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EXTENT AND THICKNESS OF THE LABRADOR ICE-SHEET [1]

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INTRODUCTION

The Labrador ice-sheet did not cover the whole of eastern America north of New York, since the Torngat region, in northeastern Labrador, and the Shickshock Mountains, in Gaspé, escaped and remained as driftless areas. On the other hand, in places the ice-sheet passed beyond the present eastern edge of the continent, covering part of the shallow sea bottom along the coast of Labrador and occupying most, if not all, of the present Gulf of Saint Lawrence. On the western side the ice-sheet at its greatest extent filled the basins of Hudson and James bays, thus meeting the Keewatin sheet. Just how far it extended southwest is not quite certain, its relations to the Patrician sheet described by Tyrrell being still only imperfectly known. The island of Newfoundland is believed to have been an independent glacial center, adjoining the Labrador sheet on the east.

It is proposed in this paper to define the eastern limits of the Labrador sheet, referring specially to the driftless areas; to estimate the thickness of the sheet at various places, and to discuss the relation of the ice burden to postglacial raised beaches and to the theory of isostasy.

[1] Manuscript received by the Secretary of the Society February 30, 1919.

Glacial Features of the Torngats

That the summits of the Torngat Mountains, in northeastern Labrador, were not glaciated has been known for many years and has been referred to by Bell, Low, Daly,[2] and others. During the summers of 1915 and 1916 the present writer studied parts of the region in some detail and made sure that the Labrador ice-sheet never crossed the region of moun-

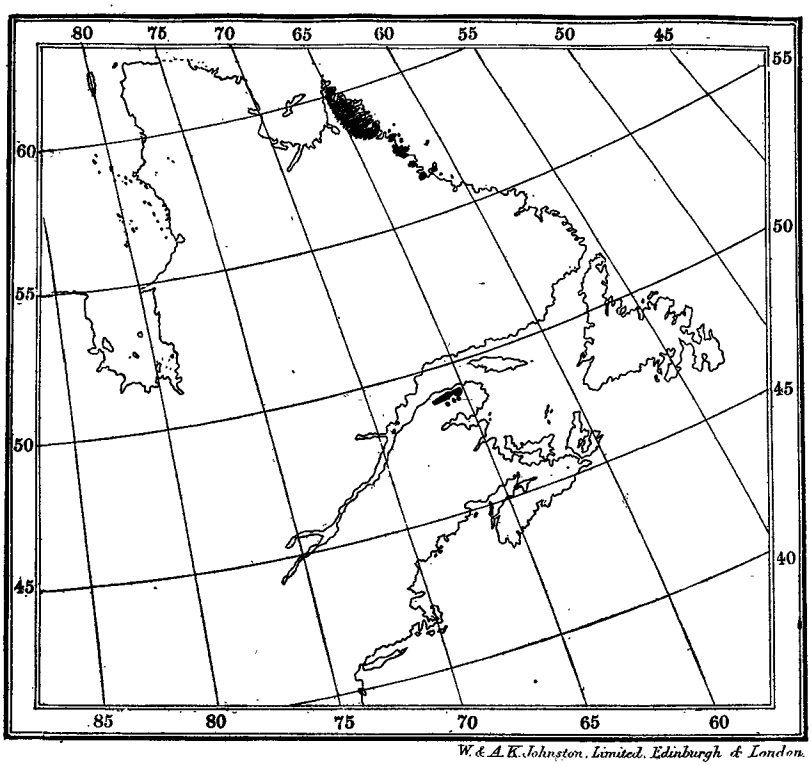

Figure 1.—*Eastern Edge of the Labrador Ice-sheet*

Driftless area shaded.

tains and tableland called the Torngats, though the eastern side of the range supported many large local glaciers which carved or deepened the valleys and left behind some magnificent fiords.

Most work was put upon Nakvak fiord and its surrounding mountains, some of which reach altitudes of 5,000 feet or over. Nakvak fiord itself

[2] Bell: Geol. Survey of Canada, 1882-1884, pp. DD 11-17.
Daly: Geol. of northeast coast of Labrador. Bull. Mus. Comp. Zool., Harvard, vol. xxxviii, 1902.

is 30 miles long, and its valley, occupied by a river and a fiord-like lake, continues 15 miles farther west, cutting across the highest part of the mountains. It did not, however, furnish an outlet for the Labrador ice to the sea, as has been supposed, but was occupied by a long local glacier fed by numerous lateral glaciers from north and south. At the head of the fiord the ice probably stood 2,000 or 2,100 feet above the sea, its surface sinking to about 1,400 feet at the outlet, so that there was a gradient of about 20 feet per mile. The highest distinct evidence of glacier-work observed in the region is at 2,650 feet in a side valley, where a cirque lake is dammed by morainal blocks.

The summits of most of the mountains are flat or rolling and are covered with loose blocks that show no effects of ice-work. In places, for instance, blocks of diabase rest upon a dike, while blocks of gneiss lie undisturbed on both sides.

For 200 miles south of Cape Chidley, the northeast point of Labrador, the mountains seem to have formed an effectual barrier to the great ice-sheet; but just north of Hebron, at the fiord called Iterungnek, it may have reached the sea. Some islands near the mouth of the fiord are well glaciated, though on Maidment Island, 10 miles out to sea, there are no signs of ice-action, showing that land ice did not reach so far.

Johannesberg, north of Hebron, rising to 2,300 feet, was a nunatak elevated several hundred feet above the ice-sheet, and its flat summit is covered with loose stones weathered *in situ*. At Hebron itself beautifully polished and striated surfaces from which boulder-clay is now being stripped give conclusive evidence of glacial work on a large scale.

For 30 miles to the south the comparatively low country has been ice-shaped; but the Mugford Mountains rose above the ice, though transported blocks are found up to 2,000 feet. A gap of 35 miles separates the Mugford nunataks from the next ones to the south, at the Kiglapait and Aulatsivik Mountains, near Nain. Proofs of glacier-work are found on all the shore of Labrador to the south, though a few high summits near Hamilton Inlet may have been nunataks.

Newfoundland seems to have been covered with a local ice-cap, though the island of Twillingate, to the north, shows no signs of land ice action. However, blocks transported by floating ice may be found up to 270 feet on the island.

Ice Boundary in the Gulf Region

The boundary of the ice to the south is somewhat uncertain. The low island of Anticosti was apparently covered, and there is clear proof of

the work of glacial ice on the Magdalen Islands[3] in the form of sandy till with well striated stones, up to an elevation of 105 feet. Above this hills of loose basaltic blocks rise to 360 feet in places, showing no evidence that a great ice-sheet ever passed over them. The islands seem too small and low to have formed an independent glacial center, and it is probable that the thin southeastern margin of the Labrador ice-sheet inclosed them without crossing the hilltops. If so, the thickness of the sheet at this point can not have been more than about 200 feet. Whether the ice, perhaps with its edge afloat, reached Cabot Straits between Newfoundland and Cape Breton is uncertain.

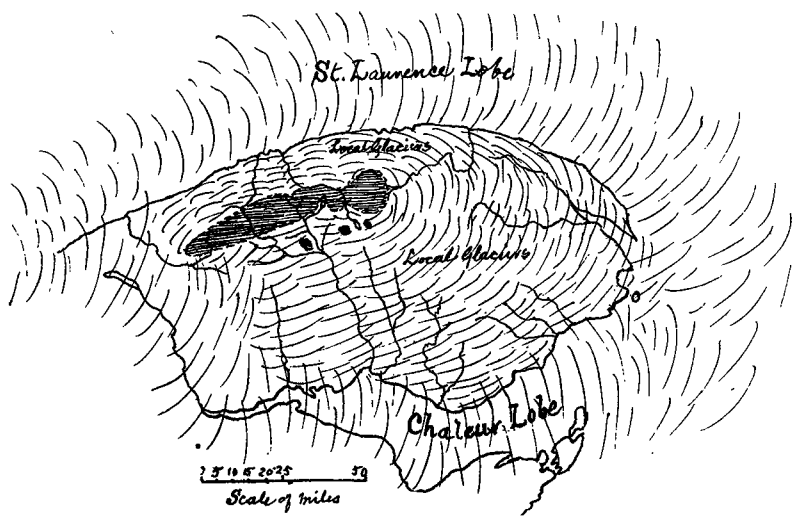

FIGURE 2.—*Map of Gaspé in the Ice Age*

Driftless area shaded.

It was thought by Chalmers that the eastern end of Prince Edward Island was unglaciated; but I have found undoubted till with well striated stones at Souris, proving that land ice covered at least the lower ground.[3] The central part of the island has not furnished evidence of the action of land ice, but the west end is more or less covered with boulder-clay containing blocks derived from the mainland. There are no hills rising much above 311 feet (Wiltshire station, highest railway point on the

[3] J. W. Goldthwait: Geol. Survey of Canada. Museum Bull. No. 14, 1915.
A. P. Coleman: Glacial history of Prince Edward Island and the Magdalen Islands. Roy. Soc. Canada, 1919.

island), so that one would hardly expect a local ice center, relations being much the same as in the Magdalen Islands.

The evidence is conflicting as to whether Nova Scotia was covered by the Labrador ice-sheet or not.[4] Kame deposits and boulder-clay occur on the western side of the province, suggesting the margin of a great ice-sheet, but in some places, as near Pictou, there are erratics which seem to have been transported northward instead of southeast, as would be expected, and Chalmers' conclusion that most of the glaciation of the peninsula came from local centers may be correct.

The Gaspé driftless Area

While the margin of the Labrador ice-sheet crossed the floor of the present Gulf of Saint Lawrence and swept southwestward over the lower part of Nova Scotia, the highest part of the Province of Quebec, the Gaspé Peninsula, was never covered by continental ice, but formed a local center of glaciation. The backbone of the peninsula is formed by the

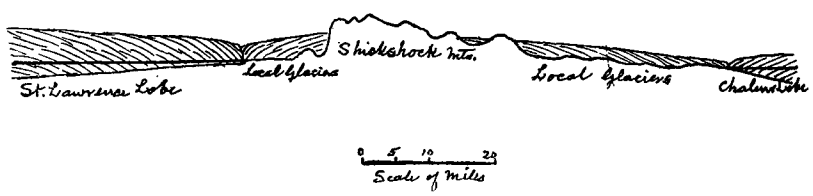

FIGURE 3.—*Section across Gaspé in the Ice Age*

Average thickness of ice, 1,300 feet.

Shickshock Mountains, rising from 2,000 to 4,300 feet above the sea, and the higher parts of the range, above 3,000 feet, show no evidence of glaciation, and may be described as a driftless area of a similar kind to that of the Torngats, in northeastern Labrador, though on a smaller scale. The flat or rolling tops of the range are formed of a sheet of weathered blocks of local origin with no foreign boulders, while glacial deposits, usually thin and sometimes lacking, spread outward from the higher parts of the mountains to the sea on each side. The most elevated proofs of ice-work on the north, or Saint Lawrence, side are found at Lac aux Americains, at 2,300 feet, while there is evidence that ice from the Shickshocks carried morainic material over the tops of mountains 2,000 feet high on the southern side.

[4] Geol. Survey of Canada. Sum. Rept., Part F, 1918, pp. 20 and 24.

One must imagine the Labrador ice as parting into two lobes on the col just west of Gaspé, where the elevation is only 751 feet on the Intercolonial Railway, one lobe occupying the Saint Lawrence Valley and the other the valley of Matapedia River and the Bay of Chaleur. Beyond the end of Gaspé the two lobes, augmented by local glaciers from the Shickshocks, met once more and continued as a single sheet to the margin beyond the Magdalen Islands, as described above.

The driftless area of the higher Shickshocks is about 50 miles long by 10 miles wide, with an area of 500 square miles; and the region which escaped the Labrador sheet, though largely covered by local ice, is 150 miles in length by about 70 in breadth, with an area of 10,000 square miles, in round numbers.

Thickness of the Ice-sheet

The Shickshocks give an opportunity to estimate the thickness of the ice-sheet. At the col 751 feet high, just west of the peninsula of Gaspé, the ice can not have risen more than 3,000 feet above present sealevel in the Saint Lawrence or it would have submerged the lower Shickshocks, of which there is no evidence. Drift boulders have been found on Carlton Mountain, 100 miles to the southeast, at 1,270 feet; so that the ice at that point must have risen at least somewhat above that level—say, to 1,500 feet. If one allows 10 feet of slope per mile to account for the flow of the ice, this gives 2,500 feet for the surface at the col—a very probable estimate. The thickness of the ice would be 2,500 feet, 750 feet, or 1,750 feet. If one assumes the specific gravity of glacier ice to be about one-third that of average rock, this would mean a load equivalent to 583 feet, which corresponds exactly to Fairchild's determination of the highest marine level at Sayabec, a few miles to the southeast.

It is possible also to reach an approximation of the thickness of ice in a north and south section through Tabletop, the highest part of the Shickshocks. On the north side of the range no boulder-clay containing Archean stones, and therefore formed by the Saint Lawrence lobe of the main sheet, has been found more than half a mile inland; and it may be supposed that the local glaciers or ice-sheet which carried blocks of granite and serpentine northward from the mountains met the Saint Lawrence ice near the present shore. The highest undoubted evidence of glacier-work on the north side of Tabletop is a moraine at the outlet of Lac aux Americains, 2,300 feet above sea. The glacier which built the moraine must have risen somewhat above this level. Assuming the slope

of the local glacier to be 20 feet per mile for 12 miles to the present shore, the ice there would have a thickness of about 2,000 feet, and presumably the Saint Lawrence lobe met it at that level, but itself sloped gently upward toward the glacial center to the north. On the south side of the Shickshocks there is proof, in the form of boulder-clay containing Table-top granites and also serpentines, near the Federal zinc mine, that a glacier crossed the summit of mountains reaching 2,000 feet or a little over, and drift blocks of the same kind with some boulder-clay extend to the mouth of Cascapedia River, on the Bay of Chaleur. From the height to which erratics have been found on Carlton Mountain, as mentioned before, the elevation of the Chaleur ice-lobe at this point may be put at about 1,250 feet. In the way suggested, the probable surface level of the ice from the middle of the Saint Lawrence to the middle of the Bay of Chaleur, a distance of 120 miles, may be inferred; and, allowing for about 20 miles of mountain with little or no load of ice, the average thickness works out to 1,300 feet. One-third of this is 430 feet, the equivalent load of average rock. Fairchild's map shows the isobase of 400 feet passing close to this line of section, which accords sufficiently well with the result.

Thickness of the Ice in the Adirondacks

No other mountains of eastern Canada were high enough to project above the Labrador sheet at its maximum, but a brief visit was paid to the Adirondacks in New York to study ice relations, and Mount MacIntyre (5,112 feet) was climbed. The valleys show powerful effects of glaciation, and erratics as well as sandy till were found in the ascent up to a height of 4,300 feet, where pebbles and small boulders of quartzite and granite occur, clear proof of glacier action, since Mount MacIntyre consists of anorthosite passing into gabbro.

Probably more extended search would disclose ice-borne materials at a higher level, and in any case it is probable that the ice reached some hundreds of feet above the lowest portion of the glacier charged with stones. The top of the mountain consists of large and small blocks of native rock, some weighing many tons, piled loosely and suggesting relationships due to weathering only. It seems to me very improbable that a great ice-sheet could have passed over the mountain top without dislodging these stones, and it is likely that Mount MacIntyre, Mount Marcy (5,344 feet), and a few other peaks a little lower were nunataks rising a few hundred feet above the ice.

If we suppose the ice to have reached 500 feet above the highest known

morainic materials, its surface would have been 4,800 feet above sealevel and 2,800 feet above the adjoining valleys, which are at about 2,000 feet. Supposing that the ice filled the valleys to 4,800 feet, and that the mountain masses occupied half the total volume below that level, the additional load of ice would average 1,400 feet. One-third of this is about 470 feet, while Fairchild's map of isobases gives the old marine level in the Adirondacks as about 600 feet. However, the group of highest peaks does not occupy much space, and the ice over the rest of the region, with its much lower mountains, would average thicker and thus supply the deficiency in load equivalent to 130 feet of rock.

I have had no opportunity to study the White Mountains with respect to glaciation, but Goldthwait believes that the ice-sheet passed over them. If so, it must have been far thicker than would be expected if the Shickshocks to the northeast and the Adirondacks to the west were not entirely covered. Is it possible that local glaciers could account for the facts in regard to the White Mountains?

Relations to Isostasy

It is of much interest to determine the limits within which inequalities of load can be sustained by the earth's crust without adjustment by bending or faulting, and the Gaspé region may be considered from this point of view. A belt of mountains 50 miles long by about 12 miles wide was scarcely at all ice-covered and over double that length and breadth there appear to have been only small local glaciers or ice-sheets, while in the valleys to the south and north there was a thickness of from 1,250 to 2,300 feet. If there was perfect adjustment to the relief from load, the borders of the peninsula should have risen from 400 to 800 feet while the mountain axis remained at its old level. The uniformly graded channels of the rivers, which are undoubtedly preglacial, show that no such differential adjustment occurred. The grade of Sainte Anne and Cap Chat rivers to their forks, well within the mountains, is so uniform that boats are poled all the way up with scarcely an interruption, their lower course being almost as rapid as the upper part. This is even more markedly the case on Cascapedia River, flowing 45 miles south from the Shickshocks to the Bay of Chaleur. There is a fairly rapid current all the way, but scows with several tons of freight are towed the whole way by a team of horses.

The excellent grading of the rivers and the almost complete absence of lakes or floodplains where they enter the sea prove that the region rose

as a whole, although the relief from load was almost confined to the north and south and amounted to little or nothing at the center.

One may draw the conclusion that the earth's crust can sustain inequalities of load amounting to 1,500 or 2,000 feet of ice, or the equivalent weight of rock, where the width of the region in question is not greater than 75 miles, the load decreasing from a maximum at the two sides to nothing in the center.

The lack of differential elevation in the Gaspé Peninsula may be contrasted with the doming up of Newfoundland after the Ice Age, as indicated by Tyrrell and Fairchild. Newfoundland is considered to have been an independent glacial center, and the isobases are so mapped as to show a doming of the interior of 400 feet as compared with the edges. This may be interpreted as meaning that Newfoundland bore an ice-cap 1,200 or 1,500 feet thick, diminishing in all directions outward—conditions exactly opposite to those in Gaspé, where the central mountains carried little or no ice, though local glaciers radiated out from them.

Newfoundland has diameters of about 300 miles by 200, and a land area of 42,000 square miles, and it seems that a portion of the earth's crust of those dimensions does not change its level as a whole, but undergoes differential elevation to correspond to the varying relief from load; or, to put it in another way, the earth's crust is not strong enough to resist isostatic adjustments where the area affected is 200 miles wide, but can support the difference of load where the width is only 75 miles, as in Gaspé.

The case of the Torngat region, in northeastern Labrador, is apparently similar to that of the Gaspé Peninsula, though it has been studied much less thoroughly. The breadth of the unglaciated core of mountain and tableland is probably 50 or 60 miles, but 30 miles of the eastern side of the Torngat Range is riddled with fiords and deep valleys, occupying probably half the surface. As these were once filled with great local glaciers reaching in places 2,000 feet in thickness, the amount of depression of the region, about 250 feet, is readily accounted for. There is no evidence that the glacier-laden coastal region has risen more than the unglaciated tableland, perhaps 20 or 30 miles wide toward the west.

The suggestion of De Geer that the pre-Cambrian shield rose, as contrasted with stationary Paleozoic terranes to the south, receives no support from the actual changes of elevation shown by beach levels. The highest actually measured elevation, 690 feet at Kingsmere, north of Ottawa, is on Archean territory; but the beach levels diminish to 225 feet, still on the pre-Cambrian, at Komaktorvik Fiord, in the north of Labrador. To

the southeast of the glacial center raised beaches occur on Paleozoic territory beyond the Saint Lawrence at 430 feet and continue for 350 miles before sinking to sealevel. It is evident that the change of level is not connected with the character of the bedrock, which is, after all, a superficial thing, the granitoid gneisses of the Archean really underlying the Paleozoic sediments and probably at no very great depths.

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