40. *NOTES on the GLACIAL GEOLOGY of ARCTIC EUROPE and its ISLANDS.*
—Part II.¹ ARCTIC NORWAY, RUSSIAN LAPLAND, NOVAYA ZEMLYA,
and SPITSBERGEN. By Col. H. W. FEILDEN, F.G.S. With an
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(Read June 24th, 1896.)

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1. Proof of Changes of Level in Northern Norway.

So much has been written about the glacial geology of Northern Norway by great authorities that I should have refrained from discussing the subject had I not recently heard a paper² read at a Meeting of this Society, in which the author suggested that the terraces in the transverse fiords of North-western Norway would be perfectly explained by the formation of ice-dammed lakes. The author, however, admitted that the authenticated occurrence of marine organisms in these raised beaches would be a conclusive argument against his views. I have never made any special study of the phenomena connected with the secular upheaval of Arctic Norway, for I had always been under the impression that few geological facts were more generally accepted as well established than the recent elevation of land in Arctic latitudes, including Northern Norway. My observations are consequently somewhat cursory, but I do not remember landing on any of the more considerable islands north of the Arctic Circle, that form the 'Skjergaard' of Norway, without noticing traces of recent elevation and deposits containing abundantly shells of mollusca of the same species as those that now inhabit the adjacent sea. The same holds good of the 'Westeraalen,' and I observed last summer a well-defined raised beach near the settlement of Rissohavn, on the island of Andö, full of the shells of recent mollusca; this beach was overlain by 4 feet of peaty soil, in which grew birch-trees.

The lofty chain of the Lofoten Islands has not been buried under an ice-cap. Their sharply peaked and serrated mountain-tops, rising from the sea to altitudes between 2000 and 3000 feet, present no evidence of ever having been overwhelmed by the Scandinavian ice-sheet. There are, however, unmistakable signs that at one period of their history great glaciers filled their valleys. The celebrated Trold Fiord near the western entrance of Raft Sund, the channel between Eastern Vaagö and Hindö, is a narrow but majestic fiord with

¹ For Part I., read Nov. 20th, 1895, see this volume, p. 52.

² Boulger, Quart. Journ. Geol. Soc. vol. li. (1895) p. 494.

Fig. 1.—Diagram of Tromsødal terrace, showing the valley when occupied by a glacier.

perpendicular walls of rock on both sides: these, to the height of some 400 feet, are polished and grooved by the action of ice, but the mountain-peaks that rise above the fiord show no signs of glacial abrasion. Attention has been called to this by earlier writers, notably by the late J. F. Campbell¹ and by Prof. Bonney.² Passing up Raft Surd, amid some of the finest coast-scenery of Norway, one cannot fail to observe the traces on all sides of former glacial action, especially on the eastern shores of the channel. There nearly every valley descending to the shore-line, now bright with green birch-woods and pastures, has the remains of great moraines at its mouth. Farther north, around Tromsø, the signs of recent elevation are common along the shore-line, and so also the signs of the retreat and disappearance of glaciers which once filled the valleys; but I see no evidence that the mountain-tops on the mainland of this part of Norway have ever been covered by an ice-sheet, even at the time of their maximum glaciation.

The valley of Tromsødal, on the mainland opposite the town of Tromsø, has a conspicuous raised terrace (fig. 1) passing across its mouth, and continued north and south along the present coast-line. This terrace must be $\frac{1}{4}$ mile wide at the mouth of the valley, and there brick-works are established. In 1894 a good section of this terrace, some 20 feet in height, was exposed, from which the clay used in the works was being taken.

¹ 'Frost and Fire,' vol. i. (1865) nos. 136-137.

² Alpine Journal, vol. iv. pp. 430-436; 'Do Glaciers Excavate?' Geogr. Journ. vol. i. (1893) pp. 481-499; 'Ice-Work, present and past,' p. 175, London, 1896.

From base to summit it is a homogeneous mass of blue clay, with boulders and stones interspersed throughout. There is not a trace of bedding throughout the mass. As I considered this deposit to be a typical example of boulder-clay formed under water, I took advantage of my journey in the neighbourhood last summer to revisit the spot. A more careful examination showed that the clay contains ice-scratched stones, and that mollusca are abundant throughout the bed; examples of *Cyprina islandica* and *Pecten islandicus*, partially retaining their colour, are common, likewise stones to which the 'bases' of a *Balanus* are attached. On ascending the terrace, which at its base is only a few feet above present high-tide mark, and looking up the valley, one can realize that apart from its composition it owes its formation to glacial causes. This terrace is flat on the top and at the outer edge slopes seaward, and the same on its opposite side looking up the valley. There can be no doubt that this valley was formerly occupied by a glacier; and when the land stood at a lower level than it does to-day, the front of the glacier was in the sea and the terrace was formed by the material which passed from under the ice, and is therefore a kind of subaqueous moraine.

As we sail from Tromsö towards the North Cape, the course takes us through Kaag Sund and past the island of Arnö. The southern shore of that island is fringed for miles by three great parallel terraces. I roughly estimate Arnö at about 1200 feet in altitude and the terraces at 50, 100, and 150 feet above sea-level. Their position on an island exposed to the full force of a stormy ocean is entirely opposed to the possibility of ice-dams having had any connexion with their construction. In Magerö Sund, which separates from the mainland the island whence juts out the North Cape, sea-worn caves, much above the present sea-level, tell of recent elevation of the land.

The remarkable terraces in the Porsanger and other northern fiords of Norway have been noticed by Bravais, Martens, J. D. Forbes, Chambers, Campbell, Bonney, and others in their descriptions of this part of Norway. The Porsanger is the first of the large fiords that run into the mainland of Finmark. It is about 18 geographical miles in length. The hills on either side are low, probably not more than 500 feet in altitude. They have an ice-planed, ice-smoothed contour. The topographical contrast between this area and the peaked Lofotens and those around and immediately south of Tromsö is striking. The island of Stor Tamsö lies in the centre of the Porsanger Fiord. Its greatest height is probably not more than 300 feet; it is about 7 square miles in extent. Evidently an ice-worn surface, it is entirely or almost entirely covered with a growth of peat, showing a depth in places of 8 or 9 feet before reaching the polished underlying rock, which is a rather felspathic quartz-schist.¹ Where I landed, the rock, smooth and slippery, passes with a gentle slope into the sea.

¹ See Prof. Bonney's determination of this rock, p. 741.

Our boat ran up this rock as over a sand-beach, while both below and above the tide-mark the rock is so grooved with glacial striae that it looks as if they had been made by the keels of boats hauled over sand which had subsequently indurated, while in reality it is a very hard quartz-schist. This island is girdled in part by a series of old beaches rising one above the other to a height of not less than 100 feet. The highest that I traced looks like a line of ancient fortification. This is due to the accumulation of peat which has spread over it, and which, sloping towards the sea, is on the land-side in many places perpendicular. Where runnels have cut through this terrace the ancient beach is exposed; in it are fragments of nullipores identical with the remains that are piled up along the shore at present sea-level, and these at a little distance look like accumulations of magnified grains of sago. The presence of the remains of this nullipore in the higher terraces effectually disposes of the theory that these beaches might have been the result of interglacial damming.

The remarkable and extensive series of terraces on both sides of the Varanger Fiord, which separates Norway from Russian territory, are well known. My friend Prof. Alfred Newton, who visited the Varanger forty years ago, kindly gave me the following note from his journal and that of Mr. W. H. Hudleston, his companion. They were journeying along the northern side of the fiord, not far from Vadsö. He writes¹:—‘We continued our walk along a raised beach about 50 feet above high water and 200 yards from the shore, where lay the bones of a whale that had probably been stranded there in old times. Each of the whale’s vertebrae was covered with turf. We scratched the ground in places and found ribs, but I do not remember that we found the head.’

On the little island of Vardö, on which the town is built, and near the fort from which the island takes its name, is a marine sand-deposit some 40 to 50 feet above sea-level. I lately took from this spot remains of seal,² cetaceans, fishes, and mollusca. I might easily enlarge the list of localities in Arctic Norway which I have visited, and where similar proofs of recent elevation are to be met with: but I think that I have conclusively shown the presence of marine organisms throughout the raised beaches of Arctic Norway, and consequently their marine origin.

2. Terrace-making in Kolguev Island.

On former occasions³ I have pointed out the part which the ice-foot performs in the formation of terraces in Polar regions. I observed

¹ Alfred Newton, *in litt.* 1895.

² Mr. E. T. Newton, F.R.S., F.G.S., very kindly identified these specimens brought from the raised beach at Vardö as belonging to *Halichoerus gryphus* (Grey Seal), *Phoca hispida* (Floe Rat), *Gadus morrhua*, with *Buccinum undatum*, *Modiola modiolus*, and *Pecten islandicus*.

³ Ann. & Mag. Nat. Hist. ser. 4, vol. xx. (1877) p. 487; Nares, ‘Voy. to Polar Sea,’ 1878, vol. ii. pp. 341-342; Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 565.

the making of a terrace lately on the island of Kolguev, not on a great scale, but still sufficiently important to be a guide. The broken ice-pack was pressed on to the western shore of Kolguev by a strong gale for three days. The width of this pack as I saw it was from $\frac{1}{2}$ to $\frac{3}{4}$ mile; it was a chaos of ice-material, blocks and fragments pressed together by the force of the gale which was raging outside, and huge waves dashing over the windward side of the pack. Standing on the beach, the crushing and grinding of the ice-blocks, with their dismal groaning, was audible above the noise of the wind. An 'angry' pack under such circumstances is a very awe-inspiring force of nature. As the ice pressed on the shore, it drove before it banks of mud and gravel; these were pushed up in ridges several feet high, and the tops of these banks were rough and irregular. The gale died away, and the ice, which had

Fig. 2.—Terraces across the mouth of the Gosina River, Kolguev Island.

[From a photograph by H. J. Pearson, 1895.]

acted as a breakwater, disappeared. Then came the influence of the sea. No longer kept back from exerting its power on the shore-line by the protective ice-barrier, the waves at the height of the tide pushed their crests over the heaped-up ridges of mud and gravel, and as they surged along levelled them as flat as a billiard-table. As successive tides came in, not so high or strong as those immediately following the gale, the raised surface was cut parallel to the shore-line as straight and perpendicular as if done by a spade

for considerable lengths, $\frac{1}{2}$ to 1 mile, according to the nature of the shore.

Now, supposing what I saw happened, as it must often do, in the autumn, at a time of great snow-precipitation, this newly-formed terrace would be strongly protected, and when the sea washed against it would rapidly be turned into ice, for snow absorbs sea-water with marvellous rapidity, and the terrace would be enveloped in a mantle as hard as glacier-ice. Supposing that this occurred accompanied by emergence of the land, we have found here one cause for rapid construction of terraces. That this does happen I have no doubt, for where I saw the terrace made, namely, between the Gosina and Kriva rivers, there were three other terraces standing behind this last-formed one. The oldest of these was apparently above the influence of present high tides, being about 100 yards inland, some 6 feet in depth, and possessing a perfect slope. For most of its extent this terrace was covered by a protecting mantle of *névé*, which was only bared at intervals; but in these places it showed perfectly regular terrace-structure.

3. Glacial Geology of the Kola Peninsula.

As we sail eastward along the Murman coast of Russian Lapland, we see on our right hand a bold and precipitous country. Its highest summits appear to rise to 500 or 600 feet. The hills are planed down to a general level, and no peaked mountain breaks the monotony of the scene. In bays and indentations, immense raised beaches are noticeable, especially to the westward of Cape Cherni. Sviatoi Nos is the prominent headland which marks the entrance to the White Sea when approaching from the westward. This promontory forms the eastern side of Sviatonoskaia Bay, and the Ukanskoe River enters its south-western angle. Here the river is about $\frac{1}{2}$ mile wide and is navigable for vessels of small draught for $3\frac{1}{2}$ miles, when the rapids commence and the tidal influence ceases. From the entrance of the river to the rapids it is more correctly a fiord, flanked on each side by steep heights of granitic, gneissoid, and dioritic rock,¹ which rise to an elevation of 250 or 300 feet. A remarkable feature in this fiord is a ridge of large boulders which lines either shore to the height of 20 feet or more. It does not seem credible that tidal influence could have ranged the boulders in their present position, although the rise at spring-tides is 14 feet.

These boulders are of the same lithological character as the rocks in the neighbourhood. On ascending to the uplands from the banks of the Ukanskoe, an elevation of some 300 feet, we find a sombre grey, monotonous expanse of ice-worn land with hardly any surface-soil. There are hills, and eminences, and escarpments of rock, with undulations and swellings in this rock-surface, but the highest points are probably not more than 600 feet above sea-level, and 500 feet, measured by aneroid, was the greatest elevation that

¹ See Appendix by Prof. Bonney, p. 742.

Fig. 3.—*View on the Ukanskoe River, Kola Peninsula, showing fringe of erratics skirting the shore.*

[From a photograph by H. J. Pearson, 1895.]

the writer reached. A remarkable and prevailing feature of the country is the vast number of erratic blocks spread over it in every direction. Standing on some eminence we see around us countless boulders, all clad in coats of shaggy lichen, reminding one of Catlin's pictures of herds of bison resting on the prairies of the Far West. But our astonishment is increased when we examine them individually, and see the extraordinary positions that some of them occupy. Here a huge block resting on a couple of others, there two or three raised directly one upon another, again others standing as monoliths. From the descriptions of the distribution of erratics in Finland and Lapland by Durocher, Wraxall, Clarke, and others, I was prepared to see a remarkable number, but their dispersal over this portion of the Kola Peninsula excited my astonishment.

When the eye becomes better acquainted with the position of these blocks, certain salient features appear. Though they are spread generally over the surface of the country and lie broadcast on eminences and slopes, yet there is a tendency for them to collect in hollows and undulations of the surface. A notable feature in these aggregations is the entire absence of earth, clay, or sand between the blocks. As all these boulders are covered with a thick lichen-growth, it is impossible to note whether they are grooved or ice-

Fig. 4.—*General view of the boulder-covered area on the tundra, in the neighbourhood of Sviatoi Nos, Kola Peninsula.*

Fig. 5.—*View of the boulder-covered area in the neighbourhood of the Ukanskoe River, Kola Peninsula.*

[From photographs by H. J. Pearson, 1895.]

scratched. Fragments which I took from some of them are pronounced, by Prof. Bonney, to be fine-grained reddish granite, moderately coarse, rather felspathic gneissoid granite, a pale red gneissoid rock, granitoid or slightly gneissoid rock, and a dull red very fine-grained felspathic sandstone.

By referring to the valuable and exhaustive appendix of Prof. Bonney (p. 742), it will be seen that these erratics agree so closely in character with the rocks *in situ* of that part of the Kola Peninsula, that there can be little or no doubt as to their local derivation. The accurate determination of these rocks by so high an authority is of great importance. It presents strong evidence that there is no importation of foreign rocks among the vast accumulations of boulders on the Kola Peninsula—that no ice-sheet bearing its cargo of rocks from the north ever passed through Barents Sea, or impinged against the northern coast of Europe. It seems to me that in this local manufacture of erratics on the Kola Peninsula we meet with a striking example of the destructive powers of an ice-sheet resting on a comparatively level area.

Considering the tendency of the erratics on this part of the Kola Peninsula to accumulate in hollows and undulations of the surface, it appears that we have evidence pointing to a somewhat sudden recession or withdrawal of the ice-sheet. I do not accept a diluvial

Fig. 6.—*Diagrammatic section of boulders in hollows, neighbourhood of Sviatoi Nos, Kola Peninsula.*

theory, such as a deluge sweeping the erratics into the undulations, but it seems probable that during the melting of the ice-sheet there was a tendency for the decomposing ice to drift the blocks into the hollows as we now see them. On the other hand, for all we know to the contrary, it may be incidental to an ice-sheet moving over a comparatively level land to push the boulders into depressions of the rock-surface beneath it. Only in one spot did I meet with a formation that had somewhat the appearance of a moraine, but as it consisted entirely of blocks, without any sand or smaller *débris* visible, it may be merely an accumulation of blocks formed under the ice-sheet. This mound stood on the edge of a ridge, which looks down towards the valley of the Ukanskoo River: its elevation is 415 feet, and it runs nearly due north and south, is about $\frac{1}{2}$ mile in length, and about 40 feet in height.

Eastward of the estuary of the Petchora River the great Bolshaia Zemelskija tundra stretches to the base of the Urals, and along it we find proofs of elevation of the land in recent times. The Arctic explorer, Mr. F. G. Jackson, in his book 'The Great Frozen Land' (p. 128), tells us:—'We had been steadily travelling

Fig. 7.—Tundra, with boulders, neighbourhood of Ukanakoe River, Kola Peninsula.

across the frozen tundra for eighteen days, when on the 1st November we crossed the Piatsoworyaha River, and on the following day, about 8 miles west of the river, entered a most interesting region. Right in front, and away to the northward, there spread the amphitheatre of an old bay, whose width would be about 15 miles, and its inmost reach at least 9 miles from the present seashore. Step above step there ranged the old sea-beaches, following the lines of the higher land immediately behind them, and girding with a terraced rampart the level basin of salt marsh into which the waves once rolled. The beaches themselves were now thickly covered with grass, and the grass with snow: but walking along the terraces I found several pools of salt water, and a number of recumbent pine-trees—one of which I measured, to find it was 40 feet long, and 2 feet in diameter at the thickest end.' From this it would appear that we are justified in assuming that the secular elevation of what is now the Bolshaia Zemelskija tundra was coincident with the emergence of the island of Kolguev, with its marine boreal beds now rising to a height of 250 feet above the sea. Further, I think that the cartographers of maximum glaciation in Europe should hesitate before extending an ice-sheet over that wide region lying between the Timan and Ural ranges, north of the Arctic Circle.

In order to connect our survey of the Arctic coast of Europe with the islands of Novaya Zemlya, I will again quote from Mr. F. G. Jackson, who, so far as I am aware, is the only educated person who has traversed the island of Waigatz in its entirety, and his observations are of interest when taken in conjunction with mine on Gooseland in Novaya Zemlya. From Mr. Jackson we learn that there are two main ridges on Waigatz, that on the eastern side composed of limestone and limestone-shale running in a north-west to south-easterly direction, and having a general elevation of from 150 to

300 feet, the other parallel to it on the western side of the island, but not rising higher than 70 feet. The intervening portion and the land bordering the sea he describes as tundra. Mr. Jackson writes¹:—‘The tundra rolled away to the point, the ridges sometimes reaching a height of 30 feet above the intervening troughs. Along the lowest level of the troughs shallow pools and lakes were frequent Down in the troughs the soil was bluish mud while on the ridges there outcropped the long friable sheets of limestone-shale which I found all over the southern part of the island and on the tundra around Habarova. . . . Round Dolga Bay (on the north-western side of the island) there is every evidence of the present shore-line being of comparatively recent existence. A raised beach about 12 feet above present level runs persistently along the cliffs.’

4. Novaya Zemlya.

My personal acquaintance with Novaya Zemlya is limited. I have visited only a small portion of the western side of the south island, between the parallels of 71° and 72° lat. N. The appearance of this part of Novaya Zemlya is disappointing in scenic effects. There is nothing in its character approaching the grandeur of the western coast of Spitsbergen. Making for the shelter of Kostin Schar or Strait, that protected reach of waters lying between Mesdusharsky Island and Novaya Zemlya proper, we pass between low-lying Gooseland and Mesdusharsky. Their topographical features are quite distinct from those of the rest of Novaya Zemlya, and they appear to be long low tracts of tundra just rising above the sea and fringing the interior highlands.

In the vicinity of Rogatcheva Bay, where we made our first landing, the country rises abruptly from the shore to the height of between 500 and 800 feet, more or less. This hilly region, intersected by valleys with many lakes, extends for some 15 to 20 miles to the base of the interior range, which rises in a series of sharply peaked and serrated mountains averaging some 2000 feet in height. At the time of our visit, in the latter part of July, the land was generally clear of snow, little even remaining on the central ridges except in their higher valleys and gorges. I detected no glaciers on their flanks, and we saw no glaciers issuing into Kostin Schar.

The rock-formations of this part of Novaya Zemlya dip at very high angles, often nearly vertical, so that their outcrops appear as ridges. On all sides these are shattered and riven by frost, so that we walk over leagues upon leagues of splintered and shivered rocks. This is the work of frost and subaerial disintegration. I can see no evidence of the former extension of an ice-sheet over this area, no ‘*roches moutonnées*,’ no glaciated surfaces, no rounded, mammillated, ice-worn contours. Had these at any time existed one can hardly suppose that they could have been totally removed by the

¹ *Op. cit.* pp. 31, 32, 37.

action of frost. I am making no reference to stratigraphical geology in this paper, but it may be mentioned that some 5 miles inland from Rogatcheva Bay I came across an outcrop of rock, apparently very similar to a characteristic series of erratics in the glacio-marine beds of Kolguev. It contains plant-remains, and is probably of Jurassic age (see p. 744). It is quite within the range of reasonable assumption that a portion of the Kolguev erratics may have been floated from Novaya Zemlya.

It is to Gooseland and the islands in Kostin Schar that I wish particularly to draw attention. The latter are worn down and abraded in contour, but as the rocks of which they are composed almost always crop out at a high angle, and as they are very shaly in character and readily decay and splinter, no marks of glaciation are left on them. From Prof. Bonney's report they appear to be sedimentary rocks of Palæozoic or Archaean age.

All of these islands which I was enabled to visit have deposits of boulder-clay lying in their undulations and hollows. I met with sections showing a depth of 20 feet; the clay is of the same colour as the rocks upon which it rests, and the included stones are angular fragments of the same rock. I did not detect an erratic, or a rounded stone, or an ice-scratched stone in any of this boulder-clay. In many places it is full of shells of marine mollusca, *Saxicava arctica* predominating, though I found other species common enough. In some localities one might gather these shells by the bushel, few of them broken, never triturated, and in some cases the two valves are in contact.

This description holds good also of the part of Gooseland that I visited, the abraded ridges, the deposits of boulder-clay in the troughs, and the presence of shells of mollusca, all being characteristic features. As I have expressed a very decided opinion that no ice-sheet has ever extended over this part of Novaya Zemlya, I may be asked to account for the presence of these widespread deposits of boulder-clay, with the assemblage of the remains of marine mollusca in them. I venture to urge the view that the wearing down of Gooseland and the islands in Kostin Schar, and the deposition of the boulder-clay, are entirely due to the action of floating ice.

I pass on to give some examples which I witnessed of the force that floating ice can exercise. Last summer I was observing a narrow pack of floating ice which for a few days hemmed in the western side of the island of Kolguev. This ice-pack was moving along the shore at the rate of 3 or 4 miles an hour. Some $\frac{1}{4}$ mile seaward from the beach on which I stood lay a shoal under water. At this spot there was a constant turmoil and hubbub in the floating ice. The unusually heavy pieces grounded on this shoal, and for a short time checked the march-past of the ice-column. The delay, however, was no long one; the pack accumulated behind, and by its pressure forced the lagging blocks over the shoal. As a rule, the accumulating pack dealt in a very summary way with the obstructionists, by passing under them and turning them upside

Fig. 8.—Sketch of Gooseland, July 4th, 1895.

[We had run through 40 miles of pack-ice, but found it impenetrable and wedged fast on Gooseland for 10 miles, closing Kostin Strait, and belting round Mesdusharsky Island.]

Fig. 9.—*Islands in Kestin Schar, connected by a glaciated ridge, or causeway, covered with shingle.*

[The floe is shown pressing up on either side: at the left-hand corner the ice is pushing against the land.]

down on the floe. The undersides of these blocks came up covered with mud and detritus from their contact with the bottom, and were swept onward by the ice-pack, their black colour being very distinguishable on the white surface of the ice-stream. Now, to force these blocks of ice, which were probably 8 to 10 feet in thickness, over an obstacle must require immense pressure, and it seems unreasonable to suppose that they do not exercise some abrading force; if not, why should the blocks have their under surfaces coated with material from the bottom? What I saw occurring at Kolguev on a small scale has doubtless been carried on extensively off the coast of Novaya Zemlya. Given a comparatively flat tract under water, such as Gooseland was, and a constant process of emergence, I see no reason why floating ice moving with a hundredfold greater velocity than a glacier should not be able to wear down ridges over which it passes, provided that the process of secular elevation is bringing the land and the floating ice into contact. The formation of boulder-clay, replete with mollusca, would be the natural sequence.

Next let us turn to a more distant part of the Polar area, where the powers of floating ice are witnessed on a much grander scale. In Smith Sound the fragments of the heavy floes of the Palæocrystic Sea are summer and winter endeavouring to work their way southward. Much of this ice is of stupendous thickness, floes 40, 50, and even 100 feet thick being met with. This vast body of ice, ever moving slowly southward through the strait, pushing over shallows, and rubbing and grinding against the shore, must surely be gifted with some wearing force. At headlands, or where the progress of this pack is interfered with, the enormous power of floating ice is exemplified. At such a point of pressure, the ice pushing against the shore exerts extraordinary force. An enormous mass of floe is brought to a stop against some part of the shore, while the check is transmitted to the ice pushing behind. The edges of these various floes are brought into contact with one another; they rise at their edges and crumble upon themselves, forming ridges of pressed-up hummocks 50 to 60 feet high. The pressure from behind forces the grounded floe to act in a similar manner against the shore. Slowly, as if urged by some hidden hydraulic force, the edge, impinging against the shore, commences to rear itself up in a chaos of ice-débris, and the blocks roll down on the floe or on to the shore. The portion that has grounded or been jammed against the shore being now pulverized, the obstruction is cleared, and the ice resumes its onward march. Is it possible that such pressure between land and floating ice can take place without some effects being produced? I think not, for at such points of contact, when we were able to reach them, we found the rock polished.

There are two or three islands lying along the eastern shore of Grinnell Land in Smith Sound, which offer some useful testimony, notably Norman Lockyer Island, which is encircled by several well-defined terraces or sea-beaches to an altitude of 300 feet. These terraces rest on rock-surfaces which show in places, where they are

laid bare, ice-worn surfaces and striations. Now, as the striæ on the limestone-rock of this island are as fresh-looking as if they had just been made, I am at a loss to understand how this can be, if they are due to the effects of land-ice. If so, how great the changes which these striæ must have encountered! First, what is now the water-way of Smith Sound must have been occupied by land-ice, then it must have disappeared, and the land must have sunk sufficiently at least to allow of the highest terrace being formed, which would be a submergence of 300 feet. Then followed a period of emergence, during all which time the island has been undergoing contact with floating ice, and yet we are asked to believe that the scratchings of the former ice-sheet have remained on the rock as fresh as they appear on the specimen that I have now in my hand! It seems more likely that the glaciation and striation went on simultaneously with the emergence of the island from the sea, and that they are the result of floating ice pushing over or along the island.

In Kostin Schar many of the islands and islets are connected by ridges, and frequently one is able to walk from one island to another over a causeway $\frac{1}{2}$ mile, more or less, in length. These causeways are covered with rounded stones and shingle, the pushed-up floe-ice lying on either side like the pictures of the 'passage through the Red Sea' in the books of our childhood. If we examine such a causeway we find that it has no character in common with a moraine, for the shingle is rounded by the action of the sea, and is only a few feet in thickness at the most, while in spots where the shingle does not lie the glaciated surface-rock appears. Now, when we reach the end of a causeway and the base of either of the connected islands, we not unfrequently find the floe-ice pushing up the ridge and against the base of the island in a way that shows it to have a scarping and destructive force. (See fig. 9, p. 734.) We can point as evidence of this to the pieces of rock and débris which have recently fallen from the escarpment of the island on to the ice-floe, and to disjointed pieces of rock ready to come away which are to be noticed at the meeting of the impinging ice and the abruptly rising land-face. Moreover, as I have already remarked, the surface of the ridge on which the edge or snout of the floe-ice is pushed up is glaciated.

I have seen similar glaciated, shingle-strewed ridges appearing above the sea, with the pack-ice grounded and pushed up on either side, in many other parts of the Arctic regions—Spitsbergen, for instance. I have in my possession a photograph of a well-marked ridge in Loom Bay, Spitsbergen (taken during Mr. B. Leigh Smith's voyage to that country in 1873), which that distinguished Arctic explorer gave me on his return. Being desirous of learning whether the views of that highly qualified observer coincided with my own, I recently communicated with him and received the following reply:—'I believe that the ridge in Loom Bay, Spitsbergen, of which you send me a sketch, was formed by the ice grounding on each side of a shallow, and forcing up the shingle from the bottom. There is a strong tide running into and out of Loom Bay. In Hinlopen Straits

there are many low islands of columnar basalt which have been polished by the ice driving over them. I do not recollect whether the ends of these islands had been worn away or whether they were connected by ridges.'

I have observed several minor phenomena connected with glacial geology in Novaya Zemlya on which I should like to make some remarks. There is a peculiar phase of rock-erosion which a photograph shows better than any words can explain. The large lake

Fig. 10.—*View on the Neckwatowa River, Novaya Zemlya, where it issues from Wilczek Lake (showing rock-erosion).*

[From a photograph by H. J. Pearson, 1895.]

of Neckwatowa, which is on the western side of Novaya Zemlya in lat. $71^{\circ} 20' N.$, communicates with the sea by a passage that has been cut through hard limestone-rocks thrown up almost vertically. The fossils in these are so badly preserved that it is not possible to indicate their precise age. (In connexion with this will be found a report by Mr. E. T. Newton, F.R.S., in Prof. Bonney's Appendix.) This channel is about a mile in length, and from 80 to 100 yards in width; the walls on either side are precipitous, and their height is 40 to 50 feet. There can be little doubt that the channel has been cut out by the water and ice passing from Neckwatowa Lake to the sea. (See fig. 10.) It will be noticed in the photograph that

on both sides of this channel at the present water-line the rock is eaten away in the shape of a semi-culvert. This is largely due, I imagine, to ice-abrasion; but at the same time does it not point to a lull in the upward movement of the earth in this part of Novaya Zemlya?

A phenomenon observable in all Arctic regions, whence the snow dissolves in summer, has not, I think, received adequate explanation. It is that tendency of the surface-stones to arrange themselves most commonly in the form of hexagons. We see this on a small scale on Scottish mountains, and very commonly in Iceland. Pajkull refers to its occurrence in Iceland, and gives a sketch¹ illustrating this disposition of the stones on an Icelandic 'Melr.' His explanation is not altogether satisfactory, though it is founded upon that of so high an authority as Prof. Steenstrup, namely, that the earth rendered soft by the melting of the snow in spring has become dried by the heat of summer; that rifts or cracks are formed in it, and when a storm occurs the small stones that lie on the surface of the 'Melr' are swept down into them. This explanation does not, however, account for their formation on the large scale met with in high Arctic latitudes. I have seen in Novaya Zemlya these arrangements of stones occurring in groups, the diameter across each enclosure being 18 inches to 2 feet—the stones composing the enclosures being of considerable size, a foot or more square; the interior was occupied by a mound resembling a mole-hill. I think that the arrangement is unquestionably connected with the melting of the snow, but why the stones should be distributed as they are is not quite clear.

To another phenomenon that we observed on Gooseland we gave the name of 'stone-bogs.' Tracts of soft mud, in which a man sinks over the boot when walking, were frequently covered thickly with stones, so much so that we could walk in comfort over these treacherous spots for a hundred yards at a stretch. The stones moved under the tread, but did not sink. They lay on the surface of the quaking mud as smoothly as if a roller had been passed over them.

5. Franz Josef Land.

We have evidence that secular elevation of the land is as recognizable a feature in Franz Josef Land as in other parts of the Polar area. Payer frequently mentions the raised beaches, visible on all sides, during his sledge journey up Austria Sound,² while the members of the Jackson-Harmsworth Expedition report that their winter house 'is situated on a raised beach 115 feet above the sea.'³

¹ 'A Summer in Iceland,' p. 21, Eng. trans., London, 1868.

² 'New Lands within the Arctic Circle.'

³ Montefiore, Geogr. Journ. vol. vi. (1895) p. 507.

6. Spitsbergen.

Spitsbergen, especially its western coast, presents the most sublime and magnificent scenery that I have met with in Polar lands. Its western shore is as easy of approach in summer as that of Norway, and secure anchorages and harbours can always be reached. It is a land pre-eminently suitable for the study of glacial effects, for not only do we find there the forces of land-ice, but also, as it is an area of rapid emergence, the phenomena connected with glacio-marine action can be seen in progress. Along the shores of the great estuaries, such as Ice Fiord, old sea-beaches and terraces, containing the shells of recent mollusca in great quantities, are frequent. But the only novel observation which I have to record is that, owing to the rapid elevation of the land, we can examine in detail immense deposits originally formed under water in front of glaciers. These deposits in many cases now lie between the present shore-line and the edge of the glacier of to-day, and their thickness and extent make them deserving of attention. A very notable formation of this nature is to be found at the head of Green Harbour, one of the minor indentations on the southern side of Ice Fiord. The front of the glacier that now occupies the valley is about a mile distant from the present shore-line. Fronting this glacier, the terminal face of which is about 50 feet in height, and extending entirely across it for $1\frac{1}{2}$ mile in length, is a range of low hills, some 50 to 70 feet high and $\frac{1}{2}$ mile in width. These hills have undergone much subaerial erosion, and channels have been cut in them by the numerous streams issuing from under the glacier. Following up one of these watercourses, which average from 25 to 50 yards across, with a very level bottom, we find sections of mud and clay, rising like walls on either side to

Fig. 11.—Diagrammatic section of glacier, moraine, and mud-hills, at the head of Green Harbour, Spitsbergen.

a height of from 50 to 60 feet. These beds contain numerous stones, but neither they nor the stones themselves show any sign of stratification; in them I found shells of *Mya truncata*, but in no great quantity. That these beds are of submarine formation is confirmed by the existence of raised beaches in the neighbouring fiords, and along the adjacent line of coast, at a higher elevation than the beds which I am describing. Between the present face of the glacier and the perpendicular wall of the mud-hills runs a sort of ditch, dry moat, or open space some 30 yards in width, along the entire front of the glacier. The bottom of this ditch or moat is thickly strewn with morainic débris composed of rounded ice-worn stones, many being deeply grooved, scarred, and scratched. Through this slope of rocks and stones the glacier-streams were pouring forth when I visited the spot in July 1894.

If the glacier, as it now does, can force this immense quantity of rounded and scratched stones from beneath it, the same process must have been going on when its snout was submerged in the sea. It seems to me that when emergence of the land is proceeding, as it is now in Spitsbergen, there must come a period when the water at the face of the glacier shoals sufficiently to allow of the bay-ice which forms throughout the winter freezing deep enough to incorporate the boulders of the moraine. This being so, quantities of ice-scratched and ice-polished boulders, stones, and pebbles must be floated away on the breaking up of the bay-ice in summer. This would be a simple explanation of the occurrence of the vast number of scratched erratics which are to be found in the glacio-marine beds of Kolguev Island.

It is well known, and has frequently been remarked by travellers in Greenland, that in the neighbourhood of many of the glaciers discharging into the sea the water is discoloured with sediment, and contains a large quantity of suspended material. That this matter must in time be precipitated is evident; and when lifting the ship's anchor from the front of some of these glaciers (notably the Tyndall Glacier in Bardin Bay on the north-western side of Greenland) I have seen it come up with many pounds' weight of unctuous mud intermixed with sea-shells adhering to the flukes. It is therefore quite evident that water issuing from under a glacier in the Polar regions, and discharging from under the ice into the sea, can lay down glacio-marine beds in the ocean, and that the occurrence of ice-scratched stones throughout these beds can be accounted for.

My object has been to set forth in this paper the effects of glacio-marine action in the alteration of coast-lines, the deposition of boulder-clays, and the glaciation and polishing of rocks by floating ice. I have not alluded to the glacio-terrene geology of the Far North, as it would have extended this paper to unreasonable limits. I have endeavoured to avoid theories and hypotheses, and have confined myself to a bare narration of facts as I have observed them and as I understand them. Do not suppose that for an instant

I compare the glacial effects of a continental ice-sheet as we find it now in Greenland, or as it formerly existed over a large portion of Europe and North America, with glacio-marine action; but undoubtedly the latter has been and still is a not unimportant factor in glacial geology.

In conclusion, I beg to thank Prof. Bonney for his kindness in adding two valuable appendices to this and my former paper. His examination and description of these rocks, some of them from remote and inaccessible localities, are valuable in themselves; but I am most grateful for the light which they throw on the origin of some of the erratics that I have met with.

There can be no doubt that many of the erratics found in the glacio-marine beds of Kolguev are of precisely the same lithological character as rocks found in place in Novaya Zemlya, and we may presume with great confidence that they were carried thence by floating ice and dropped to the bottom in that part of Barents Sea which has now risen into dry land. Again, it is extremely interesting to find, from Prof. Bonney's investigation, that the vast accumulations of boulders on the Kola Peninsula are derived from local rocks, without, so far as we know, any foreign admixture.

APPENDIX.

REPORT on SPECIMENS COLLECTED by Col. H. W. FEILDEN in ARCTIC NORWAY, etc. By Prof. T. G. BONNEY, D.Sc., LL.D., F.R.S., V.P.G.S.

In the following notes the specimens collected by Col. Feilden are grouped according to localities and arranged in the order of the dates on the labels.¹

(i) FROM ROCK IN PLACE, STOR TAMSÖ, PORSANGER FIORD, NORWAY.

(28.) A fine-grained, faintly speckled, light grey rock, apparently either a quartzose gneiss or quartz-schist, without strongly marked foliation. On examining a slice, quartz proves to be the dominant mineral. It occurs in rather elongated irregularly-outlined grains, with borders of a different tint (with crossed nicols). A dark olive-brown biotite is present in both fair-sized flakes and tiny flakelets, with some felspar, but much less than one would expect from the macroscopic aspect of the rock; there are also a few small garnets, a little iron-oxide, and zircon. Macroscopically and microscopically the rock reminds me of some quartz-schists which I have collected near Braemar, Aberdeenshire, and in the neighbourhood of Clifden, Connemara.

¹ The numbers are those affixed to the specimens by Col. Feilden. Sections were prepared for the microscope in cases where the rock seemed likely to be specially interesting. In other cases a fragment was powdered, and the material was mounted on a slide and examined.