GENERAL VIEW OF VICTORIA GLACIER AND TRIBUTARY

GLACIAL STUDIES IN THE CANADIAN ROCKIES AND SELKIRKS

(SMITHSONIAN EXPEDITION, SEASON OF 1904.)
PRELIMINARY REPORT

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The glaciers selected for special investigation and report are located in Alberta and British Columbia, along the line of the Canadian Pacific Railway; being those which are at the present time most readily accessible to the tourist, or student of glacial phenomena.[1] They represent the outflow from the great snow-ice masses which accumulate, season after season, upon the higher slopes of the Rockies and Selkirks. These five glaciers, upon which a preliminary report only is here offered, lie in north latitude 51° 12′ to 51° 38′ and west longitude 116° 12′ to 117° 30′, about 100 miles north of the international boundary. Owing to the interposition of three minor ranges between the Canadian Rockies and the warm waters of the Pacific, all of them having a north to south trend, the moisture-laden westerly winds yield an abundant precipitation upon the western slopes of these ranges, leaving relatively little for the main range itself. This loss, however, is more than compensated by extra altitude and by the greater size of the catchment basins between the ranges of that great stone heap known as the Rocky Mountains. The records of the Canadian Meteorological Service, available since 1890, give for Banff, lying just east of the continental divide, an average annual rainfall of 12.89 inches and of snow 81.9 inches. When reduced, this represents a total precipitation of 21.08 inches, or in snowfall 17.57 feet. At Glacier House, in the Selkirks, near which are located the two westernmost glaciers studied, the total average precipitation is 2⅔ times as great, giving 56.63 inches as rain, or 47.19 feet when all reduced to snow. Practically this entire amount over the collecting areas is available for the making of glaciers, since when it rains in the valley it very commonly snows over the nevé region and when rain does fall here it is absorbed and soon converted into ice.

[1] A brief report of this expedition appeared in the Quarterly Issue of Smithsonian Miscellaneous Collections, Vol. 47, p. 298.

I. VICTORIA GLACIER.

1. *Nourishment.*—Because of its activity and varied phenomena this glacier, lying between Lake Louise and Mt. Victoria, is of especial geological interest and some six weeks' time was devoted to its study. Starting from Abbott's Pass, upon the continental divide, with an elevation of 9,400 feet above tide, it flows to the north and then northeast for a distance of three miles and before wasting away reaches an altitude of some 6,000 feet. About one mile back from its nose it receives a tributary, the Lefroy glacier, from the southeast which is fed by the snow that accumulates upon either side of the Mitre and the eastern shoulder of Lefroy. Plate LX[1] shows the

FIG. 64.—The making of avalanche cones, Victoria glacier. Photographed by De Forrest Ross.

relation of this tributary to the main stream. The nearness of the medial moraine to the right lateral (the glacier's right) shows that the Lefroy is contributing relatively little ice but most of the rock debris with which the lower part of the Victoria is completely mantled. The extensive snowfield upon the eastern slope of Mt. Victoria, receiving an annual fall of 20 to 25 feet, is avalanched into the narrow valley lying between Mt. Lefroy and Mt. Victoria and this is the chief source of supply for the Victoria, it being, to a large

[1] Reproduced here through the courtesy of the Detroit Photographic Co.

extent, a reconstructed glacier. During the hot days of the summer these avalanches are of frequent occurrence, crashing into the valley hundreds of feet below with the sound of thunder and the blast of a tornado (fig. 64). In the narrower portion of the valley, known as the "Death Trap," they may shoot completely across and thus contribute rock fragments to all parts of the glacier.

Aberdeen. Lefroy.

FIG. 65.—Debris covered nose of Victoria glacier.

2. *Frontal Changes.*—The Victoria presents an oblique front of nearly one half mile, the general direction of which so nearly corresponds with the main axis of the glacier that there is much doubt as to whether we have the actual front or the side (pl. LXI, *a*). An inspection of the ancient moraines in the valley shows that the front has been gradually swinging around into this position, the ice melting more rapidly upon the western side where less protected by debris. Here for a distance of about 1,600 ft. there is a distinctly stratified ice front, inclined from 35° to 50° and reaching a height of 75 ft. to 100 ft. In midsummer of 1898, there fell from the face of the ice an exceptionally large red quartzite boulder, which was photographed by Prof. C. E. Fay while still in position and a week later when it had fallen. One year later the distance of this boulder from the ice front was found by George and William Vaux to be 20 ft.; perhaps one-half of this distance being due to recession. In

the five years which have elapsed since, the base of the ice front has receded 55 ft., or an average of 11 ft. a year.

Some distance down and upon the eastern side of the valley is located the real nose of the glacier (fig. 65), the ice being completely concealed by the debris from the right lateral and medial moraines. Owing to the protection from the sun afforded by this veneering of rock, combined with the sluggish condition of the ice along the side, this nose is stagnant, or practically so, at the present time. The last episode was one of advance, indicated by the manner and extent to which the glacier has pushed into the forest of spruce and fir (pl. LX). The fallen trunks and cut stumps, however, now seen here were produced by a small snow slide, some decades ago, which came down from between Castle Crags and Mt. Aberdeen, encircling the nose when the ice stood somewhat farther back than at present. Accurate measurements were made with a steel tape between blocks of an ancient moraine and others firmly planted in the face of the frontal slope, here having an angle of about 38°. These measurements showed that the latter blocks had settled backward an inch in the 66 days from July 9 to September 13, and the inference is that the ice beneath is slowly wasting faster than it is replenished from behind. Confirmatory evidence of such wastage is furnished by a small stream of clear, ice-cold water which issues from amongst the rocks just west of the nose. So long as present conditions persist, the recession will continue here with extreme slowness, but it is obvious that a very slight additional impulse from behind would inaugurate an advance.

3. *Forward Movement.*—At the lower end of the sharply crested, left lateral moraine shown in plate LX, a line of eighteen steel plates was set, approximately 100 ft. apart and back 3,600 ft. from the nose. The down-valley movement of these plates was accurately determined with a transit for a period of ten cool days (July 9 to 19) and then for a similar period of relatively warm ones (July 19 to 29).[1] As was to be expected the movement was found to increase from the sides, where it was practically nothing, towards the center and to have been appreciably less for the cool period. The maximum forward movement occurred in the broad, general depression in which is seen the surface drainage channel, two-thirds of the way across, and averaged for the cool period 2 inches daily, for the warm

[1] For the cool period the average daily minimum near the nose was 38.76° F., average maximum 60.36° F., total range 30.9° to 74.0° F., precipitation .671 inches. For the warm period the average minimum was 39.59°, average maximum 67.96°, total range 34.8° to 75° F., precipitation .84 inches.

period 3.6 inches daily and for the entire period (July 9 to 29) 2.75 inches, which latter figure may be taken as the average daily summer motion for this part of the glacier. If we assume a minimum winter motion of one-fourth this amount we shall get as the probable yearly motion here about 52 ft. Further up where the inclination is greater there is reason for thinking that the rate of movement is much greater.

4. *Ablation.*—Accurate elevations upon the steel plates used in the above work were taken with a spirit level for the purpose of constructing a cross-section of the glacier here and also for the purpose of determining the amount of surface melting for a definite period. It was thus found that the surface of the ice was being lowered most rapidly in the neighborhood of the plate which showed the maximum forward movement and from July 9 to August 4 amounted to 3.794 ft., or a daily average of 1.75 inches. This effect is produced mainly by the sun, which in the rarified atmosphere of these high altitudes, strikes with surprising force, transforming the water from its solid to its liquid condition, without changing its temperature. Other agencies are the atmosphere, generally above the freezing temperature during the summer months, and the rain, 1.506 inches of which fell during the above period of observation. Subglacial erosion and melting may assist also in lowering the surface of the glacier at any given point, as may also the longitudinal stretching, or lateral spreading of the ice, but for limited periods these effects may be disregarded. From the above data it would appear that the surface melting over the lower third of the Victoria for July and August should be about 9 ft. Independent observations upon the lower Lefroy showed that the ice surrounding certain morainic heaps had been lowered during the season by about this same amount. No glacial tables of this height are to be found, owing to the undercutting effect of the sun's rays and their consequent destruction of their pedestals. The broad medial depression lying to the west of the medial moraine (pl. LX) has been produced by the relatively greater melting here and this is permitted by the thinner covering of rock debris, the ice of this portion of the glacier coming from the Lefroy side of the valley. This depression continues down the valley for 2,200 feet, where it thins out, apparently by surface melting. If the estimated forward movement is approximately correct and continuous for this region it would require about 42 years for the ice to pass from the line of plates to the lower edge, during which time, at the rate of 9 ft. a year, about 378 ft. of ice could be melted, and this should represent the approximate thickness of the

ice beneath the line of plates. The work with the level gave a difference of 393 ft. between the base of this ice at the margin and the plate which gave the maximum surface melting and forward movement. This would leave but 15 ft. for the rise in the valley floor in the 2,200 ft., an amount which is very probably too small and it is likely that the surface melting becomes less toward the lower margin owing to the concentration of the debris.

5. *Shearing.*—The steeply inclined ice front at the western side of the valley shows a succession of ice strata, more or less well defined, which dip back into the glacier at rather a steep angle. At the mouth of an abandoned drainage tunnel, seen in pl. LXI, *a*, these strata have a dip of 26°, which is somewhat below the actual dip when measured at right angles to the strike. There is some sand, a little fine gravel and, occasionally, a cobble-stone between these strata but the amount of foreign material is small and inconspicuous. A few consecutive days' visits to this part of the glacier, in early July, showed that a differential movement between adjacent strata seemed to be taking place (fig. 66). In order to test whether or not such was actually the case a point was selected upon the face 52 ft. above the valley floor, the ice slope being 45°, and six heavy spikes driven into the ice until their heads were flush with the surface. Three were thus placed in the base of the upper stratum and three corresponding ones in the upper part of the subjacent layer, the former projecting beyond the latter 19.7 in. July 21. Two days later, July 23, it was evident that the melting was greater upon the face of the upper stratum, in spite of which this now projected 24.4 in. beyond the lower. The spikes were now visited regularly each morning until August 3 and then reset after the amount of melting and apparent differential movement had been determined. The measurements were necessarily rough but they showed each day that the melting was greater upon the upper stratum, the average amount for each spike being 1.75 in., while that for the lower series was 1.53 in., or nearly ¼ in. in excess. Some sand and fine gravel, washed down from above, daily accumulated in the lee of the projecting upper layer and gave the appearance of a concentration of dirt in the upper part of the lower (fig. 66). When this dirt was small in amount it was observed that melting was accelerated; when greater, that melting was retarded. The upper stratum continued to gain slowly upon the lower and reached a maximum of 26.6 in. on July 27, after which it fluctuated slightly, the observations closing with it at 25.6 in. Time did not permit the verification of these results at other points where the same thing appeared to be occurring,

a. Front of Victoria glacier showing mouth of abandoned drainage tunnel

b. Across Lefroy glacier to Mt. Aberdeen

but there seemed to be no doubt but that the upper layer was moving bodily over the lower. This movement represents a shearing of the glacier itself, the shearing-plane lying between the adjacent strata, but not a shearing of the ice proper.

6. *Discharge.*—The conversion of ice into liquid during the heated season gives rise to surface streams upon the lower, slightly crevassed portions of the Lefroy and Victoria, which attain the magnitude of small torrents and do considerable cutting into the ice. In plate LX

FIG. 66.—Front of Victoria glacier showing stratification and shearing.

three such streams may be made out passing down the Victoria in the main longitudinal depressions and disappearing in crevasses or moulins. The water of these streams is clear and has a temperature of 32° F., or a small fraction above. Upon the glacier's right there is no visible marginal drainage at the present time, but upon the left there is, for a short distance, a vigorous stream and a small lakelet, the discharge from which disappears into the side of the glacier. These surface and marginal streams, along with others of subglacial origin, unite beneath the ice into a single brook which issues at a point between the nose and the oblique ice front, cascading over the rocks of the lately formed moraine. At times during the summer there is more or less discharge from here up as far as the reference boulder. Formerly the main discharge was through a tunnel, now clogged with frozen ground moraine, the mouth of which is shown in pl. LXI, *a*. The opening is 12 by 7 ft. at the lower end and extends obliquely backward under the ice for a distance of 160 ft. The fluted walls and ceiling show that it was at times completely filled with torrential waters (fig. 67). The temperature of the

FIG. 67.—Abandoned drainage tunnel, Victoria glacier.

water from the main exit varies from 32° to 33° F., rendered somewhat higher, undoubtedly, by the marginal stream. During the late spring and early summer the melting snows upon the mountain slopes contribute considerable warmer water to the glacial brook which empties into Lake Louise, but only immediately after rains do these side streams supply an appreciable amount of sediment. For a distance of some 600 ft. there has been built out into the lake a low delta of sand and gravel, the material for which, in the main, has come from beneath the glaciers which occupy the head of the valley. Determinations of the amount of sediment and volume of discharge across this delta were made at 9:00 A. M. and 6:00 P. M., after a week of minimum and another of maximum activity. Just at the glacier it was found impracticable to get the volume of water discharged, but the sediment carried per cu. ft. was found to be .230 oz. for the period of minimum melting, during which time .671 in. of rain fell near the nose. For the maximum period the amount

FIG. 68.—Stony till, left lateral moraine of Victoria glacier.

of sediment per cu. ft. was found to be .506 oz., with .03 in. of precipitation. During the former period there was delivered to the lake 73 cu. ft. of water per second and during the latter 93 cu. ft. The total amount of sediment brought from the glacier daily was estimated as six tons for the maximum period and about one-third this amount for the minimum.

7. *Surface Moraines.*—The two lateral moraines of the Victoria are made up essentially of a stony till, consisting of bruised and glaciated rock fragments, embedded in a matrix of bluish clay (fig. 68). Upon becoming saturated with water mud flows occur which carry forward fragments of considerable size (fig. 69). Over this material, which has been produced subglacially, there is a sprinkling of unglaciated, angular fragments, such as are more characteristic of surface moraines. This ground-morainic material for the left lateral has been manufactured beneath the extensive hanging-glacier which cloaks the entire eastern slope of Mt. Victoria, having

FIG. 69.—Mud flow from stony till in left lateral, Victoria glacier.

FIG. 70.—Stony till concentrated by surface melting. Lefroy glacier.

Double nevé field of Mitre glacier, showing bergschrund. Snow filled crevasse in the foreground

an area of perhaps two square miles and a vertical front of 200 to 400 ft. Fragments of ice, frequently as large as a city block, are crowded over the cliff and fall a distance of 1,200 to 1,500 ft., carrying with them more or less ground moraine and being ground into fragments by the force of the fall (fig. 64). The medial moraine also contains a certain amount of similar material which has been derived in the same manner from the hanging glacier upon Mt. Lefroy. Figure 70 shows this emerging through the snow and ice near the nose of Lefroy, from where it can be traced into the medial moraine. The right lateral is made up still more largely of this same stony till arranged in two or three sharply crested ridges, which may be followed continuously around the base of Mt. Aberdeen, where it passes into the right lateral of the tributary (pl. LX). There are a number of couloirs running up the side of Aberdeen, at the base of which detrital cones of angular debris are being built upon the ice but there are no ice fields upon the mountain (pl. LXI, *b*) to supply any ground moraine as in the two preceding cases. Many hours were spent in staring at these till ridges, diving beneath the great rubbish heap plainly derived from Aberdeen, and in trying to understand how the tributary could get its ground moraine upon its own back and arrange it in ridges parallel with its side. The matter remained a mystery until the last day of the five weeks' camp in the valley. A climb the day before up the side of Mt. Whyte to the Devil's Thumb revealed a feature which had hitherto escaped our observation, and the investigation of this furnished what we believe to be the real explanation of the puzzling phenomenon.

8. *Parasitic Glacier.*—The steep snow slopes upon either side of the Mitre give rise to two small ice streams which remain permanently covered with snow. These unite to form a single glacier (pl. LXII), which is also snow clad during the year but farther down becomes bare during the summer and reveals a very weak medial moraine. For this glacier the name Mitre, originally used by Allen, should be retained. It flows lazily down the valley for about a mile between Mts. Lefroy and Aberdeen, joins the Victoria and suffers much compression as previously noted. From the hanging glacier upon the eastern shoulder of Lefroy it receives a relatively large quantity of snow and ice which is heaped up along the base of this mountain and gives rise to another glacier which is not only nourished differently, but has a different direction of motion, a different set of strata and a different rate of velocities (pl. LXIII). It is for this overlying, parasitic glacier that the name Lefroy may best be used. Its movement is across the Mitre, but with reference to the valley

floor its motion is the resultant of its own motion and that of the Mitre beneath, so that it delivers its ground morainic material, derived from Mt. Lefroy, upon the Aberdeen side of the valley, but near the junction of the Mitre and Victoria (pl. LX; pl. LXIV, *a*). When the map is completed it will be possible to determine the relative motion of each member of this double tributary. The stratification of the Lefroy may be clearly observed in the crevasses, dipping at angles of 12° to 26° towards Mt. Lefroy. The ground morainic

FIG. 71.—Avalanche from hanging glacier on Mt. Lefroy.

material then in the right lateral of the Mitre and Victoria is derived from the shoulder of Mt. Lefroy, is avalanched into the valley below (fig. 71), incorporated into the newly formed strata, pushed across the surface of the Mitre and dumped upon its eastern edge, some of it arranged in ridges, parallel with the *front* of the Lefroy as well as the *side* of the Mitre, where it is slowly delivered to the Victoria. The feature observed from the Devil's Thumb which furnished the key to this rather complicated arrangement was a very sharply defined line which runs *lengthwise* of this double tributary (pl. LXIII).

Mitre Lefroy Abbott's Pass Huber

MITRE AND LEFROY GLACIERS, SHOWING "DIRT ZONES" VICTORIA GLACIER, SHOWING FORBES' "DIRT BANDS"

9. *Dirt Bands.*—A close investigation of this line (fig. 72) showed that it marks the junction of two outcropping ice strata, the lower one containing a considerably larger percentage of foreign matter and that it is simply one—the most conspicuous one—of a series, the outcropping edges of which give rise to one type of "dirt bands."

FIG. 72.—Dirt zone, Lefroy glacier, confused with the dirt *bands* of Forbes. The latter show dimly upon the distant Victoria.

Such bands normally have a transverse direction upon the glacier and while these extend lengthwise of the Mitre they are normally located with reference to the Lefroy, to which they actually belong. The strata here are too thick to represent successive snowfalls, or even the entire year's precipitation, and such strata must correspond to short "cycles" of variable activity of the glacier making agencies. For this phenomenon the term "dirt zone" may be satisfactorily used.

When viewed from a distance of a half mile, to a mile, the Victoria, opposite its tributary, shows an entirely different and much more significant type of "dirt bands," the original bands of Forbes. Opposite the nose of Mt. Lefroy they appear as straight, transverse bands across the crest of a relatively steep ice slope, passing down which they gradually become more and more convex down stream at the center. For a short distance the bands may be traced, upon the Lefroy side, into crevasses which are swinging from a transverse into a longitudinal position. Some 23 of these bands may be made out (pl. LXIII), becoming more crowded together and more sharply bent before they are obliterated by surface melting. The explanation of this feature as given by Tyndall seems to be the correct one. As the ice flowing down a relatively gentle incline suddenly changes to one sufficiently steep, there is developed a system of transverse crevasses, because of the inability of the ice to yield suddenly without rupture. During the summer when the motion is most rapid there is produced either a single such crevasse or a series of parallel crevasses, more or less closely approximated. The sun rounds off the edges of the single crevasse and cuts rapidly into the exposed walls which separate neighboring ones (pl. LXIV, *b*). At the bottom of the slope, or upon the slope itself, when the crevasses are healed, there still remains a more or less well defined depression, into which atmospheric dust and the debris from the surface of the glacier may collect. During the winter there will be a fewer number of crevasses formed and either from the weaker solar action, or the protection afforded by the snow, the edges are not appreciably affected and the crevasses later are perfectly healed. The result of this action is that there is formed each year a depression and a ridge, each of which becomes more and more curved because of the more rapid central motion of the ice. Where the incline is steeper the motion is greater and the successive bands are farther apart, but as the ice becomes more sluggish upon the gentler slope the bands become more crowded. Each season, as the result of melting and rains, more and more material is washed into the depressions, so that they become better defined up to a certain point when, as a result of melting the surface acquires a uniform slope, the dirt becomes more uniformly distributed and the bands are obliterated. The method of formation here described is beautifully shown in the Deville glacier (fig. 72, *a*), situated in the Selkirks and here reproduced through the courtesy of Mr. Arthur O. Wheeler and the Canadian Topographic Survey.

Especial interest and importance is to be attached to this type of "dirt band," since it gives a clue to the actual, as well as relative, forward motion of the ice and a certain insight into the nature of this motion. Standing upon the Victoria it is possible to recognize about three-fourths of the bands which may be counted from a distance, and to determine approximately the successive intervals. Starting with the one at the base of the ice slope and measuring

a. The Lefroy glacier parasitic upon the Mitre. The moramic accumulation at the base of Mt. Aberdeen consists mainly of *ground* moraine, manufactured beneath the hanging glacier on Mt Lefroy and carried *across* the Mitre by the Lefroy

b. Formation of Forbes' dirt bands. Asulkan glacier

roughly from center to center, we have the following distances expressed in feet: 180, 138, 135, 159, 123, 114, 114, 102, 87, 102, 69, 84, 84, 72, 69 and 75. Upon the 26th of July, 1899, George and William Vaux marked the location of a certain large boulder upon this part of the Victoria and July 24, 1900, they found that it had moved 147 ft. This boulder was found to lie in 1904 opposite the ninth band in the above series, but somewhat to the west of the

FIG. 72 *a*.—Formation of Forbes' "dirt bands," Deville glacier, Selkirks. From summit Mt. Fox, looking eastward. Photographed by Arthur O. Wheeler, 1902. Canadian Topographic Survey.

maximum line of movement, as indicated by the form of the dirt bands themselves. In 1899 it should have been opposite what is now the fourth band and during the year following have moved across what would correspond with the fourth interval above or 159 ft. approximately. The above table of distances enables one to predict the approximate movement of these boulders during the next few years and gives a clue to the amount of longitudinal compression to which the ice must be subjected from year to year.

There remains still another striking feature, especially well shown upon the Lefroy, Wapta, Illecillewaet and Asulkan glaciers, to which the name "dirt band" is also applied and which may best be briefly described here for comparison with the preced-

FIG. 73.—"Dirt stripes," side of Illecillewaet glacier. The laminæ here would be conformable with the strata, providing the latter were present.

ing types, with which it has absolutely no connection. Much confusion has arisen in the thinking, the oral discussion and the literature because these three entirely independent features have not been clearly distinguished and separately named. The first two can be recognized to the best advantage at a considerable distance, this last must be seen at close range, along the margin of a glacier fairly free from coarse debris, and subjected to more or less surface melting. The surface here looks as though it had been swept with a wire broom, the strokes being very long and regular and parallel with the side of the glacier. The fine dirt, mostly wind-blown, is arranged in delicate, parallel streaks separated by similar streaks of relatively clean ice (fig. 73). The dirt is entirely superficial although one might think otherwise from the manner in which these bands run down into the crevasses (fig. 74) and cover the marginal

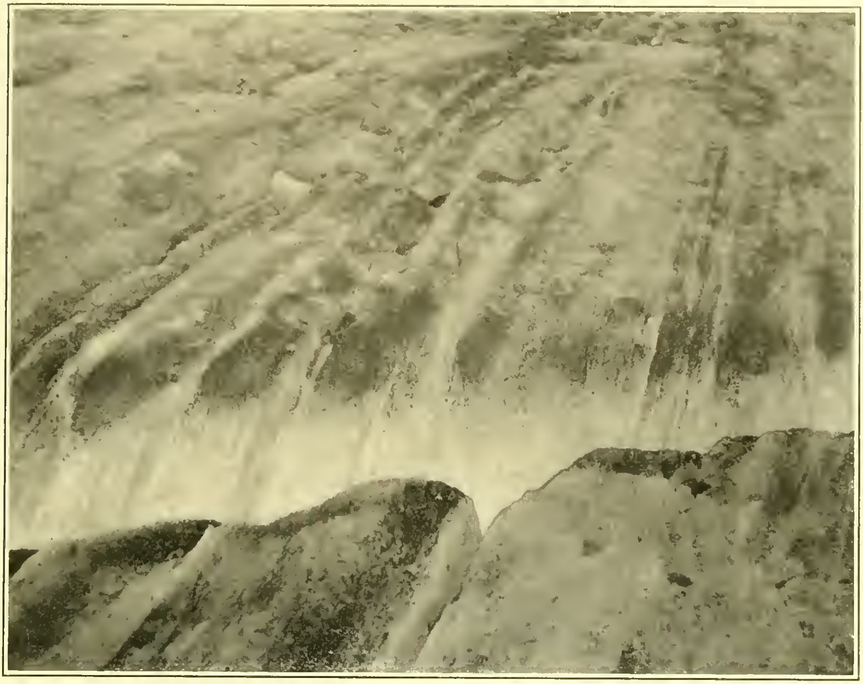


FIG. 74.—"Dirt stripes" and laminæ, Lefroy glacier, cutting strata at a high angle.

slopes. They may be so fine as to average but one-tenth of an inch in breadth, but are generally considerably coarser. This feature is dependent upon the laminated structure of glacial ice and is of importance in that it enables one to judge of the size, number and arrangement of the laminæ, directly from the surface. The outcropping edges of the "blue bands" of solid ice resist the action of the sun somewhat better than the white, vesicular layers by which they are separated. As a result there is produced a series of fine troughs, or furrows, separated by corresponding ridges, into the former of which fine dirt accumulates, reproducing in miniature the dirt bands of Forbes. It is suggested that the term "dirt stripes" be used for this phenomenon.

10. *Ice Dykes.*—A phenomenon not known to have been noted elsewhere, seen frequently upon the lower Lefroy in midsummer

and very sparingly upon one or two other glaciers, may be termed ice dykes. These consist of narrow crevasses, two to fifteen inches across, completely filled with columnar ice, the columns being arranged horizontally, in a double series, at right angles to the walls of the crevasse. In general the inner ends of the columns of each series interlock at the center and the crevasse is completely filled.

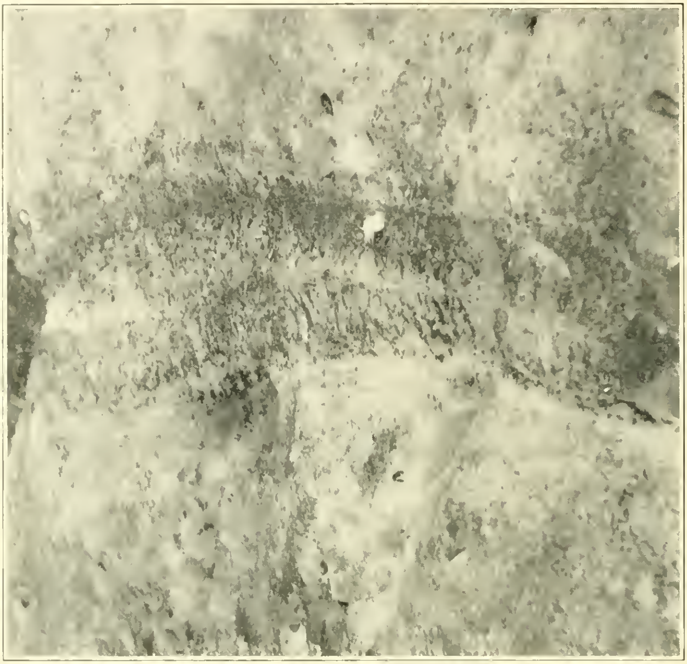


FIG. 75.—Ice dyke, Lefroy glacier.

In a few cases the columns do not meet and a narrow space is left, exceptionally the columns are more or less uniformly curved. These dykes are formed, in all probability, by crevasses becoming filled with water and then freezing from the walls inward, the columns forming at right angles to the freezing surface. The ice structure comes out imperfectly in a photograph (fig. 75). In some few cases ice dykes were noted which contained granular, instead of columnar ice, which must have had an entirely different history.

11. *Heat Reflection?*—Still another phenomenon not known to have been previously reported was observed as the snow was leaving that portion of the glacier usually bare in the summer. It consists of a large melted area upon the *northern* side of the boulders protruding

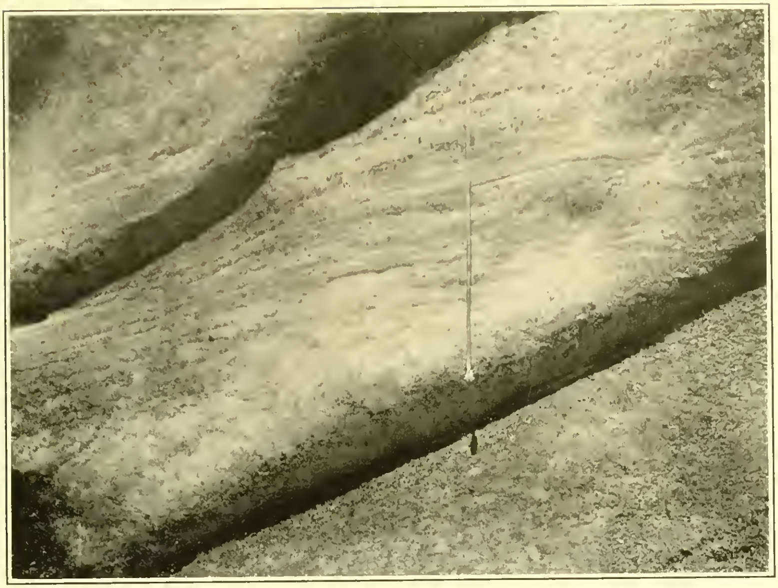
through the snow, which areas bear a certain relation to the breadth, height, shape and possibly position of the boulders themselves. The phenomenon was of very frequent occurrence upon the Victoria and Lefroy, and a suggestion of it was seen upon the surfaces of the avalanche slides about the margins, but all boulders did not show it. Figure 76 is of a white dolomite beginning to form a table, 5 ft.

FIG. 76.—Melted area on the *north* side of a surface block, Victoria glacier.

long and standing 20 in. high, with a melted area 5 ft. broad at the base, 70 in. long and with its longer axis N. 8° W. Another block is shown in fig. 77, a gray quartzite standing 10 in. high, with the melted area conforming in size and shape to that of the rock. The farther, right hand corner of the rock is lower than the general surface and the corresponding corner of the area is seen to be rounded and incompletely melted. The melted area, in all cases, is much greater upon the northern than upon the southern side of the rock. Ten of the axes of these areas, selected at random, gave an average of N. 25.5° W., magnetic, with rather less range than was observed in the axes of the glacial tables. The magnetic variation in this region, as obtained by the Canadian Topographic Survey, is N. 25° 5′ E., so that these areas are oriented with reference to the position of the noonday sun, and might have been used for determining approximately the magnetic variation. The natural inference is that the phenomenon is due to the reflection of heat from the upper surface of the boulder, this action being at a maximum when the sun is upon the meridian and reaching much farther out on the northern side than upon the southern, where the rays would strike but a short distance from the base of the rock. A tin reflector, such as is used for cooking, was found to give the same effect when left for a few days upon the snow. This explanation, however, was found to be unsatisfactory in certain cases where the upper surface of the boulder was inclined in the wrong direction to deflect the heat to the north, and so left the entire matter in doubt.

FIG. 77.—Melted area on the *north* side of a surface block, Victoria glacier.

12. *Ice Temperatures.*—A few observations were taken upon the temperature of the ice near the front, in the abandoned tunnel to which reference has been previously made. A hole was bored with an auger into the face of the ice, back 140 ft. from the entrance, and a standard minimum thermometer inserted. This was estimated to be 70 ft. back from the ice-foot and about 17 ft. from the actual ice face. During the week July 31 to August 7, the readings were 31.8°, 31.6°, 31.8°, 31.9°, 31.7° and 32° F., the maximum temperature of the air in the tunnel ranging from 31.4° to 33° F. Owing to the effect of



a. Non-conformity of the laminæ ("blue bands") and strata Victoria ice front. Steel tape run out to 50 cm.

b. Lake Louise from surface Victoria glacier Ancient block moraines

the candle and warmth of the body it was found impracticable to get the actual temperature of the air in the tunnel at the time of observation and the maximum temperature, between visits, could be obtained only with the aid of a freezing mixture poured over the bulb of the thermometer.

13. *Lamination.*—Many observations were made upon the "blue bands" of the glaciers studied with the hope of shedding some light upon their position and direction in the ice and their relation to the granules and strata. In general it was found that they are well developed along the margins and front of the ice streams and that they are entirely independent of the stratification, cutting the strata as a rule at high angles. The laminæ and strata approach conformity more nearly along the side where no pressure is felt from either bed rock or lateral moraine (fig. 73), but where such pressure is apparently present the laminæ curve upward from the interior of the glacier and come to the surface at angles of 75, 85 and even 90°. Their outcropping edges extend parallel with the sides of the ice stream and generally give rise to the dirt stripes previously described (figs. 73 and 74). Towards the center they become less steeply inclined in a simple stream, and are rendered inconspicuous, or disappear at the surface. Under the medial moraine upon the Victoria they are highly inclined and somewhat fan-like. At the mouth of the tunnel they were found to average from 15 mm. to 19 mm. in thickness and to dip back into the glacier at an average angle of 9°, while the strata here average 26°. Plate LXV, *a* shows the nonconformity of the laminæ and strata. They seem to sustain a certain relation to the direction of maximum pressure and to represent neither ice-filled crevasses, shearing planes nor planes of stratification. Sufficient pressure from a different direction may induce a second set without obliterating the first and differential ice movements may give rise to irregular, contorted patterns (fig. 78).

14. *Block Moraines.*—From the present nose of the Victoria there extends across the valley and up obliquely upon the west side, an ancient moraine, composed of massive blocks of sandstone, quartzite and schist; lichen covered and partially disintegrated. There is a surprising scarcity of fine material except from the soil formation, in situ, which has given rise to a scanty growth of trees and shrubs. The material is arranged in two main heaps, one upon either side of the valley with a break between through which the glacial brook escapes. The blocks of stone are angular, practically unglaciated and show no signs of stream action. From 200 to 1,000 ft. farther down the valley a similar, but much more massive moraine, reaches

across the valley with a break at the center, most of the blocks being accumulated upon the western side where they attain a height of 40 to 50 ft. (pls. LXV, *b*, LXVI, *a*). These blocks are mainly quartzite, are dark and lichen covered and have but slightly disintegrated. Whatever fine material may exist it is entirely overshadowed by the massive blocks thrown tumultuously together. The largest one

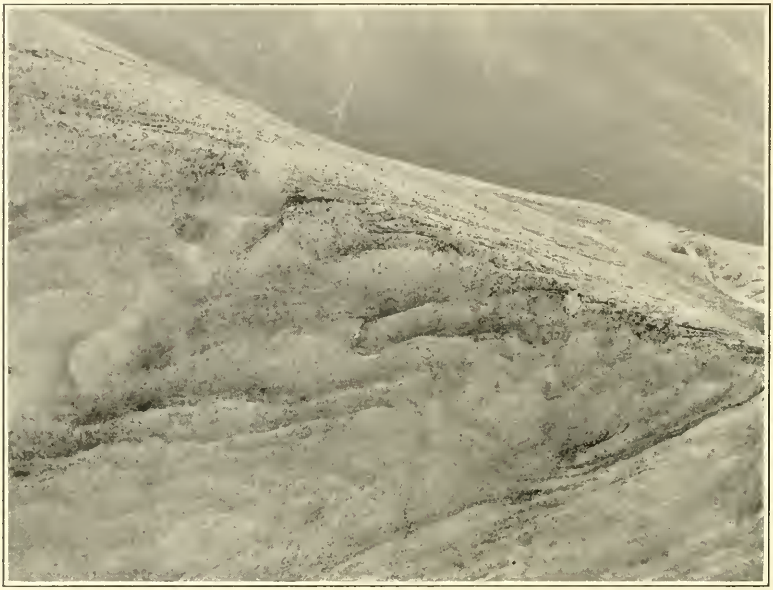


FIG. 78.—Contorted laminæ, Wapta glacier.

observed split in falling and must have originally weighed about 970 tons. These also show only rarely signs of glaciation and were carried either *on* or *in* the ice and were not carried, or pushed along beneath it. Those blocks upon the eastern side of the valley came from Aberdeen, the Mitre and Lefroy; those upon the western side were derived mainly from Victoria. The central part of the glacier was not so heavily laden as the sides. No matter how long the ice front should now halt it would be incapable of forming such a moraine. One-quarter mile still farther down the valley there is a double detrital cone which partially covers a triple moraine, composed of fine and coarse material, with some till and not differing essentially from what is being formed at the present stage of the glacier (fig. 79). There was a time between the formation of this moraine and the present stage when the glaciers occupying the head

a. Quartzite blocks of old Victoria moraine

b Front of Wenkchemna glacier, showing a recent encroachment upon the forest

of the valley carried a different kind of load, presumably acquired in a different manner. The rings of growth in the spruce and fir of the Lake Louise region were found to average .884 mm. in thickness, with a range of .51 to 1.26 mm. in individual trees. The largest tree found growing upon the younger of the two block moraines gave a circumference of 221 cm. at a distance of 50 cm. from the base and should be approximately 400 years old. The largest spruce observed upon the older should be about 450 years old, while one just on the outer edge must be approximately 580 years of age. The last rings are added with extreme slowness owing to the

FIG. 79.—Brook from Victoria glacier cascading over an old moraine and double detrital cone.

relative reduction in leaf surface as the trees grow older, combined with the short growing season, the small amount of precipitation and the various disadvantages attendant upon having to live in a valley and especially one with a general north-south trend.

II. WENKCHEMNA GLACIER

1. *General Data.*—Nestling close in behind the northern base of that grand array of peaks for which the Canadian Geographic Board has recently adopted the name Wenkchemna Group, lies the Wenkchemna glacier. It occupies the southern half of the upper third of the Valley of the Ten Peaks, facing north while the valley itself

slopes east and then northeast. It is reached most conveniently from Laggan, via Lake Louise and Moraine Lake, at which place the Canadian Pacific Railway maintains a camp during the summer, located two miles from the glacier. The glacier is of peculiar shape, having a breadth of two miles and a length of one-half to one mile, presenting a total frontage of nearly three miles (pl. LXVII). It is fed by the snows which fall to the eastward of the continental divide, not differing greatly in amount from that of the neighboring Lake Louise valley, but there is no extensive collecting area, a small nevé

Deltaform. Hungabee.

FIG. 80.—Debris covered surface of Wenkchemna glacier.

field and a correspondingly small amount of ice supplied the glacier. It has survived probably only because the surface and front are so heavily veneered with rock debris (fig. 80), from the nearly vertical cliffs at the back, that it is difficult to catch a glimpse of the ice. The peak of Deltaform, the highest crest of the Divide just here, is 10,945 ft. A. T., but the glacier itself lies mainly between 8,000 and 6,000 ft., according to the maps of Messrs. Wheeler and Wilcox.

2. *Piedmont Type.*—A general survey of the surface of the glacier shows that it is formed by the lateral coalescence of ten to twelve ice streams, each of which maintains its identity, more or less perfectly, from its origin to its nose and is separated from its neighbor

Moraine Lake

Deltaform

WENKCHEMNA GLACIER, A PIEDMONT TYPE. THE WENKCHEMNA GROUP OF PEAKS CONSTITUTES HERE THE GREAT CONTINENTAL DIVIDE

Photographed in 1903 from Mt. Temple by Arthur O. Wheeler, Canadian Topographic Survey

by a medial moraine. This is the piedmont type of glacier, only one other—the Malaspina—having thus far been described, which accounts for the peculiar form and behavior of this ice body. The component streams at the eastern and lower side are longer, better defined and flow northward, at right angles to the rocky wall in the rear. Toward the west they are deflected to the right and are less well defined because of the steep inclination of the valley floor and the interposition of a tremendous block moraine, too massive to be pushed aside.

3. *Frontal Changes.*—Attention has been called by George and William Vaux to the fact that portions of this glacier are encroaching upon the forest which skirts its front for a considerable distance, but no data have been available for determining the rate of advance. Dead trunks, from which the bark has fallen, are seen projecting from near the edge of the frontal slope (pl. LXVI, *b*), some of which were probably killed by a forest fire which swept through the valley 70 to 80 years ago. Other trees in similar position and condition still retain their dead boughs, without any evidence of fire, and seem to have been killed by the ice advance some years ago, since which time the glacier has advanced its frontal slope less than a dozen feet. This would indicate a very sluggish condition of the ice. In order to get something more definite by the close of the season, as well as for future reference, a series of eight sets of reference blocks was established, between which accurate measurements were taken with a steel tape. From August 9 to September 12, an interval of 34 days, no movement whatever had occurred at a point just east of the discharge brook. Passing westward along the front and up the valley, the next two stations showed a retreat of 1.2 and .7 in., due to the wastage of the ice beneath. The next two stations gave an advance of 1.9 in. and 1.3 in. The glacier was found to be again wasting away slowly as indicated at the next two stations by a retreat of 1.0 in. and 5.0 in. At the last station, nearly opposite Deltaform, a more marked advance had occurred, from August 14 to September 12, amounting to 14 in. Occasional rocks were here rolling down the frontal slope, giving evidence of activity beneath, and freshly cut trees were observed about this particular nose. It is thus seen that in glacial streams lying side by side, nearly their entire length, some are stationary, some in slow retreat and others advancing; a dozen different factors, at least determining in what way any particular stream will behave.

4. *Drainage.*—At the eastern and lowest side of the glacier there issues from beneath the frontal moraine a stream of perfectly clear

water (fig. 81) which seems to fluctuate but little during the day, or from day to day. The volume was estimated at about 90 cu. ft. a second and its temperature, during all hours of the day, ranged from 35° to 36° F. Less than a mile below, this stream enters Moraine Lake (pl. LXVII) where there is not even the suggestion of a delta, showing that the glacier is not only not eroding its bed now but that it has not done so for centuries. The temperature of the water and

FIG. 81.—Drainage stream from Wenkchemna glacier.

the regularity of its flow indicates that it is derived, to a considerable extent, from some source other than that of the melting of the glacier itself, such as the small side streams which enter the glacier and the drainage from Wenkchemna Lake (fig. 83). It is evident from the above data that we have here an exceptionally indifferent mass of ice and can understand how a glacier of such magnitude may be maintained by such a relatively small nevé area. The key to the situation is the high wall-like cliff which here has an east-west trend, entirely across the glacier, which not only shields the nevé and adjacent glacier directly from the sun but supplies it liberally and uniformly with a rock mantle for its further protection.

FIG. 82.—Ancient Wenkchemna moraine serving as a dam for Moraine lake.

FIG. 83.—Great block-moraine, Wenkchemna glacier, enclosing Wenkchemna lake.

5. *Lake Barrier.*—Entering the Valley of the Ten Peaks from the Bow valley and passing Moraine Lake, one encounters a somewhat puzzling morainic feature from which the lake has derived its pres-

ent name. This consists of a sharply defined heap of rock debris, about 400 ft. long, placed at right angles to the main axis of the valley and serving as a barrier (fig. 82). The lake has a double outlet, one across either end of this moraine, since with its flow divided, short season and no sediment, it can accomplish almost nothing in the way of deepening either outlet. The moraine increases in height, rather gradually toward the west, attaining a height of about 70 ft. and then ends abruptly, with no trace of a continuance across the valley. This feature has led some to consider the entire mass as a rock slide from the adjoining mountain slope. It is, however, a moraine such as a piedmont type of glacier is capable of making. This represents the place of halt of the front of the most eastern component stream of the Wenkchemna glacier at an earlier stage, the adjoining stream to the west reaching farther down the valley and, very probably, making a correlative moraine. The western end of this barrier moraine, while it was being formed, abutted against a solid ice wall, the removal of which by later melting allowed the debris to assume the "angle of repose." At the present time the easternmost component stream of the glacier is still relatively short compared with its neighbor and were the front to make a sufficiently prolonged halt there might be reproduced this same type of moraine.

6. *Block Moraine.*—Along the western front of the Wenkchemna glacier, for a distance of over a mile, there occurs a tremendous accumulation of huge morainic blocks of a red and brown sandstone, much disintegrated by the weather, but each roughly maintaining its own shape and size (pl. LXVIII, *a*). Near the upper end of the valley it must be a half mile across, reaching from the present ice margin to the foot of Pinnacle Mountain and surrounding the Wenkchemna Lake (fig. 83). Toward the east the moraine narrows up and an apparently older portion is soil-covered and forested. Nearly opposite Deltaform there is an accumulation of coarse, lichen-covered blocks at the edge of the ice, apparently part of a massive moraine which is overridden by the eastern half of the glacier. At the western side the ice has not been able either to mount this obstruction, or to push it ahead, and has been deflected down the valley, as previously noted. At an earlier stage the glacier must have extended quite across the valley and have been carrying a tremendous load of fragments of the peaks to the south. The formation of the moraine began, with which the ice continued in close touch, being unable to either override, or push it ahead, and there resulted a continuous deposit for a half mile, but with relatively little height.

a. Disintegrated sandstone blocks of old Wenkchemna moraine

b. Wapta glacier head of Yoho valley

Photographed by De Forrest Ross, Aug., 1904

Special attention was not given to the question of the *dual* character of this deposit but the writer's general impression is that the outer and lower portions are distinctly older, maintaining a heavy growth of lichens, some shrubs and larches. That portion of the moraine lying between Wenkchemna Lake and the present ice front has only a scanty growth of lichens and no herbs, shrubs or trees. It is possible that this morainic deposit is to be correlated with the two block moraines found in the Victoria valley, but of greater amount because of the better facilities for acquiring such a load and the greater friability of the bulk of the rock. The Wenkchemna at the present time is incapable of making such a moraine.

III. Wapta Glacier

1. *General Data.*—This great glacier, the largest of the series studied and known only since 1897, lies at the head of the Yoho valley and is easily reached from Field, via Emerald Lake. A day's trip, over a fairly good trail, up a most picturesque valley which is in the same class as the Lauterbrunnen and Yosemite, brings one to the summer camp maintained by the Canadian Pacific Railway. The glacier lies 3 to 4 miles beyond and with its great size and freedom from debris better meets the popular idea of what a glacier should look like (pl. LXVIII, *b*). Its nevé is collected in the depression surrounded by Mts. Habel, Collie, Baker and Gordon, and is a part of the great Waputehk Snow Field, lying just to the west of the continental divide. The ice cascades into the valley and, according to Habel, reaches an altitude of 5,680 ft., some 300 to 400 ft. lower than the Victoria and Wenkchemna, because of the greater volume. This increased volume of the Wapta results from the somewhat greater precipitation, probably equivalent to 30 ft. of snow, but mainly from the greatly increased size of the catchment basin. The main body of the glacier is much crevassed and impracticable for crossing, but the lower tongue has a fairly regular slope of 20 to 25° and, by cutting a few steps upon the western side, may be safely traversed. Upon the eastern side of the glacier there arises an embossment of rock, partially forested with spruce and fir, about which the glacier has built a sharply crested moraine. At a former stage of glaciation this embossment was completely overridden by the ice; later it was simply surrounded—a rock island in an ice stream—to which the term "nunatak" is applicable.

2. *Ice Distributary.*—Between 200 and 300 years ago the relatively narrow arm of ice which passed around this nunatak to the east separated from the main stream at its lower end and formed a minor

ice tongue, which has since been in slow but nearly steady retreat, wasting at the end, the surface and eastern side (pl. LXIX, *a*). The lower portion is so smooth and free from crevasses that three distinct drainage areas have been developed, two marginal and a central one, which possess large numbers of surface streams through which is conducted the water resulting from the melting of the ice and that which falls upon the surface as rain. The central area has

FIG. 84.—Three hundred-foot archway, Wapta glacier, from which issues the North Branch of the Kicking Horse. Photographed by De Forrest Ross.

developed a single trunk stream which passes lengthwise of the tongue, eroding a relatively large channel in the ice and delivering its waters to the glacial brook at the nose. The ice closely hugs the nunatak which it has been glaciating and "plucking."

3. *Drainage.*—Since its discovery the Wapta has maintained, just west of its nose, a great archway of ice, with a span of 250 ft. and height of perhaps 70 ft. (fig. 84). Through this there issues from the glacier the North Branch of the Kicking Horse, a rapid but shallow stream 240 ft. broad. This stream represents the wastage

a. Side branch of Wapta glacier, a kind of ice "distributary"

Sir Donald Mt. Bonney

b. General survey of peaks and snow fields from Roger's Peak, looking southeast Selkirks
Photographed by Arthur O. Wheeler, 1902. Canadian Topographic Survey

from the glacier itself, from its distributary and the drainage from the adjoining valleys. Its water is somewhat turbid, but not so much so as that which issues from the Victoria, and its temperature in mid-August averaged 34.25° F., varying a degree in either direction. During the summer a crevasse opens across the arch, permitting the ice to incline forward until it collapses finally and lies a heap of azure ruins until removed by water and sun.

4. *Ice Retreat.*—The nose of the glacier lies just east of the archway and rests upon bedrock. In August, 1901, independent marks were established by Miss Vaux and H. W. DuBois, from the former of which it was found that the ice here has retreated 111 ft. in three years, or at an average rate of 37 ft. a year. This measurement was made to the glacier itself and not to the detached block which has been the nose. Measured to this block the distance was 92.1 ft., giving an average of nearly 31 ft. a year, with a retreat of 23 ft. for the year 1903-4. The glacier seems to have been steadily retreating for a number of years, so far as may be judged from the weak development of terminal moraine. It should be noted, however, that even a considerable halt could produce only an inconsiderable moraine because of the small amount of debris carried.

Between the nose of the glacier and its distributary, upon the eastern valley slope, there occurs an interesting ridge of tree trunks, resting upon a slight morainic ridge and parallel with the present margin of the ice. It lies about 260 ft. up the slope and represents the work of an avalanche against the side of the ice when it occupied this position. The oldest living trees found in the path of this avalanche gave 47 rings of growth. This avalanche probably occurred between 1850 and 1860, since which time the side of the glacier has been retreating down the slope at the average rate of between five and six feet a year.

5. *Modified Moraine.*—Some 800 ft. down from the present nose of the Wapta there occurs a peculiar group of low knolls and crescentic ridges, lying to the east of the drainage stream, and connected with the weak, left lateral by faint ridges. Six concentric series may be made out, the ridges having their convexities directed down stream (fig. 85), diminishing in height and distinctness toward the glacier. These ridges vary in height from one to 12 ft. and the longest is in the form of a semi-circumference with a radius of 20 ft. They all possess the smoothed, rounded outlines of drumlins, but lack their profile and arrangement. They consist of a core of ground morainic material with a thin dressing of sand and gravel. They have apparently been produced about the nose of the glacier,

the ice getting a *purchase* upon the thin covering of ground moraine and by a series of minor advances and retreats pushing it up into concentric ridges and detached knolls. Later a more general advance permitted the ice to override the structures, but so lightly that they were simply smoothed and rounded without being completely destroyed, and the surface dressing of sand and gravel was applied

FIG. 85.—A suggestion of Wisconsin-morainic topography; in front of Wapta glacier.

as the ice finally retreated. In miniature, with their smooth contours and undrained basins, they strongly remind one of the morainic topography left by the latest ice sheet in America and Europe.

6. *Glacial Granules.*—In both the Wapta and Illecillewaet glaciers, on account of their size, unusually good material is to be obtained for the study of the granules, of which the glacier from its nevé to its nose is known to be composed. About the lower end of the Wapta these granules range from 5 to 70 mm. in maximum diameter and seem to average between 20 and 30 mm., becoming gradually smaller towards the nevé. These granules are irregular polyhedrons with their faces so firmly pressed together in general that no interspaces occur and the ice appears homogeneous and of uniform color.

Thin sections of such ice, however, when examined with the polariscope, reveal the component granules and each is seen to be a single, although incomplete crystal, giving the ice mass the appearance of very coarse marble. Sections cut in various directions from the ice near the nose of the Wapta, Illecillewaet, Asulkan and Victoria glaciers, showed a tendency toward a vertical arrangement of the principal optic axis. In *horizontal* sections of such ice from one-fourth to one-third of the granules remained dark when revolved

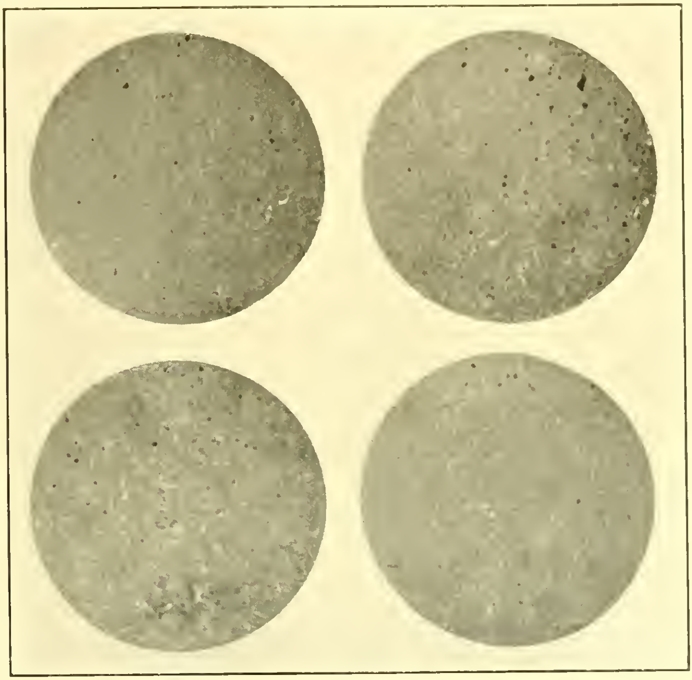


FIG. 86.—Glacier capillaries, uninjected. Wapta.

in the polariscope. From this it was concluded that there exists a tendency towards orientation of the granules, which has been affirmed by some and denied by others.

7. *Capillary Structure.*—Glacial ice which has not yet begun to melt either externally or internally is solid and firm and contains simply the air cavities enclosed in the processes of granular growth. Such ice is not penetrated by water, or colored solutions, except to very slight extent. When internal melting begins there is opened up a more or less continuous network of delicate capillaries, situated at the lines of junction of three, or more, granules. These are cir-

cular in cross-section and, judging from the way water passes along them, quite free from air. Their walls reflect the light strongly and give the appearance of a network of silver threads, more or less perfectly outlining the granules. From beneath the ice it was possible to get limited areas of them upon a photographic plate and these are reproduced in fig. 86. By using a strong solution of potassium permanganate it was found that they could be beautifully injected, the solution entering the ice in a few minutes to a depth of several feet. Such injected capillaries from the Illecillewaet glacier are

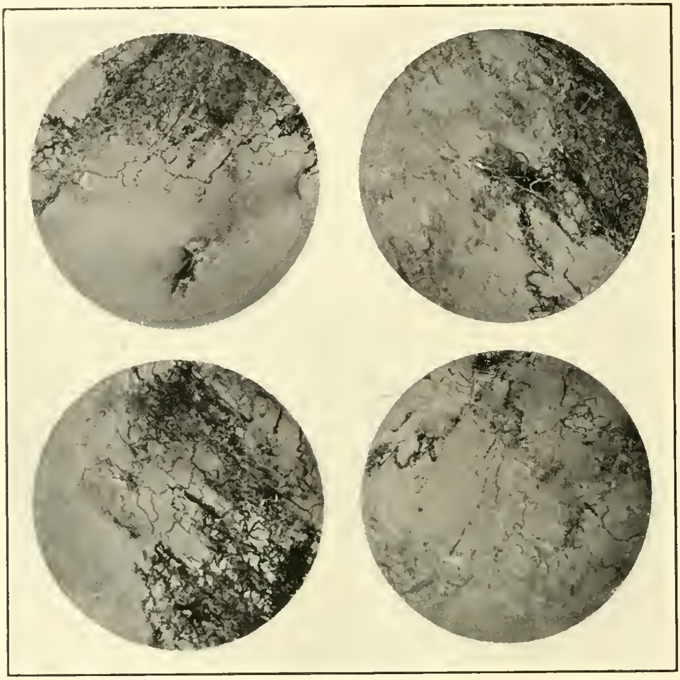


FIG. 87.—Glacier capillaries, injected. Illecillewaet.

shown in fig. 87. Upon the faces of crevasse walls and ice caves these tubes are frequently seen in longitudinal section, forming a pattern by which the granules are outlined. As melting proceeds, within the ice, the capillaries become irregular and crinkly, spaces are opened up between the adjoining faces of neighboring granules, and the original network becomes obliterated. With this increased reflecting surface the beautiful blue color of the ice gives way to white and in places causes it to again resemble the nevé. A small amount of pressure now, or a blow, will cause the ice to crumble into its component granules, the surfaces of which are seen to be covered with a system of fine ridges and rows of points, about 1 mm. apart and resembling, more than anything else, the markings upon the ball of one's thumb. Internal melting of the granule gives rise to the "Tyndall melting figures," originally figured by Agassiz and described by him as flattened air bubbles.

8. *Extensive Plucking.*—A peak, as yet unnamed, lying between the nose of the glacier and Mt. Balfour, is made up of a succession of curved, concentric strata, the upper of which are a dark limestone, dipping to the southwest at an angle of about 30°. This peak

FIG. 88.—A "plucked" mountain peak, head of Yoho valley.

was overridden by ice moving from the north, which ripped off bodily the strata, leaving the more resistant portions, overlapping and projecting (fig. 88). Upon the upper surfaces and upon either side of these remnants the disrupted blocks were completely removed, but in their lee they accumulated as shown in the figure. Evidently the entire mountain peak has been reduced in height to a considerable, but unknown amount, by the process of "plucking."

9. *Block Moraines.*—Not realizing at the time the significance of this type of moraine, no special study was made of them in the Yoho valley. Two massive ridges are crossed but they are soil covered and forested and their real nature was not investigated for lack of time. They may be mountain spurs or rock slides, but are more probably moraines; rather too old, apparently to be correlated with the block moraines previously described. If they are not really

present in this valley their absence may be satisfactorily accounted for by noting the scarcity of rocky cliffs from which the blocks might have been derived.

IV. Illecillewaet Glacier

1. *General Characteristics.*—Passing from the Rockies to the Selkirks, the next chain to the west, there are marked evidences of the increased precipitation. The mountains are more completely forested and less rugged and the extensive snowfields send down hundreds of ice tongues which reach a considerably lower altitude

Fig. 89.—General view Illecillewaet glacier, Sept., 1904.

than in the Rockies. The glacier in the two Americas which has been visited by more people than any other is the Illecillewaet, reached in a half hour, over a good trail from Glacier House. It is fed by a snow-ice field covering from five to six square miles, lying to the south of Mt. Sir Donald and having an elevation of 8,000 to 9,000 ft. (pl. LXIX, *b*). The lowest part of the rim of this collecting basin is upon the north side and through this the ice spills over and cascades into the valley, forming innumerable crevasses and seracs, and reaching an altitude of 4,800 ft. General maps of the region have been made by Green, Bell-Smith and Wheeler and large scale maps of the lower extremity by the Vaux Bros. and Penck, but no

ILLECILLEWAET GLACIER, 1888.

Photograph by Notman and Son, Montreal.

ILLECILLEWAET GLACIER, 1904. FROM SAME VIEW POINT AS PLATE LXX

detailed map, or general description, of the entire glacier has yet been prepared. In the size of its collecting area, freedom from debris, and crevassed condition it is similar to the Wapta, and like it has been in steady retreat for a number of years (fig. 89).

2. *Ice Retreat.*—For some years previous to 1887 the Illecillewaet was stationary and engaged in building a small frontal moraine. In 1887 the front was photographed by the Vaux Bros. and its position

FIG. 90.—Rôche moutonnée, Illecillewaet glacier.

with reference to a massive block definitely determined. One year later it was photographed by Notman and Son, as well as others, as it was starting to withdraw from the moraine (pl. LXX). Since this retreat began numerous reference blocks have been established and the rate determined from time to time and published. The rate of retreat has thus been found to vary according to the season. In the entire 17 years the ice front has receded 603.5 ft., measured horizontally, or at an average rate of 35.5 ft. a year; the recession for the past year being but 11 ft. when measured to the nose which has shifted to the west (pl. LXXI). The ground moraine thus exposed constitutes a "boulder pavement," the boulders at the last having been so lightly ridden by the ice that they were slightly striated, without being disturbed. Beneath the margin of the ice the boulders are seen to produce flutings upon its underside, some of these extending 70 to 80 ft. beyond the boulder by which they have been produced. The melting about the nose and sides of the glacier concentrates the relatively small amount of dirt enclosed in the ice. This was found to contain about 14 per cent. organic matter, enough to make it dark colored and to give it an offensive odor when set away moist in a warm room. For several years back the glacier has been uncovering a mass of bed-rock upon the west side.

FIG. 91.—Block-moraine made conjointly by the Illecillewaet and Asulkan glaciers. Strewn with avalanched timber.

This is a quartz schist with beds of coarse conglomerate and here are to be seen good examples of polishing, scratching, rôches moutonnées (fig. 90), lee and stoss phenomena, plucking, chatter-marks, knobs and trails, basins and troughs.

3. *Block Moraines.*—Some 1,400 ft. from the present nose of the glacier there extends across the valley an ancient moraine, about 400 ft. broad, made up of massive blocks of quartzite. These blocks are blackened with lichens and carry enough soil to support trees of considerable size. A cut spruce with a circumference of 128 cm. gave 243 rings of growth. A hemlock near at hand has a circum-

ference of 320 cm. and, by calculation, should be 447 years of age. About one-third of a mile farther down the valley, where the Asulkan and Illecillewaet valleys meet, a still more massive moraine of this same type is seen. The blocks are very coarse, scarcely any fine material showing, and consist almost entirely of quartzite, the largest seen being estimated to weigh 1,250 tons. The moraine swings out from the base of Glacier Crest, obliquely across the valley, from 200 to 300 ft. across and from 60 to 70 ft. above the valley floor, most of the material being concentrated upon the west side of the stream. The blocks are blackened with lichens, but have disintegrated so little that the moraine supports only a scanty growth of timber and shrubs (fig. 91). Upon its eastern side it is nearly covered with shattered tree trunks which were swept down from the side of Mt. Eagle by an avalanch, showing one way in which soil may be acquired by such a moraine. The largest tree found growing between this moraine and the preceding was estimated to have been 520 years old when it died and, from the condition of the wood and bark, to have been dead about 30 years, giving a total of about 550 years.

V. Asulkan Glacier

1. *General Characteristics.*—This glacier, or rather two glaciers, to which the name has been applied, lies at the head of the Asulkan valley, some five miles from Glacier House. The nevé region lies between the Dome, Castor and Pollux and Leda upon the west and the Asulkan Range upon the east, separating it from the Illecillewaet nevé (pl. LXXII). The mass of ice supplied is considerably less than in the preceding glacier and the main ice stream reaches an altitude only of about 5,600 ft., the nevé lying between 7,000 and 8,000 ft. Portions of this nevé are beautifully stratified. The inclination of the bed seems quite regular and in only one or two places is the ice badly shattered by irregularities. Toward the nose the inclination of the surface is quite gentle, only about 6°, increasing finally to 25°. The glacier is transporting comparatively little material at the present time, but has sharply crested lateral moraines, with cores of stagnant ice.

2. *Frontal Changes.*—Points of reference for the study of the frontal movements of the main Asulkan stream were established August 12, 1899, by George and William Vaux. Last year, September 17, 1903, the nose had pushed 13½ ft. beyond this line, plowing into the ground moraine and overturning boulders. One of the stones marked by the Vaux Bros. had evidently been pushed forward some 14 to 15 ft. Upon August 27, 1904, the nose was 12½ ft.

beyond the Vaux line and still plowing into ground moraine, indicating a very slight change for the entire year.

3. *Drainage.*—The drainage from the two ice streams is not strong, but more turbid than either the Illecillewaet or the Wapta, indicating a greater relative amount of subglacial erosion. From the main Asulkan two streams issue, one upon either side of the nose, fluctuating some from day to day and during the day itself. This fact, as well as the temperatures averaging 32.7° F. and 32.2°

FIG. 92.—Left Asulkan moraine shedding its rocky covering and exposing the ice core. East side.

F., would indicate that this water is derived almost entirely from the melting of the ice.

4. *Morainic Core.*—It is difficult for the ordinary visitor to believe that the high, sharply crested embankments, lying parallel with the main axis or sides of the glacier, are in reality *ice* ridges with only a comparatively thin dressing of rock fragments. The left lateral of the Asulkan is showing, in a most interesting manner, the real structure of such a moraine and the passage from a single ridge into a double one. About a quarter of a mile back from its lower end it begins to shed its rock cover, the debris sliding down and forming a ridge upon either side. The eastern side is not completely

Mt Donkin and Asulkan Pass Leda Pollux Castor

GENERAL VIEW OF ASULKAN GLACIERS AND SNOW FIELDS

bare (fig. 92), but the western side is entirely so and we see an ice ride 25 to 30 ft. in height (fig. 93). This exposure of the ice permits its rapid melting, even below the level of the ice upon which the two ridges are now resting and instead of the ice ridge we find farther down the valley a depression, with a small morainic ridge upon either side.

5. *Block Moraines.*—From the outermost of the two block moraines of the Illecillewaet there curves across the mouth of the Asulkan valley a similar type of moraine, made up of identical blocks in the same condition. From their position it is evident, as pointed

FIG. 93.—Left Asulkan moraine shedding its rocky covering and exposing the ice core. West side.

out by Penck, that the Asulkan glacier operated conjointly and simultaneously with the Illecillewaet. The bulk of the material is deposited upon the eastern side of the valley and appears to have been derived mainly from Glacier Crest, Lookout Mountain and the Asulkan Range. In retreating up its relatively narrow valley, instead of a single prolonged halt, it made two or three minor ones and built coarse moraines, at the same time distributing coarse material along the valley floor.

6. *Rate of Retreat.*—From an examination of a number of trees, of the different varieties found in the Asulkan and Illecillewaet valleys, it was found that the average breadth of an annual ring of

growth is here 1.14 mm., as compared with .884 mm. in the Lake Louise valley. Some exceptionally large spruces and hemlocks are found at the entrance to the Asulkan valley, two of which, by calculation, appear to be 525 and 598 years of age. Toward the head of the valley the trees become smaller and younger and the rings of growth somewhat coarser. It is about two miles from these trees up to where the Asulkan brook enters the narrow valley and has excavated some 30 to 40 ft. of schist since the retreat of the glacier. One of the largest firs here shows 161 rings of growth and a still larger hemlock near is not far from 250 years of age. So far as such data can be depended upon, it would seem that the Asulkan withdrew up this portion of the valley in about 350 years and at an average rate of 30 ft. a year. From the schist cut to the present nose of the glacier the valley opens and for this quarter mile the rate would presumably be less, perhaps not more than one-half or one-third as great, owing to the greater mass of ice to be melted away. Similarly the retreat from the outermost block moraine into the narrower portion of the valley would also probably be slow.

VI. Significance of the Block Moraines

Since this entire report is simply a summary of the most important observations made no resumé in closing need be attempted. It is desired, however, to point out here what seems to the writer, in his present state of knowledge, to be the significance and importance of this special variety of terminal moraine. While in the field they were a perplexing puzzle and not until the snow-clad Rockies had disappeared upon the western horizon did even a plausible explanation present itself. The theory of their formation will need to be tested by observations in many of the valleys adjoining those studied. As has been pointed out they are made up of very coarse fragments of the surrounding cliffs and peaks, the actual size of which is not so remarkable, knowing what a transporting agent a glacier is, as the *average* size of the fragments composing the moraine. The finer materials, commonly present in a terminal moraine, are completely overshadowed by these massive blocks and such fine material was apparently not present from the first. These blocks were carried on or in the ice, not beneath nor pushed ahead and appear to be in a double series in four of the five glaciers selected for study. None of the glaciers observed could now make such a moraine, no matter how prolonged the halt. Periods of excessive weathering would certainly load the glacier with much fine, as well as coarse material. The prevalence of the phenomenon prevents our resorting to the rock slide for an explanation. Proceeding thus by a process of elimination the conclusion seems forced upon us that there is here evidence of a double seismic disturbance of the entire region. Coarse fragments, more or less weathered to start with, were shaken loose from the overtowering cliffs and peaks and dropping into the nevé, or upon the ice, were not ground into fragments as they ordinarily are when they descend into the valley. The protection afforded the ice by this material brought about a halt in the frontal retreat then in progress and the blocks were concentrated into two moraines more or less separated. As soon as the bulk of the material, resulting from each disturbance, had been deposited the glacier then resumed its slow retreat.

If this is the correct explanation then it may be predicted that glaciers favorably situated for receiving such loads, as the Dawson, Geikie and many others, will show similar block moraines, providing they have not been overridden, or destroyed by later advances of the ice, as is partially true in the case of the Wenkchemna. Remnants of ice streams, which at the time of the disturbances were tributary to other main trunks, would in no case have independent moraines of such a type. Neglecting the differences in the time of transportation, due to the varying velocities of the several glaciers as well as the different distances that the material must be transported, these moraines in the various valleys may be correlated in time. If the approximate age of any one set can be determined we shall have the data for estimating the average rate of recession of all those glaciers having such moraines, as well as ascertaining the approximate date of the seismic disturbances. The oldest trees found growing upon the younger of the two moraines in the Illecillewaet and Lake Louise valleys are 447 and 400 years of age respectively. In the Asulkan valley a rough estimate would be obtained by adding to 250 years, the time required for the glacier to retreat about 1¾ miles at the average rate of 30 ft. a year. This would give about 560 years, the excess over the preceding estimates probably being required for the formation of sufficient soil to allow the trees to start their growth upon such coarse moraines. The younger of the two block moraines may be regarded as between 500 and 600 years old and, allowing for the transportation of the material, the earthquake, if such really occurred, probably happened during the thirteenth century. The outer moraine is probably 150 to 200 years older than this inner.

Through the kindness of Mr. Frank B. Taylor the writer's attention was called to a rather remarkable earthquake which seems to have severely affected Canada and the adjoining portions of the United States in 1663.

It is described in the Jesuit Relations,[1] and in spite of the apparent exaggeration and superstition there seems to have been wrought widespread geological changes, many times greater than would have been needed to load the glaciers with their rocky burden. The following quotations will serve to show the severity of the disturbance which continued from February until August.

"On the fifth of February, 1663, toward half past five in the evening, a loud roaring was heard at the same time throughout the length and breadth of Canadas."

"According to the report of many of our Frenchmen and Savages, who were eye-witnesses, far up on our River, the Three Rivers, five or six leagues from here, the banks bordering the Stream on each side, and formerly of a prodigious height, were leveled—being removed from their foundations, and uprooted to the water's level. These two mountains, with all their forests, thus overturned into the River, formed there a mighty dike which forced that stream to change its bed, and to spread over great plains recently discovered."

"New Lakes are seen where there were none before; certain Mountains are seen no more, having been swallowed up; a number of rapids have been leveled, a number of Rivers have disappeared; the Earth was rent in many places, and it has opened chasms whose depths cannot be sounded."

"On level ground, hills have arisen; Mountains, on the other hand, have been depressed and flattened. Chasms of wonderful depth, exhaling a foul stench, have been hollowed out in many places. Plains lie open, far and wide, where there were formerly very dense and lofty forests. Cliffs, although not quite leveled with the soil, have been shattered and overturned."

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[1] Thwaite's Translations, Vol. XLVII; pp. 37–57; 183–223.