulations and they have all the appearance of being superimposed upon the underlying morainal material(Figs.31,32). The very noticeable uniformity in height and evenness of deposition of the ridges would indicate that the deposition was made by moving ice since ice which was stationary or receding would leave the material in heaps or short irregular ridges.

Another topographic evidence of considerable importance is the presence of what might be called "benches" in the upper Arapahoe Valley bordering the Triple Lakes(Fig.33). These benches are very plainly to be seen, even from a considerable distance. The highest

Fig.31. "Perched" morainal ridge. Notice evenness of depositiom. Rock Lake Trail.

Fig.32. "Perched" ridge on old moraine. Notice ridge-like form of highest drift. Silver and Gold Trail.

bench is a little over 11,000 feet in altitude and from its position with regard to the peneplain remnants it is very evidently a part of it. The next

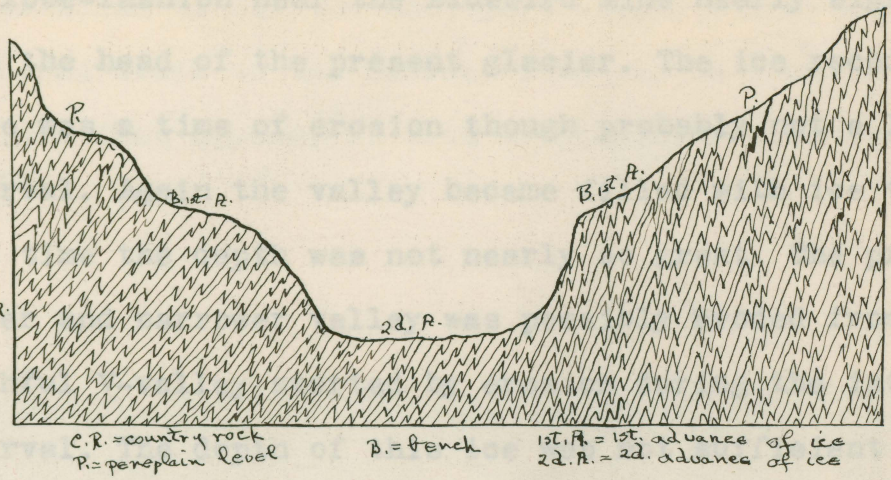


Fig.33. U-valley showing "benches" and old peneplain level. At Triple Lakes.

lower bench, however, at an altitude of 10,800 feet very evidently is not a part of the peneplain. It shows evidence of having been gouged by the ice and a little morainal material of the more angular variety may be found upon it. Below this bench is the valley proper with rough ice-worn sides, rock slides, and talus slopes. The floor of the valley is between 200 and 300 feet deep from this last bench to the Triple Lakes below. The ice, on the first advance, possibly filled the valley to somewhat above the level of the first bench above the present valley. The maximum depth of ice on this first advance was probably not over 600 feet. This depth gradually decreased as the ice flowed down the valley but there was still enough to travel over the rock ridge just west of University Camp. The ice traveled down the valley of North Boulder Creek depositing the short parallel ridges,as well as the long lower ridge,all of which run out lobe-fashion near the Bluebird Mine nearly eight miles from the head of the present glacier. The ice receded and there was a time of erosion though probably not a long interval. Again the valley became filled with ice though this time the depth was not nearly so great. The present deeper and narrower valley was possibly eroded from the youthful V-valley started by erosion during the interglacial interval. The depth of this ice was not suffieient to carry it over the rock ridge west of University Camp. It did,however,carry approximately to the top of the ridge and the material was deposited in an even lateral ridge. This ridge ends just east of Arapahoe Falls. The west lateral perched moraine,while not as high as the one on the east side of the valley,may be seen to follow a similar direction and ends at the south side of North Arapahoe Creek valley opposite Devlin's Park(Fig.34,See Fig.17 ,page 34). The ice on the second advance probably went no further than this point. Examination odf the material collected here bears out this point,as will be shown later. That the ice went no further on the second advance is also indicated by the fact that the deposits at this point occur as knolls and short ridges very unevenly deposited(See Fig.34). See also Plate III,page 54).

The second type of evidence for two advances of the ice is the nature of weathering of the drift. The east side of the east moraine ridge slopes more gradually and the material is for the most part rather evenly distributed, extending south to the Maxwell road and in some places 500 to 1,000 feet beyond. At Hill's Mill, north of University

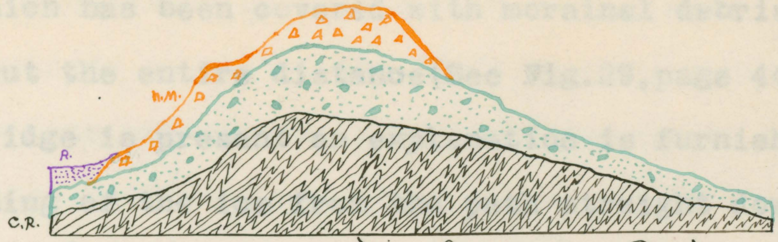
Fig. 34. Terminus of west lateral moraine. Notice uneven deposits in short ridges and knolls. From Maxwell road just beyond Arapahoe Falls.

Camp, lobe-shaped ridges of the moraine extend eastward. They are much steeper and more ridge-like than the main east side of the moraine. At different points on the east side of the moraine steep slopes, like the side of a ridge may be seen. These places are covered with boulders and are the result of snow-sapping.

At various places between Hill's Mill and the

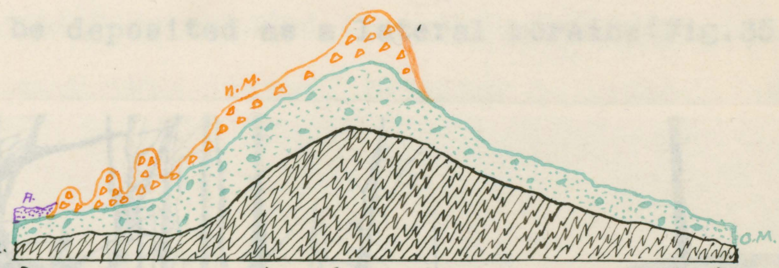
Plate III

A.



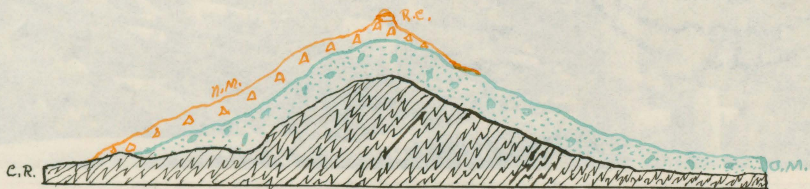
Diagramatic section of moraines, Rock Lake Trail

B.



Diagramatic section of moraines, 300 feet north of Maxwell road just east of Arapahoe Falls.

C.



Diagramatic section of moraines at road cut on Maxwell road just east of Arapahoe Falls.

N.M. = new moraine
O.M. = old moraine
C.R. = country rock
R.C. = railroad cut
A. = alluvium

Perched moraine and old moraine on the main ridge.

Maxwell road there are outcrops of rock and the morainal deposit is very thin. Since these outcrops are a part of the main morainal ridge they suggest the presence of a ridge which has been covered with morainal debris throughout the entire distance(See Fig.29,page 44). If such a ridge is present an explanation is furnished for the turning of the ice from the path straight down the valley. In its journey down the valley upon coming to this rock ridge the ice would be partially turned from its course and the large amount of debris present on the ice would be deposited as a lateral moraine(Fig.35.

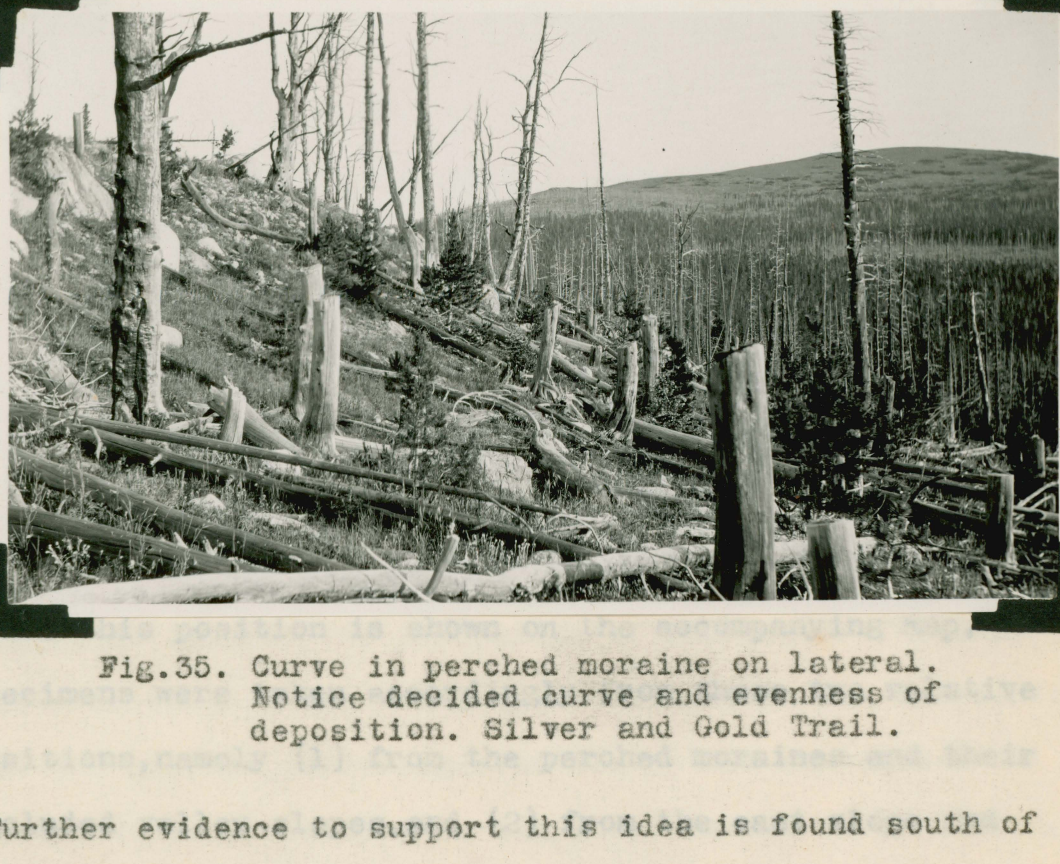


Fig.35. Curve in perched moraine on lateral. Notice decided curve and evenness of deposition. Silver and Gold Trail.

Further evidence to support this idea is found south of the Maxwell road,east of Devlin's Park. The deposition of the moraine at this point in heaps and short ridges indicates that much of the ice melted at this point. The large boulders found in this area indicate a thick mass of transporting ice and consequently a long time during which transportation and deposition took place.

Boulders in all of the drift area outside of the perched ridges are decidedly more weathered and pitted than are the boulders upon these ridges and in the valley between. Of the material composing the drift the granites show the greatest amount of weathering. Material on the perched ridges and in the valleys between is more subangular and less rounded than that outside these ridges. It is also much less pitted. In order to procure some sort of definite evidence from the material of the moraines themselves for two advances of the ice the following data were gathered. It is intended to show the relative amount of weathering of the drift of the perched moraines and included valleys and of the drift outside of these valleys. Five hundred specimens of boulders of the drift were gathered and examined. Since the hypothesis states that there were probably two advances of the ice and describes the relative position of the two deposits of drift and since this position is shown on the accompanying map, specimens were taken accordingly from these two relative positions,namely (1) from the perched moraines and their included valley slopes,and (2) from the east slope and corresponding west slope of the main lateral moraines. In other words material from the suggested old drift was compared with that from the suggested newer drift. From each point at which specimens were gathered they were taken (1) from the surface, and (2) from beneath the surface. The accompanying chart(page 58)indicates the points at which the specimens were gathered. Upon examination of these specimens it was apparent that the greatest amount of weathering and pitting, kaolinization of feldspars, and oxidation of boulders of the drift had taken place upon those specimens gathered from the east slope of the east main lateral ridge . The weathering, pitting, kaolinization, and oxidation of the boulders on the perched ridges and included valleys, while apparent, seemed to be much less. Not all the specimens in either location showed these characteristics but the predominating number did. In order to make the examination of the specimens as accurate as possible a method of measurements was next resorted to. Each of the specimens was measured upon the weathered rim after breaking. An ordinary pair of dividers was used and the measurements transferred to a millimeter scale. The number of millimeters of weathered rim for each specimen was recorded and the average for each set of specimens was computed. Finally the percentage of difference for each set from each of the two compared locations was calculated and the average percentage for the entire number was obtained. The results show the least amount of weathering in the drift on the perched ridges and their included

Location	Set No.	New Moraine				Old Moraine				Difference		Percentage Difference	
		No. Specimens	Depth Weathering Surface	No. Specimens	Depth Weathering Underground	No. Specimens	Depth Weathering Surface	No. Specimens	Depth Weathering Underground	Surface	Underground	Surface	Underground
Silver and Gold Trail	1	16	2.34	13	1.42	13	2.54	11	3.00	.20	.58	78.74	19.33
Rock Lake Trail	2	15	1.73	8	1.50	20	2.65	9	2.17	.92	.67	34.71	30.78
400 feet south of Rock Lake Trail	3	26	1.81	17	2.09	16	3.81	18	3.64	2.00	1.55	52.49	42.30
1100 feet south of Rock Lake Trail	4	18	2.08	13	1.54	16	3.19	12	2.58	1.11	1.04	34.79	40.31
1700 feet south of Rock Lake Trail	5	15	1.53	16	1.59	15	2.93	14	2.86	1.40	1.27	47.78	44.40
400 feet north of Rock Lake Trail	6	18	2.06	9	1.77	14	3.36	13	2.31	1.30	.54	38.69	23.38
1100 feet north of Rock Lake Trail	7	17	1.44	11	1.45	16	2.09	14	207	.65	.62	31.10	29.99
Average percentage difference												46.90	32.94
Arapahoe Trail	8	6	2.00			6	2.66			.66		24.81	
Random	9	6	1.58			6	2.58			1.00		38.76	
Bluebird Trail	10					15	2.83	10	3.23				
Railroad Cut Bluebird Mine	11					5	3.00	5	2.60				
Caribou Creek Cut	12	13	1.14	11	1.45								
Ridge mile west of railroad cut Blue bird Mine	13					4	2.87						
Total No. Specimens		150		98		146		106					

Legend

Comparison of the depth of weathering on boulders from the surface and beneath the surface

Data in millimeters

500 Specimens.

FORM E4

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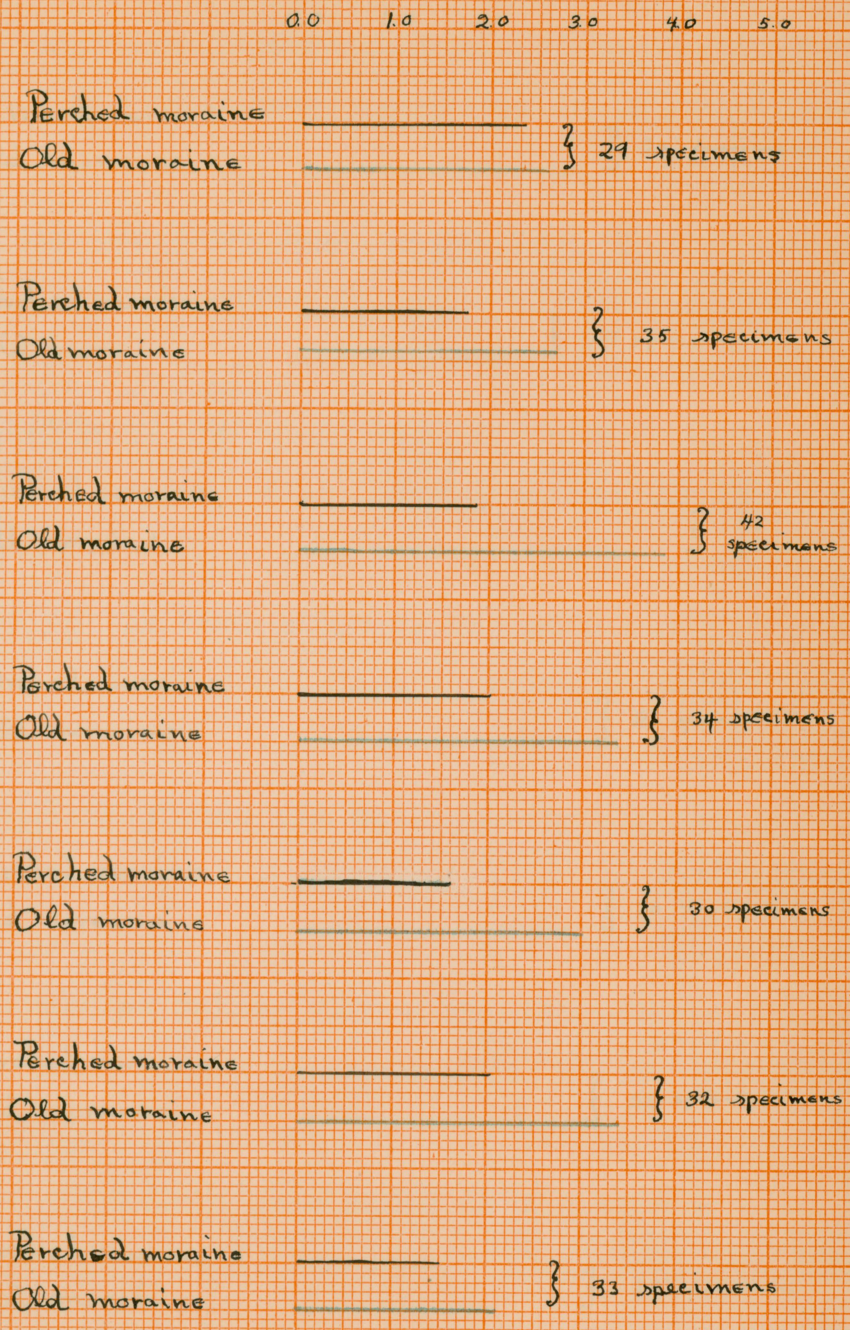
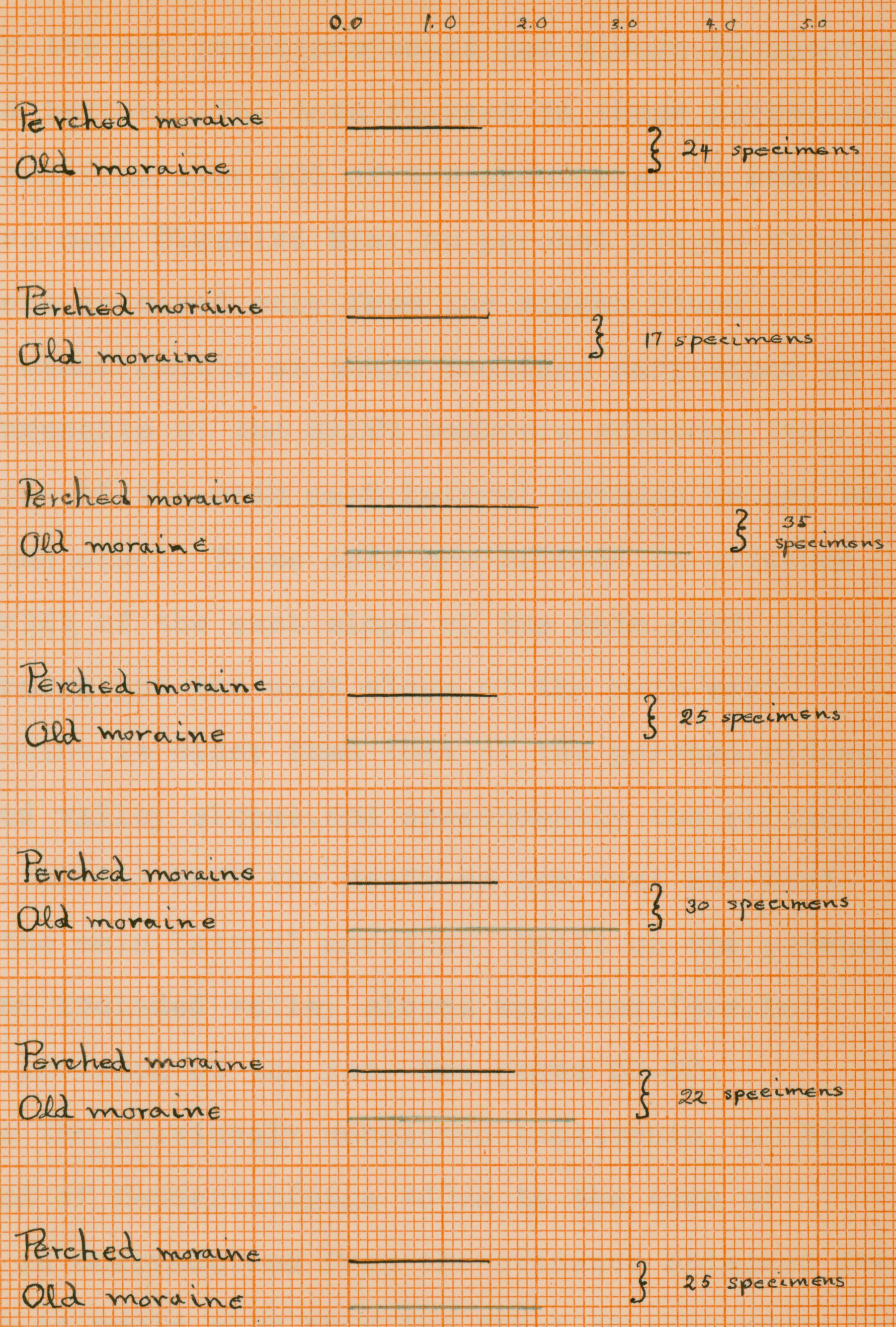


Comparison of depth of weathering on boulders from the surface.
Depth of weathering indicated in millimeters.
Two sets of specimens in any group came from same locality.



Comparison of depth of weathering on boulders from beneath the surface.
Depth of weathering indicated in millimeters.
Two sets of specimens in any group came from same locality.

valleys. As large a variety as possible of the kinds of drift boulders was gathered so that the results vary rather widely in some cases due to the fact that the boulders in the two positions could not always be matched in size and texture. The data figured in these percentages were gathered from over 400 of the specimens. In some places, for instance near Bluebird Mine, no perched ridges occur so boulders were gathered only from the ridges found. Weathering measurements on these boulders correspond to those measurements on the drift boulders obtained from the east side of the main east lateral moraine as may be seen from the chart. These data are offered as evidence that the drift of the east slope of the main east lateral moraine and the west slope of the main west lateral moraine is older than that of the perched ridges and included valley slopes, and consequently the earlier advance of the ice left the drift on the east and west slopes of the main lateral moraines. Drift on the perched moraines and included valley slopes was, therefore, left by a later invasion of the ice. See pages 58-60.

From the previously mentioned statements of Bastin and Hill and of Henderson (page 46) as to the time of glaciation in Colorado, and from the evidence obtained from this region, it would seem that the first advance might be placed at early Wisconsin time which has been estimated by Chamberlain at from 20,000 to 40,000 years ago. If the evidence obtained from the measurement of these specimens may be used as a basis for an estimate, roughly, of the time between the two advances of the ice then an estimate of 14,000 to 50,000 years ago as the time of recession of the second advance or about late Wisconsin time would perhaps not be too long.

5

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