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(With Twelve Plates)

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LYELL GLACIER

The first glacier of the Canadian Rockies to be described with detailed accuracy was the Lyell, discovered by Dr. Hector, of the Palliser expedition, in 1858. His description enables one today to judge with a fair degree of certainty the condition of the ice at that time, its extent, and the alterations which it has undergone during the years intervening. It is the oldest record that we possess concerning a glacier of the North Saskatchewan system and, within limits, the deductions made from it may be applied to other ice-streams of that region.

Encamped in the valley of Glacier Lake, Dr. Hector wrote [1] of the present Southeast Lyell glacier as follows:

> After crossing shingle flats for about a mile, we reached a high moraine of perfectly loose and unconsolidated materials, which completely occupies the breadth of the valley, about 100 yards in advance of the glacier. Scrambling to the top of this we found that to our left a narrow chasm, with perpendicular walls, brought down a stream from a glacier, descending by a lateral valley from the south,[2] but that the greater bulk of the water that formed the river issued from ice caves that were hollowed out beneath the great glacier of the main valley. By rough triangulation, I found that the width of the terminal portion of the glacier in view from this point was 550 yards . . . . we followed round the lower end of the glacier, having to wade through several streams issuing from below the ice, till we found the surface forming a uniform slope unbroken by crevasses. This was immediately beyond a point where a great longitudinal fissure seemed to divide the glacier into two halves up the centre of the valley; that portion to our left being pure ice much crevassed, but free from dirt on the surface; while to our right the surface we now ascended was less steep, smooth, and unbroken, but so discolored by foreign matters, that at a little distance it might have passed for a talus of rocky fragments. . . . . I now saw that the glacier I was upon was a mere extension of a great mass of ice that enveloped the higher mountains to the west, being supplied partly through a narrow spout-like ice cascade in the upper part of the valley, and

[1] Journals, Detailed Reports, and Observations relative to the Exploration of British North America, p. 110. Captain John Palliser. Folio. London, 1860.

[2] The present Mons glacier.

partly by the *resolidifying* of the fragments of the upper *Mer de Glace,* falling over a precipice several hundred feet in height, to the brink of which it is gradually pushed forward. A longitudinal crack divides the glacier throughout nearly its entire length,[1] sharply defining the ice that has squeezed through the narrow chasm, from that portion of the glacier that has been formed from the fallen fragments, the former being clear and pure, while the latter is fouled from much débris resting on its surface, and mixed in its substance. The more rapid melting of the dirty portion of the glacier[2] gives it a smooth undulating surface, which is much lower than the adjoining surface of the pure ice, which beside is much cut by crevasses and ice valleys, through which flow considerable streams, that often disappear into profound chasms. . . . . The ice was beautifully veined in some parts, and the streaks were often contorted in a manner exactly like the foliation in metamorphic rocks.[3] The precipice at the head of the valley stretches for more than two-thirds its width; the remainder is occupied by the ice cascade. The blue pinnacles of ice, tottering over the edge of the cliff, were very striking, and it was the noise of these falling which we had mistaken for thunder a few days before when many miles down the valley.

The present writer spent the period July 4-14, 1926, in making mountain ascents from the valley of Glacier Lake, devoting a portion of that time to observations of the glacier.

It has apparently changed but little since Dr. Hector's time. A huge rock promontory[4]—Gibraltar in miniature—rises from the gravel flats just below the ice terminus. Near its eastern timbered extremity it is split by the narrow cleft which Dr. Hector noticed, now containing a stream of clear water, but giving evidence that at no remote period it served as an outflow for the Mons glacier, lying in the adjacent southern valley. At one time, before Dr. Hector's day, the Mons and Lyell tongues were united, and swept over part of the great rock promontory, a portion of the stream following its present course directly into the main valley, while a smaller volume escaped through the narrow canyon at the eastern end of the promontory (pls. 1 and 2).

From Dr. Hector's description, and the size of the trees on the terminal moraine, one would judge that this moraine was formed at least

[1] This crack or fissure was not seen by us, although the pressure ridge forms a definite line of division between the clear and the dirt-covered ice.

[2] Dr. Hector fell into error on this point, probably because the dirt-covered ice was lower than the clear ice. Dirty ice normally melts more slowly than clear ice owing to the dirt cover absorbing the heat.

[3] Professor James D. Forbes had first pointed out this veined structure to Agassiz, on the Aar glacier, in 1841, seventeen years previously. It is not unlikely that Dr. Hector was familiar with the work of Forbes, as this was the period when glaciers were first studied intensively.

[4] Lake Moraine (5,116 feet), Station No. 65 of the Interprovincial Survey.

200 years ago. It forms a barrier, averaging 25 feet in height, across the main valley, and is cut through nearly at the center by the river. The Lyell tongue is now about 440 yards from the terminal moraine, a retreat of 340 yards since 1858, or 15 feet annually—an extremely slow recession rate, although one must not forget the possibility of short cycles of advance during the period elapsed.

At the present time, the Mons stream runs along the western margin of the rock promontory, the stream having been "captured" by the Lyell torrent, which it joins and deflects, the combined river flowing with great force transversely across the Lyell ice-front, eroding it as fast as it advances, well above the point where the ice terminus would normally be found.[1] The water swings in a great curve before starting down the valley, in a boiling flood, perfectly impossible to ford, carrying down blocks of ice weighing tons (pl. 3).

The ice facing the river rises above it in a cliff, 20 to 50 feet high. At the angle where the Mons stream joins the Lyell we found a bridge of broken seracs over which we could cross. This disappeared entirely within a few days, and one could never be certain of a route of approach. The tongue below the icefalls is flat, and about two miles long. The longitudinal crack splitting the glacier, which Dr. Hector recorded, is no longer present; but throughout its length there is a sharply defined midline, dividing the clear southern ice of the precipitous fall adjoining Division Mountain (9,843′), from the northern, débris-strewn segment derived from avalanches, pushed over the cliffs from the higher levels of the icefield. Dirt-bands are well formed in the area below the southern icefall; this ice is supplied under pressure, and in volume considerably exceeding that from the adjacent avalanche ice. Consequently the clear ice forms a huge pressure ridge, in the longitudinal direction of the dissipator tongue, rising in a bulge or fold along the junction with the northern, dirt-

[1] As recently as 1919, Dr. Charles D. Walcott, who visited the region, noted that: "All of the water from the Mons glacier passed out through the narrow canyon or cleft on the south side, and when the ice was melting on a warm day the stream from it spread out all over the flat. At that time the ice from the Lyell glacier abutted against the rock, forcing the Mons stream to pass out through the cleft." In the present writer's opinion, it is equally correct to state that the Lyell glacier abutted against the rock *because* the Mons stream found exit through the cleft. If the Mons stream in its present state be cut off (as it may be in winter), or if it should be diverted to its former bed, it is probable that the Lyell tongue would very soon re-advance and make contact with the rock promontory.

For the appearance of the terminal drainage in 1919, see Smithsonian Misc. Coll., Vol. 72, No. 1; Fig. 1, facing p. 1.

covered segment, maintaining a level of more than 20 feet above the latter (pls. 4, 5, 6, 7). The glacier, below the ice falls, presents the largest moulins we have seen in the Rockies: circular shafts of at least 20 feet in diameter and unfathomably deep.

The formation of dirt-bands in the dissipator tongue is unique. They are developed not only in the clear southern segment below the icefall, but also in the northern segment derived wholly from avalanches. The southern segment of clear ice moves downward with a faster rate of flow than the rock-covered northern segment, so that the bands do not connect throughout the width of the tongue. Furthermore, the northern and southern segments each have a motion faster at the center than at the sides—there is retardation along the central pressure ridge—with the result that an observer looking down on the tongue sees two series of concentric parabolas, one beside the other.

The southern third of the head-cirque of the glacier is occupied by icefall, with a narrow middle moraine near the southern margin, connecting the dissipator with the main icefield; the northern two-thirds is formed by the bare precipice, over which avalanches are pushed from the icefield, to be reconstructed and incorporated in the dissipator. During summer days the falls occur with great frequency, scarcely 15 minutes ever elapsing without one or more sizable avalanches. These occur in six distinct depressions on the cliff, almost evenly spaced across the face, several being occupied by waterfalls of considerable volume (pl. 8, fig. 1).

According to the Interprovincial Survey, the area of the Lyell icefield, with its outflowing glaciers, is 20 square miles. The Mons field, adjoining and loosely connected with it on the south, contains 10 square miles. The Lyell icefield is split into two nearly equal parts by the Continental Divide, the five peaks of Mt. Lyell rising on its northerly margin.

Into the lateral valley, immediately north of the dissipator tongue, a small glacier descends from the icefield, reaching a level of about 8,000 feet, terminating about a mile short of where it would join the main glacier (pl. 8, fig. 2). It is beyond the purpose of this paper to consider the remaining effluents of the Lyell icefield, although it should be remembered that on the west it drains to the north and south branches of Bush River; on the north to Alexandra River; and on the east to Arctomys Valley as well as to Glacier Lake.

There was neither time nor opportunity for making an instrumental survey of the southeastern tongue, draining to Glacier Lake, but the foregoing observations are of interest as being the first, in any detail, since the discovery of the glacier 68 years ago.

SUMMARY

The Southeastern Lyell glacier presents a dissipator tongue, partially reconstructed in type, which has undergone relatively slight recession during the period 1858-1926. It has receded at a rate slower than has been recorded in other measured glaciers of the Canadian Rockies. Its terminus affords a remarkable example of the effects of captured-stream erosion, with effacement of the ice above the normal balancing-point between forward motion and dissipation.

FRESHFIELD GLACIER

Arriving at the Freshfield Group on July 14, 1926, the afternoon and the following day were devoted to checking on some of the observations made in July, 1922,[1] in order to determine the advance or recession of the ice during the four years intervening. The results of this examination are as follows:

MEASUREMENT OF SURFACE VELOCITY

Station A, on the north lateral moraine, was occupied on July 15, and the vertical reference line on Station B, on the opposite side of the glacier, used for reestablishing the line A-B.

From this line direct measurements were made with steel tape upstream to the Great Boulder and the Glacier Erratic marked "1922." Their distances above the line were respectively 1,046 and 640 feet, as compared with 1,551 feet and 1,306 feet in 1922. This represents an advance of 505 feet and 666 feet in four years. In 1922, the two rocks were 350 feet apart; in 1926, they were found to be 440 feet apart.

	Motion 1,463 days Feet	Average daily motion Inches
Great Boulder	505	4.1
Erratic "1922"	666	5.44

On careful search we were able to locate all of the fourteen numbered stones, lined out 50 paces apart in 1922, except numbers 1, 9,

[1] The results were reported by Howard Palmer, whom the writer assisted in 1922, in two papers, "The Freshfield Glacier, Canadian Rockies," Smithsonian Misc. Coll., Vol. 76, No. 11; and "Observations on the Freshfield Glacier, Canadian Rockies," Journ. Geol., xxxii, 1924, p. 434. These papers should be consulted by anyone interested in making comparison with the present article. Designation of stations by name or number correspond throughout the papers.

During the observations of 1926, Mr. A. J. Ostheimer, III, assisted in the taking of measurements on the dissipator tongue.

and 14 which had no doubt fallen into crevasses. Numbers 12 and 13 were measured with steel tape and found to be respectively 390 feet and 381 feet below the line A-B. Numbers 10 and 11 were advanced several feet further, while the remainder had progressed a trifle less. Time did not permit of further measurements, but 380 feet fairly represents the average advance along the line A-B.

OBSERVATIONS ON MOVEMENT OF STONES IN RELATION TO LINE A-B SET ACROSS THE FRESHFIELD GLACIER JULY 13, 1922

Station	Distance from north margin of glacier Feet	Motion 1,463 days Feet	Average daily motion Inches
A	255	0	0
12	2285	390	3.2
13	2500	381	3.12

These figures check well with those of 1922, showing that the slightly slower winter activity brings down the average daily motion for the year as compared with the average daily motion during summer months.

It was surprising to find so many of the 1922 stations, which were left *in situ* and will be of use in further observations.

OBSERVATIONS ON THE ORIENTATION OF ERRATIC BOULDERS

The Great Boulder, the Glacial Erratic marked "1922," and other sizable erratics, because of their large cubic content and consequent absorption of heat rays, are constantly rising on ice pedestals and forming glacier tables. The large surface area of the boulders shades the ice and consequently the pedestals are broader and taller than would be the case were the rocks smaller. The mass of the large erratics is so great that when they eventually fall from their pedestals there is considerably more displacement than with smaller rocks.

This emphasizes a singular phenomenon. The main axis of the Freshfield glacier is from southwest to northeast. The cutting action of the sun's heat upon the ice pedestals of glacier tables is chiefly from the south. Consequently the erratic is subject to the action of two forces applied from different angles; with the result that, in their rising and falling, the erratics, whose orientation in 1922 was determined and photographically recorded, are turning slowly in a counter-clockwise direction. In four years this rotation has been almost 90° (pl. 9, figs. 1 and 2; pl. 10, fig. 1). The little cairn erected by Edward Feuz on the downstream tip of the Great Boulder in 1922 has fallen over, and this point is now directed toward Coronation Mountain.

OBSERVATIONS ON THE TONGUE AND ITS RETREAT

The evergreen tree, its trunk painted with a white band, still stands at the Camp Station, now 2,379 feet from the forefoot of the glacier. The stream of clear water, formerly at the foot of the bank, has disappeared.

A photograph of the tongue from this point (elevation 5,300 feet) shows very well the vertical shrinkage since 1922, as well as the stream erosion at the extreme right (pl. 10, fig. 2). The moraine (M) has also suffered through erosion by the glacial stream.

Test photos of the tongue were taken from Station C, on the north lateral moraine, on July 19 (pl. 11, figs. 1 and 2). All of the three sizable stones near the edge of the ice in 1922 have now been left behind on the morainal flat. H, the most advanced, is 330 feet from the nearest ice, an average daily retreat of 2.72 inches during a four-year period[1] (pl. 12, fig. 1).

Two additional stones, now at the extremity of the ice, were marked, each with a letter T. The lateral abutment of the terminal ice against bed-rock was marked at the northwesterly angle by a vertical reference line and the numerals '26.

The forefoot drainage of the glacier has altered considerably, the streams issuing from the center of the snout and, to a greater extent, from the northwesterly angle where, at the extreme right, adjacent to the lateral moraine, a low broad ice arch is forming.

GENERAL FEATURES OF THE GLACIER

The dissipator tongue shows notable changes in the terminal portions due to retreat, vertical shrinkage, and lateral cutting from the stream descending the Garth-Coronation gully.

The main reservoir appears more broken than when previously examined, and the upper icefalls, especially between Mts. Gilgit and Pilkington, are more open. In the opinion of the guide, Edward Feuz, climbing routes followed in 1922 would now be more difficult.

In heavy showers, on the afternoon of July 15, the writer climbed to the Niverville meadow to obtain test photographs of the lateral-alcove tongue. This secondary tongue has followed the general retreat of the main tongue and, although measurements could not be made, appears to have receded at least 100 feet (pl. 12, fig. 2).

[1] This gives a figure of 85 feet per year, as against the 46 feet per year estimated by Palmer for the years 1902-22. Assuming the latter figure to be correct, it would indicate that the dissipator tongue has considerably increased its rate of retreat—a fact in agreement with what is known of the recession of other glaciers in the Canadian Alps.

SUMMARY

The Freshfield glacier is definitely in a cycle of retreat and, although the annual frontal recession during the period 1922-26 is less than has been observed in other glaciers of the Canadian Alps (excepting the Lyell), it is certain that the recession rate has increased during the past 20 years.

The topography of the areas discussed will be found in the detailed maps of the Interprovincial Boundary Commission, Sheets 18 and 19, which may be obtained from the Topographical Survey of Canada, Ottawa.

Southeast Lyell glacier and Division Mtn. from flats above Glacier Lake. Mons Pk. and glacier are seen at the left.
Photograph by C. D. Walcott.

Division Mtn. and the rock promontory against which the Lyell tongue formerly abutted. Through the cleft is seen the Mons tongue, whose stream, formerly finding exit through this gap, now runs behind the promontory and joins the Lyell stream. Photograph by C. D. Walcott.

Ice-front of Lyell glacier, showing junction of Mons and Lyell streams. The ice formerly abutted against the rocks on the left. Photograph by M. M. Strumia.

Southeast Lyell glacier, showing pressure ridge in tongue between clear ice supplied through the icefall and débris-covered ice reconstructed from avalanches. The old terminal moraine, through which the stream has cut a channel, is seen in the foreground. Photograph by C. D. Walcott.

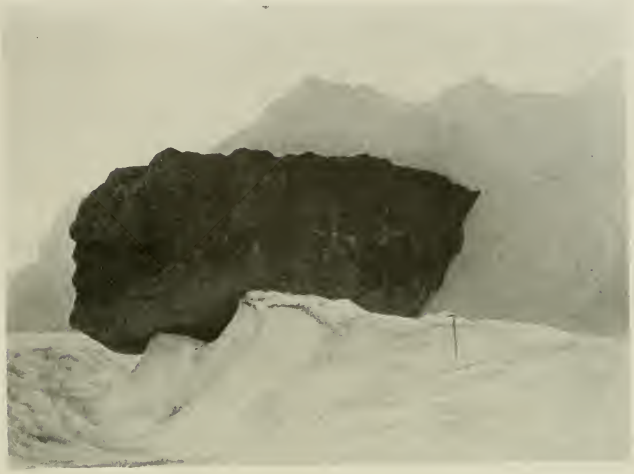
Icefall of the Southeast Lyell glacier. Note junction of clear and débris-laden ice. Photograph by C. D. Walcott.

Mons glacier from the Lyell tongue, showing icefall by which it precipitates from the snow basin between Mt. Forbes and Mons Pk. Photograph by C. D. Walcott.

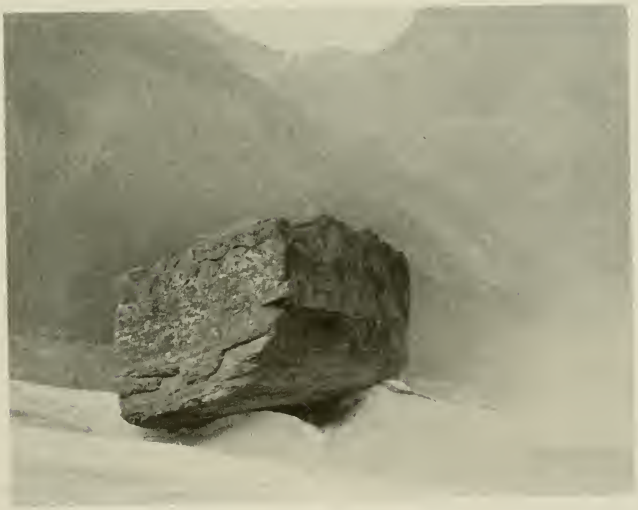
Mons glacier as it appeared in 1919. Due to retreat in succeeding years the course of its terminal stream has altered considerably. Photograph by C. D. Walcott.

1. Division Mtn. with icefalls above reconstructed portion of Lyell glacier. Bush Mtn. is seen across the Lyell icefield.

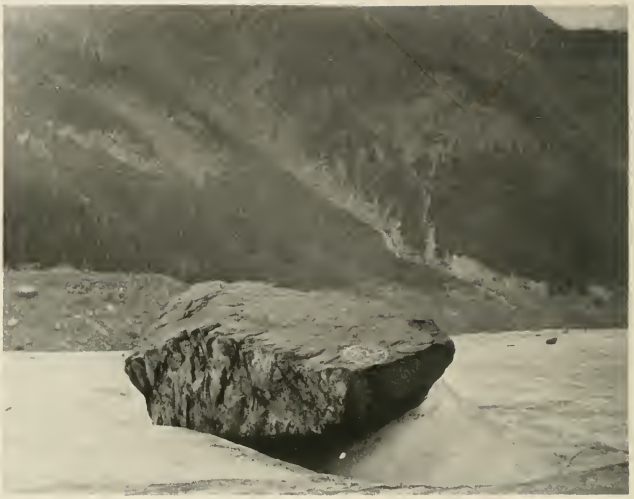
2. Central area of Lyell icefield, showing ridge of Continental Divide. In the foreground is a small tongue draining to Glacier Lake.



1. Great Boulder, showing ice pedestal formed since 1922. (Compare size with ice axe in right foreground.)

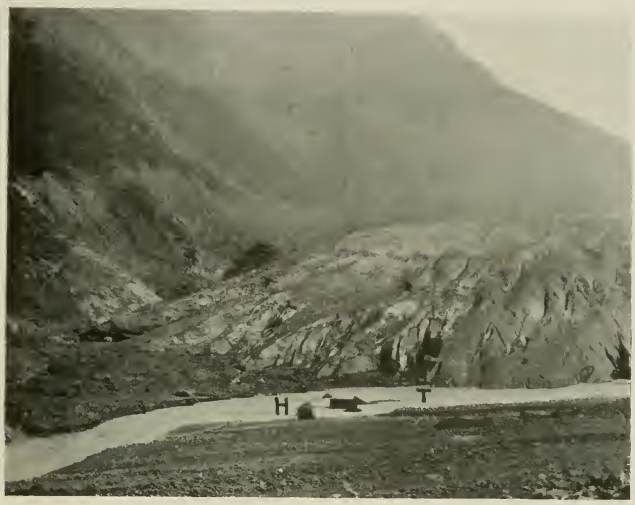


2. Great Boulder, from position of 1922 test photo, showing altered orientation.



1. Erratic Boulder marked "1922," showing ice pedestal and falling of block toward south.

2. Freshfield glacier from Camp Station in 1926. The old moraine (M) has undergone further erosion, while the ice-tongue shows marked vertical shrinkage and recession.



1.

2.

Figs. 1 and 2 form a panorama of the Freshfield tongue from Station C. The boulder, H, was in contact with the ice in 1922. Boulders marked T were in contact in July 1926. The Great Boulder on the glacier is seen immediately below the arrow. The terminal stream issues mainly from the northwesterly angle (right).

1. Looking from the Freshfield tongue toward Camp Station. The emergence of the stream from the northwesterly angle of the glacier is seen. The boulder, H, in contact with the ice in 1922, is now 330 feet distant.

2. Lateral depression below Niverville meadow, looking toward the Freshfield reservoir and showing retreat of secondary tongue.