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### Notes on the geography, geology, agriculture, and economics of Iceland

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# THE SCOTTISH GEOGRAPHICAL MAGAZINE.

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## NOTES ON THE GEOGRAPHY, GEOLOGY, AGRICULTURE, AND ECONOMICS OF ICELAND.

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ICELAND stands unique in that it is an island touching the Arctic circle, and therefore within a region of intense denudation; at the same time this area, larger than Ireland, owes its whole origin to volcanic action, and all its rocks are directly or indirectly due to igneous processes at the surface. Its geography is therefore so interlinked with its geology that the two go hand in hand.

In the summer of 1890 I was most kindly invited by Dr. Tempest Anderson of York to accompany him on a trip to Iceland, and I take this opportunity of sincerely thanking him. Our object was to travel eastwards along the south coast as far as the renowned Skáptárdalur, examine the seat of the great eruption of 1783, and returning by the mountain backway, rarely traversed, behind the triplet of the Myrdals Jökull and its fellows, examine Hekla, the Geyser district, and Thingvellir. In addition we were able to devote some days to the Reykjanes peninsula, with an excursion to Hengill. It will thus be seen that we traversed a very considerable distance, and I shall only attempt in these lines to give a sketch of some of the principal, though rough, observations that could be carried out in such a journey. I shall endeavour to compare the volcanic phenomena as exhibited in the part of Iceland we examined with the other three active volcanic districts of western Europe which I had the good fortune to have visited within the year previous to our trip, and with most of which I am intimately acquainted. It has now become an old superstition that two great phases exist in the physical history of Iceland, and most authorities I have read on the subject,

without saying distinctly that such was the case, lead one to suppose that a considerable period of inactivity separated the earlier from the later great eruptive displays. I would therefore say that, so far as I could see, there seems to have been no break whatever—that, in fact, eruption has succeeded eruption whether the area was covered with the great ice-sheet of the Glacial Period or not.

South of Reykjavik, on the road to Hafnarfjörður, comparatively old lava beds are met with, and high up on the sides of the creeks water-deposited agglomerates and other evidence of relatively recent emergence are obvious. As we approach Hafnarfjörður, we encounter and traverse a comparatively recent lava stream, and soon after quitting that town we plunge into the great Gullbringu Sýsla district, with that of Thingvellir and Skjaldbreiðh, for the greater part a vast lava desert 125 km. in length and extending away to the south-west for another 30 or 40 beneath the sea, so that we may credit it with a length of at least 150 km., and a breadth of 25 km.—an area equal to several good-sized English counties. Its general shape is elongated and curved, so that while it follows roughly a north-east to south-west trend from the great cone of the Skjaldbreiðh at the north to the Fuglasker islands, where volcanic disturbances are frequent, its southern edge is convex. Its northern extremity tends to run more north and south and the maritime end to run more east and west. The interest of this we shall see when we study the general tectonics of the entire island. The whole of this region is characterised by evidence of intense and still persistent volcanic activity. Nearly all of it is covered by recent lavas, some as fresh-looking as if they had been emitted only a few years ago, and most dating back not much earlier than the colonisation of the island in the tenth century. Scattered over this region there are said to be upwards of fifty solfataras. Winding through it, always following the same direction and always tending to the same curves, are the great *gjás* or rifts, some of which may be followed for 20 or 30 km., especially in the Reykjanes peninsula. The volume of some of these lava fields is enormous, and as we cross from Hafnarfjörður to Krisuvík, we are astonished by the enormous outflows, some of which have spread over dozens of square kms., and whose actual limits would require careful surveys to determine. On this part of the journey the relationship of the newer lavas to old tuff hills and lavas of more ancient date is well seen, the former winding in and out of the valleys and abutting against the escarpments cut in the older rocks. In fact it is on the slopes of these older rocks, facing south, that some of the clumps of brushwood grow that represent the woodland of the island of frost and fire. These newer lavas in this region have fairly rough surfaces, rarely corded, but covered by not very porous masses of scoriaceous rock, showing that no inconsiderable quantity of  $H_2O$  was contained in the lava at the time of its emission. When we crossed the Reykjanes peninsula, travelling northwards from Staðhr, the whole way was over such lavas, interrupted here and there by cones of varying dimensions, some being considerable volcanoes, which mark the points of exit of these lavas. These cones are composed of scoria-cakes, and though of rather a dense kind, they indicate that considerable violence accompanied



No. 1.

the ejection of the lavas. The low gradients that large areas of the flows present demonstrate their great fluidity, no doubt due to their initial high temperature at the time of outflow and their basic nature. Their surfaces are now thickly clothed by a luxuriant growth of lichens and mosses, which often attains a thickness of a decimètre or more, and renders walking over the surface much more easy, though the ground is sometimes treacherous, than over similar lavas at Etna and Vesuvius, where the *Stereocaulon Vesuvianum* makes a very poor show as a lichen by the side of its luxuriant Arctic rivals. The peculiar greenish-grey sheen of such a lichen-covered surface produces a striking effect in bright sunlight near sunrise or sunset. Could some use be made of this material besides as fuel, for which it is not well suited, a large and profitable industry might spring up to help the poor Icelanders in their hard struggle for existence.

The great *gðs* or rifts that have been mentioned are, of course, later than the lavas they traverse. They are great fissures trending fairly straight over wide areas, for a distance, say, of 500 m., though zig-zag for short distances owing to the absence of homogeneity in the lavas, and consequent irregularity of fracture. Their breadth varies, but averages from 1 to 3 m. Their depth is unknown, for they can rarely be sounded beyond 20 or 30 m., as falling blocks have choked them, and the snow is never thawed in summer below this depth. The accompanying photograph exhibits a good specimen, with the snow in its bottom, and is part of the Hrafnagja in the Reykjanes peninsula (Photo. No. 1).

Evidence of solfataric activity is most marked, though to some extent localised in definite areas. Two of these centres we were able to examine in detail, namely, those of Krisuvik and Cape Reykjanes. The foci at Krisuvik are traversed by the road to that farm. Here a great number of fumaroles are now smoking, depositing sulphur, halotrichite and other alums, with gypsum and a little fluorite. A company was started some years ago to collect the sulphur, but the expenses of transport were so great that it soon failed. Here occur very interesting boiling springs.

The violent bubbling and splashing is not due to the escape of carbonic acid or any other gas as in an intermittent spring (*Sprudel*), but is actually caused by ebullition, and therefore the spring is really a small geyser. There were several of these in different grades of violent activity, and I was fortunate to obtain some good photographic records of them. Their mineral contents are very small. There were also some good mud springs, as they are called, but the less elegant though more expressive name of the Devil's Paint Pot is more applicable to them. One of them was a deep, bell-shaped hollow, with a blue-grey mud bubbling up quite hot at the bottom. This crater-like hollow is really due to the escape of the hot vapour and sulphuretted hydrogen that bubbles up gently under ordinary conditions from its bottom, but at times escapes with explosive violence. The blue mud is nothing more than the neighbouring rock in a fine state of comminution, mixed with a large quantity of sulphur and sulphides deposited from, or generated by, the escaping vapours which constantly churn up the mud into a homogeneous paint-

like paste, and project splashes of it against the crater sides and even beyond its border. The effects of the fumarolic action on the surrounding rocks is very marked by the genesis of all the usual deposits of sulphur, sulphides, sulphates, gelatinous silica and pulverulent deposits of alumina, and hydrosilicates variously coloured by different combinations of iron. At one point we obtained a remarkably brilliant red bole almost rivalling cinnabar in its intense coloration.

At Cape Reykjanes, close to the lighthouse station, is another solfatara, perhaps as important as that of Krisuvik. Here all stages from springs of clear boiling water to hot jets and thence to Devil's paint-pots can be studied. In fact, small lakelets occur with almost clear boiling water in the centre, milky-looking water farther out with innumerable bubbles of gas, and beyond this thick deposits of sulphurous mud with escaping gases. In spite of my familiarity with such man-traps, one of my feet suddenly sank through a hardened crust up to my knee in this mud; but I was able fortunately to save myself and get off with a mineralised mud poultice over the whole of my leg applied hotter than is usual for medicinal purposes. Close at hand to these last-mentioned springs are the remains of an old geyser cone composed of the finest siliceous sinter I have seen in any collection. The geyser is quite extinct and the cone and basin much ruined. We were able to collect and bring away some beautiful specimens of the ripple-marked sinter, ranging from pure white through pink to dark red, and exhibiting in a striking manner the deposition of this interesting substance.

It is in the south-western extremity of this district that volcanic activity seems at present to be mostly concentrated. Earthquakes are very common about Cape Reykjanes, and the name Fuglasker or fire-islands clearly refers to the frequent submarine volcanic disturbances in this neighbourhood. It is not unlikely that the great rifts that attain their greatest perfection between Reykjanes and Kálfatjörn are the great fractures that every earthshock enlarges and, possibly, extends. It would well repay the trouble to carry out a series of measurements and to fix marks to the lips of these rifts to show whether they are undergoing any change. Such an observation station situated at the south-western extremity of the Hauksvörðhugjá would cost little, for it could be looked after by the lighthouse keeper at Reykjanes, and it might afford most valuable and instructive data.

What these rifts are really due to is not an easy matter to determine. I could see no signs of shifting or faulting horizontally, and very little vertically, though the rough lava surfaces through which the fissure runs prevent any very accurate determination of small displacements. In this respect, together with the fact that these rifts gape and are not jammed together, they differ absolutely from faults, which are really the planes of differential movements. I feel inclined, myself, to believe them to be great axial fissures along the ridges of anticlinal folds, for they correspond with the usual trend of the great ridges and synclines, with the lines of drainage, and with the chains of volcanic vents. Such synclinal folds may be due to true tectonic movements, or to the formation of great elongated laccolites. Were they simply due to tectonic

foldings, we should rather expect the *gjas* to run along the middle of such folds, and the chain of volcanic vents to run parallel, but in the flanking synclinals. I am therefore tempted to look upon these *gjas* as great axial fissures over elongated laccolites that are gradually being filled from below, and from which at times emissions of lava take place along the great hump. As the filling goes on from below, the rifts extend, accompanied by fracturing and earthquakes.

We thus see that the rifts are formed simultaneously with the shocks, *but are not due to the shocks*, as so often stated regarding earth fissures in general.

At Reykjanes cape we have an illustration of what is going on in the direction of the Fuglasker islands, as well as evidence of recent elevation. Of this latter we have innumerable examples, one of which I shall also refer to when speaking of Dyrhólaey—evidence rather contrary to the unjustifiable generalisation that all volcanic districts are areas undergoing depression. The rock upon which the Reykjanes lighthouse stands is a fine specimen of a submarine basalt cone, cut into and dissected by the sea. A considerable part of it is built up of globular basalt. This globular basalt is due to the ejection of the lava paste into the sea water as globular, pyriform, or sausage-shaped blobs, which soon crust over and sink upon those that preceded them, but are prevented from becoming soldered to them by the crust already cooled upon the surface. They have at Reykjanes been slightly flattened out by their own weight, or the pressure of those immediately above them. As they cool, a radial columnar structure is set up. At Acicastello in Sicily the lava was less plastic, and there has been little or no flattening. The process may be imperfectly imitated by injecting a very thick, coloured syrup through a fine syringe, the beak of which is plunged beneath a vessel of thin, uncoloured syrup. In such eruptions the first and more vesicular globules may reach the surface, or be projected above it, as in the recent eruption off the coast of Pantelleria. To convince oneself of the relationship of these different structures, the so-called scoria bombs of Pantelleria, with their peculiar concentric arrangement of rock of different grades of vesicularity, should be compared with the vesicular globules of Acicastello, and these with the more compact globules of Reykjanes. No doubt each submarine eruption off this south-west corner of Iceland means the building up on the sea bottom of such a cone as the lighthouse hill once was, but which has since been raised above sea-level.

Before quitting the Krisuvik region I may draw attention to other monuments of terrestrial disturbances well worthy of attention, as throwing light on the formation of certain crater lakes and on the pipernoïd structure of certain rocks considered to be lavas.

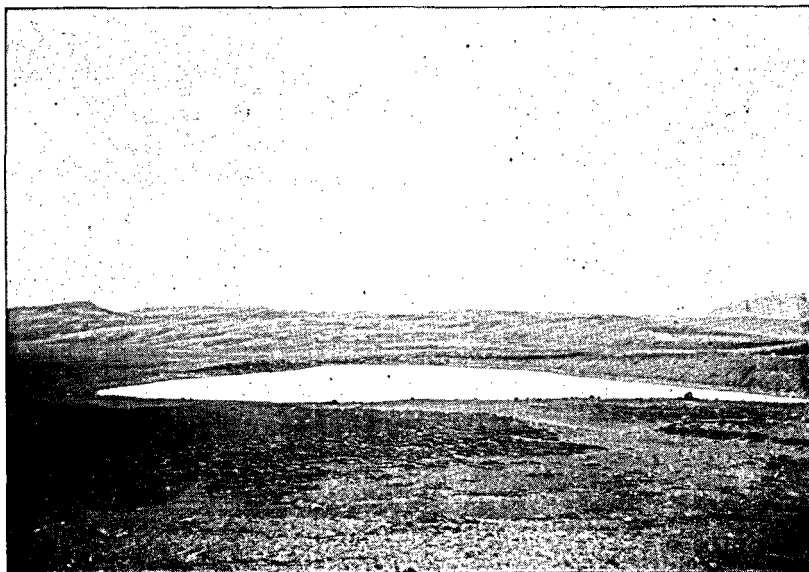
Beyond the solfataras, a short distance nearer the farm of Krisuvik, we may, by ascending a little to the right or west, come to the edge of an elongated lake with very little ring or vallum around it. During our short stay I could find in its neighbourhood no *essential* eruptive ejecta; the only materials that were ejected seem to have been all of an *accidental*<sup>1</sup>

<sup>1</sup> See H. J. Johnston-Lavis on the 'Fragmentary Ejectamenta of Volcanoes.'—*Proceed. Geol. Assoc.*, vol. ix. pp. 12, and 1 pl.

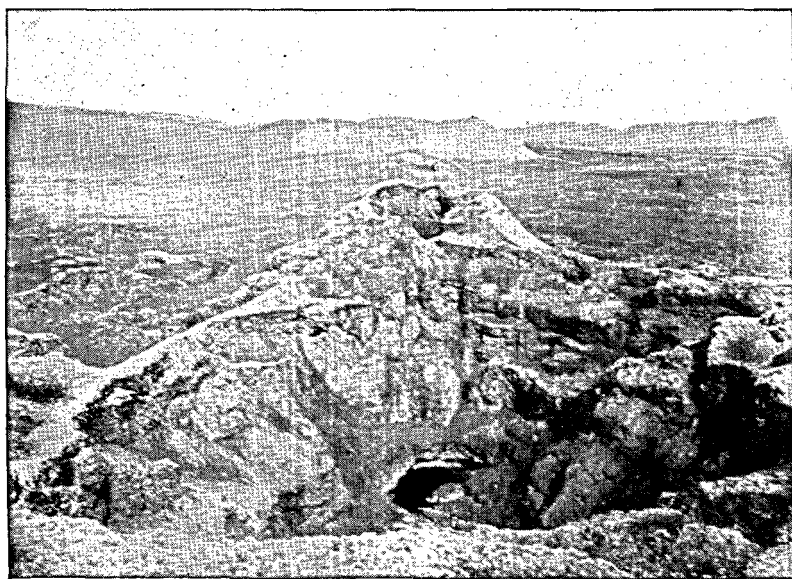


nature, and to be parts of the loose alluvium, breccia, and scoria beds that this crater was drilled through. It is hardly possible to imagine a crater of such dimensions being formed by the explosion of vapour pure and simple, and the only explanation I can offer is that the pumice, if such existed, was small in quantity, very light, and carried away by a strong wind, or, by the enormous expansion in frothing, reduced to fine dust or filaments as in the thread lace pumice and Pele's hair of Hawaii. At any rate, this is a fine example of a crater lake, and, above all, one with practically no *essential* volcanic ejecta surrounding it. More interesting, however, is a series of crater lakes well seen from the path lying almost parallel to it on the east. These range down to quite small ponds remarkable for their circular form, precipitous sides, and almost total absence of crater ring or annulus. The largest and most northern is known as Grœnavatn because of the light-green colour of its water (Photo. No. 2). It is nearly circular, with very steep sides, so that its depth must be considerable at the centre. It is about as large as Lake Avernus, or perhaps a little smaller. As will be seen, it possesses little or no annulus, and I could find no indication of *essentially* eruptive ejecta along, at least, three-quarters of its circumference. In fact, the slight elevation that surrounds the lake is composed of the same miscellaneous detrital matter that surrounds the first-mentioned lake. Stretching away to the north-east is an almost horizontal mass of rock that at first sight appears to be a lava stream (well seen in the photo.). Approaching it, we find that its nearly vertical section that faces and almost overhangs the lake is some mètres in depth at its central part, thinning off at each edge, so that the whole mass is a much elongated lenticle, and therefore fusiform in section. It is a very compact, black, lava-like rock, marked, however, by horizontal flackers of brownish and more scoriaceous patches, but in the central part of the mass quite continuous and passing imperceptibly into the more compact black material above and below. So intimate is the connection that these different parts have little influence on the fracture. Towards the top and sides, and to some extent at the bottom, these brown scoriaceous veins are far more numerous, and, finally, near the surface the supposed lava is represented by loose cakes of this more scoriaceous material not welded together. This mass is not a lava stream, failing as it does to possess many of the essential characteristics. It is too horizontal to have flowed, and there are no remnants of any cone from which it could have issued. Even were we to suppose that such a cone once existed and had been blown away by the formation of the subsequent crater now filled with water, we could hardly expect such an explosion crater to have had exactly the same axis as the cone it destroyed. Besides, we should certainly expect to find some remnants of such a cone, or the materials of which it was built. Lavas do not flow from craters of explosion, and if any fluid rock had issued from that of Grœnavatn, there is no reason why it should be confined within a long and narrow radius, and, curiously enough, in the track of the prevailing wind. Finally, the slopes contradict the flow theory in the case of a mass of basic lava so narrow, so thick and unconfined in a pre-existing valley.

The real history of the Grœnavatn lake I take to be this: first, a



No. 2.



No. 5.

highly aquiferous magma blew out the crater, all or most of the eruptive material being reduced to dust and carried away by the wind. Later on, when less aquiferous magma rose from greater depths, where it had been enclosed deeper in the earth and therefore in drier rocks, and consequently had absorbed less  $H_2O$ ,\* it issued as blobs of scoriaceous lava, which were carried by the prevailing wind in one direction, falling along a line to the leeward of the crater. So rapid was the ejection and so small the loss of heat in vesiculation and the loss to the atmosphere that the blobs fell upon those that preceded them, to which they were re-fused or soldered, and those that followed repeated the process. As the mass increased in thickness the pressure aided the re-soldering, so that in the deepest parts the mass again became continuous, marked only by a slight variety in colour and vesicularity. Towards the sides fewer lava cakes fell, and the thickness is therefore less and the soldering-together less complete. The same imperfect union is seen towards the top of the mass, dependent likewise on the greater intervals between the ejections towards the end of the eruption, and the absence of superincumbent weight.

This pipernoid lava differs from true piperno in that the latter is a soldering together of the fragments of the same magma, but in two very extreme conditions of saturation with  $H_2O$ . The Grönavatn rock is extremely fine-grained, and, so far as the microscope reveals its structure, it may be looked upon as a basalt. Scattered through it are numbers of fragmentary crystals, and sometimes fairly perfect laths of labradorite and bits of pyroxene. These, however, are evidently derived from fragments of a coarse crystalline gabbro-like rock, which occurs in numerous lumps, up to the size of a coco-nut or larger, enveloped in the basalt, and as bomb-like masses on its surface.

This enclosed gabbro is no doubt part of the same magma, cooled under intratelluric conditions of slowness and high pressure, and has been split up and ejected by the explosive escape from greater depths of the unsolidified portion of the same magma.

The browner scoriaceous parts of the rock mass are almost identical with the black compact portion, except that they are more vesicular, with less defined magnetite grains, and with plenty of dirty dark-brown glass.

In this great tract of recent volcanic activity of which we have been speaking, and which stretches from the Skjaldbreidh to the Fuglasker islands, it must not be supposed that the surface is entirely new. On the contrary, much of it is old and composed of old cones and platforms of lava, in the hollows and valleys of which the newer outflows have found resting-places. As we quit the Krisuvik district and wend our way along the road by Strandar Kirkja towards the mouth of the Olfusa, we are able to notice some interesting points in the tectonics of the district. Some three to five kilometres inland from the coast we see ancient sea-cliffs cut back by the waves into the lavas, breccias, and tuffs of more ancient date. At one time the sea had in this way isolated a

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\*  $H_2O$  is used to denote a chemical compound without defining its physical condition, as the words steam, vapour, water, ice, are on that account often objectionable in speaking in relation to volcanic action.

large tract of land of which the culminating point is Lángahlidh. New mouths burst forth on the shelving plateaus above, and probably along the foreshore, so as to give egress to floods of lavas which have reclaimed these three to five kilomètres from the sea, aided to some extent by detrital deposits brought down from the higher ground. Much of this foreshore is little above the level of high-water, and is composed of basalts that exhibit a surface, so far as I know, undescribed, and quite different from the ragged scoriaceous or corded surface of most volcanoes. The crust is remarkably smooth and broken up into low convex segments of spheres several mètres in diameter and looking like low domes or Italian vaulted roofs. I shall refer more in detail to this vault-surfaced lava later on.

On arriving at the banks of the lake-like estuary of the Olfusa, we reach a large low-lying alluvial plain extending to Haukadalr on the north and Hekla and the Eyafjalla Jökull to the east. This district, Ran Gar Valla Sysla, is the most fertile and thickly populated district in Iceland, and owes its existence for the greater part to the alluvial detritus brought down from the Lang Jökull and the Hofs Jökull by the Hvitá, and from the Túngnafells Jökull and the whole west side of the Vatna Jökull by the Thjórská and its tributaries. In this work the Vestri and the Eystri-Rángá and other branches of the Dhverá and the Markarfljót draining Hekla, the Torfa, Eyfajalla, and Godhalsands Jökulls have also played their part.

What more especially strikes one is the remarkable direction that these rivers follow in the highlands. This is particularly the case with the Thjórská which flows in a remarkably straight line for nearly 100 kil. Their larger branches tend to do the same, except where they join the main stream, to do which they make sharp turns at right angles. With the Túngnaá this is no doubt due to the growing up of Hekla, but, where free from interference, drainage in this part of the island follows a north-east to south-west direction. But more of this presently. When these great rivers reach the alluvial plain, where the main tectonic features are hidden, they meander about, without any definite direction, and form great shallow, lake-like estuaries, with narrow mouths, due to the throwing up of a great sand bar across their mouth by the south-west current.

Travelling in this district is wearying in the extreme, and travellers for days together have to wade interminable rivers, often split up into from six to eighteen hardly fordable streams with dangerous bottoms of quicksand. When, in addition, rain pelts down, the amphibious life has little attraction for any one. It was therefore with pleasure that we reached Holt beneath the triplet of Jökulls. Along this coast are several objects of interest, such as the cascade of the Skogar-foss, one of the drains of the glaciers above, well known from guide-book descriptions. The main drain, however, of the triple Jökulls is the Fúlilækr Jökulsá, which carries off a good deal of the subglacial water from the three Jökulls collected in the triangular depression between them. This Jökulsá is renowned for its stinking water, due to the presence of sulphuretted hydrogen. This is no doubt derived from solfataric action under the ice-cap in the neighbourhood of

the Kötlugjá, a vent lying between and to the east of the Godhalands and Mýrdals Jökull, and which has been time after time one of the most disastrous centres of volcanic activity during the last nine centuries.

Along this coast are many interesting rocks, especially basalts in sheets, dykes, simply columnar or globular, tuffs, and agglomerates more or less palagonitised in places. The most interesting point, however, is Dyrhólaey or Portland, the southernmost point of Iceland. Natural archways are always beautiful, more especially when on the coast. I have seen many, but I can recall none that was so perfect an arch, or more strikingly situated and interesting than this one. The dimensions are usually given by authors as sufficient to allow a *ship* to pass under it. But *ship* is a most indefinite standard of size, and I doubt if more than a small yawl could get safely through, though I should hardly care to try the experiment with the sea that was running the day we were there. The main mass of the rock, with the adjoining archway, represents the remainder of a submarine basalt cone, like a wedge-shaped slice out of a cake. The picturesque reefs that stand out to sea are the old basalt stocks, representing one or more chimneys of the cone. Towards the land the sides of the cone are exposed in section, with the tuff deposits which exhibit current sorting and false bedding to perfection, indicating the subaqueous nature of the deposit, and the complex currents set up by the eruptive action.

Against the south-west cliff is an enormous talus of sand, with its apex in the most concave part, and reaching nearly to the top. This is a remarkable specimen of a sand-dune, arrested by a wall of rock and moulded by the influence of the air-currents that are directed into the greatest concavity of the escarpment normal to the prevailing or south-west wind, so that the sand is compelled to occupy the bottom of this concavity.

Another point that struck me was the pebbly beach. Pebbles of flint and other fairly homogeneous materials should theoretically be spherical, but for several reasons rarely attain perfection, being usually slightly flattened ellipsoids or ovoids. Basalt pebbles are usually of this form, but those on the broad and magnificent beach of Dyrhólaey are not of those shapes. Here range after range of sorted pebbles of different sizes occur, but all remarkably flattened and disc-like in form. I could find no satisfactory explanation of this resemblance in shape to pebbles derived from foliated or finely stratified rocks, and it is a question whether a peculiar conformation of the coast, certain peculiarly shaped waves, or special currents may explain this phenomenon.

On quitting Dyrhólaey, on the little plain to the north of the shores of the small salt lake, two of our horses were nearly lost by sinking into a dry quicksand. Quicksands are one of the greatest dangers to travelling in Iceland, and the ponies seem to have acquired great caution by heredity, natural selection, or constant practice, so that, if left to themselves, they stop when a river bottom is in the slightest degree dangerous. Our head-guide, Zoega, declared that quicksands could be detected by the presence of white grains amongst the black ones, and those he showed me were sands composed of ordinary basaltic *débris*, with a small admixture of rounded grains of pumice. I collected several specimens, but

unfortunately they were mislaid, and I could not make a careful study of them, as had been my intention. Most of the quicksands we experienced in Iceland were wet, or even covered with water, but this one near Dyrhólaey was quite dry. I do not remember to have seen dry quicksands recorded, nor do I quite see how such great mobility can exist unless the grains be quite spherical, smooth, and very light, but very incompressible.

Our next stay after our visit to Dyrhólaey was at Höfðhabrekka farm, a place interesting from many points of view. In the first place, it is the last habitation before entering on that vast and weird desert of the Mýrdalssandr, some 40 km. of which we had to cross at one stretch to reach Asar. This vast alluvial flat is in great part due to the eruptions of the Kötlugjá, which, taking place amidst the great snow deposits of the Godhalands and Mýrdals Jökulls, melted enormous quantities of the snow, with most devastating effects. As we wend our way across this desert we see the great mass of subangular boulders of all kinds of rocks mixed with gravel and sand that were brought down by these great rushes of water. Deep-cut ravines and dry torrents mark the last stage in the great inundation. The heaviest rains since then have done little to disturb the old surface, and the only change is that many of the boulders have been split, and crumbled to fragments by the action of frost. The tremendous violence of the inundation is shown by the large boulders, dozens of kilometres away from the foot of the Jökulls, which have been transported, for the most part, over a surface of very small inclination. Guide-books to Iceland usually describe these disasters, and record how this once fertile and populous region has been again and again overwhelmed, until only a few eminences, such as that on which the farm of Höfðhabrekka stands and the hill of Hjörleifshöfði remain. In fact these great sand and boulder deserts stretch along the coast, for some hundreds of kilometres, as far as Holtar, encircling the southern base of the great Vatna Jökull, and are, no doubt, at any rate in part, the result of similar violent deluges of ice, water, rocks, and volcanic ejecta, which have swept down when eruptions have taken place in the ice-fields above.

Very little of these great *sandrs* supports vegetation, for they are too frequently renewed by fresh outbursts of eruptive activity in the snow-fields to which they owe their origin. No doubt, were no further eruptions to take place, they would eventually become as fertile and thickly populated as the Ran.Gar Valla Sýsla district, which not improbably owes its alluvial origin to eruptions in the Lang, Hofs, Vatna (W. side), Godhalands, and Eyjafjalla Jökulls. In fact that part of the great *sandrs* least exposed to disturbances, between the Kúdhafjót and the Skaptaros, already yield some return to human industry at Thykkribær, Langholt, etc. The similarity between these two great detritus plateaus is the peculiar shallow, lake-like character of the estuaries, with their exit almost closed by sand bars.

To return to Höfðhabrekka, which is a typical Icelandic farm, owing to its isolation and distance from trading stations, and so afforded us some interesting observations, my description of which I shall supplement from other localities we visited. To tell most people that the Stone Age still persists in Europe up to the dawn of the age of aluminium would

expose one to ridicule; yet such is the case, and it is another proof that such epochs of human civilisation as are denoted as stone, bronze, or iron ages are but relatively correct. In Iceland stone is used for many purposes, and most frequently for hammers. At most coast farms a large stone hammer, with roughly spherical head as big as a human skull, is used on a sort of concave stone anvil or mortar for breaking and pounding up the dried heads of cod-fish, with which the horses and cattle are partly fed during the winter. Hammers and sledges of different sizes and shapes are in frequent use. I saw one man who did tinker's work beating out his tinned plate with a well-made stone hammer, which I bought of him. It was well worn, and answered the particular purpose quite well, although the association of stone hammers and tinned plate manufactured at Neath seems rather incongruous in Europe. Most of these hammers are made from suitable pebbles of basalt, of which a great variety can be chosen from the beaches. A hole is chipped about two-thirds through the centre and widening inwards; at the bottom of this is placed a wooden wedge, and a stick, ready split at the end and just the size of outer opening of the cavity, is driven down on to the wedge, spreading it out so as to hold the head of the hammer quite securely. At the farm above mentioned we found the bob weights on a steelyard balance likewise made of stone, but still more curious was the wheel of a wheel-barrow chipped out of solid stone. Of course in England we have stone rollers for fields and gardens. At the neighbouring Skáptárdalur farm, where we also stayed, we found in the garden a basin formed out of a section of a large basalt column. Advantage had been taken of the cup-like concavity and convexity of the transverse joints of a basalt column, and a thin-sectioned one had been chosen. The concavity had been enlarged and the edges well rounded off, but the old pentagonal outline was still quite visible. The weight of it was very great, and it was no longer in use, being replaced by blocked tin utensils; but the farmer told us it was in constant use when he was a boy. All the fishing-nets at Höfðhabrekka were weighted by sections cut from the tubular shafts of mutton bones. The astragalus or knuckle bone, with a hole drilled in it, was in use for winding yarn upon, and the pointed splint bones, likewise drilled, were strung together ready for pegging out seal and other skins on the ground to dry. Stirrups, spoons, pulleys, hooks for harness, and many other articles were fashioned out of horn, some of them being beautifully and artistically carved. Speaking of carving brings to my mind a box I bought made without nails, but with wooden pegs and wooden hasp, from painted deal boards thrown up from wreckage. The low-relief carving, in most typical Runic style, had been so done as to utilise the painted surface for the scrolls in relief, while the sunk parts were, of course, in the bare wood.

It is not that the Icelanders are conservative, but the absence of roads and bridges, and the distance of trading stations, compel them to use the materials at hand, especially for fragile and heavy articles, so that one can understand their using heavy sledges of stone or segments of basalt columns instead of carrying a fragile crockery basin or a heavy iron sledge three or four hundred kilometres on pony-back across some

of the most dangerous and diabolical country to be traversed in any part of the world. Stamped tin ware, cheap, light, and unbreakable, has, however, put an end to dining out of basalt columns.

Near the Skálm, towards Asar, we began to exchange the Mýrdals-sandr desert for one of lava, and near the track some interesting examples of an underground stream again coming to daylight could be examined. Such phenomena are of very frequent occurrence in Iceland, where lava streams have blocked up valleys, and the water has eventually found its way underneath.

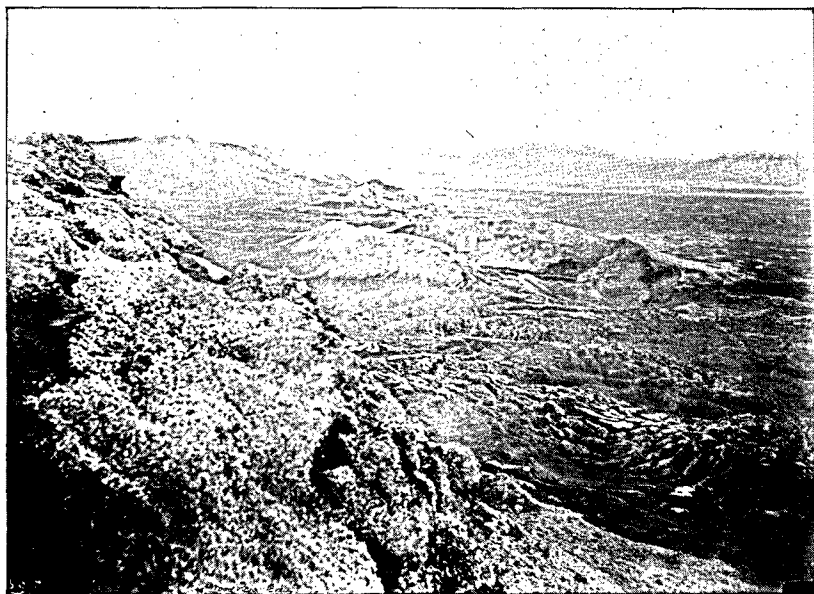
As we wandered over lava or boulder deserts, without a trace of other vegetation than the lava lichens, and often with little of this, we were struck by cylindrical or slightly conical columns of earth covered by luxuriant turf, and often by flowers. Such pillars are usually situated on some elevated position commanding an extensive view, where they are most exposed, and least likely to collect earth. Frequently we saw a bird perched on the summit eyeing the surrounding country. These pillars owe their material, with their great fertility, as well as some of their vegetation, to the droppings of the birds, who use such spots as observatories. They, no doubt, form important centres for the spread of vegetation over lava fields or on boulder plains.

As we approached the Skáptárdalur we had to cross the great Skaptár lava stream, where it occupies the bed of the river. Though at this point very narrow, no less than sixteen different streams had to be traversed, which together represented the single stream that once occupied the valley of the Eldvatn. The valley has been filled up to some considerable depth by the lava that poured down through it, and, spreading out, covered an area 20 km. long by 24 km. broad. So nearly level did the lava fill the valley of the Eldvatn, that only the slight irregularities in the surface of even the most fluid lava have been mapped out by the river that now again flows over it, constantly dividing into a number of streams and reuniting again, so that what would otherwise be a dangerous and impassable river is just fordable in some places. Even as it is, rough, jagged surfaces of scoria at the bottom of a ford make crossing no easy matter. The effect on a sunny day of the silvery glistening streams in black rugged beds is most striking.

The great Skaptár eruption, as is well known, produced the greatest outflow of lava known to have occurred in historic times. Two streams were poured out—the larger one, about 78 km. long and with a maximum breadth of 24 km., issued by a long fissure running south-west to north-east, but curving somewhat towards the south-east, like the area extending from the Skjaldbreidh to Cape Reykjanes I have already described. Along this line lie a great number of crater-cones, some of which rival in size and variety of shape the splendid examples on the slopes of Etna.

Near the northern end of this great fissure another extended nearly at right angles in a south-easterly direction, and gave vent to a lava-stream estimated at 32 km. in length and 8·5 km. in maximum breadth. It was our object to examine, as far as time, weather, and means of access would allow, the features of this great lava flood, which in 1783 continued to issue forth during some months, and caused tremendous





No. 3.



No. 4.

destruction of human life, domestic animals, and pasturage. I refer the reader to the books of the history of Iceland, in which all the details are given.

On quitting Skáptárdalur farm we had to depend entirely on our own resources. We followed the east bank of the Eldvatn, and were able to examine an interesting tuff cone, which, as well as we could make out from its position, must be the Leidhólsfell on Gunnlaugsson's map. This seems to have been a tuff cone subsequently truncated around an axis excentric with regard to its original plan, while the formation of a second cone on the lowest part of the crater edge has produced a certain similarity with the Somma-Vesuvius volcano.

We finally pitched our camp on the Skaptár lava field, between the Hellisá and the Varmárdalur, the farthest point where we could find any pasturage for the ponies.

The view from our camp was interesting in many ways, for, notwithstanding the levelling effect of the lava floods, the position commanded a very considerable area. The extent of country covered by the great outpour of lava is enormous, for its limits are well marked out by the highlands on each side. These too are interesting, for their summits are frequently very pointed or of a regular conical form terminating in a rather flat top. The cause of this I shall refer to later on. Unfortunately, Icelandic ponies will not eat corn or other easily transportable fodder, and consequently our journey up the Varmárdalur was limited to the distance we could traverse, there and back, in one day. Starting at about 2 A.M., in bright sunlight, we pushed on until we came to the nearest cones, most of which we examined, photographing many. When we had reached as far as we dared to take our horses, considering the horrible nature of the ground, we advanced some distance on foot, and finally, promising my companions that I would be back in three hours, I ran on some miles examining the line of rift and photographing the features of most interest. It was impossible to reach the bifurcation of the two great Skaptár lava-streams, but many varieties of cones, craters, and lava-flows, etc., of this great and unique eruptive display, which occurred in historic times, were recorded in notes or photographs (Photos: Nos. 3 and 4—Panorama). The photos give a very fair idea of the great lava-fields high up the stream and but a few kilometres from the bifurcation. The panorama is taken from the side of one of the eruptive cones, and another, fairly regular, is seen in the distant foreground, with a row of somewhat similar vents rising behind it. Their chain-like arrangement is remarkable, and very similar to that on a radial dyke of a volcanic cone. The only difference in the Skaptár cones is that they extend to a much greater length and over a country but slightly inclined, and hence are evidently arranged along a great dyke which, however, has nothing to do with any great cone as a centre, unless it may be regarded as being a radial rift in some volcano composing the western end of the Vatna Jökull. The linear arrangement is admirably shown in Photo. No. 5, which also exhibits the variable size and shape of the cones. The twin pair in the foreground are very steep, both within and without, and one contains a small tarn in the bottom. These were

formed by the ejection of great lava-cakes which adhered together and so allowed the building up of steep-sided cones. In the distance, however, is well seen another type, built of more fragmentary scoriaceous material, so that the soldering together was less complete, and the cone has gentler slopes both within and without. The cone in Photos 3 and 4 is of this type. The distance between one cone and another varies much, sometimes two or more occurring almost superposed on each other as in Photo. 5, or a distance of several hundred metres or more may intervene. Strangely enough we usually find cracks and small rifts marking the line of junction between two cones, and at one point a whole chain of remarkably perfect little cones only a few metres apart form the connecting links between two large ones. This arrangement I have never met with elsewhere in anything like the same regularity and beauty (Photo. No. 6).

The appearance is very well shown in the photograph I took from the lower of the two cones. The dimensions of the Skaptár cones vary very much, ranging from one or two metres in diameter up to several hundred metres, the latter rivalling some of the finest parasitic cones of Etna. Many of them are breached, and some in a remarkable manner, a large part of one side being carried forward just as at the bursting of an earth-dam.

One fine example is, singularly enough, also breached on the upper side, a phenomenon unknown in parasitic cones that stand on steep slopes. The fact that the bases of the Skaptár cones are nearly horizontal explains their greater tendency to crack in large breaches and allow lava to escape which can rise to some height within the crater, whereas in parasitic cones it finds an outlet beneath the lower crater wall.

On the lava-fields little vegetation has yet taken hold; the lichens are still thin and isolated, but on the slopes of some of the more scoriaceous cones thick patches of moss and lichen flourish.

In many accounts of this eruption it is said that the lava was five to six hundred feet thick. I saw no evidence of such a thickness, but I must likewise say that I saw nothing to contradict the statement. If really such a depth was attained, it must have been very local. At any rate many of these eruptive cones must have had a greater height than at present apparent, for as they grew their bases must have been buried in the lava flowing around them, though it seems impossible to believe that their original height was 200 m. greater than their present height.

The Skaptár outflow we must look upon as the most perfect type of a fissure eruption of which we have any record, and although the floods of lava were enormous, yet a fair amount of explosive action undoubtedly occurred to have built up so many dozens of cinder cones, a large proportion of which are of very considerable dimensions.

I quitted this district, satisfied on the one hand with what I had seen, but regretting on the other that the highest or most northern point of this great lava fissure had not been reached. When any future attempt is made I feel sure that the base should be at Bratland or Seljaland, as lying much nearer to the goal.

On our return we endeavoured to ford the Eldvatn near a locality

marked Hrafnar on the map, but one of our guides who tried the river just escaped drowning, and we were compelled to follow the stream and recross lower down at Buland.

Our plan was to make our return journey behind the triple Yökulls by the Fjallabaksvegr-nyrdhri or mountain backway. This track, where track exists, is ninety miles in length, and has to be travelled over in two days, as there is only one oasis of pasturage half-way across, sufficient to support the ponies for one night. This fact, of which we were previously unaware, prevented us making an attempt to ascend the Godhalands Jökull and examine the renowned Kötlugjá, the eruptions from which have on several occasions been so disastrous to life and property. Dr. Tempest Anderson had come fully prepared with ropes, axes, and other mountain gear, and we were deeply disappointed. This mountain backway is one of the most desolate places it is possible to imagine; one wanders over kilomètres upon kilomètres of black basalt lapilli, sand, and lava streams, with rarely a patch of marsh or sign of vegetation of any kind; here and there skeletons of horses that have died on the journey in snowstorms, combined with the stories of our guides as to the finding of their masters' bodies, made us feel still more the difficulties of the journey. Road there is none, and only one who has already followed the track could find his way. Add to this a cold cutting wind, blowing off the great ice-fields that hemmed us in on both sides, and constant storms of drifting sleet that might give place to snow at any moment, an occasional fall of a pack-horse through the arch of a snow-bridge, and other misfortunes, were not calculated to promote the equanimity favourable to scientific observation, and made photography a drudgery.

Much of the district, as I have said, is a desert of black basalt lapilli, and the Mœlifellssandr is in large part composed of these. They are probably derived from the Kötlugjá, and perhaps also from Hekla, between which the desert lies. The scenery is grand and weird in the extreme. Combined in one landscape are collected black, bare, rugged and pointed mountains, with patches of permanent snow scattered in the hollows on their flanks; the distant ice-fields of the triple Jökulls, blending at some places with the many-tinted clouds above, at others, spots glistening in the distant sunlight; torrential streams coursing along the valleys in the full swing of their work of erosion, here aided by the most favourable proportions of frost and water, and the practical absence of vegetation. In fact, wherever we look there is striking evidence of the fight between volcanic productivity and destructive erosion. These great Jökulls, when seen from behind, are remarkable for their extremely flat, dome-shaped form, and well deserve the name of ice-caps. During the whole of our journey along the mountain backway we saw no true glaciers. The ice-cap comes right down to the plain, seems to sink some distance into the sand and there to thaw, probably owing to warmth from below. No streams flow away from the edge of the ice, as all the water trickles down through the porous lapilli and no doubt finds its way into the rivers some distance off.

If we examine such a river as the Markarfljót, we are struck by its

volume in proportion to the short distance it flows, and the few surface tributaries it receives. It no doubt is to a very large extent fed by innumerable subterranean tributaries of glacial and other waters. This fact will also no doubt explain its very rapid increase of volume as it passes the Jökulls, and the extraordinary broken condition of its course near Eyvmdarmúli, each channel being fed by springs gushing up from the bottom.

I have on several occasions mentioned the peculiar pointed-conical or truncated-conical form of the mountains. These are, of course, frequently volcanic cones, yet they do not owe their peculiar shape to eruption. Their sides slope too steeply, and their truncated summits are not always occupied by craters. The following explanation, I think, will show how some at least have been modelled. During a good part of the year every mountain-top in Iceland is effectually protected by a snow or ice-cap, which never thaws, except at lower altitudes. The sides of the mountain, however, are exposed to frequent alternations of frost and thaw, and are constantly scaled away by this action, so that, as we approach one of these mountains it looks at a certain distance like a tremendous pile of material for macadamising roads, and on a nearer approach the resemblance is more striking, except that the fragments are frequently as big as coco-nuts or still larger. The angle of repose of these materials is very large, and the fragments around the base are carried away by erosion, so that these mountains in a short time acquire very steep flanks. Gradually this process is continued, until the ice-cap is mined away and falls piece by piece, disappearing at last altogether, and then the summit becomes acute. In fact, the process is very analogous to the formation of earth columns, only the ice-cap replaces the boulder or the stratum of rain-resisting rock. The water from the ice-cap aids also in keeping the surface moist, the condition most favourable for action of frost and thaw. Many of the great Jökulls show these peculiar steep, cliff-like flanks, which are no doubt due to the same phenomena. Of course, I do not exclude the effect of old marine erosion, but I think that where such once existed it has been rapidly effaced by the active processes of frost and rain. A striking example of this is the Laufafell at the east foot of Hekla, close to which we passed after quitting our half-way camp.

Running beneath the Laufafell is the valley of the Markarfljót, the sides of which are terraced for great distances in a most perfect manner (Photo. No. 7). Two long terraces are noticeable, with one or two subsidiary ones. The whole valley seems once to have been a vast lake, produced by its damming up at some lower point towards its mouth. How this was accomplished it was impossible for us to see, and it would require a careful survey to settle the point. Where, however, the Markarfljót doubles back on itself around the Grœnafjall, it is closely hemmed in between this mountain and the Merkr Jökull, a part of the Godhalands Jökull, and possibly it was temporarily dammed by a great avalanche of water, ice, and boulder detritus during the eruptions of the Kötlugjá, or some other rent in the triplet of Jökulls. This collection of detritus may now be represented by the Mœlifellssandr.

All along the road to the south of Hekla this remarkable terracing of



No. 6.



No. 7.

the valleys is noticeable, and I believe that in many cases those are not ordinary river terraces, which are usually very irregular and broken, whereas these show that remarkable uniformity of height and persistence for long distances that characterise the old shore-deposits of lakes.

We took up our abode at Galtalœkr farm, intending to make the ascent of Hekla from that point. We waited for three days while it rained in torrents, and, what was worse, the mountain was enveloped in mist almost to its base. We could find no one who had courage enough to guide us in the ascent, and after making a few excursions around its base we had to abandon the idea.

I found many points of similarity between Etna and Hekla as to the products, and more especially the lavas. Yet the quantity of fluid rock that pours forth at intervals from Hekla within a given time seems to be much greater. The surfaces of jagged crusted lava-streams are marked by larger and more prominent humps, and some of the corded surfaces are enormous in dimensions. This is the largest surface of corded lava I have ever seen. Close to Galtalœkr farm the Vestri-Rángá cuts through some of the peculiar dome-surfaced lavas, already referred to (p. 448), and exposes them in section. They are basalt, slightly vesicular, more especially towards the surface, where more vesicular zones can be seen in curves parallel to those of the domes. This lava divides into fairly regular columns which radiate slightly so as to be normal to the surfaces of the domes.

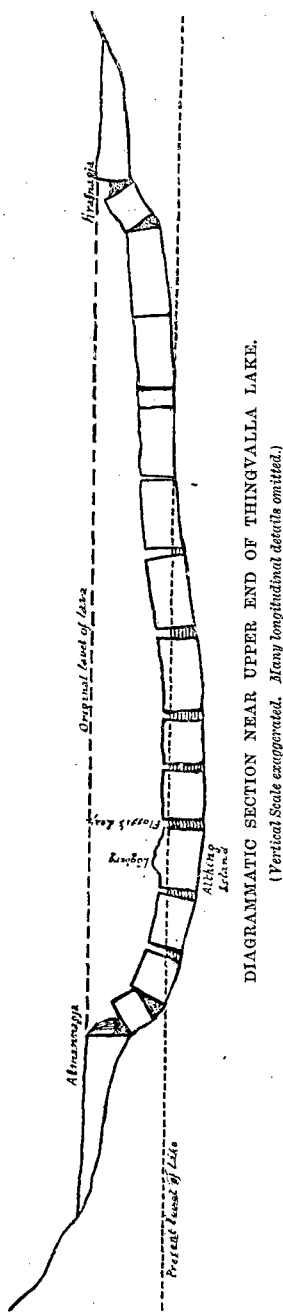
One of the remarkable points about Hekla is its irregular form and its greater length from north-east to south-west, with a somewhat curved plan, the convexity being to the south-east. It is essentially a great ridge of this form, with a great number of parallel ridges and furrows. Most of the parasitic vents upon its slopes are arranged along lines parallel to the general trend of the mountain, and show no indication of the radial arrangement so common in most volcanoes. In these features Hekla totally differs from Vesuvius, Etna, and numbers of other volcanoes. There is, I think, only one explanation, and that is that Hekla is nothing but a volcanic pile built up along a main fissure running north-east to south-west, with probably subsidiary clefts running parallel to the main one. In fact, Hekla may be looked upon as rising over a vent very similar to that of the larger Skaptár fissure, only that freer exit has been found at one particular point instead of along a more extensive stretch of country.

Our journey from Hekla to the geysers presented little of general interest, but rather attractive from geological detail. Most of the mountains and hills are old volcanic rocks entirely remoulded by denuding agencies. Here and there occur hot springs, indicating that, although the rocks look old, igneous activity is still going on not far beneath the surface. Fine radiating columnar basalts were met with side by side with tuffs. Both basalts and tuffs are rich in secondary deposits of zeolitic material, as one would expect in a region of hot springs. From a geographical point of view, perhaps the crossing of the great rivers is of most interest; for the large volume of water rushing down a high gradient, and carrying seawards so much sediment, is striking. In fact,

this high gradient demonstrates the recent upheaval of the country, which is not unlikely actually going on at present.

Of the geysers little need be said, as we possess so many good and detailed descriptions of them. The Great Geyser seems, from what we were told, to be in a state of gradual decline, and during a stay of a day and night did not afford us the opportunity of seeing a display. The Strokkur, on the contrary, responded to the usual emetic of grass tufts, and went off in grand style. The sinter basin of the Grand Geyser is of a dirty, earthy-brown colour, and quite different from the sinter of Cape Reykjanes. This I attribute to the dirty state of the water, due to visitors throwing in earth and turf in the hope of starting the Great Geyser in the same way as is done with the Strokkur.

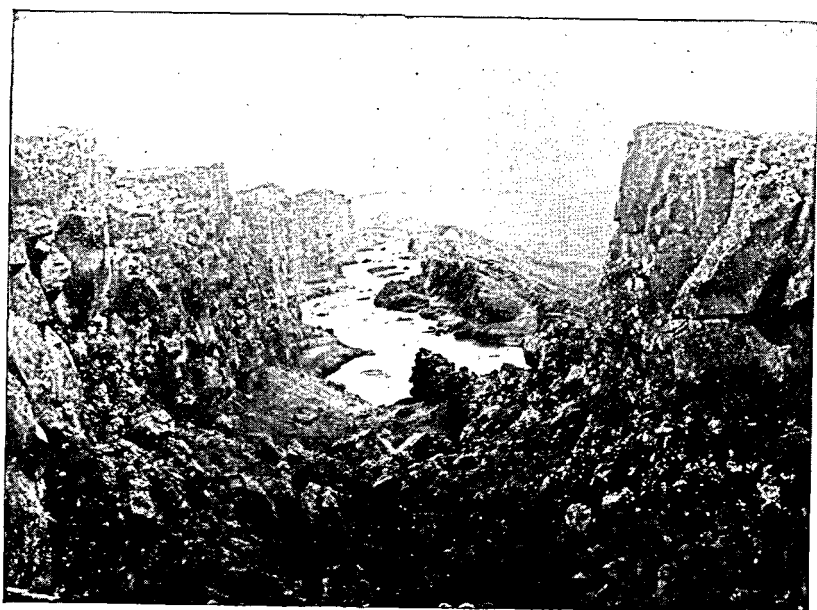
No point in Iceland is of more interest historically than the district of Thingvellir, and I doubt if any other can surpass it from the point of view of geography and vulcanology. At no distant date, though anterior to the colonisation of Iceland, a vast quantity of lava was poured out in the broad Thingvellir valley. Whether this took place from the Skjaldbreidh, or from a prolongation to the south-west of the fissure upon which that volcano lies, is not easy to determine. At any rate great floods of lava that rivalled in quantity the Skaptár outpour filled the Thingvellir valley. Whether this depression was then an empty valley, or was already a lake of water, is a subject for further investigation; if such a lake did not then exist, we must suppose that a dam was formed simultaneously with the eruption. This may have taken place by the upheaval of a cone at the lower end of the valley, perhaps one of a series of which the cone of Sandey, that now forms an island in the lake of Thingvalla, is one. The dam for some time retained the flood of lava, which rose until it filled the enclosed valley to the height of the terrace above the Almannagjá. By that time a crust of at least 32 m. had consolidated on its surface towards its edges, if not all over it. The enormous hydrostatic pressure of this lava lake, with a specific gravity of two and a half times that of water, finally burst the dam, and the fluid rock beneath the crust escaped. The amount of lava must have been enormous, for it probably covered



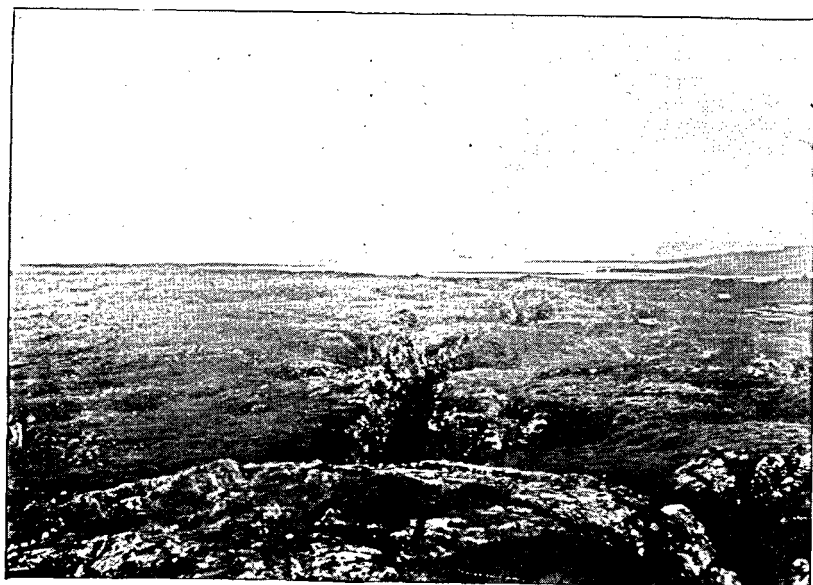
DIAGRAMMATIC SECTION NEAR UPPER END OF THINGVALLA LAKE.  
(Vertical Scale exaggerated. Many longitudinal details omitted.)

a roughly rectangular area about 8 km. broad by 35 km. long, or 280





No. 8.



No. 9.

square km. The great crust settled down, except where supported by the shallower sides of the valley, just as a rim of ice hangs along the banks of a river if the volume of water diminishes. The line of rupture along each side is now represented by the great Almannagjá on one side of the valley, and the Hrafnagjá on the other. The adjoining diagram will make this clear. As the unsupported part of the crust sank, the pieces near its edges swung round and remained tilted on the side of the old valley bottom. At present a small river, the Oxara, flows over the precipice marking the edge of the undisturbed crust, and then flows along the Almannagjá, being shut in between the above-mentioned precipice and the ridge formed by the tilted edge of the sunken part of the crust. The Oxara after a short distance passes through an opening in this ridge, and finds its way downwards and forwards to the lake. The accompanying photograph shows extremely well this remarkable disposition, and the striking scenery it has produced (Photo. No. 8).

The central part of the lava crust that sank till it rested on the old valley bottom is broken up into a number of longitudinal islands by rifts, due partly to contraction, and partly to the irregularities of the old bottom as indicated in the diagram. These rifts, as we approach the lake of Thingvall, are filled by water up to the lake's level. It is on one of these islands that the renowned Icelandic parliament or Althing was held for many centuries, the laws being proclaimed and annually recited from a boss of lava of greater height near its northern end, and known as the Lögberg, and which commands a magnificent view over Thingvall lake and Sandey island. With the exception of a narrow isthmus, the Althing is a complete island surrounded by a deep moat of water occupying rifts or *gjás* in the lava, and ranging from two to five or more mètres across (Photo. No. 9).

It was at the narrowest part that Flossi made his great leap to escape from the pursuit of his adversary, as recorded in one of the most renowned of Icelandic sagas.

The Almannagjá and the Hrafnagjá of Thingvellir therefore differ entirely from the rifts of the Reykjanes peninsula. The Icelandic *gjás* or rifts are no doubt of various kinds, and this view has been confirmed by my friend Dr. Tempest Anderson in the case of those in the northern part of the island, which he has examined more recently (*Brit. Ass. Reports*, 1894).

Unfortunately, Iceland is much neglected by English geologists, notwithstanding its easy accessibility; and although Englishmen hold a high place in the history of vulcanology, they seem to have paid little attention to this interesting land. No spot would probably better repay careful detailed investigation than the old lava lake of Thingvellir and the present water lake of Thingvall. After our return to Reykjavik, having a couple of days at our disposal, we made an excursion to Hengill, with the intention of seeing something of the lower end of the lake. Weather was against us and frustrated our plans, obliging us to return from Hengill without being able to see anything there, as we had to contend with an impenetrable mist and torrents of rain. The journey from Reykjavik is, however, interesting, as about half-way a patch of very

recent-looking scoria cones occurs, worthy of note as not showing any marked linear arrangement.

Where the road passes near the Olafsskardh and Vifilsfell, the lava exhibits some small and striking spiracles in the forms of small cones and craters. The syrupy nature of the lava is shown by the way that the blobs or splashes which fell and built up the crater ring have guttered down into stalactites and drops, as admirably shown in the accompanying photograph (Photo. No. 10).

This is the most perfect example that I have ever seen or heard of of this type of spiracle. I doubt in this case whether they owe their origin to any volcanic vent directly underneath. I take them rather to be due to the local action set up by the lava flowing over a marsh, notwithstanding that similar cones, though less perfect, are often produced by the escape of vapour derived from a body of lava collected in some deep hollow. In other cases such spiracles, though usually in the form of spires, are produced on the roof of a lava-tunnel by the escape of vapour with a little fluid rock from the stream beneath.

I will terminate this somewhat disjointed record of facts by a few speculations that I have indulged in.

Iceland, if not absolutely the largest, is one of the most extensive areas of the earth's surface presenting an entirely volcanic mask of rock. We should expect therefore to find some characteristics not to be met with in such limited areas of volcanic country as are scattered over different parts of Europe, and more especially in a chain of patches extending throughout Italy. Where we have to deal with the oldest Icelandic volcanic deposits, the surface configuration has been so altered by old marine denudation, combined with that produced by glaciers, and subsequently further accentuated by subaërial erosion, that nothing very definite can be made out. The only fact clearly apparent is that during the Glacial Period ice forced its way down to lower levels by the most expeditious route possible. Many geologists would maintain that water would do the same; but the effects of the two are very different. Permeability influences pluvial erosion to an enormous extent, whereas cohesion of rock masses has most influence on the action of glaciers. An incoherent scoria cone is practically indestructible by rain, until its surface is rendered impermeable by decomposition, or by a mantle of volcanic dust from some neighbouring vent, and can serve as a water collector. Such a cone occurring in the path of a glacier would be immediately and entirely cleared away by the advancing ice without leaving a trace of its existence. Enormous scoria cones on Etna have remained practically unaltered for nearly 3000 years, and perhaps much longer; but, were Etna to be so situated as to collect an ice-cap and form glaciers, these cones would not last a dozen years. It is obviously, therefore, almost impossible to form any theories concerning the surface configuration of Iceland, which was to a large extent built up like other volcanic regions of incoherent fragmentary ejecta before the Glacial Period. Some traces may no doubt exist, for we must suppose that a long valley cut out of soft tuffs and filled by a deep and dense lava stream would, after exposure to intense glacial action, appear as a great lava ridge overhanging and

flanked by parallel valleys scooped out of the soft tuffs that had once held the lava flood. Ridge and valley will have changed their relations to each other, and the only trace, therefore, of pre-glacial configuration will be the trend of the country. But even such deductions as these, which may be applicable to subaërial denudation by agents of moderate force, are less reliable when ice is under consideration, for, if the highlands are so situated that the glacial flow is normal to such pre-glacial lava-filled valleys, it is evident that the resulting glacier valley will not correspond with them. Much caution is necessary when we attempt to examine the general features of Icelandic geography, and we are safer, therefore, in limiting ourself in the main to the more recent centres of volcanic activity. It is still more necessary to be cautious when we are treating of an area of which practically nothing is known in detail, and where large tracts of the interior are almost *terra incognita* to the scientific geographer and geologist.

Thus, for instance, we cannot generalise at all on such areas as that between Mosfell and Hvannefvi, the great north-western peninsula, or the east coast. Again, the great ice-field of the Vatna Jökull totally hides what is beneath it.

We may conventionally divide Iceland into a northern and southern portion by the line of watersheds. This line is nearly straight, and may be considered to extend from Hof on the east coast along the back part of the Vatna Jökull to Snæfells Jökull. Now what is most strikingly evident is that in the southern half of Iceland we have almost innumerable examples of a trend of the principal features from north-east to south-west. The axis of these ridges and furrows is not straight but is curved, with the convexity to the south-east, so that towards the south the trend becomes more westerly, and to the north more northerly, falling in with the north and south trend of the features of the northern half of the island.

We have already seen that a similar direction is followed by the *gjás* or rifts and the line of recent vents and solfataras of the Reykjanes and Skjaldbreidh tract. Not improbably the Láng Jökull covers the continuation of this line of vents to the north. To this same band probably belong the lavas around Eriks Jökull and at Oldur. Another band seems to include the Merkrhraun, near Olafsvellir, and the Hof Jökull, and the lavas and hot springs south-west and north of it. Ridge-backed Hekla forms another band with the Hágaunguhraun and the western part of the O'dádhahraun Myvatn, and the lavas and hot springs along the valley of the Laxa at Múli an Nes and the *gjás* near the Vikingavatn. Next, we have a band starting in the Westmanna islands, including the Kötlugjá, the great Skaptár fissure with its main rift curved but running in the prevailing direction, the eruptive centre that some years ago showed itself in the great Vatna Jökull, the great centre of Askja, and the lavas and rifts of the Skinnstakkahraun, the neighbourhood of Gardhr and Presthólar.

The next band may possibly include the lava of Kálfafell, part of the Vatna elevation, and the string of vents of the Kverkhukarani. Finally, the Svidhinhornahraun not improbably corresponds to vents hidden beneath the eastern end of the Vatna Jökull.

The only exception to this rule seems to be the vents of the Snæfells peninsula. Not improbably they are points along several other bands that stretch away to the south-west beneath the waters of the Faxa Fjörðhr.

When we pass to the hydrography of the island, we again perceive the same trend to the south-west. The distribution of drainage will not only be dependent on the sites of more recent eruptive centres but to a large extent on the earlier structural characteristics of a country. Mention has already been made of the courses of the great rivers, the Hvítá, the Thjórsá, the Markarfljót, the Skaptár streams and their tributaries, and to these may be added the two great rivers or Jökulsás of the north-east which flow into the Héradsflói, running quite independent of, but parallel to, the east coast. Notice, again, the extraordinary chain of the Fiskivötn which drain into the Túngnaá, and owe their existence simply to the impediment of Hekla thrown up across the line of drainage of which probably the Ytri Rángá and the Eystri Rángá are remnants. I have referred slightly to the influence of old lava streams in fixing the trend of the country, even in the face of great erosion, so that these peculiar parallelisms between the water-courses and the bands of volcanic vents are quite comprehensible. When we examine the map of Iceland, we are struck by the great numbers of ridges and rows of more ancient volcanoes in a direction from north-east to south-west. I will name only a few of them: Klukkutindar, Kalfstindar, near Midhdalr, the hills to the south-east of Blodhufell, and dozens of such elevations on a line drawn from the latter to Hekla, most of the valleys and ridges in the Skaptár neighbourhood, and, lastly, the country immediately north of the Vatna Jökull.

When we examine the northern watersheds of Iceland, we there see an equally marked trend of country and of recent volcanic vents, but with this difference, that in the main the direction is north and south. The same applies to the great *gjás*. In fact, the farther we advance to the north the more does the curve sweep round, sometimes almost to north-north-west. In describing the form of these curves over the whole of the island we may say, that as we advance towards the north-west the radii of the curves diminish, as if they were segments of circles described around a point situated somewhere near Sæbol or Stadhr in the extreme north-west of the peninsula, and between this and Snæfells Jökull. Even the fjords of the north-west peninsula seem to indicate the same arrangement. Along the peninsulas of the north of Iceland we see a similar extraordinary trend of the chains of hills. In such curves lie the two great Jökulsás of the east country, which run along the main tectonic axes, as indicated by me, of the island, and quite independent of the unimportant fjords along the east coast, although parallel and close to them—a peculiar conformation analogous to that of the Nile and the Red Sea. When we ask ourselves what these curves really represent, we have to consider some of the points concerning the distribution of volcanoes.

If we travel south to Scotland we shall there find, I think, the true explanation. Sir Archibald Geikie and others have shown the remark-

able systematic arrangement of the igneous dykes of Scotland in a series of almost parallel curved lines, and if we compare a map of Scottish dykes with a tectonic curve map of Iceland, the analogy is very striking. It is quite obvious that, if volcanic vents assume a chain-like or serial arrangement over parallel dykes, the drainage of such a country will sooner or later be forced into a similar parallelism, and that, notwithstanding deeply-cut resculpturing by glacier action, the old lines of softer or harder rock will sometimes reassert their influence in directing the line of waterflow, when subsequently exposed to subaërial aqueous denudation.

I think also that, as such tectonic curves are in the first place dependent upon the lines of crumpling of the earth's crust, we ought to be able to find some indication of such plication, for it is not to be supposed that folding of this kind stops simultaneously with the initiation of volcanic action. Possibly the great *gífts* of Iceland, exclusive of course of those of the type of the Thingvellir district, may possibly be surface manifestations of such folding now going on, unless the other suggestion I made be true—that these rifts are simply indications of plication over laccolites.

The peculiar tendency for secondary lines of weakness to run at right angles to the main ones is possibly indicated by the sudden sharp turns of some of the rivers or by the affluents joining the main stream at a large angle. Such examples can be found in the Laxa branch of the Hvítá and the Thjórsá at Búrfell, the branches of the Thjórsá on its north-west bank, and the Túngnaá. Then, again, the Eldvatn and its connections in the Skaptár show this in a remarkable manner. Still, most of these bends may be simply accidental and due to obstruction occurring in their line of flow. The frequent occurrence of subsidiary faults at right angles to the main ones is a fact of common geological knowledge. Dykes also not infrequently run at right angles to each other and may be of contemporaneous origin or not. At any rate, these are considerations to be borne in mind in studying such an extensive tract of volcanic country as Iceland.

Reference has been made to the denuding agencies of ice, frost, and water, but there is yet another of no mean importance, especially from the point of view of agriculture, and that is wind. Only those who have experienced it can form an idea of what wind is in Iceland: Not that it is of the nature of tornadoes or cyclones, which are immediately destructive, but it is rather remarkable for its steady persistence in one direction for days together. The wind may make or mar a farm in a few years, and, as such changes are common over the whole of that part of the island we visited, it is a subject worthy of some consideration. I have seen somewhat similar effects produced on a smaller scale in other recent volcanic districts. The effects of wind are agriculturally of far more importance in a country in which lavas predominate, as in Iceland, than in a tuff country where any amount of wind would fail to denude the surface of material fine enough to form vegetable soil.

If we examine such a district as Roccamonfina or that of Naples, we see how the showers of volcanic materials that have fallen on bare sterile limestone hills in the neighbourhood have converted them into fertile

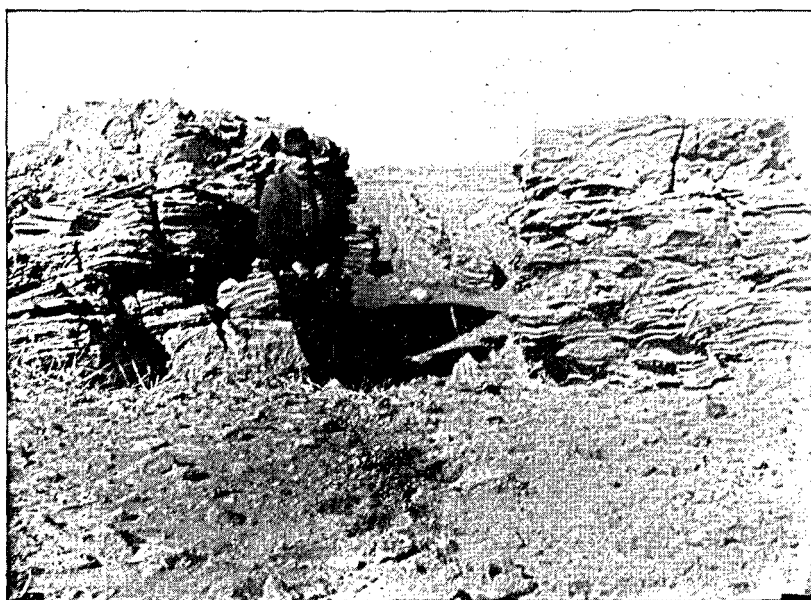
slopes which have remained such for many centuries, except where man by tree-cutting has allowed rain to undo the fertilising effects of former volcanic outbursts. The same remark applies to the rugged inhospitable surfaces of lava streams which require many centuries to become sufficiently decomposed to support other vegetation than lichens. On Vesuvius luxuriant pine forests, vineyards, and gardens cover portions of very recent lava streams that have been favoured by a mantle of fine lapilli, dust, or alluvium, whereas other portions of the same or much older streams not so covered are as barren as the year they were emitted. Large tracts of Iceland that have received such a mantle of fine volcanic dust and lapilli now support luxuriant pasturage. In some cases this earth-covering has been deposited direct from the air at the time of the eruption or eruptions that ejected the material constituting it. In most cases, however, it is the result of several eruptions, as shown by its fine stratification, which persists over wide areas. Thus, I could recognise a peculiar white band of minute pumice over some hundreds of kilometres of the country we traversed. This band increased in thickness and in the size of its components as we advanced by one road, and diminished as we retreated by another. Had we had time we could have traced this pumice up to its origin, as I have in several cases been able to do in other volcanic regions. The strata constituting the agricultural soil of South Iceland are composed of materials varying in size of grain, in colour, and cohesion, so that when seen in section they exhibit a band-like arrangement. Some soils are clearly composed of secondary or similar materials transported from other districts and redeposited, and these of course show the usual dune-like false bedding. As long as the turf over a field is intact the winds add to the quantity of productive soil, for the dust and sand that falls, provided it is not sufficient to bury the grass and so kill it, is caught and retained between the blades and increases the depth of the soil.

If, however, but a small hole is made in the turf, woe betide the field and perhaps the farm. The frost scales up a layer of earth which on drying crumbles and is carried away by the wind and falls into some river or the sea, or goes to enrich the soil of the farm to the leeward. The hole increases in size and depth like a corroding ulcer; the larger it gets the more rapidly does it extend, and soon the surface of the subjacent rock is laid bare. In the next stage what was once a fertile meadow is reduced to a bare rock surface, with a few islands of turf overhanging crumbling heaps of vegetable soil, and in a year or two all has disappeared. These peculiar eroded, ulcer-like patches of wind-denuded agricultural soil are quite a feature in the scenery, with the peculiar meandering outlines of the boundary between bare rock and turf marked out by the parti-coloured strata-banding of the soil mantle. The careful Icelandic farmer is aware of these facts, and stops any hole in his turf as soon as possible, unless the field be well sheltered from the wind. It was often interesting to hear our guide's expression of disgust when he saw a farm being gradually blown away in consequence of the negligence of the owner.

I have described the destruction of turf-covered soil—a most obvious



No. 10.



No. 11.



process; but it may be asked, if the wind will do this, how is it that it has ever allowed any dust or soil to remain long enough to become covered with vegetation? This was a great puzzle to me at first, but I think what I saw will explain away the difficulty, in part if not entirely. The process is a long one, and commences by the growth of the extraordinary crops of lichens so luxuriant in Iceland. These act as dust traps and pave the way for the growth of mosses, which eventually give sufficient hold for grass, ground willow, or birch bush. Then the soil increases in thickness by further additions brought by the wind or falling from the air during some distant eruption.

Of course in sheltered localities grass grows easily and wind erosion has no destructive effect, but, on the other hand, in wind-swept regions vegetation seems powerless either to obtain or retain a hold. Thus the Reykjanes peninsula is remarkably bare, covered with sand dunes, and exposed to the most dreadful dust storms. One of these we experienced, and it quite equalled anything in the Sahara so far as the mechanical effect went. I photographed the storm, but the negatives are all sand and cloud-like, just as some battle pictures are all smoke. All around Cape Reykjanes the rocks are eroded and polished by these natural sand-blasts. In the accompanying photograph the flow structure and variations in vesicularity are beautifully etched out by the cutting action of the blown sand on a low basalt cliff (Photo. No. 11). This is the more remarkable because basalts in general, and this rock in particular, show little of such flow-structure on an ordinary fractured surface. In fact, most of the older rock surface of this district is rounded and polished by the sand blast.

Another striking feature is the remarkable humpy nature of the pastures, which often renders travelling over them a dangerous and tedious process. They may best be compared to a churchyard with grave-mounds very closely packed, so that the space between one hump and another is little more than the breadth of the foot. The height of these humps is often that of the knee of a man or horse. The size varies in different localities, but is fairly uniform over any one district. The causes of this humpiness seem to be various. Not unlikely the irregularity commences with the original lichen covering. When grasses spring up amongst this it will be in separate patches. The more prominent tufts will entrap more dust from the wind. If the soil becomes boggy, the grass will grow better on the drained tops of the humps than in the waterlogged trenches, as we see in our own marshes. Then, again, the swarms of birds always perch on the humps, which are rendered more fertile by their droppings. Finally, the snow will always be thawed on the tops of the humps first, and the grass on them will get the start in sprouting at spring-time. Frequent mowing tends to obliterate these humps, as the grass in the hollows is more protected from the scythe and gets light and sun when that of the top of the hump is kept short.

Many writers on Iceland have referred to the special industries of the people, but few of them, as far as I have read, offer suggestions for improving the lot of the Icelander, who is a most deserving man, and whose remarkable literary culture eminently fits him for applying scientific

and technical methods. The three greatest difficulties that the Icelander has to contend with are absence of limestone, forests, and roads. The consequence is that, with the exception of a few constructions of corrugated iron, the farm buildings of Iceland are very primitive, affording cramped, unhealthy, and imperfect shelter to man and beast. Irregular slabs of lava alternating with strips of turf form a very imperfect wall. This is indeed made less pervious by a lining of wood, which, however, must be used most sparingly, whether it has to be carried many miles on ponies or is obtained from teredo-bored drift logs thrown up on the coast. Partly in consequence of defective shelter the death-rate of the people is high, and large numbers of sheep die during the winter. To a large extent two of these difficulties would disappear if good roads were made round the island, especially if cheap narrow-gauge railways were constructed beside them. Large quantities of dairy produce, meat, fresh and salted fish could be brought to the trading ports, and sent to England, France, Germany, etc., in a few days, whilst timber, coal, and lime, besides flour and other commodities, could be obtained by the farmers in exchange.

It has always puzzled me why there are no trees in Iceland. One is told that about once in ten years the ice-pack sets on the north coast and spoils the summer; but surely there must be some trees of subarctic regions, that thrive in far more rigorous and uncertain climates, which could be introduced into Iceland. I saw many sheltered spots where whole forests would find a congenial home, and where the stunted birches and willows indigenous to the island thrive in luxuriance. I could hear of no serious attempts even at acclimatising trees of any kind. There is, then, in one way or another, a large field open for the employment of capital at only a few days' sail from the great Scotch and English markets.

With such means of communication as I have suggested, Iceland offers, especially to the fisherman and devotee of the gun, unrivalled opportunities, while the tourist would have within reach a new field for his summer or autumn holiday, enjoying a summer climate superior to that of Scotland and accessible by a short and pleasant sea trip. The invalid would find relief in the innumerable and varied hot springs of the island.

No doubt, were road communication introduced, handicrafts would gradually spring up, giving occupation to the people during the long winter, and adding to their prosperity.

In any case, Iceland offers to the geographer and geologist a wide field of investigation which, however, must be pursued by them conjointly, as these two branches of science are inseparably interdependent, perhaps even more so in the land of frost and fire than in any other.