III.—On Drift Ice as an Eroding and Transporting Agent. —By W. H. Prest, *Bedford, N. S.*

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Introductory.

In the following notes, although I may not be able to bring forward any new facts of importance, I can at least add my testimony to that of those who have studied in the same line.

Having had an opportunity, while in Labrador, during the the past summer, of observing the action of drift ice as an eroding and transporting agent, I submit the following, prefaced by a few notes on the elevation now going on there.

On the north-east coast of Labrador, where my observations were made, the action of purely drift ice is more marked than anywhere else in the same latitude; and during the melting and transportation of the northern ice there is abundant opportunity for gathering information relating to the subject.

During the short Arctic summer the northern ocean pours forth a tremendous stream of ice. This stream, borne southward on the bosom of an Arctic current, sweeps from side to side, the sport of ever-changing winds, like the tail of a gigantic kite. Sometimes this stream or tail is swept out into the Atlantic, then against the rock-bound coast of Labrador, and often through the Straits of Belle Isle into the Gulf of St. Lawrence. The field- or pan-ice inshore, and the bergs in deeper water, here exhibit their capabilities under many varying conditions. Their action in deep and shoal waters, or on steep shores and submerged ridges, and their power as erosive and transporting agents, can be seen to advantage. There are several reasons why this coast should be considered the best known station for the observance of the effects of drift ice :—

1st. Its convenient nearness to civilization and the source of ice supply.

2nd. The direct and continuous action of ice upon a coast line nearly 1000 miles in length, and reaching from the source of supply almost to the limit of its drift.

3rd. The phenomenon of a rapidly rising coast line.

My enforced detention here by ice blockades drew my attention to these advantages for study and evinced the close connection between present conditions in Labrador and the later Pleistocene of the Maritime Provinces.

General Appearance.

The shore along the northern side of the Straits of Belle Isle is generally sloping, sometimes steeply so, rising at a short distance into high rounded or rugged hills. On these slopes the sea has written both history and prophecy, the record being marked by ancient shore lines. Here and there, as at Henley Harbor, bold cliffs line the shore and give variety to what would otherwise be an intensely monotonous waste of rock and moss. North of Battle Harbor the mountains approach the shore more closely, and being of a rugged outline and pierced by deep inlets, and often faced with precipices, present a wild and forbidding appearance. Along the whole outer coast, for nearly 100 miles north of the straits, a tree is not to be seen. The islands especially are barren and storm-swept to a degree that makes this coast more like perfect desolation than any other place in the same latitude. The fine deep harbors, however, partly compensate for the extreme desolation of their surroundings. Thence, onward to Hamilton Inlet, the coast is lower; and long gentle slopes run up from the sea, and the hillsides are often clothed with trees. The headlands and islands, however, continue bare, even moss being absent on some of the most exposed points and headlands. Such a thing as tillable soil, as we know it in Nova Scotia, I have not seen on this barren shore. Only on the flowage plains of the large rivers is there any soil worthy of the name; and on this ice-scoured shore its presence would be strange indeed. There, since the last glacial epoch, through

subsidence and elevation, the annual stream of Arctic ice has washed and scoured until every vestige of lighter material has been slowly but surely swept into the ocean.

Elevation of Land.

A condition that has influenced, somewhat, ice erosion in Labrador, is the elevation now in progress in that region. The resulting raised beaches and escarpments on the Straits of Belle Isle and elsewhere, are the most marked of the minor features of that coast. These evidences of former subsidence extend from the valley of the St. Lawrence around the whole coast of Labrador and Arctic America. The subsidence reached its greatest development in the St. Lawrence Valley and on the shores of Hudson Bay, where ancient shore lines are seen at heights of 600 to 875 feet The highest of the shore lines of south-eastern Labrador are between 150 and 180 feet above the sea level. They are four to seven in number, of which the second is the most prominent and shows the longest period of rest for the elevating agencies. Then follows the third, while the fourth and fifth are barely traceable in some places. These escarpments do not mark the full number of pauses in elevation on the Labrador coast, but only the principal ones. Mr. Low, of the Canadian Geological Survey staff, noticed 14 small terraces within a few yards at the mouth of the Northwest River, Hamilton Inlet. This process is also shared in by the west coast of Newfoundland, the evidence of which can be seen almost to Cape Ray. On this coast, however, there appears to be a pivot or centre of oscillation, as the south coast of Newfoundland is sharing in the subsidence now general from Prince Edward Island to New Jersey.

The rise in Labrador does not seem to have been gradual, but to have proceeded in a series of pulsations which, apparently, are still going on. In fact the recent rise of "Mad Moll," a ledge of Sandwich Bay, seems to indicate the present as another period of elevation. The oldest inhabitants claim to remember when this ledge was visible only at low water. Now it is seldom

covered even by spring tides. The first appearance of "Mad Moll" was a noteable event in the life of the preceding generation. The north or main passage of Sandwick Bay, not many years ago navigable for small vessels, is now impassable for anything but boats At Mullen's Cove and Black Island, raised beaches are seen composed almost entirely of mussel shells, some of them unbroken and clean as if thrown up yesterday. These shell deposits are of course seen only in the more sheltered coves where they are protected from the grinding action of drift ice. The rate of elevation here indicated is considerably greater than some recent estimates, and I would like to hear new evidence on this point.

One noticeable point is, that the hillsides above the escarpments show the same smooth and storm-swept appearance as between and below them, as if they had been subject to the same influences and wear by drift ice. Whether the upper escarpment marks the limit of subsidence or not, the natural inference seems to be, that a gradual and regular elevation of a sloping exposed surface, especially when comparatively rapid, leaves no traces of ice action. The retiring sea and ice washes off and carries to lower levels the debris formerly covering the solid rock. Only when the downward movement is arrested, does it form escarpments and beaches, and the fact that no escarpments nor beaches are seen above the highest shore line is no proof that the sea level had not once been higher. Neither on nor around any of the hills near Battle Harbor and Cape Charles (some of which are 700 feet high), is there any sign of glacial debris; and had it once been there it does not seem possible that either land-slides or fluvatile action could have banished it so thoroughly from both hill and valley.

The raised beaches are seen only in sheltered bays where not exposed to the possibility of being swept away by water or landslides from above, or intense ice action from the sea below.

A. C. Low, from observations on Hudson Straits, supposes that part of the coast to have come to a standstill. But on the Straits of Belle Isle the last escarpment seems to be rapidly advancing beyond the level of mean tide.

Drift Ice as an Eroding Agent.

A great part of the erosion now acknowledged as due to other causes has often been ascribed to drift ice. Formerly great stress was placed on erosion by drift ice, particularly by icebergs as in opposition to drift ice. No doubt some erosion was actually effected, but that its traces in the form of striations are still retained above the sea level is very doubtful.

In the official reports of some of the Canadian Geological Survey staff, and also in the writings of other geologists, we can trace a gradual conversion from the old theory to the new, in which ice-action is confined almost solely to the polishing out of former inequalities and striæ. In some of the latest reports, erosion by drift ice is considered possible only under exceptional circumstances. The cause is often proved by circumstantial evidence, or entered with a mark of interogation. It is also admitted that only where a low point or ridge is exposed to an ice jam forced over it by a storm, is striation possible, and then only when the ridge can also be reached by stones to act as graving tools.

Some of the results of my observations on ice action are as follows: Ice action on a steeply sloping shore occurs with an onward rush of water carrying immense masses of ice 5 to 15 feet in thickness. When reflex action begins the ice is poised for a few seconds on the rocks until the water drains partly away. Then, being deprived of support, it slides back with a tremendous plunge into the next advancing wave, dragging with it into deep water such rock fragments as it may have been able to reach. And what is very important, these rock fragments are never carried forward again; for the next wave lifts the ice pans forward, high over every obstruction. The scoring, if any, in this case is done while the ice mass is sliding into the water with stones beneath it, as it exerts little downward pressure when rising with the rush of water. Where exposed to the Atlantic swell, ice pans 15 feet thick and 50 feet in diameter are often carried forward through a perpendicular distance of

25 feet, sweeping everything clean before them. The result is, that in very few places in Labrador are there any boulder ridges such as we see in Nova Scotia. Therefore, these latter can hardly have been the product of exactly the same conditions as are present in Labrador.

Ice action on ridges, shoals and low points, consists of an onward rush of ice as described above, but the ice in front is left poised on the ridge until pushed forward by other ice masses brought in by succeeding waves. Loose stones moved on those nearly flat or slightly sloping surfaces are nearly always rolled, and not pushed. But any stones caught beneath the ice, act as gravers and score the rock over which they slide. Striæ made by stones in such a position are easily distinguished from the straight scratches left by retiring ice on a sloping shore, and also from striæ of acknowledged glacial origin. Such striæ are sometimes curved owing to the swinging of the ice mass and consequent change of course of the graver beneath. But they often form a furrow of which different parts run in different directions. This latter is owing to irregular and repeated pushes from ice in the rear.

Another form of marking is made when a large quartz or granite boulder is rolled on a soft slate bottom. It then produces a series of notches and irregular scratches.

But it must not be forgotten that the first ice thrown up in the spring usually cleans off the debris previously gathered, after which it is exposed to months of continuous wear by ice, sand, and water. And should such striæ be covered by a layer of debris, this is certain to be worked over to a great extent before being swept into deep water, or thrown beyond the reach of the highest tides. Therefore, the preservation of striæ in such positions seems to be well nigh impossible, except on the inner side of the ridge or point, where its formation is extremely doubtful.

There are, however, two classes of marine striæ which are not usually polished out.

To one class belong the scratches caused by the expansion of harbor ice holding large stones which are pushed up from shoal water. These are most prominent in the best protected positions, where it appears impossible for glaciers or drift ice to act.

The other class of marine striæ is formed by large boulders lying usually at high watermark, and which have been rolled down from frost-shattered cliffs near by. They are pushed back by ice jams or by ice hurled against them in a storm, and move a foot or a few inches at a time. These striæ are partly protected from obliteration by the boulder itself.

In regard to the question of erosion by icebergs, the first point to be considered is whether bergs carry stones in positions suitable for eroding.

Observers in the far north, as well as those who have examined glaciers in more temperate latitudes, maintain that debris falls into cracks, or is lodged on the surface of those ice masses and are then carried to sea when the bergs are detached. But it is plain that stones attached to the sides and bottoms would melt off during their long voyage, and this contention is supported by much negative evidence. Although I saw many overturned bergs I saw no stones attached. I therefore feel compelled to fall back on the theory that bergs striate the sea bottom only by bringing their great weight to bear on loose rocks. Should such striæ have been formed before the old shore lines were raised to their present positions, they could not possibly have emerged above the polishing influence of the field ice. Being formed only in the positions afterward exposed to the wear of pan ice, I am thoroughly convinced that such a phenomenon as striæ by ice-bergs does not exist above the sea level.

A rising coast as in Labrador, exposes a well worn rock bottom, smoothed by ice action during the preceding subsidence; and in an exposed position all protecting debris is speedily washed into deep water, and all signs of berg erosion obliterated.

A sinking coast carries its striæ with it, if such striæ can be retained long enough to get below the intense ice action seen in Labrador.

Finally some of the most exposed situations show no signs of abrasion by floating ice. Such are the Magdalen Islands and Labrador, although in the latter place I have made special search for such evidence. And though sea-borne ice may be counted on as an eroding agent of moderate possibilities, as a factor in the production of existing continental striations it can be allowed only a very minor position, if indeed it cannot be altogether eliminated.

Transportation of Debris by Sea-borne Ice.

It has been maintained by some of our foremost geologists, that the Grand Banks of Newfoundlaand as well as the banks off the Nova Scotia coast are chiefly of sub-Arctic origin. Concerning this, questions like the following may arise in the mind of an inquirer: If so, where are the moraines, the certain results of glacial transportation from the provinces mentioned? What has become of all the debris carried from these provinces when the river valleys were excavated, and when they stood at a higher level than now?[1] Also, is the quantity of material brought south equal to the formation of such immense accumulations?

I do not know that any very extended observations have been made to find out to what extent this debris is being transported. Several observers in the polar regions have noticed large quantities of loose stones and earthy matter on pan ice or attached to icebergs, notably, Scoresby, Wilkes, and Sir John Ross. Based on these statements, many investigators have given great prominence to the transporting power of Arctic ice, and write as if earth-laden ice was a common sight off the Newfoundland and Labrador coasts. But of those who have given their time to the question, I know of none who have made actual observation among the drift ice the basis of their theories. Only by getting a fair idea of the quantity of debris remaining on the ice toward the close of its long voyage, can a just opinion be given of its capabilities as a transporting agent.

[1] See papers by W. H. Prest in Transactions of N. S. Institute of Science, 1891-92, page 143; 1895-96, page 153.

I think that a great mistake is made in making no allowance for the melting of drift ice by water and air during its 1000 or 2000 miles journey to the temperate zone. When we reflect that icebergs 300 feet in height are common in the Arctic regions, and that very few of these are seen off the Newfoundland and Labrador coasts, the waste must be enormous. Many thousand tons of ice from the exterior of the bergs, containing, of course, the greater part of the debris, have been dissolved by air and water or have been washed away by the waves and surf of these stormy seas near their starting point. Icebergs, of which I saw several hundred from 40 to 200 feet high, were washed as clean as surf and melting water could wash them Overturned bergs showed the same cleanly condition. Icebergs excavated to a dept of 100 feet by wave-washed caverns showed the purest and most beautiful blue, untinged by the slightest impurity. This melting process which is done chiefly by the sea, is so rapid at the water's edge that before they reach the Straits of Belle Isle many of the smaller bergs assume the form of gigantic umbrellas and finally topple over. These ice umbrellas, by the way, are one of the most fantastic sights of the northern seas. Often the caps are 30 to 60 feet in diameter with a stem 3 to 6 feet thick, and 5 to 15 feet high. They do not appear to be always perfectly poised, but the immense weight of the lower portion keeps the upper part erect. And this ice is always free from impurities.

In regard to field or pan ice, I have examined it from high hills with a powerful glass, and have chopped my way through it in an open boat, but have very seldom seen a discoloured pan.

The only ice-borne debris worthy of mention is that frozen to the bottom of field or pan ice while grounded on shoals at low tide. Sand or mud is frozen to the bottom; then at high tide this is covered by a layer of pure ice, which process is often repeated. Though the probabilities are that nearly all shoal-water ice from the far north will be inter-stratified with debris yet the fact is that an exceedingly small part of what came under my observation was thus stratified. Though watching

for many days the upturned edges of the ice floes as they were driven on shore, I saw very few with debris thus frozen in. The deposits seen by me were often very unequally laid on, and frequently absent near the bottom, where they naturally should be. Sometimes an overturned ice pan showed sand, but for the old idea that field ice obtained most of its debris from overhanging precipices I could find no evidence.

Conclusions.

After having spent two months surrounded by ice fields, and often beset on all sides with its difficulties, I have concluded that very little of all the debris seen on the ice in polar regions ever reaches the latitude of the Straits of Belle Isle, and also that the Grand Banks are only receiving a fraction of the amount of material formerly supposed. Consequently the Banks from Newfoundland westward are almost solely the products of the period of the greatest extension of ice erosion when the source of the debris was our own provinces. It appears, therefore, that those submerged banks are but the marine representatives of the sand dunes and flats of New Jersey, Long Island, Cape Cod and other places, and are principally the natural result of greatly prolonged wave action on true glacial moraines; with, however, this difference, that while the western deposits were formed almost solely from the detritus from Apalachian and local glaciers, the eastern have been added to in the later Pleistocene by an Arctic current. The paucity of transported material on the ice in the latitude of the Straits of Belle Isle convinces me that it takes but a short time for storm and surf to clean thoroughly all the ice brought down by the Greenland current. Therefore, we cannot look farther north than Eastern Labrador and Newfoundland for the source of any debris that may have been added to the Grand and Sable Island Banks. In regard to Sable Island, a recent paper by Dr. A. H. MacKay, on a fresh water sponge found there, may furnish food for speculation as to its origin. This, however, I do not think would affect my conclusions. The sponge, if not an evolution from a marine

form, may have been transported from the continent in a block of river ice.

As to the period of this age of transportation, it probably coincided with the retirement of the continental ice-cap and the elevation of Canada and the Arctic regions. Before this, the glacier ice was shed directly into the ocean in front. The elevation of the polar sea-bottom probably greatly strengthened the otherwise weak Greenland current, thus turning the debris-laden Labrador and Newfoundland ice to the southward.

In connection with this, the beautifully precise theories of oceanic currents do not seem to apply fully to the Labrador and other northern currents, as the constant outpouring of polar waters is not met by an equal inflow. Even the most northern branch of the Gulf Stream is stopped at Spitzbergan, and returns by way of the east coast of Greenland, apparently forced to do so by the current which carried the "Fram" in a southwesterly direction. The rapid rise of the north Polar regions seems to contribute largely to all the currents which flow outward from that point. The great depth of the Polar ocean as proved by Nansen would supply the surplus water needed, through the constant rise of its bottom.

With the increasing amelioration of the climate of the north temperate zone, came the gradual retirement of the Labrador glaciers and the consequent cessation of the supply of the building material to the Newfoundland banks. Therefore, the transportation of sea-borne detritus has been gradually lessening owing to the retirement of the source of ice supply, in spite of the fact that the power of the Greenland current had been probably increasing until it reached its maximum a few centuries ago, when the flow of ice to the southward was much larger than it is now.

The building, or increase of submarine banks, is doubtless still going on, but the work in now confined to the neighbourhood of Greenland and northern Labrador.

How long this ice-bearing Arctic current will continue to flow, must depend largely on the rise of the land in the polar

regions. The narrow channels through which the water flows from the north and northwest have been gradually getting shallower and narrower, and should the present elevating process continue the force and bulk of this current must be greatly lessened, if not altogether extinguished.

There is much room for investigation in this subject; but circumstances compel me to leave to my more professional brethren the work of proving or disproving fully the conclusions I have arrived at.