

Collier Glacier - A Photographic Record

By DR. RUTH E. HOPSON

FOR NINETEEN different years between 1934 and 1960 inclusive, I have photographed Collier Glacier from the terminal moraine near Collier Viewpoint. Time has benefited this study. Compared with geologic time, twenty-six years is infinitesimal, yet photographic observations on a glacier over this span show significant changes, especially during a critical period in the life of the glacier.

That such a record would prove worthwhile was suggested to me by the late Dr. Francois E. Matthes of the United States Geological Survey, then chairman of the Committee on Glaciers of the American Geophysical Union. During a chance meeting in the summer of 1936, he told me that the mountain glaciers were diminishing and that a photographic record of one would become more valuable as the years passed. In September of that year, I took the second of the series; the first I had already taken in the fall of 1934 when I discovered the terminal lake that was not there the previous year.

Collier Glacier is the largest of the 14 glaciers of the Three Sisters region in the Central Cascades of Oregon, the largest of all the glaciers in Oregon, and the largest of those of the United States at or south of its latitude, approximately latitude 44°9' N. The Three Sisters Quadrangle, United States Geological Survey, 1932, shows Collier to be about one and one-half miles long by three-fourths of a mile wide. The glacier lies between the North Sister on the east, the Middle Sister on the south, and Cirque Rock and Little Brother on the west. Collier Glacier flows north-northwest from an altitude of about nine thousand feet to one of about seventy-four hundred feet.

Collier Glacier may be seen from the summit of the McKenzie Highway or from Scott Lake, or from several other points along the highway where the North and Middle Sisters are visible. From these locations it appears as a large snowfield that lies between the two mountains.

Three trails lead from the McKenzie Highway to the foot of Collier Glacier. These are the Oregon Skyline Trail (Pacific Crest), and

combinations of this trail and Scott Trail, or Obsidian Trail.

GENERAL DESCRIPTION

Location of Features

All views in the series on Collier Glacier are taken from the same part of the terminal moraine, sometime between the middle of July and the first of October of the respective years. The photographic record is for 1934-36-37-38, 1940-49 inclusive, 1950-51-52-54, and 1960. The view is toward the south-southeast.

The peak to the right of the head of the glacier is the Middle Sister. Cirque Rock is the next prominent feature to the right of the pictures. The slope that rises steeply above the lake, also on the right, is that of the lateral moraine below Little Brother. The lower slopes of the North Sister bound the glacier to the left of the photographs.

Lateral moraine on the east appears to lie against the side of the North Sister. Both this moraine and the one below Little Brother rest upon the ice of the glacier and move with it, separated by a trough from the mountains.

The terminal lake is drained by White Branch. This stream emerged from under the ice at the snout of the glacier until 1934 when the lake was formed. White Branch appears first in this series of photographs in 1940 at the northwest edge of the lake between the terminal moraine and the western lateral moraine.

Type

Collier is believed to be a post-Pleistocene glacier, dating back about 4000 years. Previous to 1939, the glaciers on the mountains of the West were considered remnant type glaciers from the Pleistocene. The large size of the moraines was the main evidence. During the summer of 1939, when a lake burst out, cutting a narrow channel through the terminal moraine of Conness Glacier in the High Sierra, an ice core was exposed. From this the "ice core" is inferred to be the general condition in the large moraines of the western mountain glaciers. These mountain glaciers represent a new occupation of the cirques, valleys, and depressions created by the Pleistocene glaciers.



CIRQUE ROCK - Ice falls of Collier Glacier - 1936

Pleistocene glaciation was widespread in the Three Sisters region. Glacially striated, gray andesite is exposed throughout this part of the high Cascades. A Pleistocene glacier must have poured out from between the North Sister and its parasitic cone, Little Brother, and must have carved a deep hollow between them, forming the depression that is now occupied by Collier Glacier.

Surface Features of Collier Glacier

Change is normal with glaciers. Variable amounts of snow, degrees of melting, rates of accumulation and types of distribution of debris result in altered drainage patterns on the glacier and fluctuating conditions in the terminal lake. Crevasses open and close in response to movement of the glacier or disappear as the surface is lowered by melting. Specific changes are described later in the discussion of the individual photographs.

Slope of the Glacier

From the edge of the lake to the head of the glacier, a little less than a mile and a half, is a gain in elevation of about twenty-six hundred feet, or a little more than seventeen hundred feet per mile. The steep slope is not uniform, since a steeper upper reach is separated from the gentler lower one by an almost perpendicular cliff at the ice falls.

Above the ice falls, the profile of the glacier is convex; below it, slightly convex, straight, or slightly concave.

Crevasses

The major crevasses are near the ice falls that result from the valley wall, about two-thirds of the way up the glacier. Here a number of large crevasses reach almost across the glacier. Below the ice falls, longitudinal crevasses are at an angle of about forty-five degrees to the transverse crevasses already mentioned. These longitudinal crevasses are almost parallel and deflected toward the west as the current of ice sweeps around the spur of the North Sister.

A secondary ice fall below the main ones and to the west, indicates a second current of ice coming from the direction of the Middle Sister.

In some places, particularly below the ice falls, the crevasses cross each other, marking the glacier into varied geometric figures, best shown in the photograph for 1947.

As the glacier is reduced by melting, ablation moraine covers the surface. The crevasses become shallower and disappear, leaving lines of debris marking their former locations. Also in the 1947 photograph of the glacier, a line of crevasse filling is continued across the mantle of debris. Apparently the

crevasse was still active beneath the covering of rocks.

Source of Debris

Steep-sided complex volcanos, composed of alternate lava flows and pyroclastics, wall in Collier Glacier. These cones are the source of the abundant debris on the surface and within the glacier. Even the lava flows and volcanic dikes supply rocks for glacial transport, since the extremes of weathering conditions at this altitude make all exposed rocks break up readily. The loose rocks are constantly rolling onto the glacier and make it dangerous to be near one of the steep walls. Some of this material lodges in the bergschrunds and the crevasses to become incorporated into the glacier. In years of heavy snow, as the snow becomes névé and finally ice, the covered rocks form layers within the growing glaciers. During times of dwindling, as with Collier throughout this study, the current accumulation joins that exposed by ablation to form the thickening mantle of rock on the lower part of the glacier.

A special part of this ablation moraine is made up of the "straight line" deposits, described in the discussions of the photographs. These appear to be crevasse fillings.

Another source of rocks within the glacier is "plucking". The ice is in contact with jointed or loose rocks at the head of the glacier as well as along the sides and on the bottom. When the rocks are frozen into the ice, they are plucked out and carried along as the glacier moves. Such places, exposed around the margins of Collier Glacier, especially in the upper reaches near the Middle Sister, clearly show such action.

Moraines

Most of this rock material finds its way eventually into some type of moraine. Some of the rocks make the journey without modification, others are ground up into rock flour, still others show all gradations in between. The altered rocks are those that are transported at the bottom of the glacier where most of the grinding action takes place, or those carried by water within the glacier or at the surface. Within the ice, rocks are transported as fresh as when they started.

Every type of rock in the surrounding mountains appears somewhere in the moraines. Huge rough boulders are perched precariously on smaller rocks, themselves un-

steady. Because of this delicately balanced equilibrium, the movement of one small rock in the lower part of the moraine may be enough to cause an avalanche of rocks to thunder down upon the glacier. Rocks of every size are mixed with the fine glacial flour. On windy days, this fine dust is picked up and transported by the wind and resembles smoke clouds over the moraines.

North of the terminal moraine, rock flour has accumulated as wind-blown deposits in such quantity as to obscure the trail to the viewpoint on the moraine. This occurrence of quantities of rock flour from a comparatively small glacier is significant proof of the effectiveness of the glacial process in reduction of rocks by grinding.

A heavy mantle of ablation moraine covers all of the lower part of the glacier except that which has been engulfed by the expanding lake. An unknown thickness of ice remains beneath this moraine and probably also beneath the lake.

On the west, the lateral moraine is in several parts, interrupted by remnants of small tributary glaciers that formerly entered from the Middle Sister. The large moraine below Little Brother is a part of this series.

On the east, the lateral moraine is continuous from below the ice falls to the end of the North Sister, where a tributary glacier formerly entered from the east. The large field of stagnant ice that lies between the North Sister and Collier Cone is all that remains of this tributary.

The terminal moraine lies against Collier Cone.

The moraines vary in height, but in places are about three hundred feet high. Ice has been exposed in the steep slope of the terminal moraine on the lake side for several years. In 1944, ice appeared in the eastern lateral moraine. Probably much of the height of all of these moraines is due to ice cores.

Debris Cones and Other Protective Effects

Debris cones were prominent features of the lower part of the glacier in 1936. Since then the expanding lake has engulfed most of them. These formations were not true cones, however, but were in the shape of pyramids.

Simple debris cones are common features of glaciers, formed when ablation moraine protects some irregularity from melting while

surrounding unprotected areas are lowered. As the cones become steeper, the surface covering slips off until finally bare ice is rimmed by rock debris. A crater is formed as this ice melts; the loose rock slides in to cover the floor of the crater; and the whole process starts again. Some unexplained factor has here modified the process to produce the pyramid shape instead of the usual cone.

Slumping of the eastern lateral moraine in 1940 covered a mid-portion of the glacier. Additional slumping in succeeding years added to this deposit. The loose rock cover protected the ice beneath from melting, resulting in a plateau, distinctive by 1942. From a plateau to a dissected plateau around the edges and finally by 1960, to a steep slope like one side of a debris cone are some of the changes in this area as the rock covering interacted with the ice of the glacier, the stream erosion and the weather.

Comparison of the position of this deposit in 1940 with its position in successive years shows that it has moved forward with reference to the hump in the eastern lateral moraine.

Tributary Glaciers

Formerly several tributary glaciers entered Collier Glacier from the Middle Sister. In the col at the summit of the glacier, a yoke made connection with Hayden Glacier, an incipient, cirque-type glacier east of the Middle Sister. This connection still existed in 1923 when Hodge (1925:72) was in this area. All tributary glaciers from the Middle Sister, except a part of the névé field that is below Black Hump, have lost connection with the main glacier, and have either melted away completely, or remain as isolated stagnant ice. In a deep hollow between Collier Cone and the North Sister is a large field of such ice, ending at the terminal lake. Although this huge field of rock-covered ice is at a higher elevation than the surface of the lake, it would be difficult to ascertain whether this was formed as an overflow lobe in the terminal part of the glacier or whether it was once an eastern tributary.

White Branch

White Branch has its source in the terminal lake of Collier Glacier. It is a typical glacial stream, that becomes a raging torrent in the late afternoon of summer days, and shrinks to a small trickle at night and to nothing

during the winter. It carries a heavy load of rock flour in suspension.

At the northwest, White Branch has always breached the terminal moraine. This stream formerly flowed from under the ice where it now flows from the lake. Before 1940, the lake merely spilled over at this point, and spread out among the rocks leaving a few stepping stones above water. By 1941, the overflowing water had eroded to a depth of one or two feet. Pressure from increased meltwater, following a hot spell in July, 1942, caused a sudden outbreak. This cut a gorge several feet deep at the outlet, and as much as thirty feet deep a few hundred yards down stream. Farther along, White Branch changed its course in a few places. As much as a mile and a half below the glacier, it spread boulders over outwash plains. It covered the lowest outwash plain with fine sediment, and generally changed the picture of upper White Branch Valley.

History of the Glacier

Dr. J. S. Newberry was probably the first scientist to be interested in Collier Glacier (I. C. Russel 1883-1884:341) as the following quotation indicates:

"The group of peaks known as the Three Sisters is considered by Mr. Diller as probably affording the most interesting field for glacial studies in the United States, with the exception of Alaska. The glaciers amid this group of peaks attracted the attention of Dr. Newberry while connected with the Pacific Railroad Survey in 1855, but no report of these observations has been published."

The late Carey F. Martin, an attorney in Salem, Oregon gave me an account of his visit to Collier Glacier in the latter part of the eighteen-eighties. He reported that Professor Collier, who led the trip, estimated the cliff of ice at the snout of the glacier as about eighty-two feet.

Descriptions and photographs of Collier Glacier are in an unpublished Master's Thesis, University of Oregon, by Ian Campbell (1923:6,7) and in Hodge (1925:72-75). Both of these picture the glacier proportionately larger than the beginning of my series, and smaller than the late eighteen-eighties.

In August, 1933, when I first visited Collier Glacier, snow extended beyond the snout of the glacier. The lake that now occupies so much of the lower glacier did not appear

until 1934. The photographic record tells the story from then until 1960.

Mr. Raymond Sims of Eugene, Oregon, has made a collection of older photographs of the glacier. He also has a number of his own, taken mostly from the head of the glacier toward the terminal moraine.

Salient Changes in Collier Glacier

Salient changes in Collier Glacier that may be noted by careful examination of the series of photographs of the glacier arranged chronologically are:

1. The size of the lake has waxed and waned.

2. The height and extent of the ice has shrunken. This feature is best seen by examining the ice front and ice surface in relation to the lateral moraine along the side of the North Sister.

3. In the upper glacier, the ice deposit appears to have increased since 1936. Comparison of the ridge between Cirque Rock and the Middle Sister, the small snow fields on the eastern side of the Middle Sister, and Black Hump on the photographs for 1936 and 1960 shows much more rock exposed in 1936.

4. Ablation moraine has thickened and spread progressively on the surface of the lower portion of the glacier.

5. Progressive slumping of the eastern lateral moraine has contributed to the ablation moraine, which has protected the glacier in that area from melting, and thus has formed a plateau. This deposit has moved forward in relation to the hump of the lateral moraine, and thus has demonstrated the movement of the glacier.

6. The number and amount of crevasse fillings that have been deposited as lines of debris on the surface of the glacier have increased as the glacier has been lowered by melting and evaporation. These lines have also moved with the glacier and curved.

7. The amount of black rock exposed below Cirque Rock has varied, usually more, but sometimes hidden by snow.

8. The western side of the lake (western lateral moraine) has changed from a gentle slope, to a perpendicular cliff, and back to a

gentle slope. The cliff appeared to be one side of a crevasse.

9. The surface drainage of the glacier has shifted from a master stream rising on the western side of the glacier to a master stream rising on the eastern side. Since the eastern drainage has become dominant, a delta has appeared in the lake at the mouth of this stream, noticeable for the first time in 1941. In subsequent years the delta has been dissected and reworked in response to the shifting level of the lake and the accumulating alluvium.

CONCLUSION

The following evidence is offered as partial proof that Collier Glacier belongs with the group of recent glaciers (about four thousand years old) rather than the remnant type.

1. From photographs, Collier is seen to form an arc around a spur of the North Sister, about midway of the glacier. Because truncation of spurs is the rule with glaciers, the fact that Collier has not yet accomplished this argues that it has not yet had time.

2. The large moraines are the result of ice cores. The base of the ice core of the western lateral moraine was exposed at the lake edge in the overhanging cliff in 1940, was modified in 1941, and was melted down to a gentle slope in the following year. The exceptionally steep slopes on the lake side of the terminal moraine result from a matrix of ice in which the rocks of the moraine are embedded. The normal angle of repose for such volcanics is much less steep. Melting and undercutting by the terminal lake have allowed the loose material to tumble into the lake, and have developed an almost perpendicular wall of ice and rock.

3. The interrelationship between Collier Glacier and the most recent vulcanism in this area also indicates that the glacier has not extended further than the outermost terminal moraine since the last volcanic activity. Collier Cone, a fresh young scoria cone, now stands at the foot of the glacier, blocking its path, yet shows no signs of glacial or any other type of erosion. Recessional moraines of Collier Glacier partly cover lavas that flowed from a vent in the west side of Collier Cone. A volcanic outcrop that exhibits many sharp fresh edges stands thirty feet or more above the moraines and separates them into two parts. The older moraines to the north-

east of the outcrop extend to within about thirty feet of the Skyline Trail. These moraines are hummocky, and are cut by several smaller volcanic outcrops that appear fresh and show no evidence of glaciation or even weathering. Typical faceted and grooved rocks are found among the rocks of the older moraines that are north of the terminal moraine. On the western side of the large outcrop the recessional moraines extend down the valley about the same distance as on the east side. Apparently these moraines were piled against the volcanic rocks by the terminal part of the glacier, where movement has been at a minimum since the outcrops were exposed. Williams (1944:56) uses the relationship of the volcanic action to glacial moraine to support the recency of the flows from Collier Cone:

"Some evidence of the recency of these last flows from Collier Cone is given by their relation to the moraines of Collier Glacier. Although the main body of the glacier now ends about half a mile to the south, moraine-covered ice can be seen within approximately 100 yards of the cone. Yet, since the cone was built, the ice has never extended beyond its southern rim. On that side of the cone, moraines cover the cinders, and debris from them has tumbled onto the crater floor. Hence, the snout of Collier Glacier has only retreated between 200 and 300 yards since the final outburst of the Collier Cone."

4. The thin mantle of valley train that has been deposited by White Branch is another indication that Collier is relatively young. Outbreaks of the terminal lake in 1942-45 caused White Branch to cut through the valley train and into cinders and volcanic ash beneath. A short distance below the glacier, the new gorge was about thirty feet deep at one time. The unconsolidated materials were unable to maintain the steep banks and soon slumped.

On the basis of this evidence—the non-truncated spurs, the ice cores that account for a large part of the moraines, the interrelationship between Collier Glacier and the most recent vulcanism, and the thin veneer of valley train below the glacier—Collier Glacier appears to represent a recent occupation of an older cirque that was carved between the North Sister and its parasitic cone, Little Brother, during the Pleistocene. Collier Glacier has little modified the hollow it now occupies.

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COLLIER GLACIER - SEPTEMBER 19, 1934

The lake in the foreground is newly formed. During the summer of 1933, the snout of the glacier extended to the terminal moraine. Islands and a peninsula of ice, veneered with rock debris, are a part of the glacier, and are striking features of the lake. Some of these islands are domed pressure ridges, proof of the force of the flowing glacier. Glacial flour in suspension in the water gives the lake the characteristic milky aspect.

A medial moraine extends onto the glacier from between Cirque Rock and Little Brother. Above this point, the steep ice slope marks the location of a former through glacier that connected with Renfrew Glacier on the Middle Sister. Ice pyramids, protected by a cover of loose rock are clustered in the lower left corner of the glacier and form a part of the medial moraine.

Notice the height of the lateral moraines on the left border of the glacier. Compare in each succeeding picture.



COLLIER GLACIER - SEPTEMBER 27, 1936

The terminal lake remains about the same as in 1934, except fewer islands indicate the melting trend in the glacier. More rock is exposed in the ridge below Cirque Rock. Scattered rocks at the foot of the lateral moraine along the left of the glacier show the beginning of the rock debris that obscures the lower glacier in later photographs. A light coating of wind-blown dark volcanic ash covers the glacier. Some of the debris-coated ice pyramids remain.

An extensive surface drainage system heads beyond the main crevassed area below Cirque Rock. This stream system is a typical consequent drainage pattern with many parallel, closely spaced streams. In later photographs a master consequent stream is developed along the foot of the lateral moraine at the left.



COLLIER GLACIER - SEPTEMBER 25, 1938

The lake is larger. Melting and possibly "faulting" (indicated by the perpendicular cliffs at the foot of the long debris covered slope from

Little Brother) have removed the peninsulas. The islands are now of two types, those still connected to the glacier under the water, and icebergs floating in the lake.

The master consequent stream has developed along the margin of the lateral moraine on the east side. In its lower reaches this stream has begun to choke its passage with deposited alluvium, to meander and form a delta.

Since more melting has taken place, the eastern lateral moraine appears higher above the glacier. This moraine is beginning to slump, particularly near the ice falls. More of the black ridge is exposed below Cirque Rock. The medial moraine has merged with the lateral moraine below the accumulating loose rock cover from Little Brother. Rock covered ice pyramids remain features of the lower glacier.



COLLIER GLACIER - 1940

This was one of the two years of maximum size for the terminal lake. No peninsulas or islands remain. An overhanging cliff, thirty feet or more high, at the foot of the lateral moraine below Little Brother reveals the ice core of this moraine. This cliff represents a "fault" or actually marks one side of a crevasse.

The consequent stream at the base of the lateral moraine below the North Sister has now become in part superposed upon slump material from this moraine, probably first becoming entrenched upon the winter snow cover, then continuing in the same position as the snow melted. Alluvial deposits at the mouth of this stream suggest a beginning delta.

Below Cirque Rock and the ice field between Cirque Rock and Little Brother is a curious "straight line" deposit of loose rock materials. This is foreshadowed on the photograph of 1938, but except for the later developments would probably not have been noticed. I believe this is a crevasse filling, exposed by the surface of the glacier being lowered as the ice melted.

This feature continues and parallel deposits appear in succeeding years.

The lateral moraine below the North Sister stands higher above the surface of the glacier, and conspicuous slumping has occurred as mentioned above. In later photographs, this deposit moves forward with relation to the hump in the moraine, recording movement of the glacier in this area. The ice pyramids remain. More of the surface of the lower part of the glacier is veneered with rock debris.

White Branch, the outlet to the lake, is on the middle right of the lake. At this time the lake overflows among the rocks, but no channel is excavated. The water of the lake carries rock flour in suspension. Even White Branch, as it emerges from the lake, is heavily loaded with this finely ground rock material. Ice probably remains below the lake, insulated from melting by alluvium.



COLLIER GLACIER - AUGUST 11, 1941

Salient features of 1941 are the conspicuous delta and the extensive slumping of moraines.

The lake continues at approximately the same size as the year before. The ice cliff has enlarged by headward erosion. White Branch still exists among the rocks without a definite channel. The delta is well established and characteristically supplied with abundant distributaries.

Material that has slumped from the lateral moraines below the North Sister now reaches half way across the glacier, and has moved forward. The formerly consequent stream is now either superposed, or in part antecedent throughout most of its length as it maintains its course across this slump material. This rock debris at the bend of the glacier has protected

the ice from melting. The resultant cliff gives evidence of the extent to which the glacier is wasting.

Two new "straight line" deposits are exposed, parallel to the one on the 1940 photographs, one below, and a shorter one above on the ice field between Cirque Rock and Little Brother.

The ice pyramids remain. The surface of the lower glacier is more extensively covered with rock materials. The lateral moraines, in spite of the slumping, stand higher above the surface of the glacier.



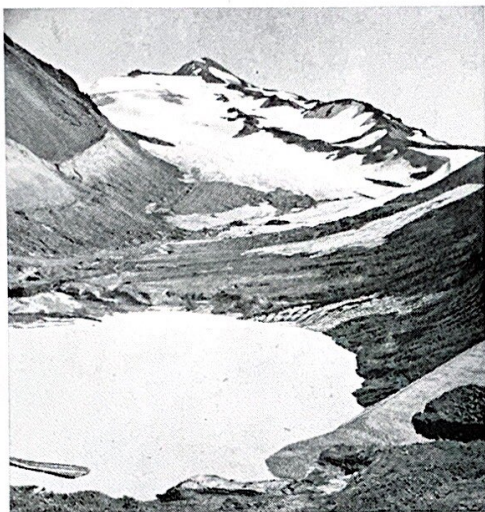
COLLIER GLACIER - JULY 23, 1942

An unusually heavy snow fall during the previous winter and a hot spell in early July combined to cause significant changes in the glacier. The upper reaches of the glacier still hold a cover of winter snow. A few icebergs float in the lake, and packed winter snow remains to the left of the outlet. Even the Middle Sister shows continuous snow from its summit over the Horse's Neck. On the other hand, the lower reaches show extensive evidences of melting. The ice cliff has melted back, the lower slopes of the moraine below Little Brother have become less precipitous, but most exciting, the pressure of meltwater in the lake has caused it to break through the moraine dam and cut a gorge from the outlet, disrupting the course of White Branch for miles down its valley. The resultant lowered local base level has allowed the master stream at the east of Collier to dissect its delta, now revealed as a veneer on the ice, and to start building a new delta beyond the old one.

The ice pyramids are now gone from the lower glacier, merged with the sediment cover and carried away by the melt water of the glacier. The "straight line" deposits are covered

with snow, except for one fragment. The master stream is beginning to carve a V-shaped valley within the glacier.

The lateral moraines to the east stand high above the glacier, and continue to slump and slide onto the surface of the glacier as the ice core melts within. This material, accumulating on the glacier, is establishing new surfaces at two levels. The ice core nature of the large moraine below Little Brother is exposed about its base.



COLLIER GLACIER - 1943

The trends established the year before continue. The sharp features that resulted from the erosion of the delta in 1942 are now rounded.

The changes can be described by applying the terminology and concepts of the wet cycle of erosion. In 1941 the lower, flatter part of the glacier represents a new land surface, cut by the extended master consequent stream. Temporary base level for this stream is the surface of the lake, where alluvium has begun to build a delta and choke the lower reaches of the stream, which responded by forming numerous distributaries. In 1942, when the lake was suddenly lowered forming a new temporary base level, the stream cut a main channel through to the lake, with perpendicular cliffs, and started to build a new delta at its mouth. The "land surface" remained in the stage of early youth.

By 1943, the smaller streams to the west had cut down to the base level of the lake, and the edges of the interfluves between main streams have rounded. The surface of the lower glacier now represents a more advanced stage of youth.

The snow bridge across the outlet on the right is a conspicuous transitory feature. The slumping of the eastern lateral moraine continues to build the deposits at two levels and to reach further across the glacier as it moves slowly forward.

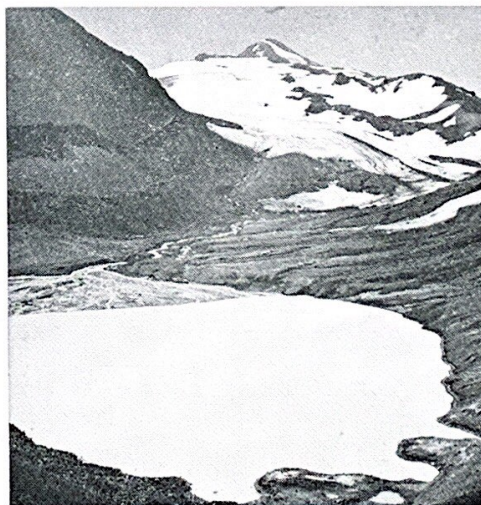


COLLIER GLACIER - AUGUST 11, 1944

Rock debris from the lateral moraine on the east now extends more than half way across the glacier. The master stream has a new course across part of this area. The erosion pattern in the lower part of the glacier has progressed another step toward advanced youth with the wasting of the interfluves between the streams. The "straight line" deposits are again in evidence and reveal that whatever their cause they are part of larger deposits.

The outlet channel shows the extent of erosion that has taken place here since 1940 when White Branch flowed out among rocks without an eroded bed.

The lateral moraine below Little Brother has been over steepened, the rocks probably held in place in the ice core.



PHOTOGRAPH BY CATHERINE DUNLOP

COLLIER GLACIER - AUGUST 8, 1945

(See description next page)

COLLIER GLACIER - AUGUST 8, 1945

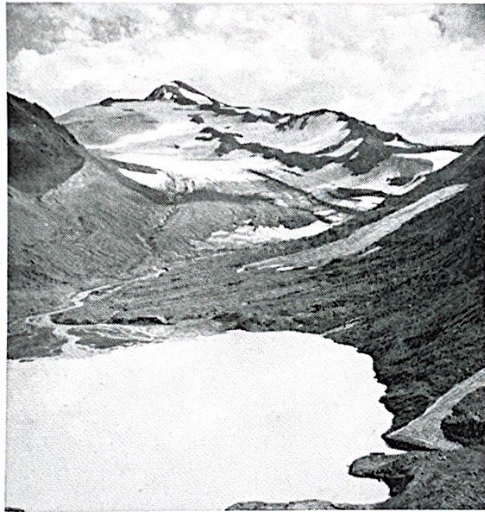
(See picture page 23)

Again, heavy snow has accumulated on the upper glacier and has connected the upper and lower snowfields on the Middle Sister.

The middle reaches of the glacier below Cirque Rock show a light covering of volcanic dust. A crosshatch pattern of crevasses is appearing in this part. Here dark lines in both directions indicate further exposure of crevasse fillings. The glacier appears to be breaking up somewhat.

The delta is extending further into the lake, developing new patterns of distributaries. The stream farthest to the right shows the first inkling of a delta.

The surface of the lower glacier has advanced a little further toward late youth in the erosion cycle.



COLLIER GLACIER - AUGUST 27, 1946

Snow patches on the Middle Sister and the remains of a snow bridge at the outlet are evidences of another good snow year. Numerous trails made by rocks from the Middle Sister and from Cirque Rock mark the source of some of the debris that is thickening and extending the covering on the lower part of the glacier. Additional sources are the lateral moraines on both sides of the glacier, and the strange "straight line" deposits, that, whatever their origin, can now be called medial moraines.

Water erosion remains active. The large delta is newly dissected and a secondary delta is well formed at the mouth of the little stream at the right. Less of the original relatively flat surface

of the lower glacier remains as the interfluves between the small consequent streams become more rounded and the valleys of the streams widen.

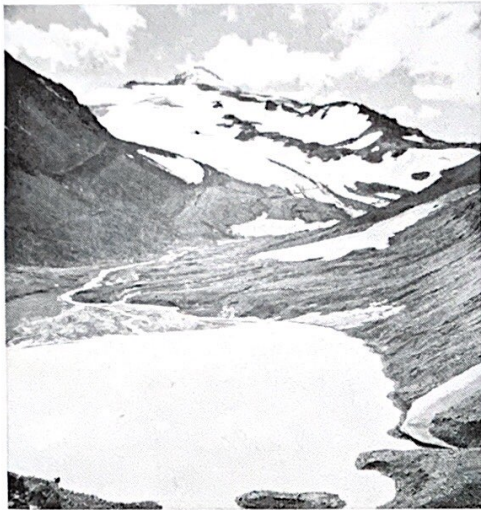
The lake still holds a heavy load of glacier flour in suspension. From the beginning of the lake this material has been gradually settling to the bottom, covering the ice upon which the lake was formed. Much has been carried away by White Branch and deposited all along its course. The surface drainage of the glacier has continued to renew this fine material in the lake whenever temperatures permitted the water to flow. Such material, coating the ice under the lake, would act as an effective insulation. No investigation has been made to determine whether ice remains under the lake. Cores of these sediments should show the varve type of deposit, and would be of interest to examine.



COLLIER GLACIER - SEPTEMBER 14, 1947

Fresh snow covers most of the Middle Sister and the upper glacier. The lower glacier carries an ever increasing load of rock debris. A third delta has begun at the mouth of a little stream between the other two. The "topography" of the flatter area of the lower glacier is a step nearer to maturity; little of the original flat surface remains, instead slopes reach back to the divides between the streams. Melting ice in the core of the moraine above the lake on the western side of the glacier has resulted in over steepening of the slope.

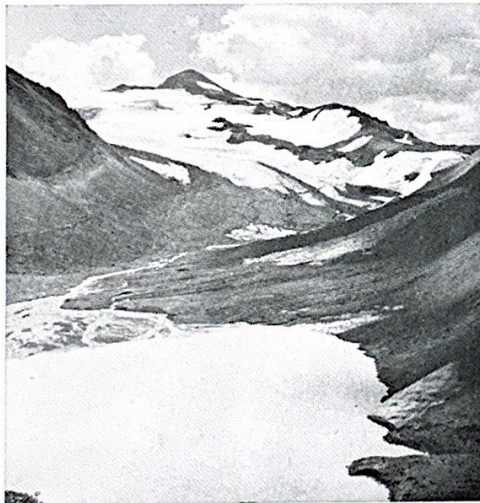
Distinctive curves have developed in the "straight line deposits". Looking back through previous years, we see that this has been a gradual change, no doubt reflecting the pattern of movement on the glacier.



COLLIER GLACIER - SEPTEMBER, 1948

Most of the trends that have been established continue. The pattern of distributaries in the large delta has changed, the eastern part is isolated at a level above that of the distributaries as a master one cuts a deeper channel. The two smaller deltas are more pronounced.

The "straight line deposits" are beginning to slump and lose their distinctive character. At this stage in their development they look more like medial moraines, developed as terminal moraines from the stream of ice that enters between Cirque Rock and Little Brother. However, the continued development as recorded on the yearly photographs seems to preclude this possibility.



COLLIER GLACIER - AUGUST 29, 1949

An abundance of meltwater from the surface of the glacier has flooded the deltas and demonstrates how new distributaries are formed. The stream at the foot of the main eastern moraine

appears to lose itself in the alluvial cone that is building up at an abrupt change of gradient where the stream reaches the surface of the glacier from the debris protected plateau.

Trends discussed in relation to the other photographs continue.



COLLIER GLACIER - AUGUST 16, 1950

The extensive snow cover in the lower glacier conceals many of the features. The limited meltwater is confined to main distributaries. Numerous rocks are descending the western moraine, accelerated by the snow.

The "icebergs" appear to be floe, remnants of surface ice when the lake was frozen over. A snow bridge remains over the outlet.



COLLIER GLACIER - SEPTEMBER 23, 1951

The haze in the photograph is caused by smoke from many forest fires.

All of the lower glacier from between Little Brother and Cirque Rock is now covered by rock debris, much of it from the slumping of the east lateral moraine. Drainage patterns that were established across this material are now obliterated. The "straight line" deposits have evidently served to protect the ice beneath them from melting and thus developed a series of terraces.

The streams from the glacier have been building the deltas farther into the lake, and the ever-changing distributaries are rearranged.



COLLIER GLACIER - AUGUST 8, 1954

Heavy snows of the previous winter have not melted away. Rocks that were exposed on either side of the Middle Sister in the upper part of the glacier are now buried beneath snow. An extensive snow bridge crosses the outlet and extends to the left. The residuum of the ice covering of the lake has not melted away, but remains as floebergs. The delta has continued to advance. Rock flour, rolling rocks, and sediment from the streams are filling the lake.

(Editor's Note: The author's photographs of Collier Glacier in 1937 and 1952 have been omitted because the weather conditions encountered in those years concealed any significant changes.)



COLLIER GLACIER - JULY 22, 1960

The change wrought by the five years I was unable to visit the glacier is startling! The lake is almost filled with alluvial deposits with the delta extending to the outlet of the lake. A snow bridge again covers the outlet. Most of the features we have been watching in the middle glacier are covered with snow.

In the far upper section of the western lateral moraine glacial flour is blown by the wind. It is this same type of finely ground rock that gives the milky appearance to what remains of the lake.

While the lower glacier has been wasting, snow has slowly accumulated in the upper reaches of the glacier. The extent of this deposit can best be seen by comparing the photographs for 1936 and 1960. In the 1936 photograph, a line of high black cliffs leads from Cirque Rock to the Middle Sister. In 1960, these are almost buried in snow. Another point to check is the small snow field immediately above the glacier on the east side of the Middle Sister. This patch of snow is much nearer the glacier in 1960 than in 1936. Less of Black Hump, to the left of the Middle Sister, is exposed in 1960. Just beyond the spur of the North Sister, a bulge in the glacier seems to mark the front of the thickened upper glacier. A new cycle may be under way! Who can say what the next twenty-six years will bring in the history of the Collier Glacier?