XIX.—*Results of the Recent Danish Explorations in Greenland, with regard to the Inland Ice* (1876 to 1884). By Dr H. Rink, Knight of the Order of Dannebrog, &c., &c.

(Read 18th February 1886.)

Since 1876, scientific expeditions on a small scale, but regularly every year, have been sent out to the coast of Danish Greenland. Accordingly, a more systematical survey of the country in connection with scientific, and especially with geological investigations, has tended to gradually complete our knowledge of these regions so far as regards their outlines, and the chief questions connected with their natural history. As is well known, the opinion has been very generally adopted, that the whole interior of Greenland is covered with a continuous glacier sheet, only interrupted by mountain-tops here and there emerging from its surface. Against this supposition, however strange as it certainly must appear in consideration of the vast extent of the country, considerable objections have been raised within the last few years. Hence one of the first problems, with regard to its geography, was to ascertain, as far as possible, the actual existence of such an ice-formation.

The task of performing this by direct examination, ascending the glacier sheet—the so-called "inland ice,"—and trying to penetrate into the very interior, could only be executed on a very limited scale. The first object was to trace out everywhere its margin, ascertain the continuity of the same, and examine its actions and movements. This investigation has now been performed for a coast-line of nearly 1000 miles, by entering the fjords, and by trying to reach the inland ice, ascending it in some places, and having a view of it in others from the highest mountain-tops of the coast regions, while its movements, too, have been carefully watched from several stations. These explorations can leave no doubt about an inland ice of the assumed extent, while at the same time observations of great interest to geology and physical geography have thrown light upon the nature of this peculiar ice-formation, which only can be studied in Greenland.

The principal interest attached to the inland ice, from a geological point of view, is derived from its being the only representative of a glacial epoch still existing. Glaciers which, sliding down along mountain-sides, hollow out the ground and carry rocky fragments into the valleys below, do not account for an action that has spread erratic blocks from the mountains of

Scandinavia over the plains of Germany and Russia. No other glacier, no matter how extensive, exhibits a similar transport of stones over a relatively horizontal ground of such amazing extent. We are now able to demonstrate that a movement of ice from the central regions of Greenland to the coast continually goes on, and must be supposed to act upon the ground over which it is pushed, so as to detach and transport fragments of it for such a distance. But what has especially rendered the recent explorations instructive in this light, is that they have revealed the traces of a by-gone ice-formation too, which has been closely connected with, or issuing as a continuation from, that still existing. While in this way we have a coast region exhibiting the same traces as those of the glacial epoch in Europe, the remainder of the icy covering that produced them still conceals and acts upon the adjacent interior of the country. We are thus able to institute an immediate comparison between them along the whole coast from south to north.

The plainest idea of the ice-formation here in question is given by comparing it with an inundation. The view of it merely from elevated points will already produce such an impression. Now, however, the exact similarity of the "inland ice" to an inundation has been confirmed by numerous observations and direct measurements. Only the marginal part shows irregularities; towards the interior the surface grows more and more level, and passes into a plain very slightly rising in the same direction. It has been proved that, ascending its extreme verge, where it has spread like a lava stream over the lower ground in front of it, the irregularities are chiefly met with up to a height of 2000 feet, but the distance from the margin in which this height is reached varies much. While under 68½° N. lat. it took 24 miles before this elevation was attained. In 62½° the same height was arrived at in half the distance. Interesting observations have been made in 71° N. lat. by ascending mountain-tops in front of the great glacier, and measuring the angle which its extreme edge forms with the horizontal line. Until the height of 3400 feet was reached on the mountains in question, the angle was found positive—viz., the edge of the glacier appeared higher than the observers' station; but from more elevated stations it turned negative, so as to reach ÷ 43' when observed from a height of 6247 feet, the "ice-horizon" showing a dip corresponding to this. Conformably to the roundness of the earth, a distance of nearly 100 between the observer and a point equal in height to his station, would be required to produce this deviation from the level line. It may be added, that the mountain-top here mentioned, as far as we know, is the highest point ascended in Danish Greenland. However, this locality was situated outside, that is, at some distance from the inland

ice. But under 62½° N. lat. a rock was mounted emerging from the very surface of it to a distance of about 40 miles from the outer margin. It was one of the so-called Nunataks,—mountain-tops of the submerged land now rising like islands in a frozen ocean. Its height was 5000 feet above the sea, and 1000 feet above the ice-plateau, which here consequently had reached 4000 feet. It seems probable that the farthest point or line of the latter, viewed here towards the inland, surpassed 7000 feet.

Finally, we have to mention the Swedish expedition under Nordenskjöld, in 1883, who penetrated into the interior of Greenland under 68° N. lat., several times farther than any expedition before. Here no Nunataks at all were met with. The gradient of the inland-road was much smaller than anywhere else. The first 40 miles offered a very uneven ice, almost without snow, and full of waterholes, ending in a height of about 3300 feet above the sea. For the next 22 miles the ice was covered with a deep sheet of watery snow, continuing until reaching 4500 feet, and finally the Laplanders of the party passed 115 miles, reaching a height of 6000 feet. The latter part of the way was quite level, with only an insignificant rise, but passing over deep snow without water, and only to be travelled over by means of snowshoes. The whole route into the interior of Greenland travelled by the expedition made more than 160 miles in a straight line, and about 400 kilometres by summing up the days' journeys.

The unevenness of the surface in the marginal part of the glacier is chiefly owing to enormous fissures (crevasses), shoal basins, and slightly indicated terraces. These irregularities, however troublesome and dangerous they may be to travellers, are too insignificant to affect the appearance of horizontality exhibited by the extensive *mer de glace* of the interior. But the idea of an inundation, to which we are led in this way merely by the view of it, is still more supported by observing the movements to which the huge covering is subjected, and by the fact discovered with regard to glacier-ice in general, that it is able to move, although in an extraordinarily slight degree, conformably to the laws of water in a fluid state. If it has been observed that glaciers of any size slowly flow down mountain sides which apparently they occupy without moving, it seems natural that a glacier of sufficient magnitude can overflow the lowland in front of them. In this way Greenland can have been inundated by glaciers issuing from its central regions. These glaciers have taken their way towards the sea, following the original river-beds, but at the same time they swelled on account of the obstacles offered by the uneven ground, so as to flow over the hills which encompassed their beds. Their growth was pro-

moted by the rise of their surface, which augmented their capability of converting the snow falling upon them into solid ice. Successively the glaciers united so as to offer one continuous margin on arriving at their present limits at the heads of the fjords. But now in examining the movement of this edge, we are struck by the unequal distribution, of its actions. Abiding by the *simile* of an inundation we ought to expect that if the ice continued to flow over, the margin would advance throughout the whole line of its extent. This is found to be the case. A general movement of the whole mass from the central regions towards the sea is still continued, but it concentrates its force to comparatively few points in the most extraordinary degree. These points are represented by the so-called ice-fjords, through which the annual surplus of ice is carried off in the shape of bergs. This fact, however, may be explained by considering the original state of the land before it was covered with ice. More or less considerable rivers must then be supposed to have drained the interior. When these large watercourses had disappeared under the level of the common ice-crust, the watersheds which had separated them nevertheless must be supposed to have been in the main still able to direct the general drainage along its original principal paths. That although they have disappeared from the surface, the lower mountain ridges still acted in this way upon the ice deep down, agrees with the necessity of supposing the lower strata of the ice to be traversed by channels through which water still forces its way to the sea in its fluid state.

Conformably to the velocity with which the ice is pushed into the ice-fjords they have been divided into three classes. In Danish Greenland are found five of the first, four of the second, and eight of the third (or least productive) class, besides a number of inlets which only receive insignificant fragments. Direct measurements of the velocity have now been applied on three first-rate, and one second-rate, fjord, all situated between 69° and 71° N. lat. The measurements have been repeated during the coldest and the warmest season, and connected with surveying and other investigations of the inlets and their environs. It is now proved that the glacier-branches which produce the bergs proceed incessantly at a rate of 30 to 50 feet per diem. This movement being not at all influenced by the seasons.

In the ice-fjord of Jacobshaven, which spreads its enormous bergs over Disco Bay, and probably far into the Atlantic, the productive part of the glacier is 4500 metres broad. The movement along its middle line, which is quicker than on the sides nearer the shores, can be rated at 50 feet per diem. The bulk of ice here annually forced into the sea would, if taken on the shore, make a mountain 2 miles long, 2 miles broad, and

1000 feet high. The ice-fjord of Torsukatak receives four or five branches of the glacier; the most productive of them is about 9000 metres broad, and moves between 16 and 32 feet per diem. The large Karajak glacier, about 7000 metres broad, proceeds at a rate of 22 to 38 feet per diem. Finally a glacier branch dipping into the fjord of Jtivdliarsuk, 5800 metres broad, moved between 24 and 46 feet per diem.

If now we would consider the significance of these results with regard to the European glacial epoch, it might probably be proved that while large glaciers on other parts of the world are nourished by the snow falling upon an area of 20 to 30 square miles, a first-rate ice-fjord will require at least 20,000 square miles for its tributary basin; in other words, a thousand times more. Consequently, in order to explain this remarkable supply of ice, we must have recourse to the central parts of Greenland; in other words, admit the possibility of ice more than a 1000 feet thick being transported several hundred miles overland. Sliding over an uneven ground with its enormous weight, this ice cannot avoid breaking asunder protruding rocks, and carrying the fragments imbedded in its mass.

A series of observations, partly likewise connected with measurements, have been applied on the margin of the inland ice in other places. But as we have now considered those parts of it in which the movement exhibits its highest degree of intensity, it may suffice to mention a locality where, on the contrary, the margin apparently remains almost stationary. In this way an idea is obtained of the mean action comprised between these extremes. Several observations have shown that where the inland ice abuts on low land, its margin must be supposed to periodically proceed and recede, so as to remain, on the whole, stationary. One of our recent expeditions was directed especially to investigate a certain locality with regard to this question. It was the so-called "Iceblink" in 62½° N. lat., well known to voyagers along this coast. That it was frequently observed and spoken of during the lapse of more than a century, was a natural consequence of its situation, as the ice-wall here projects almost to the open sea, from which it is separated only by a narrow and marshy plain. No locality could be more favourable for observing the slower movements of the ice than this. In the first place, it is here protruded as a tongue between high headlands bordering it to the south and the north. Secondly, it is dotted with "Nunataks," which are peculiarly fit for indicating the nature of the movements, by opposing their walls to them, just as rocks or piles fixed in the ground may act towards the currents of the sea. Nowhere else is there a better opportunity for observing how the huge, solid, and fragile mass assumes the character of a fluid substance. It

is stopped by the "Nunataks," but accelerates its course when pressed between them. In fact, it may be considered as forming real currents, the directions of which, chiefly judged from the unevenness of the surface, are indicated on the maps laid down by the expedition. The whole surveyed area of the inland ice in this place is calculated at 450 square miles, and forms, by means of the tongued shape of its foremost part, in some measure a separate district, in which the principal changes of the whole margin, excepting the ice-fjords, are represented. Towards the interior it is bordered by a row of "Nunataks," distant about 40 miles from the seaward edge which our travellers had ascended as their starting-point. Here the origin of the ice over which they had passed was at once plainly visible, namely, that it could not have been formed on the spot, but was brought thither from the interior of the continent. The Nunataks had been an obstacle to this movement: on their east side, facing the interior, the ice was broken and piled up several hundred feet against the rock like the breakers of an ocean; while to the south and north, and between the Nunataks, it poured down like frozen waterfalls to be embodied in, and levelled with the crust over which our explorers had travelled. Considering this powerful action by which even here, though far from the ice-fjords, still a remarkable supply of ice is received from the inland, it appears strange that the outer wall of the "ice-blink" has, as far as we know, not at all advanced towards the sea during a period of more than 100 years. In travellers' accounts from the middle of the 18th century it was described just as it presents itself now-a-days. The expedition here in question, however, has revealed facts satisfactorily explaining these apparently contradictory observations. It was on the 13th of July when the travellers started from their camp near the sea-shore and ascended the glacier. On the 24th they reached their furthest point, and after having experienced many dangers and hardships, they returned on the 5th of August. Of the whole surveyed area, making, as mentioned, 450 square miles, about 120 square miles were less than 2000 feet above the sea. Not before this height was reached was the surface covered with snow. Considering that this lower part (about a quarter of the whole) as early as the 20th of July was bare of snow from the last winter, it will not appear impossible that during the lapse of ages the heat of the sun has counterbalanced the supply of ice from the interior. A similar conclusion may be drawn from what is noted above concerning Nordenskjöld's remarkable journey in 1883.

The recent explorations, as already mentioned, have proved that what now we designate as coast land free from ice was formerly covered with ice like the interior. This ancient ice-covering

reached, in the immediate vicinity of the present inland ice, a height of 3000 to 4000 feet, and further seaward, 2000 to 3000 feet above the sea. All the usual traces of ancient ice-actions, the erratic blocks and the ground rocks, are the same here as in northern Europe. These facts, however, do not necessarily demand the supposition that merely a change of climate should have caused the ice to recede in such a remarkable degree. The ice-fjords, as we have seen, bear sufficient evidence of a large surplus of ice still being produced by the interior. Should it happen that the bottom of the sea in front of them was raised so as to prevent the icebergs from going adrift and being dispersed, the fjords as well as the adjoining land could not escape being levelled again with the inland under the same ice-covering. The ice-fjords, as we have seen, afford the drainage of a country in which the snow is unable to reach the sea in a liquefied state. But valleys or channels which are able to gather and carry off the downpour of snow and rain, partly as a solid mass, must be submitted to changes far more violent than those of ordinary river beds. It therefore may be supposed that during the ancient glacial epoch in Greenland, new outlets have opened for conducting and discharging the excessive production of ice into the ocean, and this, I believe, to a certain degree at least may account for the ice-crust having disappeared from tracks formerly buried under it.

A similar consideration might lead to partially explain the much wider extent of the European glacial-formation in a direction between south-west and south-east. We only need to suppose that the movement of this widely spread glacier was not so concentrated to certain points as now that of the Greenland inland ice, but more equally distributed over the whole margin; and secondly, that the latter did not meet an ocean deep enough to carry off the detached fragments,—in other words, that no ice-fjords existed.

Of course I cannot conclude the present Paper without giving a complete list of the Danish travellers, to whose zeal, courage, and perseverance we are indebted for the results which I have communicated in this brief account. Until the end of 1884 they were:—

Geologist, K. J. V. Steenstrup (eight summers and two winters); Lieutenant G. Holm of the Royal Navy (five summers and one winter); Lieutenant R. Hammer of the Royal Navy (three summers and one winter); Lieutenant A. D. Jensen of the Royal Navy (four summers); Geologist and Botanist, A. Kornerup (three summers); Geologist, Sylow (two summers); Painter, Groth (two summers); Supernumerary officer, Larsen (one summer); Lieutenant Garde of the Royal Navy (two summers and one winter); Geologist, Knutsen, Norwegian

(two summers and one winter); Geologist, Petersen (one summer); Botanist, Eberlin (two summers and one winter); Painter, Rüs Carstensen (one summer).

It may be added, as regards the object of the present Paper, that the investigation of the ice-fjords was performed chiefly by Messrs Steenstrup and Hammer; and the journeys over the inland ice, in 62½° N. lat., by Mr Jensen as leader, in company with Messrs Kornerup and Groth.