CONTRIBUTIONS

TO

THE PHYSIOGRAPHY OF ICELAND

WITH PARTICULAR REFERENCE TO THE HIGHLANDS WEST OF VATNAJÖKULL

BY

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WITH 32 PLATES AND 9 MAPS

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PREFACE

The material on which the present work is based was for the most part compiled on a journey in 1927, The Second Danish-Icelandic Expedition, the members of which were:—

Pálmi Hannesson, B. Sc. (now Rector at the Grammar School in Reykjavík).
Steinþór Sigurðsson, B. Sc.
Sigurður Jónsson frá Brún, schoolmaster and farmer.
Niels Nielsen, Ph. D.

Some of the material, however, was collected on my former journeys in Iceland in 1923 and 1924, and, though it plays no great part from the point of view of quantity, those journeys have had a particularly important bearing on the work because, through them, I had become fairly familiar with the technique of travelling in Iceland and also had formed a certain concrete view of the tasks that presented themselves when we made a start on the work in the field in July 1927. I am greatly indebted to all my companions for work well done and for their enjoyable society; I would especially extend my thanks to my old travelling companion Pálmi Hannesson for a collaboration which, spread over many years, has been an inexhaustible source of knowledge to me. Nor can I omit to express my gratitude for the kindness and helpfulness I have always found among the Icelandic authorities and in Icelandic homes. Mr. W. E. Calvert has undertaken the translation in a most carefull manner.

The funds necessary to cover travelling expenses were procured from grants kindly made by the Carlsberg Foundation and the Dano-Iceland Union Foundation, while the Carlsen Lange Endowment Fund, by means of its stipend to Steinþór Sigurðsson has greatly promoted the handling of the cartographic material. The translation expenses was defrayed by the Rask-Ørsted Fund. I tender my heartfelt thanks to these institutions.

Copenhagen, October 1930.

Niels Nielsen.

A. The Landscape west of Vatnajökull.

1. Situation and History of Discovery.

The region to be dealt with in the following lies in Central Iceland in lat. 64—65 N., long. 18—20 W. Its total area is about 1600 sq. km., and the mean height above sea level is about 700 m. On the north it is bounded by Vonarskarð and Túngnafellsjökull, on the west by Þjórsá, on the south by the Túngná, and on the east by the Túngná and Vatnajökull.

Of the whole of Central Iceland this area is one of the most difficult to penetrate, because a whole series of obstacles to the forward march of man combine there; travelling through it is difficult enough — a sojourn of any duration still more so. If one attempts to come from the south and along by the glacier one meets a system of wild lava fields that are by no means easy to force. Coming from the north one must first pass through the great desolate wastes north and northwest of Vatnajökull, and thereafter one meets the glacial river Kaldakvísl, of which a great part of the upper course runs in ravines and thus forms a very effective hindrance. The easiest way into the region is from the southwest, as without much difficulty it is possible to get from the Hekla region as far as to Fiskivötn by making use of the regular ford over the Túngná at Bjallar, north of Mount Loðmundur. With this, however, the difficulties have not been overcome. The whole area is so to say bare of vegetation, and in two places only is it possible to obtain so much pasture that a number of horses can live for any length of time, viz. in Illugaver and Fiskivötn. In good summers one may also expect to find grazing in August in the small oasis Botnaver, just west of the margin of Vatnajökull; the quantity of grass there is only small, however, and can only feed five to ten horses for a few days.

At one or two other places it is possible to cross the Túngná. Both Thoroddsen and Erkes have crossed it at the bend at Námskvísl, and Björn Gunnlaugsson indicates a ford across the Túngná southeast of Fiskivötn, probably identical with the one used by Pálmi Hannesson at the remarkable tuff column Tröllið, fig. 24. Both these fords, however, have the disadvantage that they are very variable and full of quicksands, so that a caravan carrying scientific equipment would if possible avoid them. Finally, it is usually possible to cross the Túngná over its tributaries in Túngnárbotnar, right up near the Vatnajökull. There the ford lies some few hundred metres above the place where the watercourse from Botnaver empties into the river, west of the highest peak of the characteristic mountain that lies just to the north of Botnaver.

These difficulties form one of the reasons why this part of Iceland has hitherto lain almost as virgin country. Another reason is that most investigators who have travelled the country — now quite a considerable number — have proceeded along the traditional, oft-travelled routes, at any rate when the object was the central highlands; the consequence is that there has been a pronounced diversity in our knowledge of that part of the country, certain routes and certain localities being comparatively well known, whereas others close by have remained terra incognita, from a scientific point of view, up to the present day.

The pass between Vatnajökull and Hofsjökull — about 35 km wide — through which the mountain path Sprengisandsvegur runs, has been travelled scores of times by explorers and sportsmen, and practically all the men of science who have made deep studies of nature in Iceland have traversed this route. Only rarely, however, have any of them attempted to go eastwards from Sprengisandur and examine the country on the west edge of Vatnajökull. The country south of the Túngná has been the scene of a very violent volcanic activity in historic times, especially in the years 1783—84, for which reason a number of investigators have visited it: Helland, Thoroddsen, Sapper, Reck and several others; thanks to their researches a part of this landscape is known fairly well.

On the other hand the country north of the Túngná has been visited by only few investigators, who have remained in these inhospitable regions a few days. Nor does the peasantry of Iceland know anything of it, to the best of our knowledge, because only the most southerly part, the Fiskivötn area, has been of any value industrially. The two oases have been known in olden times, but little or nothing else.

The first to record his observations in these regions was the highly gifted Icelandic physician and naturalist Sveinn Pálsson, who went to Fiskivötn in 1794. His visit was quite a short one, and the report in his diary consists of an account of the main topographical features and some biological observations. The knowledge we have so far had of Fiskivötn was almost exclusively derived from a journey made in 1889 by Þórvaldur Thoroddsen, with the farms of the Hekla-region as his starting point. He worked in the area five days and thereafter went up to the edge of the Vatnajökull, discovered the oasis Botnaver, and then travelled southwards, discovered Langisjór, and went back to Fjallabaksvegur nyrðri. The accounts of this momentous journey are contained partly in the Ferðabók and partly in Geografisk Tidsskrift, Vol. 19, and both in Thoroddsen's geological map of Iceland and in his large manuals we find the results of that exploration.

Access is much easier to the regions round Túngnafellsjökull, and in fact they have been frequently travelled by investigators. In August 1839 Björn Gunnlaugsson went through Vonarskarð, the pass between Túngnafellsjökull and Vatnajökull, and to this day his observations and measurements form the basis of our knowledge of the main topographical features of this region. He stayed two days at the oasis Illugaver, which has also been visited in recent times by several travellers, although their stay has been very brief, and there is little information about the geography of the region.

In Nýidalur, on the west side of Túngnafellsjökull, there is a small oasis where many travellers have sojourned a short time. Among them particular mention must be made of Reck and Erkes. The former went round the whole of the mountain group in 1908 and had the opportunity of making a number of valuable geological and topographical observations, to which I shall revert later.

In 1925 and 1926 the Danish minister to Iceland, F. de Fontenay, made two journeys up there. At the beginning of August 1925 he went from the oasis Illugaver to the mountain group known as Kerlingar on the edge of Vatnajökull, climbed the edge of the glacier and went round the mountain group in question. On this journey he discovered the very interesting tectonic fissure Heljargjá, established that the flow from that part of the glacier was southwards, and recorded much other information of value concerning this land, up to that time entirely unknown. In 1926 he went to Fiskivötn together with Pálmi Hannesson. There they remained for some days, but their work was greatly hampered by unfavourable weather.

In 1924, Pálmi Hannesson and I, the sun beating down upon us, stood on Hofsjökull looking out over the country between it and Vatnajökull, spread before us like a map far below. We then made a compact that our next journey should be to that region, and that it should be on such a scale that we should be able to work through practically the whole of that interesting terrain. However, it was not until 1927 that we were ready for that journey; on the other hand we were able to make a stay of about two months. The plans for the journey, the technique we used, our equipment, programme of work, etc. have already been described in my preliminary reports, to which I must here refer (Nielsen 1927 and 1928).

2. Topographical Conditions.

Our present knowledge of the topographical conditions in Iceland is of a very heterogeneous nature, and as a result the reliability and value of the various maps as aids to scientific work is also very varied. Of about half the coast lands we may say that the maps meet all the requirements of a modern, topographical survey in detail, the south, west and a part of the north coast having been surveyed by the topographical section of the Danish General Staff, whose material is represented in the form of 118 map sheets on the scale of 1 : 50,000 and 5 on the scale of 1 : 100,000. These carefully drawn and handsomely got-up maps provide most valuable material for the study of a number of geographical and geological problems, of which one, for instance, is dealt with in the closing chapter of the present work.

For the most part, our knowledge of the topography of the east and northeast coast land is based upon a triangulation made in the years 1801—15 under the auspices of the Dano-Norwegian Government. In connection with this work the Icelandic topographist BJÖRN GUNNLAUGSSON (1831—43) energetically and with great skill surveyed important parts of the then entirely unsurveyed interior of the country, and these two series of surveys were then combined in a map which, for its time, was a most excellent piece of work: Uppdráttur Íslands 1844, which bears the name of BJÖRN GUNNLAUGSSON (NØRLUND 1930). Unfortunately, the difficulties bound up with satisfactorily coping with the task of making a map of the interior of Iceland were far in excess of the powers of one man — especially when one considers how very modest were the conditions under which BJÖRN GUNNLAUGSSON worked — and so it is no wonder that the result is full of defects, as a few examples in the following will show. Nevertheless, GUNNLAUGSSON's was a pioneer labour of great value, and to this day it is of fundamental importance to our knowledge of these parts of the country. His method of working has been described in a small book in Danish and Latin dated 1834. The map was reproduced by KÅLUND in that deserving work: Bidrag til en historisk-topografisk beskrivelse af Island, Copenhagen 1877—82, and has been the foundation for the cartographical representations of Iceland during the succeeding half century.

Since then THORODDSEN, DANIEL BRUUN, HEINRICH ERKES and others have made numbers of corrections on the basis drawn up by GUNNLAUGSSON and have remedied a number of its manifold defects. THORODDSEN's map has been published piecemeal in a great many special works and in its entirety in the large Handbook of 1905—06, as well as in the geological map of Iceland, scale 1 : 600,000, published separately in 1901. On his tourist map of Iceland DANIEL BRUUN inserted a number of corrections, most of them the results of his own observations; and finally an Icelandic commission in 1928 published an orographic wall map, which included the results of the surveys made up to about 1925.

But while a part of the coast land is thus well known topographically, it is by no means possible to say the same of the interior highlands. The maps of that part of the country are for a great part based upon purely rough sketches, drawn without the use of instruments to any great extent. As a rule they have had the character of route notes, and, as only very few investigators have remained for any length of time at one place in the interior — usually with other objects of study than topography pure and simple — the result is a very uncertain one both with regard to the course of the main topographical contours and with regard to the placing of the features of the terrain. Only in very few cases has a small area been measured with any great accuracy, and even in these cases the details are lacking in accuracy. Among them are those of CAROC in Askja, HELLAND's at Laki, WUNDER's in Kerlingarfjöll and OETTING's in the terrain between Hofsjökull and Langjökull.

It is evident that, as far as the interior is concerned the investigator will usually have to make his own map of the region he is working in. On the 1924 journey we were only two who busied ourselves with scientific work and so we had to simplify our methods as much as possible. Our surveys were made in this manner: in each of the areas examined we set up a measuring station, and from it, using the Bussole, we measured the angles to some prominent points in the terrain, and their distance from the station was then measured with HYMAN's pocket rangefinder. On this skeleton we then drew the sketches on which the geographical and geological results were entered. We found North by means of a meridian line calculation, as the magnetic variation was subject to such great local disturbances that the compass was useless for the purpose. No general orientation in relation to the topographically surveyed region at the coast was obtained, however. A method of this sort is of course unsatisfactory, but much to be preferred to the sketch method pure and simple, without the use of measuring instruments. In 1927 we were able to check some of our 1924 measurements by triangulation, and it turned out that the topographical picture was correct on the whole, even if there were errors of up to 5 per cent. in the distances.

The object of the journey in 1927 was not essentially topographical; but if we were to place the phenomena observed, we had to procure a map of the area in some way or other. The fact is that our knowledge of the region between Túngná and Kaldakvísl was in advance very slight. The surveying work was organized in this way: one of the members of the expedition, STEINÞÓR SIGURÐSSON, with the necessary assistance from the other members, was detailed to triangulate the whole of our field of operations and to measure up as many of the prominent points in the surrounding landscape as possible for the purpose of obtaining, firstly, working sketches, and secondly, the map worked out on the scale of 1 : 200,000 for the present publication.

The base of the measurements was a line of 637.99 m., measured with the measuring tape on the plain at Vatnakvísl. To assist in sighting we built about two hundred cairns here and there on the ground. The measurements were then taken with a small theodolite, which was no heavier than that a man could climb about with it. Orientation was secured by means of sextant observations and by means of an area in the south part of the country, surveyed by the Danish General STAFF, with which we connected during the final stage of the journey. Heights were obtained trigonometrically in some cases, in others with the barometer. The aeronoid barometer used for the latter was corrected at every main station with the hypsometer, whereby we obtained confirmation of our earlier experience than an aneroid barometer, even when packed with extreme care, does not stand a horse-back journey well, as the correction was found to vary very considerably at the different stations. From four high trigonometrical stations we then measured a number of prominent points in the whole of the southern part of the Icelandic highlands, right from Langjökull to the nunataks in the south and west parts of Vatnajökull, while from two points in the north part of the region we have taken a number of sights to various points in Ódáðahraun and the highlands north of Hofsjökull.

These measurements have demonstrated that hitherto there have been various errors in the placing of the main topographical contours of the south highlands, and, as the map page . . . shows, the differences are rather great. On the map are shown the glacier boundaries and rivers as plotted on THORODDSEN's map of Iceland, and for purposes of comparison the boundaries shown by our measurements. The principal results are as follows:

The geographical length of the west edge of Vatnajökull is in all essentials correct on the earlier maps, and this means that the east to west extent of that glacier must also be correct. According to TRAUTZ (1912) its northwest corner is if anything placed too far south; Kverkfjöll, too, according to KOCH and WEGENER's measurement of the distance between it and Esjufjöll (65 km.), may be assumed to be somewhat more to the north than hitherto thought. Thus the area of Vatnajökull is scarcely less than indicated by THORODDSEN, and probably is something over 8000 sq.km.

Both the size and placing of the other inland glaciers must, however, be revised to some extent. From the observations of DANIEL BRUUN and HEINRICH ERKES we have had reason for presuming that the distance between Hofsjökull and Vatnajökull on the maps was given too short, but no exact measurement had hitherto been taken, and one could not determine where the error lay. Our measurements show, however, that the explanation is an incorrect idea of the size of Hofsjökull. The fairly primitive measurements of 1924 (cf. Map No. 2, NIELSEN 1924) already showed that the distance between the southwest and southeast corners of this glacier had been put at too high a figure, and our triangulation in 1927 has confirmed this to the full. The central point of Hofsjökull is indicated correctly, but the edges to the south, east and west have been pushed too far forward. THORODDSEN estimated its area at 1350 sq.km., but actually is it much less, in fact about half that size, as according to the present measurements Hofsjökull may be estimated to cover a surface of about 700 sq.km. It is only right to add, however, that with regard to the north edge we have not sufficiently complete measurements to enable us to outline the course of the ice margin with certainty.

For Túngnafellsjökull THORODDSEN indicates a size of 100 sq.km., but this, too, is an exaggeration. In 1908 RECK explored the mountain region and was able to state that the area of the glacier must be round about 30 sq.km. This corresponds well to our measurements, which may be incomplete, but nevertheless are sufficient to show that THORODDSEN's idea of the size of the area of this glacier does not harmonize with reality.

This brings us to another question: the mutual situation of these glaciers. Vonarskarð, the pass between Túngnafellsjökull and Vatnajökull, has practically the breadth indicated by THORODDSEN, and thus the error when drawing in the former glacier lies in the size, not in the placing. On the other hand the distance between Hofsjökull to Túngnafellsjökull has been greatly underrated, as, instead of 12 km., it must be put at 25 km.; this is a part of the aforementioned over-estimation of the area of the Hofsjökull. A similar distortion is revealed by a revision of the maps of the area between Hofsjökull and Langjökull. The big pass there, Kjölur by name, is actually much wider than earlier maps indicate; it is true that the angle of intersection between our sight-lines is rather more acute than desirable, but we believe we have established that the distance from Blágnýpa to Hrútafell exceeds 20 km. and thus is more than twice as great as hitherto believed. The correctness of these measurements has been fully confirmed by the German geologist OETTING, who in 1928 made a topographical survey of this landscape, from which it appears that the distance between the two points is about 25 km. (OETTING 1930).

There is no doubt that our maps of Langjökull also need revising, but our material contains only a single measurement that is of any interest in this connection, namely, that Hrútafell — a large and widely-visible mountain just east of the glacier — must be moved about 15 km. to the northwest. Here it must be observed that the situation of the south edge of this glacier has been established by the surveys of the General STAFF, and that there is furthermore reason for supposing (based upon BJÖRN GUNNLAUGSSON's intimate knowledge of this district) that the west edge of Langjökull has been drawn without much inaccuracy. It this supposition is correct, we arrive at the result that the north part of Langjökull is somewhat narrower than it has been taken to be, from which again follows that its size, estimated by THORODDSEN at 1300 sq.km., must be reduced somewhat. I shall not enter upon any estimate as to how much the reduction should be, but I am certain that Langjökull is larger than Hofsjökull, and that in future it will have to be given place as the second largest of the Icelandic glaciers.

It is thus evident that the main error in our past ideas of the topography of Central Iceland may be traced back to the fact that the size of the glaciers, with the exception of Vatnajökull, has been much overrated, quite a natural consequence of their completely dominating the landscape with their height and massive contours, whereas the extent of the intermediate plateaux — differing so slightly as they do in ground features — has been correspondingly underrated. I believe that the total area of Langjökull, Hofsjökull and Túngnafellsjökull has been put at about 1000 sq.km. too much by THORODDSEN.

Within the region specially explored it would be supposed that a systematic survey would lead to a far-reaching revision of our ideas of the topographical conditions; this has indeed proved to be the case. Not only has it turned out to be necessary to alter and add details, but the course of the main topographical lines: waterways, ice-margins, valleys, mountains and sea beaches, is somewhat different than hitherto believed. A comparison between the previously existing maps and the one now published makes the difference apparent at once. The most important errors in earlier maps are: Both the Kaldakvísl and the Túngná are placed too far to the south, and the direction is also erroneous, as in their upper course they both run southwest and are almost parallel; the lake group Fiskivötn—Litlisjór is wrongly orientated, the edge of Vatnajökull runs differently to what has hitherto been assumed, and, as shown by DE FONTENAY's observations in 1925, its waters run into the Túngná, which rises away up in the mountain group known as Kerlingar; the latter, too, must be moved about 10 km. further north.

The mapping of the lakes deserves some brief reference. BJÖRN GUNNLAUGSSON entertained the belief — the result of information given him by BJÖRN SAL ÞÓRVALDSSON in Stóradal — that there were the following lakes north of the Túngná: Two large lakes, i.e. Stórisjór and Litlisjór, as well as a number of small ones lying together in a group and called Fiskivötn. According to GUNNLAUGSSON, who did not know the region personally but only through what the peasants told him, the mutual situation of these lakes was: Nearest to the glacier was Stórisjór, then next came Litlisjór, and, furthest southwest, Fiskivötn. On this question SVEINN PÁLSSON writes: "Of the known lakes the following are the largest: Stórisjór, furthest north, largest of all, winding, perhaps comprising several small lakes, extends further north than one has travelled .... from Stórisjór towards the southwest a river runs under "Hraunet" (the lava) to Stórafossvatn, which again empties into Litla-Fossvatn." The same names are used by THORODDSEN on maps and in travel diaries and handbooks, whereas DANIEL BRUUN (1925, p. 38) says that north of Grænavatn one comes first to Litlisjór and then to Stórisjór, which previously had erroneously been called Litlisjór by some people; on the map accompanying his paper, however, he has only shown Stórisjór.

In his paper 1925 DE FONTENAY, p. 130, summarises the problem of Stórisjór, and comes to the conclusion that the Stórisjór of THORODDSEN and SVEINN PÁLSSON are identical and the same as the lake which GUNNLAUGSSON calls Litlisjór. Undoubtedly this is correct. Nowadays this lake is called Litlisjór by the peasants, and therefore we must give it the same name, regardless of the terminology used by the writers named. But then the question arises: Is there a Stórisjór, or, put more correctly, is there between Litlisjór and the glacier a large lake that can bear this name? Among the country people in the Hekla region one sometimes meets with this belief. Nevertheless, our investigations show that there is no such lake. It is true that there are several small lakes in that terrain, but they are all very small, rarely exceeding 1 sq.km. and thus much inferior to Litlisjór in point of size; the result is thus that there is no Stórisjór, and that the traditions both among the peasantry and in the literature about this lake are simply a myth without foundation in reality. We do not know definitely how this interesting example of myth-growth has started, but my companion PÁLMI HANNESSON has advanced the following theory: The lake north of Fossvötn is, and always has been, called Litlisjór, that is to say "the little sea", and this is a name that fits it very well for, seen from the south, the lake really seems to be of imposing size; later on the origin of the name has been forgotten, and it has been thought that if the ancients called the lake Litlisjór, there must also be a Stórisjór that was bigger; and where else than up in those wide and unknown wastes north of Litlisjór could such a lake be situated? Both SVEINN PÁLSSON and THORODDSEN, who have both been to Fiskivötn, call the largest lake in the area Stórisjór and allow the other name to fall, whereas GUNNLAUGSSON and DANIEL BRUUN believe that there really are two large lakes in that region. And so, when after his great journey in 1889

THORODDSEN has to name the big, elongated lake south of Botnaver, he calls it Langisjór because of the other names Stórisjór and Litlisjór. It is in this manner that we find the explanation of the remarkable fact that in this region there are three lake names ending in "sjór", although in Icelandic a lake is called "vatn", whereas "sjór" means "sea".

Northwest of Fiskivötn and Litlisjór is another lake, Þórisvatn, shown by BJÖRN GUNNLAUGSSON and on all later maps. His cartographic placing and outlining leave much to be desired and would seem to indicate that he did not have the opportunity of seeing it during his aforementioned sojourn in Illugaver; indeed it would rather seem that he has learned of its existence through the verbal communications of the country people. THORODDSEN, however, visited it in 1889, and we know that some other investigators have seen it since. Thus on his great journey from Arnarfell out over the Kaldakvísl in the interior, HELLAND (1883, p. 262) passed Þórisvatn, but he went astray and could find no grass; only after great privations and difficulty did he get out of the desert and bring his caravan safely down to the Hekla region. DANIEL BRUUN has also seen it, as have HEINRICH ERKES and possibly HERMANN STOLL. Among the peasants in the south country it is well known, many of them having been to it when rounding up sheep in autumn.

THORODDSEN reached the northwest shore of the lake and from the surrounding heights received a mostly correct impression of its shape, size and situation, and on this, as on so many other points, made a valuable revision of GUNNLAUGSSON's map. He considered that its area is about 100 sq.km. and that it is thus of almost the same size as Iceland's largest lake, Þíngvallavatn. DANIEL BRUUN came to the conclusion (1925, p. 39) that it is the largest; but our measurements show that this is not the case, as its area is about 80 sq.km. Þórisvatn must therefore be content with second place among the lakes of Iceland.

3. Principal Features of the Structure of Iceland.

The opinion that the structure of Iceland more than anything else is a result of the activities of volcanic forces was already advanced by one of the first of the investigators who have occupied themselves with the study of nature in that country: the Icelander SVEINN PÁLSSON, who lived in the closing years of the eighteenth and the first years of the nineteenth century. Since his time many scientists have endorsed the correctness of that view. This, however, is not the place for a general account of the developments through which our views of the geology of Iceland have passed since the time of SVEINN PÁLSSON, so much the more as the literature already contains several exhaustive dissertations on this theme, among them THORODDSEN's great collective work: Landfræðissaga Íslands, Reykjavík and Copenhagen 1892—1904, HELGI PJETURSSON: Om Islands Geologi (1905), and HANS SPETHMANN: Der Aufbau der Insel Island (1909).

Iceland forms a part of the great North Atlantic basalt region, or, as it is called with a modern term, the Thule Region or The Brito-Arctic Petrographic Province (TYRELL and PEACOCK 1927). To this region we include the whole of Iceland, the Faroe Islands, Jan Mayen, the most of Franz Joseph's Land, as well as peripheral parts of Scotland, Greenland, Spitzbergen and King Charles' Land; we may reasonably add the two submarine plateaux Rockhall Bank and Porcupine Bank in the Atlantic west of the British Isles. The whole of this region has a pronouncedly eruptive character, and the predominating rocks are basalt lavas. Iceland's peculiar feature, in contradistinction to the other parts of the region, is the occurrence of a very complicated rock series that forms such a decided contrast to the regularly deposited basalt strata that the very founder of Icelandic natural science, EGGERT ÓLAFSSON, distinguishes between "regular" and "irregular" mountains, and thus draws attention to the two predominating surface forms of the country, widely different as they are petrographically as well as morphologically.

In the course of time the "irregular" formation has been known by several names, i.a. the breccia formation, the tuff formation, the palagonite formation, and many others. The latter name especially has played a part in the literature on Iceland and is probably the one most frequently used, despite the fact that its justification has been seriously doubted. It was first used by SARTORIUS VON WALTERSHAUSEN, because he found a brown or yellow substance, palagonite, in certain of the rocks of the formation, and this he presumed to be a separate mineral. In 1879, however, PENCK showed that this was not the case, and he even went so far as to say: "Es darf gerechtfertigt sein anzunehmen, dass ein als Palagonit zu bezeichnender Körper nicht existiert." All the same, the term palagonite formation has been used by most writers right up to the present day, though with some reservation and criticism. THORODDSEN used it as late as in 1914, and v. KNEBEL-RECK even wrote (1912, p. 108): "dem Palagonittuf, wie es seit dem klassischen Untersuchungen SARTORIUS VON WALTERSHAUSENS nach einem seiner Mineralbestandteile genannt zu werden pflegt." In his earlier works Pjetursson uses the term "the glacial palagonite formation", but in later works tries to get away from it. In recent times, however, the Scottish petrographers MARTIN A. PEACOCK and G. W. TYRELL, have resumed the use of the term in the form of "The volcano-glacial Palagonite Formation". On the basis of modern petrographical examinations of the rocks they assert that, although palagonite may not be a mineral, it is a petrological substance of such a consistence that it is justifiable to set it up as a separate mineraloid, i. e. a naturally occurring, homogeneous, amorphous substance with such a constant complex of properties that it can be verified petrographically, and, even if in point of quantity it forms no great part of the rocks in question, it is so characteristic, and so important a component to our understanding of the creation of the formation, that we ought to continue to use the term without reserve.

According to TYRELL and PEACOCK, the finer-grained Icelandic tuff deposits of glacial age may be characterized either as sideromelan tuffs or as palagonite tuffs.

"Sideromelan is a black, lustrous, most anhydrous basalt which is pale coloured and translucent in thin section; it is known only in fragmental volcanic ejecta. In Iceland, sideromelan is a product of drastically chilled, sub-glacially extruded basalt magma. This mode of formation results in the invariable fragmentation of the material and the inhibition of ore-separation producing the characteristic translucency. Sideromelan tuffs are found near the margin of the present ice-sheets at heights up to 2000 feet. Sideromelan may be classed as a mineraloid.

"The palagonite tuffs are the older sideromelan tuffs which have suffered hydration, usually by submersion or by hot-spring action.

"Palagonite is the hydrogel of sideromelan. It is a yellow, colloidal material containing up to 28 per cent. of water, the greater part of which is liberated at 105 C. When hydration has taken place at low temperatures by submersion, isotopic gel-palagonite tends to form; when hydration results from hot-spring action, obscurely birefracting fibro-palagonite is the main product. The change from sideromelan to palagonite is further accompanied by a partial loss of lime and soda, an almost complete oxydation of iron and a progressive lowering of refractive index.

"Palagonite is unstable; it tends to crystallise with a partial loss of water into chlorites and zeolites." Tyrell and Peacock 1927.

According to these investigations the occurrence of sideromelan and palagonite in the Icelandic "palagonite formation" is a consequence of that series having been partly formed by subglacial eruption, sideromelan being the primary product, whereas palagonite is the product of a subsequent hydration of it, a process called by these writers palagonization, and thus it is warrantable to maintain the use of the name palagonite formation, provided that the views advanced above prove to be tenable.

A general stratigraphical treatment of the Icelandic series is an undertaking of the greatest difficulty, for it has not been possible to find even one continuous horizon that can be identified with certainty, neither by faunistic, floristic nor petrographic methods; as a consequence we lack definite guides in our stratigraphical orientation. The principal reason is that fossiliferous strata are very rare and of slight horizontal extent. It is true that the petrographic differences are considerable; we find eruptives of different types, glacial and volcano-glacial deposits, marine, æolic and lacustrine sediments, and in so far one might presume that there was a possibility of a stratigraphy on a petrographic basis; but the characteristic feature of these deposits is that they are of purely local nature as a rule and that the country has been built up by the activity of innumerable locally-governed forces. The result of working stratigraphically is thus that one's material becomes a series of elementary phenomena whose mutual relationship is very difficult to establish.

And, indeed, we find the most widely diverging opinions on the connection, chronology and dating of the Icelandic series. The main features of the course of developments are as follows:

Krug v. Nidda (1834) assumes that the western and eastern parts of the country are older than the central part, but this theory is strongly contradicted by later writers, such as Sartorius v. Waltershausen (1847), who avers that the whole country lies on a foundation belonging to the palagonite formation on which the ligniferous deposits and large layers of trachyte lie. During the next half century opinions change completely, for in that period two important features in the geological structure of Iceland have been ascertained. Although with some uncertainty, the age of the lignite deposits has been fixed at Tertiary (Miocene), and the presence of moraines and the marks of glacial erosion on the present surface of Iceland has been proved — results that are partly due to the progress made in Icelandic exploration itself and partly to the great improvement in the science of geology in that period.

The chronological sequence of the series was set up by Thoroddsen in the following schema, which appears in his work of 1899 and which is the foundation for his later writings on this subject:

a. Alluvial and diluvial deposits.
b. Preglacial dolerite.
c. Volcanic palagonite formation.
d. Basalt formation with interbedded miocene lignite deposits.

The year before, Thoroddsen had concluded his systematic travels in Iceland, the untiring and, in many respects, fundamental work of eighteen summers. The schema above gives us the results compared with the results of half a century's investigations, now revised and collected by the tremendous effort of one man. And then, the very same year the strange event occurs that the student Helgi Pjeturss(on) makes a discovery that will always ensure his name a prominent position among the scientists who have been of importance to the exploration of Iceland.

Thoroddsen, and all other investigators too, assumed that the dolerite and the palagonite formation were preglacial; but now Pjetursson, under the dolerite in the palagonite formation, found series that undoubtedly were moraines and rested on surfaces striated by ice. The necessary inference was that both the "preglacial" dolerite and the palagonite formation must be placed to the Quaternary, which of course upset Thoroddsen's schema. During the subsequent heated debate between Thoroddsen and Pjeturss(on) the latter added to his material concerning the occurrence of moraines in the Icelandic series. He observed several superimposed moraine horizons not only in the palagonite formation but also in the upper series of some basalt regions.

There is a collective account of these matters in the work of 1905, where Pjeturss(on) arrives at the following conclusions: Iceland is built of an early, regional, and a later, insular basalt formation, between which there is very great unconformability. Possibly the volcanic activity was at rest in the period corresponding to this; there was considerable erosion, and a series of marine sediments, ascribable to Crag, was deposited. Towards the end of the Pliocene period the volcanic activity started again, resulting in the insular basalt formation between whose dolerite beds one finds quaternary moraines, glaciofluvial deposits, as well as marine glacial and interglacial deposits. The considerable quantities of tuff and breccia that are found in the upper parts of the insular basalt system are the ruins of pleistocene volcanoes. The postglacial volcanism is a continuation of the pliocene. The terms regional and insular basalt formation are used as expressing the following views: The regional basalt formation is that part of the Icelandic series that was formed while the land bridge between Great Britain and Greenland assumed by many writers to have existed was still there, whereas the insular basalt formation did not appear until after the bridge was broken down and Iceland had become an island. The upper part of the regional basalt formation is built up of rather light-coloured dolerites, the grey stage, in which there are both moraines and striæ, and as that stage is assumed to be earlier than Crag, Pjeturss(on) arrives at the conclusion, surprising to the reader as to himself, that one must assume the occurrence of widespread ice-sheets in the Tertiary period, i. e. at a time when, to use his own words, one should rather have expected to find remains of great forests.

Later investigations, however, have made Pjeturss(on) doubt the tenability of these latter views. Based upon a series of observations in southwest Iceland he arrives at the conclusion that "man am richtigsten tut, die Annahme vom tertiärem Alter der Glazialbildungen der "regionalen" Basaltformation fallen zu lassen" (1907, p. 618); but, as his paper of 1908 shows, Pjeturss(on) has not entirely abandoned the idea of the tertiary (miocene) moraines, although he adds: "Unterdessen hat man noch keinen palæontologischen Beweis für ein miocänes Alter dieser Altmoränen erbringen können, und so werden wir wenigstens vorläufig zu der Annahme hinneigen, dass die ältesten noch aufgefundene Glazialbildungen Islands wirklich dem Eiszeitalter entstammen." In his 1910 work the "miocene" moraines are not mentioned, and thus it is indeed natural to abandon the terms regional and insular basalt formation and, instead, to differentiate between Tertiary and Quaternary formations, the latter then being divided into Early Quaternary and Late-Quaternary.

The result of this interesting sequence of developments is thus that, thanks to Pjeturss(on)'s works, we have arrived at a new view, nowadays generally recognized, of the stratigraphy of Iceland; its central point is that under the Quaternary we have to place not only the palagonite formation but also the latest part of the "basalt formation" which was formerly regarded as a continuous stratigraphical unity; in order to avoid the terminological difficulties arising out of such a radical rearrangement of opinions Spethmann (1908) suggests the following terms for the main grouping of the Icelandic series:

1) Postglacial systems,
2) The glacial-volcano formation,
3) The Tertiary-volcano formation

whereas PJETURSS prefers the terms "the Tertiary" and "the Quaternary basalt formation". A more detailed survey is to be found in PJETURSS' work of 1910, on which the following synopsis is mainly based.

The postglacial systems are formed partly of eruptives, both lavas and loose products, and partly of sediments of marine, lacustrine, fluviatile, æolic, glacial and organogenous origin.

The Quaternary formations may be placed in two age groups, an early and a late, both well-differentiated in a petrographical sense but otherwise imperfectly known. To the late group belong several series of glacial deposits, viz. one or perhaps several systems of quite late, unhardened moraines. Interglacial and interstadial deposits occur at the coast in the form of marine sediments, and probably the extensive, superficial, doleritous lava streams that are so characteristic of the southwest country and parts of the interior highlands, may possibly be assumed to have been formed in interglacial times. The early group is represented by a series which, according to PJETURSS, has a thickness of 6—800 m., most of which is of eruptive origin and composed of basaltic lava separated by glacial, moraine-bearing and interglacial, fossiliferous sediments.

Pliocene deposits are known as a mostly sedimentary series of a thickness of at least 700 m. (BÁRÐARSON 1925), whose extremely fossiliferous content indicates a transition from a temperate to a boreo-arctic climate.

Pre-pliocene deposits form a thick series measuring at least 3000 m. and consisting most of all of basalt layers, intrusive rocks, loose volcanic material, and æolic (HAWKES 1916) and organogenous sediments. The latter are of vegetable origin and occur in many localities in both the northwest and east, some of them in the form of inorganic deposits with slight admixture of organic substances, and partly as pure lignites. It is held that the flora represented in them is of miocene age; but there are certain indications that the lignites in the different parts of the country are of somewhat different ages. Below the lignites are very large basalt layers, which must thus be taken to be miocene and pre-miocene, but what underlies them is not known, and there is nothing definite to work on when attempting an estimate of the time of their formation.

Roughly, the regional distribution of the different formations is: The Tertiary volcano formation or basalt formation crops out on the surface in two regions, viz. the west fjords and the east country, but in great parts of the country it is overlain by Quaternary deposits and can only be recognized where tectonic and erosive changes have exposed it. The postglacial eruptives crop out for the most part along a rather narrow zone from Axarfjöður in the north to Reykjanes in the southwest, and they are of widest extent in Ódáðahraun, the country west of Vatnajökull, the Hekla region and the Reykjanes peninsula. The distribution of the deposits on the surface is mostly symmetrical in relation to the southwest—northeast line mentioned, and is so arranged that the latest deposits lie along this zone and the earliest farthest away from it.

In the terrain west of Vatnajökull no fossiliferous deposits have been found, and the character of the rocks provides only little guidance for a definite determination as to age. Uppermost lies a series of recent rocks having the appearance of being even particularly late. Its various facies will be dealt with in greater detail when describing the landscape forms; at this point it need only be said that one mostly meets with late lava fields, loose volcanic material and rebedded sand of æolic origin; the recent moraine material is of little importance, whereas one comes across glacio-fluvial deposits of considerable extent and thickness. In contrast to these present-day deposits is a series of rocks that is exposed in the higher parts of the terrain. The stratification shows that they were deposited and hardened before the depositing of the recent series. Furthermore, in the interval there had occurred a considerable difference of level between the various parts of the landscape, mostly the result of tectonic processes. The rocks in the early series are mostly tuffs, but there are also quantities of breccia of undoubtedly volcanic origin, grey, basaltic lavas, and lava with the peculiar globular structure that is now taken to be a sign of subglacial origin. Breccia has been observed in Túngnárfjöll, in Skálafell, Þóristindur, in the regions east of Þórisvatn and at Botnaver. Basalt with globular structure is found in large quantities in the eastern part of the area, in the foreland of Vatnajökull and in the region near Heljargjá.

The rocks very closely resemble certain complexes from the palagonite formation in the southwest of Iceland, but moraines have not been found between the Kaldakvísl and the Túngná, and, if there are any there, they are at any rate insignificant. It is scarcely to be doubted that they belong to the same main group of Icelandic formations, but they have been formed in a rather different manner than the glacial volcano formation in southwestern Iceland. Finds of dolerites in the blasted debris from certain volcanoes indicate that deep down there are deposits of these, but the violent volcanic activity in the area has covered up the early deposits. On the whole the different petrographic condition of this region must be placed in connection with this volcanic activity, which has probably extended for a long period, perhaps so violently that a glaciation in the usual sense of the word could not proceed, and which has resulted in the depositing of a layer of tuff about 300 m. thick, now to be seen in the southeast part of this region. If there is any early moraine material, it is probable that in some places it has been so much disturbed by volcanic action that it is now extremely difficult to find it.

In the region round the Kaldakvísl there is another type of landscape, recalling that common to the west highlands. There one meets large, doleritous, striated layers with a southwesterly dip. The striæ run in the same direction, and overlying the dolerite is a deposit of moraine material with several boulders, dolerite as well as liparite. Fig. 26.

Conditions in Sauðafell are very interesting and call for further attention. The mountain rises about 300 m. above the plateau and is to be seen from great distances on all sides. Its ground area is about 15 sq. km., while its greatest dimension lies in a northeast—southwest direction. For the most part the rocks are tuffs, but among them lie doleritic lavas and hardened moraines. The slopes of the mountain are quite even and the profile line differs greatly from what one sees for instance in the mountain Loðmundur, which otherwise is built in quite an analogous manner. As these two mountains each represent a type in the Icelandic landscape they must be dealt with in greater detail.

Loðmundur has a ground area of about 5 sq. km. and a relative height of about 500 m. Its petrographic composition is quite the same as that of Sauðafell. Both mountains contain tuffs, breccia and hardened moraines, and at the top they both consist of tuff and breccia. The walls of Loðmundur are very steep, and are regularly so on all sides. At the top is an almost vertical surface, 100—200 m. high, running into a talus at the foot with a dip of about 45 degrees. At certain places the veitical edge is broken by some clefts where the talus runs right up to the uppermost edge of the mountain, and by means of these clefts it is possible to climb it. From a distance one does not observe these small irregularities, and the mountain looks very compact and uniform. The profile of the upper edge is serrated and sharp, and one gets the impression that the lateral superficies intersect in a sharp ridge. Having climbed it, however, one sees that on its summit the mountain has a small plateau surface of about 2 sq. km. with some small rounded hills and a few sharp pinnacles, of which the highest, reaching about 50 m., stand along the north edge of the plateau (Fig. 47 and 48). They have been formed by the weathering of a volcanic breccia. On the top one finds evidence of a temporary water erosion of the same type as that referred to later on p. 71, 253. There are several ponds, patches of snow that have withstood the summer, and traces of a lively solifluction. As already indicated, the walls are so steep that climbing is impossible in most places. The edges between the plateau surface and the sides are quite sharp, and the clefts referred to are narrow and not conspicuous in the terrain. The material carried by solifluction to some extent slides down towards the clefts, which in summer are dry, but undoubtedly lead water when the snow is melting, and this brings about a sorting of the material, the finer being washed down into the surrounding depressions while the coarser remains in washed state on the slopes and moves down at a much slower rate.

This form of mountain is extremely characteristic of large parts of South Iceland, where in certain cases the great mountain masses completely dominate the landscape. Very often they appear to be quite young, especially on account of the almost complete absence of traces of water erosion, despite the fact that swift streams are formed down the sides every year. Sometimes the formation of the plateau surface is petrographically indicated. If at the top a mountain has a cap of lava with underlying, less-resistant rock such as tuff or breccia, the subaerial denudation will not attack the upper edge of the mountain side so fiercely as further down, and in these cases there is a tendency towards an undermining of the edge, resulting in a landscape form of an habitually similar type, characterized by the occurrence of a high plateau surface with steep slopes down towards lower surfaces surrounding it. The forming of the "Tafel-Form" ("table" shape) in some cases must thus be associated with the activities of denuding forces. Loðmundur and many other mountains of the same shape, however, have no such protecting cap of lava, and, as will be explained later, one must assume that they have been formed by the activities of tectonic forces, so that they must be regarded as being horsts.

On Sauðafell there are two separate sets of traces of an ice covering which cannot be contemporaneous. One set forms a part in the structure of the very core of the mountain and is overlain by lavas, breccia and tuffs; it contains striated stones and has hardened in the manner characteristic of early Icelandic moraines. But in addition there are traces of another and later glacial activity, which has first taken place when Sauðafell rose as it does now up over the surrounding plateau surfaces. For in the higher parts of the mountain there are traces of a radial ice erosion of modest extent, but sufficiently powerful to cause veritable Botn-formations and striae that are not orientated in relation to the main direction of movement of the ice down the fall of the landscape, but appear clearly as local formations associated with a local ice-sheeting process, the direction of whose movement was governed by the difference of level between Sauðafell and the surrounding plateaux.

This duality in the ice traces is confirmed by another observation, likewise from Sauðafell. There are two mutually unconformable moraine series, and in the youngest of these there are boulders of earlier, hardened moraine material. This can only be explained in one way: that there must have been at least two glaciations, with an intervening period in which the first series of moraines became hardened and overlain by lavas. In certain places a later ice sheet has had an opportunity to erode the earlier moraines and has carried lumps of them away in the form of boulders.

In this period between two ice sheets there must also have been a difference of level between the higher and the lower parts of the present terrain. How this has happened has scarcely been laid clear in all cases, but on Sauðafell it is reasonable to assume that there have been tectonic changes. Whether or not the same interpretation may be applied to the mountains in the other parts of the highlands of Iceland has not yet been established and of course must be investigated in every case. In some, however, one must assume that it is tectonic processes that have been active.

The question of a plurality of glaciation within the borders of Iceland has already been treated on a former occasion. On the coast there have undoubtedly been pauses — and long ones at that — between the periods. This is shown by the occurrence of considerable interglacial deposits, of the presence of which we are gradually learning in various Icelandic localities, among them being especially Fossvogur and Snæfellsnes. These deposits are marine and contain so much fauna that their identity is not to be doubted. It is another matter whether several ice periods can be proved in the interior. No interglacial deposit of limnian character has been found, but there are other signs of interglacial periods. In the first place v. Knebel found in South Iceland unconformable moraines between whose deposition a very long space of time must have elapsed. It must furthermore be assumed that the great layers of dolerite must have erupted at a time when the highlands were not covered with ice over a stretch comparable with the present one. For as far as we know, streams of lava do not form under ice, while the position is that the dolerite layers rest upon moraine-bearing material and that on their own upper side they have striae and a layer of moraines. In the highlands these dolerite layers are to be found at a height of at any rate up to 5—600 m. above sea level, and to that height the land must have been free of ice — probably still higher. The lava-dome Baldheiði, east of Langjökull, with a height of about 740 m., must have been ice-free almost to its top. And not only that: if there have been still higher parts of the country, the ice moving down from them cannot have got down to the present plateau surfaces; in other words, during the eruption of the dolerite layers the ice cannot have had a much greater extent than it has at present, with the consequence that the snow line in the last interglacial period must have gone back to the same level as it has now; this corresponds very well with the conclusions regarding the climate at the coasts that can be drawn from the composition of the fauna in the interglacial, marine deposits.

4. Volcanism in the highlands west of Vatnajökull.

As has been stated, a number of circumstances indicate that volcanism in this part of Iceland has been very active during the last glacial period; its traces, however, are very difficult to find, because the later volcanic and æolic activity has been so violent that it has covered the signs. The latest eruptions in the neighbourhood are of a very youthful character and it is probable that the processes have not yet discontinued. Thus we must be prepared for further eruptions in this part of the country and, as we may take it that they will be of the same type as those immediately preceding them, i.e. mass eruptions, they will provide a most interesting study, though suffering from the drawback that the area is difficult of access.

The more recent volcanic activity is not evenly distributed over the whole region, but is concentrated in three fields that are well separated topographically, and as they exhibit typical differences with regard to the course of the eruptive processes, it will be natural to deal with them one by one. The most northerly centre is in the region east by south of Háganga syðri, and, as the recent lava fields there are known under the name of Hágönguhraun, this term will be used in this work too, despite the fact that the two mountains themselves, Háganga nyrðri, and syðri represent a peculiar type of eruption differing considerably in point of time, as well as petrographically and morphologically, from the mass eruptions in Hágönguhraun and for that reason will be dealt with in a separate chapter (d) of the present account. South of this region is a volcanic field whose most prominent topographical peculiarity is that it encloses the lake group Fiskivötn; and finally, the system of volcanic eruptions that have taken place in the northern part of Landmannaafrjettur, in the vicinity of Frostastaðavatn, must be regarded as separate. Thus the following account of the recent volcanism in the highland west of Vatnajökull may suitably be divided into four sections.

a. The Háganga Region.

This volcanic field lies between the upper course of the Kaldakvísl and the northwest corner of Vatnajökull, and comprises a number of vents, some of them in the foreland of the glacier itself, some of them in the terrain in front of it up to a distance of 15 km. from the present ice margin. For the most part the eruptions have been in the form of basalt mass eruptions with an enormous output of lava, and only in few cases have insignificant examples of eruptions of other types been found. As map No. 1 shows, the masses of lava have a very considerable horizontal spread, about 440 sq. km., and as they are also of great thickness, they have succeeded in giving character to the landscape, both morphologically and topographically, even at great distances from the vents; but, despite this enormous productivity, it is only possible by means of very close study to show whence the various streams of lava have come, because the accumulation of material round the vents is so small that they are not at all prominent on the terrain.

The pre-eruptive terrain, i.e. the terrain prior to the present eruptive activity, has had a marked influence upon the distribution of the products of the eruptions. Taken as a whole the terrain slopes to the south and west, the pass between Túngnafellsjökull and Vatnajökull representing a point on the northwest—southeast axis of elevation. This general direction of fall, however, is interrupted by two large valleys running northeast—southwest, watered by the Kaldakvísl and the Túngná respectively, both of which have exercised an influence upon the spreading of the lava.

Apart from these valleys (their effect upon the terrain will be dealt with later), the pre-eruptive landscape is built in the form of a plateau land with two different surface systems, each forming its distinctly marked terrain stage. One is formed of a continuous plateau surface, on the south lying about 500 m. above the sea and from there rising evenly towards the northeast until, in the region of Vonarskarð, it reaches a height of about 900 m. The other stage is represented by a number of separate mountain regions rising from 200 to 500 m. above the plateau surface, so that its upper part lies at a height of from 900 to 1600 m. above the sea. These mountains have steep sides, but on the top they are flat and have the form of high plateaux whose areas vary within very wide boundaries. The largest is Gjárfjall, with a plateau surface of about 100 sq. km., but it is possible to make out numerous smaller hills whose area forms only a fraction of a square kilometre; between these extremes are all possible sizes. Thus the terrain is formed of three principal elements:

1) The low surface system.
2) The high surface system.
3) The slopes between them.

As will be shown later, the difference of level between the two surface systems generally must be taken as being due to the activity of tectonic forces.

The places of eruption are not definitely associated with any one of these landscape elements, but are situated both in the high and in the low surface systems, and sometimes in the slopes between them. Regardless of their situation, however, the lava is spread on the lowest surface system whereas the high plateaux are mostly bare of it.

Most of the vents in the northern part of the region are linear eruptions, though some of the lines are quite short and thus form a smooth transition to the group of central eruptions. The material erupted is almost exclusively lava, but there are examples of stratic eruptions, as for instance at Botnaver, where, in the immediate vicinity of the edge of the ice, amid the moraines and glaciofluvial deposits from the present ice margin, there are several volcanic cones. Several of the mass eruptions have had a final phase accompanied by the eruption of adhered slag, which has been carried by the lava streams up to several kilometres from the vents; this is observable at the two fine scoria craters Gámur and Gima in the southern edge of Vatnsleysuöldur.

Between Kerlingar and Vatnsleysuöldur are at any rate three large fissure eruptions lying parallel in the direction of northeast—southwest. Two of the fissures are only a few kilometres long, but the middle one has a length of about 15 km., and is thus one of Iceland's large volcanic fissures. It is, if anything, right-lined and, as is usually the case with this sort of phenomenon, has split the terrain regardless of the hindrances that were there. Both edges of the fissure are marked by a continuous mound, formed at the concluding phase of the eruption by the ejection of lumps of plastic lava which, while coagulating, have been welded together into a porous mass. Only here and there have the mounds a height of 50 m., and their volume is thus negligible in comparison with the quantity of lava produced, so that one must design these eruptions as mass eruptions.

The lava is basalt, coal black, and torn and irregular in the forms it has assumed on cooling. In certain parts of the area of its spread, particularly close to the places of eruption, the upper layer is very porous and of a consistence resembling cinders, whereas the lower layers of the streams — 10 to 15 m. deep at any rate — have coagulated in coherent and compact form.

As a result of the direction of the fall of the terrain described above, the lava has spread very little towards the east, whereas towards the north it has gone up on to the plateau that is called Köldukvíslarbotnar and has advanced to the southern part of Vonarskarð. It is possible, however, that the lava in this area partly originates from other vents as yet unknown; but the situation is not very clear because the meltwater rivers from Vatnajökull have covered the whole of the surface with a thick layer of glaciofluvial gravel and sand. On the northwest it has spread right over to the foot of Háganga syðri, and on that stretch has forced the Kaldakvísl to turn westwards and erode a narrow gully in the very mountain side. The pass between

Háganga syðri and Vatnsleysuöldur is likewise filled with lava, and there the Kaldakvísl has formed a very shallow bed across the lava; at the south edge of it the river falls down into a deep cañon in the form of great waterfalls and rapids. The parts of the lava moving west of the Kaldakvísl have met with rather rugged terrain, where it has split up in the depressions in the form of large tongues, flowing round the higher parts of the pre-eruptive surface. Here we have an example of the commencing stage of the formation of a volcanically filled-up plateau, characterised by a net of anastomosing lava streams, between whose branches the pre-eruptive surface still emerges like islands. The edges of the streams take the form of block walls 10 to 15 m. high, and this would thus seem to be the minimum thickness in this part of the region.

The eastern edge of Vatnsleysuöldur has cut off the advance of the lava westwards, and only at the south edge has it found a way through the 7—8 km. wide pass between that mountain and Gjárfjall on the south. Through this pass, which is filled from one mountain foot to the other, mighty streams have run down into the lower land on the south and west, where they have spread right over to the Kaldakvísl.

On this stretch the course of the river has also been much disturbed by the eruptive masses. At those places where the lava has got down to the valley of the river the latter has been forced out in curves towards the west, where it has been compelled to form new courses, usually of the cañon type. Above the places where it was dammed there are areas with only a slight fall where the river branches and has deposited flat areas of gravel.

Most of the lava has, however, rounded the northwest corner of Gjárfjall and has run towards the south and southwest. The southwest part of the stream has made its way between the wide depressions down towards Þórisvatn, where the water level and outlet have been greatly influenced by lava embankments; this circumstance, of which there are parallels in many other recent-volcanic areas, will be dealt with at greater length in the chapter on hydrographic conditions. The streams that have run southwards have spread into enormous layers out over the plateau surfaces down towards Fiskivötn; the lava has not stopped until it got about 50—60 km. away from the vents, sometimes forming block walls, at other places like a slab of a few metres thickness, the smooth coagulation forms bearing evidence of the fact that the course of the lava has ended there without disturbance of any kind. The occurrence of numerous small areas of pre-eruptive surface, jutting up through the covering of lava, indicate that the thickness of the stream there in the border zone has been much less than in the central parts of the area of eruption, but nevertheless has been sufficient to conceal all the details of the pre-eruptive relief; thus the landscape appears as a **lava-levelled plane.** Fig. 3.

After this series of giant eruptions has run its course there have been a number of smaller eruptions, by which both the extent of the lava fields and the thickness of the layers have been somewhat increased. South of Gjárfjall there has been an eruption of lineal form which has produced very considerable masses of lava, although owing to the terrain their extent is slight in comparison with those just described. Another recent volcanic field has been formed in the southern slope of Vatnsleysuöldur. In this case, too, it has doubtless been a fissure eruption, but its length is very slight; nevertheless it has produced very considerable quantities of lava which, through large canals (now collapsed) has spread out over the earlier lava fields from the fissures on the east over towards both Gjárfjall and the southwest down towards Þórisvatn. The situation of the eruption fissures is marked by two very fine adhered-slag scoria craters, Gámur and Gima, of which Gámur as the largest reaches a relative height of 50—100 m. The lava as it streamed out has broken great clefts in the ring-shaped mounds of scoria and has carried enormous quantities of loose material down to the plains below, where the lava at good distances from the vents is covered with an almost unbroken carpet of loose scoria of a remarkable, distorted form.

The last mass eruption in this region came from a fissure lying to the west of the principal fissure referred to above, between it and Vatnsleysuöldur. From it the lava has exclusively spread over earlier lava fields and thus has merely increased the thickness of the layers, but not their extent. In a morphological sense this stream contains several interesting details which will be dealt with in greater length below. The spreading of the lava has been greatly affected by a tectonic disturbance which has taken place in the period between the older series of eruptions and the very recent mass eruption just referred to; it has led to the forming of a subsidence, Heljargjá, as to which more information will be given in a later chapter. When the youngest lava on its way to the southwest met this fissure, it has fallen over the brink in great cascades and has covered the whole of the northern part of the bottom of the fissure with an indescribable confusion of blocks. It is doubtless an offshoot of this same stream that has filled Heljargjá at the point where the fissure runs into Gjárfjall, and has also been able to send a long tongue of lava further along the mountain side on top of the old lava from the Háganga fissures and right down over the lava from Gámur.

With the time and labour at our disposal it has not been possible, however, to make these matters clear in all their details, as the manner in which the lava has spread and come to rest is difficult to account for in any other way than by simply following the various streams throughout their entire length, and as, owing to the torn structure of the lava fields, these journeys represent such long and wearing toil that we have been quite unable to complete them, we have had to be content to try and establish the lines of distribution by means of binocular observations from the heights of the region Háganga, Sauðafell, Vatnsleysuöldur, Gjárfjall, the mountains at Kerlingar and those at Þórisvatn; these observations have then been worked into the results of four or five journeys across the lava fields.

While the principal mass of the lava has, as we have seen, run towards the south and southwest, smaller quantities have found their way south, east about Gjárfjall through a valley along by the ice margin of Vatnajökull between Kerlingar and the mountain which DE FONTENAY has given the name of Hádegisfell. Towards the north the valley is three or four kilometres wide, but midway between Kerlingar and Botnaver it shrinks in to a very narrow port a few hundred metres wide, through which the lava has poured like a foss down towards the plains on the south. This port has probably been formed by the Túngná's northern tributary, which rises at the ice margin north of Kerlingar and follows the glacier in a curve right down to Botnaver; the lava, however, has forced the river out to the side, where it has cut itself a steep-walled channel in rock belonging to the glacial volcanic formation. After breaking through, the lava has spread into a region that is also the scene of local eruptions, most of which are isolated central eruptions with a very considerable lava output and a concluding phase in which the production of adhered slag has been predominant. Certain signs indicate that the two lots of lava are almost contemporaneous, but we have only been able to spare a very short time for the investigation of this area, and so I would not venture to attempt any definite interpretation of the events that have led to the bringing about of the conditions now prevailing. That the thickness of the lava fields is very great appears from a consideration of the subsidence areas, up to 10 m. deep, of which there are many in the terrain north of Botnaver and whose form and distribution show that it is not tectonic changes that have been the cause, but that they are subsidence holes caused by contraction or branching out in lava masses of great thickness. The pre-eruptive terrain, at any rate in the northern part of the plain, is completely effaced and the lava has spread as far south as down to the Túngná southwest of Botnaver, where at high water the river has gone up over the lava and has covered a part of it with glaciofluvial gravel.

There are small eruption fields in several other places in the terrain. Mention may be made of a small stratic field just north of Botnaver, a few hundred metres from the edge of Vatnajökull, amid the morass of water-soaked moraines and glacio-fluvial deposits that here border upon the ice margin. The output of this field has been very small, and it is scarcely of much interest in a volcanological sense; but it displays the interesting circumstance that the recent volcanic activity has taken place at any rate right up to the ice margin and that at this spot the glacier has since the end of the eruption remained behind the line that is marked by the situation of this field.

The whole of this extensive volcanic region, the Háganga region, has developed with very little variation as will be seen from the above description; it has exclusively been the scene of mass eruptions, and in this respect it forms a pronounced contrast to the Fiskivötn region on the south of it, where matters are very varied as regards the nature of the eruptions. But in the most southerly part of the lava fields formed from the Háganga region there are some volcanoes, purely local and isolated, of a type that is different to those just referred to and form a transition to the volcano forms prevailing at Fiskivötn. Thus in the west edge of the lava fields at Botnaver there is an oval lake with a basin that must doubtless be regarded as a maar formation. Unfortunately we did not get so far as to make a close examination of its surroundings, and therefore no definite statement can be made; but quite habitually it is very like a maar-lake even if other interpretations cannot be rejected.

There is no room for any doubt as to two enormous maar's east of Þórisvatn in the southern part of the lava fields. Their dimensions are almost the same, the diameter of both being about 1 km. and the maximum height of the surrounding gravel mounds is about 200 m.; that on the north is circular, that on the south oval, with its greatest length lying southwest—northeast. The mounds consist partly of substratum dipping periclinally in relation to the vent of the eruption, and partly of rejected volcanic gravel of small grain; both volcanoes must be placed to the type described and set up in the following as a special type and named blast crater. It is peculiar that they both lie on the line that has been struck by the aforementioned tectonic fissure Heljargjá and that the long axis of the oval eruption coincides with the direction of the fissure. The ages of the various processes at this spot appear from the following observations: The thrust has affected both the "maar"s and the surrounding lava from Hágönguhraun, and must thus be assumed to be later than both these eruptions, while the distribution of the lava shows that both explosive volcanoes are older than it is. At the "maar" on the north conditions are especially very clear and perspicuous. Its bottom has lain much below the surface of the lava field, and consequently the stream has made its way into the already existing basin and has filled it, and, as coagulation here has proceeded under uncommonly quiet conditions, the surface has assumed the form of an unusually regular and finely developed sheet-lava, consisting of circular shields of a diameter of 20—30 m. These features show with certainty that the "maar"-basin is older than the Háganga lava. Fig. 7.

The situation of the two explosion volcanoes on the same line as the later fault naturally brings up the question of whether we may assume that there has been any direct or indirect combination of causes between the two phenomena. As the distribution directly shows, it is not probable that the fault is a consequence of the volcanic outbreaks, for there is no reason at all why two relatively small eruptions of loose volcanic material should have a tectonic, disturbing effect along a lineal zone of a breadth of 1 km. and a length of about 30 km.; furthermore, the volcanoes are at one end of the fault, and there is no trace of volcanic activity along the whole of the remainder of the fissure. Then the question remains as to whether the coincidence is merely accidental or whether in that zone, prior to the eruptions, there has been a structural peculiarity which may have tended towards the occurrence of both eruption and fault; it is possible that there may have been a previously formed line of weakness that has first served as a channel for the eruptions and thereafter as a zone of release for tectonic tensions; from the observations so far made, however, it is impossible to settle the question definitely.

Surface forms of the lava.

In the lava area that has originated from the eruption field dealt with in the foregoing the detail of the surface forms varies considerably. There is every possible stage between the smoothest plane surface sheet-lava (Icel. Helluhraun) to the wildest block lava (Icel. Apalhraun).

The impression given by a field of lava of this kind seen from a distance, whether of the one or the other type, is that the landscape is a plain of strikingly uniform structure. One sees nothing but endless black spaces devoid of valleys and heights. The fall in the direction of the lava diffusion is so slight that from a distance it is usually impossible to determine from which direction it has come. Nor can the eruption vents be seen in a mass-eruption area, as already indicated. Mostly the surface is only broken by the higher parts of the substratum which in some cases jut up like islands over the lava sea. The lava fields of the Icelandic highlands look completely desolate; no green breaks the blackness of the land, animals are very seldom seen, everything is uniformly black and dead. Fig. 4.

To the inexperienced traveller a lava field looks easy to cross — and even veteran Iceland travellers are time and again misled into underrating the difficulty of getting over even very narrow spurs.

Whereas the distant impression is one of unique constance from a landscape point of view, one's close-up impressions change rapidly. As already stated, one can distinguish between two main forms of surface: sheet and block lava, but these two forms are not sharply separated, and in many cases it is a matter of taste whether one applies the one or the other term. Fig. 7 shows the sheet lava in its pronounced form, the simple explanation of which is to be found by making a study of the circumstances under which hardening proceeded, cf. p. 28, 210. The other extreme form, typical block lava, is represented by Fig. 8. One's immediate impression is of an altogether irregular, chaotic, piled-up mass of blocks with jagged, pointed and sharp edges, heaped up pell-mell with wide intervals between the various blocks. The points and edges are often brittle and easily broken off, and even blocks weighing many tons can be made to topple over without much effort. In such a block-lava area the only means of advance is by clambering, and it is most difficult to obtain anything like a safe foothold. Even for men who are accustomed to moving about in lava fields and are quite familiar with the difficulties there, movement is most arduous and often risky, and obviously it is impossible to take a horse caravan through.

A more intimate study of this chaos of blocks, however, reveals that very often there is some regularity in the distribution of the unevennesses, which to some extent recall the waves of a storm-beaten sea. In the most disturbed areas one frequently observes an alternation of ridges and valleys running almost parallel to one another. The ridges rise about ten to thirty metres above the valleys, and the distance from one to the other is about fifty to a hundred metres. They are quite narrow-backed, like the roof of a house, and their sides are as steep as the loose piling of the blocks permits. Often they can be followed for a distance of several kilometres in this confusion of blocks from one to five metres high, which show signs of having hardened while in rapid movement; the sides that hardened last very often bear striæ from their collision with the sharp edges of other, already hardened blocks. The valleys must undoubtedly be regarded as fallen-in channels into which the lava has streamed, i. e. mass eruption's analogy to the well-known sub-surface canals of smaller streams of lava, of which such fine examples are to be seen for instance on the west slope of Hekla, where several investigators, von KNEBEL for instance, have observed and interpreted them. A miniature example in the Fiskivötn region is shown on fig. 17. Lava channels of this kind have, however, only been observed up to a few kilometres from the vents and they seem to be a morphological peculiarity associated with regions where warm and fluid lava streams of great depth have prevailed.

Further away from the vents the lava surface is more even as a rule, and the heights and hollows are of other types than those just described. First of all there are the hornitos formations which have been described morphologically and genetically by other writers, especially by SAPPER (1908 and 1910). They form where large quantities of gases have collected in or below the masses of lava and come out into the air when these gases force their way out. SAPPER (1908 p. 4) differentiates between primary and secondary hornitos; by the former he understands those formed on the vent itself, whereas those formed out on the lava fields are called secondary. In its typical form a hornitos consists of adhered slag, but sometimes a considerable element of loose slag is included. Another morphological peculiarity is, if not a hornitos formation, at any rate one that is analogous. On the lava fields one very often sees round domes having a diameter of up to 100 metres and a height of up to 10 metres. They give the impression of having been formed as one unit, but most of them are split up by deep cracks. They may be taken to be a kind of hornitos in its preliminary stage, arising when the gases working in the magma have not been powerful enough to break the surface. They can be clearly observed on lava surfaces where there has been an abundance of sand, the lower parts of them being full of sand whereas the domed parts stand out as heights with a clean-blown surface of lava. Fig. 19.

Another type of unevenness occurs when the lava surface hardens sooner than the deeper parts of the stream. As a consequence of the continued movement the surface will be broken up, and the fragments then take up all kinds of positions and coagulate in the form of oblique floes, whose fracture edges jut far out into the air and often form large penthouses while at the same time the surrounding floes are pushed out of position.

One special coagulation form occurs in lava streams of great depth but slight horizontal breadth and slow movement. In several cases the following morphological combination has been observed (figs. I—II). The edges of the stream are higher than the central parts and are pronounced block-lava; inside this marginal zone there is a belt of sheet lava, and in the middle one or more areas with deep subsidences. The figure shows an example of this kind with the height rather exaggerated in proportion to the horizontal length. The difference in height between the block-lava on the margin and the sheet lava inside it has been measured at 7 to 10 metres. These circumstances indicate a very considerable decrease of volume during the cooling process, whether due to contraction during coagulation and escaping air, a reflow of lava in the vent, or a combination of both processes — the latter being the most probable in certain cases.

The lava streams at Hagönguhraun display all these surface types in great variety of form and from place to place. The monotony that is characteristic of one's distant impression of the lava fields is thus broken up on closer examination into a wealth of different detail forms, each of which is an illustration of the course of the volcanic processes just at that spot. As a whole one may say that the lava fields south of a line from Sauðafell to the east are, although somewhat disturbed in places, sheet lava more or less easily passable for a horse caravan, whereas the whole of the northern area is more or less pronounced block-lava. This is particularly true of the youngest of the lavas originating from the very recent vent east of Vatnsleysuöldur. I have seen many quite recent streams of block lava in Iceland, but none even approximately so wild and torn. Fig. 8 gives a faint notion of the conditions, but a very faint one indeed. There are hornitos in several places, and in the vicinity of the extreme edges of the lava streams are the cracked domes shown on fig. 19. Subsidences were especially observed in the lava field north of Botnaver, where the collapsed areas are so extensive that we used them as roads through the lava because the drift sand had collected there and greatly facilitated travelling.

In many of the areas there have been post-eruptive changes. That part of Hágönguhraun that lies north of a line from Háganga syðri was on the east covered with glaciofluvial deposits from the glacial rivers. From the ice margin in Vonarskarð run two large-sized rivers that unite with two coming from the east into a very complicated net. In addition there is a large watercourse that drains the south part of Túngnafellsjökull. All this tremendous mass of water collects and forms the river Kaldakvísl just under the eastern slope of Háganga, but there, as already mentioned, the whole system has been dammed up by the lava streams. As a consequence, the fall north of that point is too gentle, and as all the watercourses carry a lot of mud, large quantities of glaciofluvial material are deposited on the surface of the lava; this again involves that the rivers are constantly changing their course, as figs. 33 and 34 show, and the result has been that the whole of this northern part of Hágönguhraun has been transformed into a plain of sand and gravel, called by Gunnlaugsson Köldukvíslarbotnar. Only here and there are hornitos and other heights visible over the plain.

In the other part of Hágönguhraun the lava surface is visible almost everywhere. Only in the hollows does one meet with deposits of drift sand of a depth of up to a few metres. This, however, holds good of the older streams only; in the young ones there are no sand deposits at all. In the southern part of the area the lava is covered with a thick layer of volcanic gravel; its origin will be reverted to later, as it comes from the volcanic region at Fiskivötn on the south.

Practically the whole of the area is sterile. For over a month we have every day passed over large and small stretches of the area without ever seeing an animal; of vascular plants there are extremely few, but here and there is an impoverished growth of moss and lichen.

The lava fields from the vents southeast of Hágöngur are of considerable size, as map No. 1 shows. Their greatest length is from northeast to southwest and is about 55 km., their greatest breadth about 20 km. The free spreading of the lava to the southwest has been hampered by Gjárfjall, which has forced the lava to make its way through the lower areas east and west of the mountain. The westerly arm is much the longer and, south of Gjárfjall, has spread out into a large continuous plain. The north part of the lava fields, north of Gjárfjall, occupies an area of about 180 sq. km., and the south part, south of that mountain, covers an area of about 260 sq. km., so that the total area is about 440 sq. km. If we assume an average depth of 30 metres — this estimate being very low, by the way — the volume of the erupted lava must be about 13 kubic kilometres.

b. The Fiskivötn Area.

I have called this volcanic region after the Fiskivötn lake group, the most prominent topographical feature in this part of the highlands of Iceland. This is so much the more warrantable as the basins of the lakes are in fact the outcome of the volcanic processes. The total size of the region is about 140 sq. km., and within that area the volcanic forces have manifested themselves very violently and peculiarly and have produced a type of landscape that is not equalled in any volcanic region of Iceland at any rate, and perhaps in any other volcanic region in the world. It is thus very deserving of a place among the units into which we are gradually being able to divide the recent and subrecent volcanism in Iceland, and it is likewise practical in this present work to treat the area separately as has been done in the following description.

The scene of the volcanic events is a landscape whose main orographical lines are orientated in the direction of southwest—northeast. On the northwest it is bounded by a chain of hills whose highest peak is the widely visible, very characteristic Þóristindur. The parallel boundary on the southeast is formed of the long, narrow plateau Túngnárfjöll, whose various sections have different names but which forms a well-marked unit as to terrain and also genetically. The volcanic activity can be traced up in the southern part of the lava fields that principally have their origin between Kerlingar and Háganga syðri and under the name of Hágönguhraun described in the foregoing chapter. The southwest boundary of the Fiskivötn region may properly be placed at the great bend of the Túngná, as at this spot the river forms a natural geographical boundary against the volcanic region at Frostastaðavatn. As will appear from the next chapter, there are furthermore such profound volcanological differences between these two adjacent areas that a distinction between them is justified.

Our knowledge of the volcanic conditions at Fiskivötn has hitherto been based upon the observations collected by THORODDSEN on his great and productive journey in 1889. This material has been published in various places, viz. Geografisk Tidsskrift Vol. 10, Ferðabók Vol. 2 Copenhagen 1914, and in the great monograph: Island, in PETERMANN's Mitteilungen, Ergänzungsheft 152, 1905—06. Like many of THORODDSEN's reports in that periodical, the article in Geografisk Tidsskrift is a publication of his diaries and as such is practically identical with the corresponding chapters of the Ferðabók. They give a very vivid picture of his method of travelling and his ability to find his bearings and assimilate a host of observations in a very short time, but they are no scientifically treated and systematically arranged account. We do find one, however, in the monograph Island 1905—06 and in Lýsing Íslands. The cartographic material was published in the geological map of 1901 and in the map accompanying the work of 1905—06. Below is the account from the latter work (p. 122) in extenso as it contains practically all we know of the region:

"Nirgends sind so viele grosze Kratergruppen auf Island vorhanden, als bei den Seen Fiskivötn im Innern des Landes, westlich vom Vatnajökull. Hier befinden sich sowohl kegelformige gröszere und kleinere Krater wie auch Vulkanspalten. Es wäre von groszem Interesse, eine detaillierte Karte von dieser Gegend zu besitzen, die aber leider nicht existiert...... Nordwestlich von den Bergen Túngnárfjöll 580—600 m. ü. M. befindet sich eine Gruppe von Seen, Fiskivötn oder Veidivötn genannt, in einer öden Gegend, von Schlackenrücken, vulkanischem Schutt, Bomben und Asche umgeben. Mehrere der Seen sind Kraterseen, aber von den gröszeren Seebassins ist jedes für sich, nicht von einem einzelnen Krater, aber von vielen Kraterringen gebildet, die miteinander verschmolzen sind; verschiedene kleinere Seen werden jedoch bei näherer Untersuchung in tiefen Kratern versteckt gefunden. Der kleine See Tjaldvatn liegt in einem alten, groszen Krater, dessen Durchmesser 2—3 km. beträgt. Der See hat viele Buchten und Wiecken, nimmt aber kaum die Hälfte des Kraterbodens ein. Die aus Lavaschutt Schlacken und Bomben aufgebauten bogenformigen Kraterränder, mit einer Höhe von 60—90 m. über dem See schliessen eine schmale Lavaterrasse ein, die einem älteren, höher liegenden Lavaboden zu bezeichnen scheint, der später gesunken ist. Die Lavaströme, welche aus der Zeit stammen, als der grosze Krater gebildet wurde, konnte ich nicht sehen, sie waren mit Schlacken und Lavaschutt bedeckt, wogegen die den Kraterboden bedeckende Lava von einer neueren Ausbruchsspalte mit mehreren kleineren Kratern herrührt, die später nicht nur diesen alten groszen Krater, sondern auch verschiedene andere, nach NO. gelegene, zerklüftet hat. In dem südwestlich vom Tjaldvatn zunächst liegenden See Skálavatn, der bedeutend gröszer und von Kratergruppen umgeben ist, befinden sich mehrere Inseln, anscheinend ausgebrannte Krater; im Boden des Sees sollen tiefe Kessel und Abgründe vorhanden sein. Nordöstlich von Tjaldvatn befinden sich auf sehr vulkanischen Terrain zwei kleinere Seen, Fossvötn; durch die Seen Skálavatn, Tjaldvatn und Fossvötn erstreckt sich die ca. 15 km. lange neuere Ausbruchsspalte aufwärts nach dem Stórisjór hin. Auf dieser Spalte findet sich eine Kraterreihe mit der Hauptrichtung nach NO., die jedoch mehrere Krümmungen macht; die kleinen, steilen, zackigen Krater bilden einen Wirrwarr und sind aus Lava aufgebaut. Viele davon sind mit Wasser angefüllt, und die zusammengeschraubten Lavamassen sind von zahlreichen Sprüngen durchzogen. Die Kraterspalte hat mehrere der alten Schlackenkrater zerklüftet und nach beiden Seiten Lava ausgegossen; nur bei den Fossvötn befindet sich eine gröszere Lavastrecke, deren Oberfläche sehr uneben ist. Das ganze Terrain um diese Seegruppe, mit einem Areal von 150—200 qkm., ist mit Kratergruppen bedeckt. Von den vulkanischen, mit Lavaschutt, Schlacken und Asche bedeckten Flächen am Vatnakvísl erhebt sich eine Reihe von Gipfeln. Ich bestieg 1889 eine der pyramidenförmigen Spitzen, welche die Umgebung um 260 m. überragte, und es zeigte sich, dasz die spitzen Anhöhen Reste von groszen, alten Kratern waren, welche die Denudation arg mitgenommen hatte. Die höchsten Spitzen des Kraterrandes nehmen sich in der Entfernung wie isolierte Pyramiden aus. In diesen aus regelmäszigen Schichten von Scorien und Bimsstein aufgebauten Kratern sind tiefe Furchen und Rinnen vom Regen ausgewaschen. Zwischen den Scorien befinden sich einzelne gröszere Basaltsteine, auch sieht man nicht selten kleine Brocken von Liparit. Die Krater haben nicht Lava ausgegossen, sondern sind unter heftigen Explosionen aufgebaut worden, bei welchen Scorien und Bimsstein sowie Stücke der Gesteine, welche warscheinlich den festen Untergrund bilden, ausgeworfen wurden. Die südlichste Krater ist von beträchtlichem Umfang und auf dem Boden desselben befindet sich ein kleiner runder See mit direktem Abflusz in die Tungná.'' Thoroddsen 1905—06, p. 122—23.

Thoroddsen's idea of the topographical conditions and the geological surface forms appears from the geological map, scale 1 : 750,000 of 1905—06. A comparison of the reproduction of a section of that map on p. . . with the map we have drawn shows that, as might have been expected, his topographical impression has been somewhat defective, as has already been shown in chapter 2 of the present work. Regarding the distribution of the various geological formations the following observations are called for: Thoroddsen has never been in the northern part of the region, and his statements in this respect are presumably based upon observations in the mountains north of Þórisvatn and on Björn Gunnlaugsson's map of the region at Vonarskarð.

As a consequence his account of the distribution of the different surface forms is not very satisfactory, nor of the south part of the region; he indicates, for instance, a connection between Hágönguhraun and some large masses of lava south of Þórisvatn which continue across the valley of the Túngná and there run together with the lava from the Hekla region. This is not correct; there is no great lava field; Hágönguhraun ends a few kilometres northeast of Fiskivötn and is not connected with the lava fields south of the Túngná. Their origin is quite different, for they have come from a very productive volcanic region of which Thoroddsen has observed a part and entered on the map under the name of Tjörfafellsgígir. The details will be seen by a comparison of the two maps. Regarding the terminology there are the following difficulties. Thoroddsen (1905—06, p. 152) states that at Veiðivötn or Fiskivötn there are six craters with a total lava area of 1550 sq. km. These craters are Snæöldugígir, Tjaldvatnsgígur, Fossvatnagígir, Vatnakvíslargígir, Botnagígir and Hágönguhraun. In the same work, p. 144, he refers to Veiðivatnahraun, to which he credits an area of 1080 sq. km. I do not understand the connection between these names and the areas given; but as a matter of fact it is of less importance in this respect, because THORODDSEN's ideas of the topographical conditions have, as already mentioned, been lacking in accuracy. As the map shows, there is no reason for maintaining the name Veiðivatnahraun, because there is no large lava field at Veiðivötn, or, to use the other name, Fiskivötn. In this part of Iceland the dominating lava area is that which from the time of BJÖRN GUNNLAUGSSON has been called Hágönguhraun, and that name it should continue to bear.

Prior to the period of eruption that has given the landscape at Fiskivötn its present character there has been a wide valley between the Þóristindur mountain range and Túngnárfjöll. The difference of level in this region has mostly been caused by the activities of tectonic processes and it is still possible to recognize the course of a great system of fracture lines in the direction of southwest—northeast. Some of these faults occurred before the period of eruption had commenced, and in the following these are termed pre-eruptive; this expression presupposes nothing as to conditions prior to the forming of the faults. Chapter 5 deals with the tectonic conditions.

In this landscape the volcanic processes have been of great violence but the manner in which they are manifested differs greatly in the various parts of the region, the result being a volcanic landscape of very complicated and most varied structure. On this point there is a most pronounced contrast to the Háganga region just described, where, as we have seen, mass eruption is the all-prevailing form.

In the Fiskivötn region the volcanic area is especially concentrated in two elongated zones, both running southwest—northeast. The two zones are separated by a depression about 3 km. wide, through whose southwest part the watercourse Vatnakvísl runs.

The field west of the Vatnakvísl consists of nine enormous centres of eruption in two groups, one on the southwest with two, and one on the north east with seven craters. THORODDSEN observed this field and on his map showed six craters in a row with the name of Vatnakvíslargígir. He climbed one of the surrounding mounds of gravel and gave a brief description of the phenomenon (Geogr. Tidsskrift, Vol. 10, p. 14; Ferðabók, Vol. 2, p. 256), its principal features being included in the last lines of the citation on p. 33—34, 215—16.

These nine craters, Vatnakvíslargígir (i.e. the eruption vents at the Vatnakvísl) lie in a straight line about 15 km. long, running southwest—northeast. They are situated on an edge, probably a small fault, formed prior to the eruptive period. The height of the fault is greatest on the southwest, where it is rather more than 100 m.

in height, whereafter its size decreases towards the northeast as far as Crater No. 8, after which it can no longer be seen. The sunken area lies towards the southeast. The eruption intensity is greatest at No. 1 and 2 and decreases evenly to No. 9; the last traces are northeast of No. 9 and appear in the form of small heaps of gravel a few metres high. The highest of the gravel cones lying round the craters is about 290 m.; as a rule their base is oval with the longest axis in the direction of the volcano line. This feature is most prominent in Crater No. 9, which is about 1 km. across the widest part, inside measurement. The mounds round the vents are all leaning over with the exception of No. 9, and in every case they lean the same way, viz. towards the southeast, the result being that the southeast part of the mounds is about 100 m. lower than the northwest part. This gives the upper edge a very peculiar and handsome curvature that is practically the same on from No. 1 to 7; seen from a distance this produces a very striking impression of uniformity. The outer sides slope about 40° and from a distance appear to be perfectly undisturbed conical surfaces; a closer examination shows, however, that the sides are grooved by long channels of slight depth, cut by the waters of the melting snow. I cannot agree with THORODDSEN that these cones are badly broken down by erosion, as this is only the case as regards one side of Nos. 1 and 2, which have been attacked by the Túngná and the Vatnakvísl, which run just at the foot of them. The side facing the crater is usually a little steeper than the outer side. In most cases the craters are filled by a lake temporarily or permanently. No. 9 for instance has a temporary lake, Nos. 1 to 4 permanent lakes. The water is clear, slightly green, and the depth is small. No. 1 forms an exception, as its water comes from the Túngná which at high tide runs in and fills the basin with muddy glacial water from Vatnajökull.

The material forming these cones differs somewhat. In the first place it is peculiar that there are no streams of lava, so that the eruptions must have been of the explosive type. To a great extent the cones are built up of loose volcanic material that has been thrown out, but in the deepest part of the cone there are some anticlinally situated, hardened tuffs, which also occur as loose blocks in the other loose parts of the cones, and these tuffs can scarcely be other than parts of the pre-eruptive substratum. Thus the phenomenon corresponds to the Erhebungskraters described by RECK (1910, p. 316), with the difference that in the example figured (fig. 9) the phenomenon occurs in pure state, whereas here it is combined with the usual gravel-cone. It would thus seem (and corresponding observations in the region we have examined confirm it) that the upward forces of the volcano succeed in lifting the ground strata periclinally round the vent without breaking them up to any great extent.

The loose material is of varied origin. There are considerable quantities of volcanic gravel of basaltic composition, as well as sharp-edged lumps of other rocks such as hardened tuffs, basaltic lava with filled cavities, and finally lumps of liparitic lava. These must undoubtedly be taken to be broken fragments of the substratum. One peculiarity is that nearly all the material is of strikingly small grain.

It is rare that one finds blocks of more than 25 cm., and the number of bigger blocks is so small that it is difficult to find stones large enough for cairn building.

In most cases the cross section of the eruptive vent has been slightly oval, and there is scarcely any doubt that the vents, at any rate in Nos. 1 to 7, have sloped in the direction of southeast. This is confirmed through the observation of a small phenomenon of detail of a character that is interesting in another way. In No. 3 a part of the inner crater side is covered with a thin sheet of lava of a thickness of about 1 m. This covering, which lies in the form of tongues reaching from the bottom some way up the sides, is in three places. One tongue lies on the northwest side and extends about 30 m. up, the other two, on the southeast side, are more than 100 m. high and extend right up to the edge of the gravel cone. From there they can be traced on down over the outerside as a thin layer of fragmented lava that decreases in thickness as it goes downwards and forms a pronounced contrast to the gravel material that is otherwise predominant.

Fig. 14 was photographed on the southeast edge of the gravel cone. Below on the left is a part of the small lake that fills the bottom of the crater. The dark patch in the foreground is a part of the one lava sheet, then follows a belt in which the stratified gravel material appears without any covering of lava, and behind this again the second sheet of lava, whose edge on the steep slope has been somewhat exposed to solifluction with the result that large and small floes have broken loose and have glided down towards the bottom. On the extreme right of the picture is the edge of the gravel cone covered with a thin layer of lava appearing as a dark stripe. In the background are volcanoes No. 4, 5 and 6. The picture was taken looking north 30° east. Fig. 15 is a close-up picture of the southeast edge with its covering of lava. In Crater No. 1 we observed a similar formation but with only one tongue, lying on the southeast slope.

On the basis of these observations I have come to the following conclusions concerning the course of the processes. The eruptions in all nine volcanos have proceeded in almost the same manner and practically simultaneously, for in every respect the whole row gives the impression of complete uniformity, and nothing has been observed to indicate a difference of age. As there are no lava streams, the eruption must be placed to the purely explosive group. It should be observed here that one peculiar sign of ordinary explosive volcanoes is lacking, viz. the occurrence of large blocks that have been thrown out by the explosions. A comparison with the complicated "maar"s at Fiskivötn is in this respect called for, and it immediately shows the difference, as will be seen in the following account of their formation (p. 50, 232, fig. 13). On the other hand the quantity of material erupted and the periclinal tilting of the pre-eruptive surface show that the pressure has been enormous. It is difficult to imagine that there have actually been explosions; far more likely is it that the process has been in the form of an escape of gases under high pressure. In this connection it may be observed that other volcanic processes of this kind have been observed, viz. the famous eruption of pumice stone in Askja on March 29th, 1875, resulting in the forming of what the Germans called the Rudloff crater. On the course of the process THORODDSEN writes (1905—06, p. 125): "Während des Ausbruchs wurde durch die gewaltige Explosion aus dem engen Kessel wie aus einem Kanonenrohre in wenigen Stunden 3—4 cbkm. Bimsstein geschleudert." Thus there is a contrast between the "maar"s proper, where explosions are the prevailing form of manifestation, and the type observed at Vatnakvíslargígir, which differs in that the process has rather had the character of a blowing off, and thus we arrive at a differentiation between two "maar"types, viz. Explosion craters and blast craters.

In No. 1 and No. 3 the last phase of the eruption has been different, as is evidenced by the coverings of lava on the inner slopes of the craters. There is no trace of any lava in the crater, and one is therefore obliged to imagine the formation of lava fountains, an explanation that is confirmed by the distribution of the lava crust. The occurrence of three isolated tongues of a very thin sheet of lava must be the result of jets of thin lava. The two larger of these in Crater No. 3 must have been more than 150 m. in height, as they have reached beyond the south edge of the gravel cone, whence they have trickled down the outer side of the volcano in the form of a broken-up, incoherent mass. The distribution of these jets of lava also indicates that the vents have been inclined, for of the four observed three of them run towards the southeast, whereas only one — and of insignificant size — has gone to the northwest.

As the figures show, the surface of the lava is not covered with loose products and therefore we must assume that the eruptive process has concluded with the formation of the inclined lava fountains reaching a height of almost 150 metres.

In the terrain northwest of Vatnakvíslargígir there are several eruption vents lying parallel to the line of eruption just referred to. As far as can be seen now, their output has been insignificant and has resulted in the formation of several small lava streams as well as a few short rows of scoria cones. In some places one also meets with evidence of the activity of explosive forces in the form of typical "maar" formations surrounded by gravel and stone mounds. Two of these enclose a small lake. In this part of the field the effects of the volcanic processes have, however, been concealed to a great extent by a thick layer of volcanic gravel, whose origin must undoubtedly be placed in connection with the row of blast-hole formations referred to above.

Thus volcanism northwest of Vatnakvísl exhibits the following characteristic features: It is of typical linear character. Outside the lines are only few isolated "maar" formations. In this region the early phase seems to have proceeded in the form of small eruptions of a mass-eruption character connected with the volcano lines northwest of Vatnakvíslargígir. The later phase, the one that is also predominant both as to quantity and landscape, is Vatnakvíslargígir, which is a linear eruption of the explosive type. Along a straight line of 15 km. the eruption has concentrated in 9 foci. The process must have been in the form of a blowing out of relatively small-grained material, caused by gases under high pressure. Block material is absent. In two of the vents the processes have concluded with the forming of lava fountains of a height up to 150 m.

The volcanic zone southeast of Vatnakvísl: Fiskivötn zone.

As a whole this region lies parallel to the linear, explosive eruption area in the direction of southwest-northeast, but is larger, about 25 km. long, and, from a morphological point of view, much more varied than the foregoing region. For the sake of clarity it will be practical to divide the region into sections from northeast to southwest, with morphological peculiarities as the basis of the division. I will simply call the zones A, B, C and D.

Zone A, the most northerly part of the region, is an eruptive fissure about 5 km. long stretching from the remarkable extension of the volcanic zone that is taking place in the zone marked B on the map, to a nameless mountain whose south edge lies about 5 km. north of the north end of Litlisjór. The eruption has the character of a mass eruption, lava being predominant and loose material quite subordinate. It is a pronounced fissure eruption which has been productive of lava throughout almost the whole of its length. Here and there are small adhered-slag craters which make it possible to follow the course of the fissure from a distance. On the northeast it runs into the aforementioned nameless mountain, which is about 300 m. high and of the plateau form that is usual in this area. In prolongation of the fissure the mountain is interspersed with cracks, and in its southern slope one can see the results of the activity of explosive forces in the form of large blocks thrown out to long distances. The obvious course is to place these phenomena in direct connection with the volcanic processes, but they may also be partly associated with the tectonic changes that have caused the difference in the level at this spot. Possibly there is some connection between Zone A and a small eruption field north of the mountain, and, if this is correct, we may assume that the cracks in the mountain were formed at the same time as the volcanic fissure. From this fissure the lava has spread to the northwest and southeast, but mostly in the latter direction. There it has covered the plain over to Túngnárfjöll and its continuation to the northeast, Vörðufell. Between these two mountains is a pass leading down to the big valley of the Túngná. Through this port the lava from Zone A has flowed down and filled the bottom from side to side. If anything it must be characterised as block lava. The edges are somewhat sandblown, especially in the north part of the area of its spread. The total lava area is about 15 sq.km., and the average thickness is scarcely less than 20 m.

As Zone C has been formed in a somewhat similar manner it may be dealt with simultaneously. Like the foregoing it is a linear mass eruption which has emerged out of a fissure about 2 km. long, stretching from a point north of Fossvötn to a point west of Litlisjór, where the volcanic field widens out to Zone B. On this stretch of

2 km. the fissure is almost continuous and lava has been emitted all along, though not with the same intensity everywhere. The lava streams are of no great extent; to the southeast they have spread to the shore of the Litlisjór and have not succeeded in veiling the pre-eruptive relief of the landscape. It has passed along in some very handsome sub-surface canals whose roofs are now collapsed. On both sides of the fissure are fine mounds (fig. 5) the inner sides of which are often covered with a carpet of adhered slag which have been thrown up in the form of soft, sticky patches of about one metre and, during coagulation, have run down the side (fig. 16). There are also some vertical, conical lava hummocks down in the fissure near its outer side. As a rule they are about 5 m. high and about 2 m. in diameter, and consist of thin caps of more or less compact lava. They seem to have been thrown up while the lava was cooling and possibly they are a parallel in miniature to the famous Mont Pelée needle. In several places the adhered slag forms arched bridges over the eruptive fissure, which is about 50 m. wide.

The most peculiar feature of this section of the Fiskivötn area must be said to be the rich development of the adhered-slag phenomenon there. All the way along the fissure is an almost unbroken mound of the characteristic agglomerate that forms when fluid, sticky lumps of lava are thrown out of the magma containers — sufficiently sticky to adhere together without losing their individuality. At certain places the production of adhered slag has been extremely active and has formed circular mounds of a height of up to 50 m. This volcanic form is very common on Iceland and plays no small part in the landscape. Often this formation bears the name of Eldborg (fire borg), as a study of the topographical maps of the recent volcanic areas of Iceland shows. The term is thus used as a proper name for a number of vents — of a certain type, it is true; but as this type is well limited and is the outcome of a certain side of the activity of volcanic processes, it may perhaps be justifiable to use the name as a common denominator for formations of this type, as a morphological category.

An **"Eldborg"** is formed round a cylindrical vent when the latter throws out large quantities of adhered slag and only small quantities of loose material proper. The result is the formation of a circular mound with very steep slopes both on the crater side and on the outer side. The height is usually small, not over 100—150 m., but the steepness gives the phenomenon a very conspicuous form. The steepness of the sides, 60—70°, in conjunction with the porosity of the material and slight coherence, often make it difficult to climb over the mound, and still more difficult is the descent on the inner side down into the crater. As a rule the upper edge is only a few metres wide, very jagged and uneven, and thus from a distance has a very characteristic, serrated profile. The whole structure bears a resemblance to the very collapsed ruin of a round borg tower, and thus the name is a very apt one, as indeed are many of the Icelandic landscape names.

Zones A and C are thus regular fissure eruptions from an easily recognizable, sharply bounded eruptive fissure with a slight output of loose material. The characteristic feature of Zone A is that the lava output is so absolutely predominant, whereas Zone C is remarkable for its small lava output; on the other hand it has had a lively production of adhered slag.

There has been another type of volcanic activity in the other two zones, B and D, which on many points resemble each other, for instance in the fact that their structure is extremely complicated. While making the preliminary survey of the terrain we found the whole utterly confused and it was impossible for me to obtain any impression of the course of developments in the landscape as a whole. Only after a month's study of the conditions and a cartographical recording of the very intricate topography of the area was I able to arrive at the views which I shall explain in the following and which, I believe, can be maintained.

Zone D is a landscape 10 km. long and up to 3 km. wide, embracing the lake groups Fiskivötn and Fossvötn with the surrounding country. The longitudinal axis runs southwest—northeast and forms a direct, straight-line continuation of the volcanic line that can be followed from the northeast point of Zone A and through that zone and the subsequent Zones B and C. About one-third of the longitudinal axis of the whole Fiskivötn system thus falls in Zone D. I have put the northern boundary at the southwest corner of Litlisjór and the southern boundary at the Túngná bend; the southeast boundary lies at the foot of Mount Skálafell, and the northwest boundary at River Vatnakvísl. Accordingly the total area of this zone is about 25 sq.km.

Within it the pre-eruptive terrain is so to say completely destroyed. Our examination has shown that at least a hundred foci of volcanic activity can be established, about 25 of them at Litlisjór and Fossvötn, whereas about 75 lie in the terrain near Fiskivötn. As a whole the terrain does not rise above the surrounding country, although here and there are small gravel hills of 50 to 100 m.; but it is lower than Zone C and, what is more, much lower than Vatnakvíslargígir. This fact alone indicates that the output of volcanic material has been small, and our investigations proved this to be the case. In many places on the edge of the volcanic field there is a mound of gravel sloping gently outwards; on the inner side the slope is steeper.

While the field as a whole runs in the direction of northeast—southwest, it is only here and there that one can find a similar arrangement of the various volcanic units in the field. In certain cases five, ten or twenty eruption foci lie together in a group without any order at all, whereas in other cases a similar number may lie in a line — usually southwest—northeast. There also occur continuous linear eruptions, and, finally, it is not seldom that one meets with isolated central eruptions where no immediate connection with any other is perceptible.

It has not been possible to organize a detailed examination of all the places of eruption; much more assistance would be necessary than I had at my disposal. A monographic treatment of this kind, going into all the details, would be a very profitable enterprise, but would require the employment of much labour, time and money. In the present work my task must be confined to an account of the elementary phenomena and then to endeavour to bring them all together into a morphogenetic whole.

The course of developments, as far as can be seen now, has commenced with an explosive phase of very violent character. Traces of this activity are to be seen in various places on the outskirts of the area, for instance in the north part of the field at Fossvötn, where the volcanic area is bounded by mounds about 50 m. high, consisting of tilted layers of tuff and, overlying them, loose explosion material. Within the mounds the volcanic activity has involved the forming of a large, unbroken basin, whose presence becomes of essential importance to the further course of the processes. Analogous formations have been observed in the north part of Fiskivötn, where we find the same combination of central basins and surrounding mounds. It has been in this manner that the greater part of the basin now containing Skálavatn, Langavatn, Eskivatn and Kvíslarvatn has been formed.

Meantime the eruptive activity has continued and has given parts of the explosion area quite another character. That these processes are later appears from the fact that they are unconformable with those just described, and that they intrude in their terrain forms and disturb them. Thus we see earlier gravel mounds, parts of which have been blown away by later explosions, and earlier basins that have wholly or partly been filled with explosion material from later eruptions. Most probably it is to some extent the same material that time and again has been blown up and shattered; it has simply been moved about as the centres of the process moved.

Several of the later phases have spread out beyond the area in which one can now find the traces of the early phase. Thus on the south shore of Litlisjór there is a narrow zone with 17 vents on a plain of about one square kilometre. They lie scattered about in no sort of order, quite close together, often overlapping so much that twin craters have been formed with "spectacle-shaped" twin lakes in the bottom. The vents themselves are about 100 m. wide, 20—30 m. deep, and in towards the crater have a slope of about 45°. The mounds are about 15 m. high. The material produced is almost exclusively loose and for the most part consists of slag, thrown into the air in a state that was plastic but not so adhesive that it became welded together. Part of the material is burnt red, but in some places real adhered slag and bombs up to a size of 30 cm. have been observed. There were no lava streams, but a number of sharp-edged blocks were seen, of an old basaltic lava with cavities filled with quartz. All this small, handsomely shaped crater group provides an example of the form of volcano that is called the explosive area eruption. On fig. 11 is a view over the region. The lake has attacked one side of the eruption field, but a number of craters are still preserved. In the foreground are the remains of three of these, one being full of water. One side of them has been broken down by the erosion of the lake, and across them there is now a raised beach.

The foreground is the south side of another "maar" formation, on whose sides one can see a thick strewing of blocks, all sharp-edged lava fragments.

In the basin enclosing the two lakes Stóra and Litla Fossvatn there are traces of several older explosion centres, but the relief produced by these explosions has been greatly disturbed by both erosion and the activities of the later volcanic processes. The character of these latter has varied greatly, as there is evidence of both explosive and mixed eruptions. They have especially been concentrated in two fields, viz. at the north end of Stóra Fossvatn and at the south end of Litla Fossvatn. From the first of these a small but deep lava stream has run southwards and filled part of the basin formed by the earlier explosions. Here are innumerable indications of collapse, hornitos formation and sub-surface canals, on the whole a series of phenomena that characterises very fluid lava streams of great depth.

In the area north of Tjaldvatn there are also marked traces of an earlier, mostly explosive phase that has later on been followed by one of mixed character. The latter activity is in the form of a line and lies in the usual direction of northeast—southwest. The process has caused a crack through the mound that separates the Fossvötn basin from the Tjaldvatn basin on the south. On the side opposite to Fossvötn the eruptive intensity has been comparatively slight and has only resulted in the formation of some small adhered-slag craters; on the south side, however, the activity has been considerable. In the first place there are two deep explosion craters, belonging to the most recent phenomena in this part of the area, for their occurrence shows that they were formed after the second main phase came to an end. This corresponds in character, and probably also in time, to the effusive phase at Fossvötn and, like the latter, is characterised by a mixed output and the lively erupting of very fluid lava. The situation of the vent is marked by a series of adhered-slag craters with small, steep cones of lumps of fluid lava welded together. Close to the centres are many hornitos formations and one or two coagulation cavities, one of which, known as Tjarnarkot, has been built up as a dwelling for the trout fishers who now and then come to this group of lakes. The lava has filled the bottom of the old explosion basin and from there has spread into the basin where Skálavatn lies, while another branch of the stream has gone down into the Langavatn basin.

As to conditions here Thoroddsen writes (1889, p. 8): "Tjaldvatn lies in a very large, old crater. The lake has made irregular bays and coves, but scarcely occupies half of the crater bottom. The arc-shaped crater rims had a height of 2—300 feet above the lake; on the inner side they have a narrow lava terrace which seems to mark the place of an old, higher, lava bottom which has later been melted again and sunk in the course of renewed eruptions and drainings. The crater cone itself is principally built up of slag and drops of lava. I observed no really old lava streams dating from the time when the big crater was formed; on the contrary, the crater bottom itself was covered with later lavas."

My investigations have confirmed the correctness of these observations, but several things have escaped his attention, presumably owing to lack of time, and as a consequence his view of the whole system is somewhat defective.

If one follows the lava fields from the centres of eruption north of Tjaldvatn down towards this lake, it will be observed that from a certain zone there is a fall of about ten metres down to the level of the lake. The surface of the lava field continues, however, on the side of the Tjaldvatn basin in the form of an unbroken lava shore line which runs into the basin in which Skálavatn lies and also into the Langavatn basin. The shore line is very distinct at Tjaldvatn where, as stated above, it was observed by THORODDSEN. It is here (fig. 9) seen as a sharp edge that has acted as an arresting ledge for the masses of gravel sliding down from above. This makes a very characteristic break in the curvature of the mountain side. In many places I have removed this gravel material in all three lake basins and everywhere found an even surface of lava resting upon the side of an old explosion crater. There is no doubt that this shore line marks the presence of a continuous lake of lava which has filled all three basins; its lifetime has, however, been brief — it has not even got so far as to settle horizontally, as the shore line lies higher at the place of eruption than in the distal parts of the lava lake.

The question then is, what has become of the great mass of lava that filled these three basins up to the height of the lava shore line. One might imagine that the lake has been emptied in the manner known in other recent volcanic localities (NIELSEN 1927, p. 121, fig. 6), but in this case this possibility must be rejected. I have examined the lava shore line along all three basins and nowhere found it broken, nor have I observed any trace of streams caused by such an emptying, despite most thorough search. It must therefore be assumed that it has sunk as a consequence of coagulation contraction; possibly there has been a re-melting as indicated by THORODDSEN.

In this connection it is of interest to know the relief of the bottom of the lake and especially the maximum depth. On this THORODDSEN says l. c. "In the bottom (of Skálavatn) there are also said to be deep hollows and abysses", and further down he refers to the occurrence of deep abysses in a connection that must be presumed to apply to Tjaldvatn and the small holes south of that lake. These ideas are rather exaggerated. The depth of the lake is remarkably constant, as a rule not more than 3—4 metres, but at some few places there are depths of up to 8—9 metres. The bottom is lava everywhere, and the relief and character of its surface is just the same as that of the sunken lava fields above the level of the water, except of course at those places where the superficial feed-waters have led gravel out into the lakes, a process that in particular has had an influence upon the bottom conditions in Tjaldvatn, where the water coming from the north has brought about the forming of small deltas. Fig. 41. In Skálavatn especially is a number of islets which THORODDSEN presumed to be craters. This is not the case. They have proved to be of the same structure as the lava mounds separating the lakes. For the most part these consist of fragmented lava, but sometimes one sees a tendency towards stratified coagulation. In many places on these mounds there are steep-walled crags of a height of up to 10 m., the most prominent being the so-called Arnarsetur, so named because the sea-eagle is said to have nested there up to a few years ago. These crags consist of lava fragments lying very irregularly and are certainly not craters; they must be regarded as a kind of hornitos. Fig. 10.

On making a comparison of my observations in this part of the Fiskivötn region I have come to the following conclusions regarding the course of the volcanic processes and the product of their activity as reflected in the landscape. The foundation is three eruptions mostly of an explosive character, which have produced three basins that today are marked by the presence of the lakes Tjaldvatn, Skálavatn and Langavatn. The two first-named have the character of area eruptions of limited extent, undoubtedly resembling the local formations that occur in undisturbed condition in several places within the region and described below. The Langavatn basin has come about as the result of a linear, explosive eruption and thus must be called an explosion pit. The three basins have overlapped at the west end of Tjaldvatn. The next phase of the developments is marked by the great eruption of lava in the north corner of the system, and it must be noted that we observed nothing to indicate effusive activity elsewhere within this tripartite explosion area. The result is that all three basins are full of lava to a very considerable height, but the output has not been large enough to overflow the mounds round the old explosion basins. The subsequent collapses, whose greatest observed depth is 15 m., are markedly great and, as stated above, their cause is rather doubtful; the result is, however, that three principal subsidences were formed corresponding to the deepest parts of the three primary explosion basins. Only at the edges of this tripartite lava lake is there a narrow shore line left as evidence of the higher level of the lava. Hornitos were formed in certain parts of the lava lake (Fig. 10). The mostly deeply sunken parts at present are below the surface of the water and have in fact given rise to the forming of these lakes. The biological conditions in and round these lakes are most remarkable; both fauna and flora are relatively rich in individuals but poor in species; naturally, conditions of life are hard, and life is sparse, but when one comes from the enormous wastes on the north and west and surrounding Fiskivötn on all sides, one rejoices in this poor little oasis and feels that it is luxuriant and good place to be in.

In the northern part of the Fiskivötn area in its strictest sense it is thus possible to form a summary of the play of the volcanic forces and separate the different phases of developments. In the southern part of the area this is extremely difficult, not to say impossible, a consequence of the very complicated course of the volcanic phenomena there, as we have not to deal with eruption phases that are separable as to time, place and character. Here the explosive forces have prevailed right up to the end of the eruptive period and have so covered up the older traces of activity that it has not been possible to account for conditions throughout a long period. Volcanism has been active throughout the whole of the landscape from the foreland of Túngnárfjöll to the Vatnakvísl, and on the whole of this domain there are not many square metres of ground that have not repeatedly been uprooted and blasted away by the explosions. The actual production of material has not been great; the highest peaks are scarcely more than 100 m. above the level of Skálavatn, and the lava streams are of small extent and have, as far as can be seen, remained within the area. But never have I seen such a typical area eruption, a surface that has been knocked about to such an extent by volcanic forces, and never have I come across such a confusion of explosion craters of all possible forms. Some of them, the most recent, are quite undisturbed, whereas the earlier ones are more or less destroyed by the later explosions, with the result that the relief is most complicated and of exceeding variety.

Some examples will illustrate this variation. Right up to the foot of Skálafell is a height that at some distance looks like a simple ring-shaped crater mount. Closer inspection shows, however, that this is a "maar" that is very complicated. In this respect it forms an analogy to the large complicated "maar" at Litlisjór to be described later. Four explosion centres can be shown in it, and the surrounding cone of gravel is not continuous, but consists of four cones running into each other, their outer sides being fairly undisturbed, whereas the parts facing the centre have been blasted away by the neighbouring explosions. Details are given on p. 50, 232 and fig. IV. Just to the west of this we find a small linear eruption, with its fissure marked by three craters of the Eldborg type (cf. p. 40, 222). From this fissure there has emerged a small stream of lava, and the conditions under which it has spread show that it must have appeared after the aforementioned masses of lava on the north at Skálavatn had found their resting place. The stream has a margin of block lava, 50—100 m. wide, and inside this we find a lower lava surface where coagulation has proceeded more quietly and has resulted in the forming of a pronounced sheet lava. In the immediate vicinity of the eruption fissure there have been great subsidences, resulting in the forming of deep pits with handsome terraces. Figs. I—II show a section through the whole series; A is the subsidence basin with the terraces, B is the sheet lava, and C is the uneven marginal zone of block lava. The course of the subsidences here has been that large areas of 2—3 hectares together have sunk 5—10 m. There is another form of subsidence just south of the most southern and largest of the three Eldborg craters. We find there a round hole, 100 m. wide, leading down to a subterranean gallery about 10 m. deep and connected with another opening of similar kind.

In the rest of the field one finds a bewildering collection of vents, nearly all of an explosive character but differing greatly in a morphological sense. Some are typical central eruptions, others are linear, and others again are small area eruptions. A very fine explosion pit, about one kilometre long, exhibits the following peculiarities: The eruption fissure itself is scarcely more than 50 m. wide, and on both sides lies a continuous homogeneous mound of gravel. The eruption has been concluded with a short lava phase, during which the bottom of the pit throughout its whole length has been covered with a lava lake in whose surface one sees the usual subsidence phenomena. Fig. 12. — In the most southerly part of the field one finds especially "maar"s of the type described below on p. 50, 232, remarkable owing to the presence of explosion centres very close together. Here and there are small lava eruptions and lava phases as a concluding or intermediate stage in a series of explosions. Here the terrain is very wet and has been eroded from the Vatnakvísl and Túngná, and

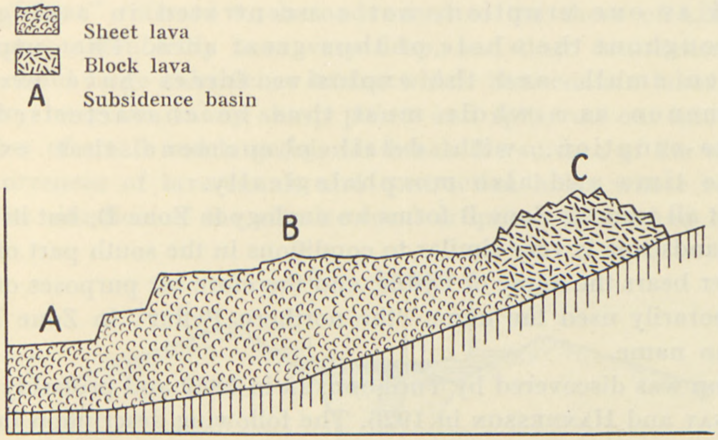

Fig. I. Section through a lava stream which has come from the left. The lava has hardened into block lava (apalhraun) (C) in the marginal zone, inside this into sheet lava (helluhraun) (B), which here and there has collapsed and formed small subsidence basins (A).

as a consequence some of the craters have been partly destroyed, usually enclosing lakes or swamps. The surrounding landscape is likewise to a marked degree charac-

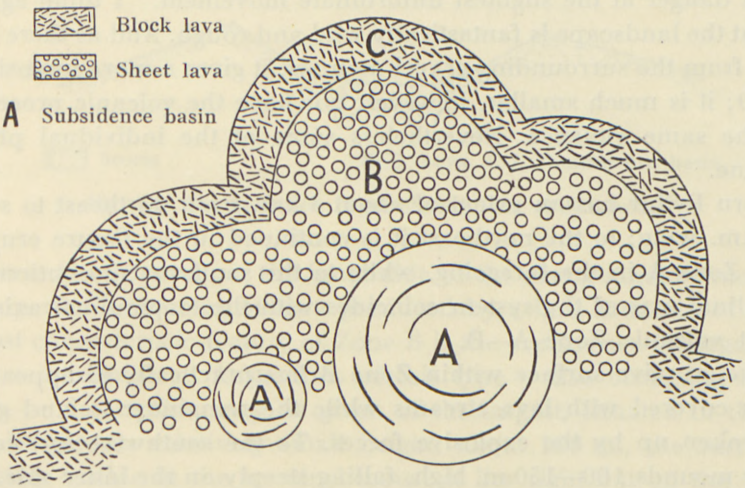

Fig. II. Three tongues of a lava stream, showing a marginal zone with block lava and a central zone of sheet lava and subsidence basins. Cf. Fig. I.

terised by the great masses of water carried down by these rivers, or originating from the considerable quantities of ground water that pass from Litlisjór down through the whole of the porous gravel masses of this volcanic field.

There is scarcely any doubt that the whole of that volcanic field, 20 sq. km., at Fiskivötn is one whole that owes its being to the same source. In reality it must be regarded as one eruption, not concentrated in a single spot but working throughout the whole of thus great area. The output of material has been small, and the explosive forces have predominated. The phenomenon as a whole must thus be characterised as an explosive area-eruption, with detail phenomena that exhibit great variety as to time and also morphologically.

In almost all respects Zone B forms an analogy to Zone D, but its area is rather smaller. The landscape is very similar to conditions in the south part of the Fiskivötn zone. The latter bears the name of Pytlur, and therefore for purposes of identification we have temporarily used the name "the northern Pytlur" in Zone B, which previously had no name.

The region was discovered by THORODDSEN in 1889 and probably was traversed by DE FONTENAY and HANNESSON in 1926. The following description in THORODDSEN may be taken to apply to the northern Pytlur (l. c., p. 11): "Such wild volcanic scenery I have rarely seen in Iceland. Many of these craters, like the old ones, are full of water, and between them the rugged and tossed masses of lava are cleft by innumerable fissures. Under the thin crust of lava are water-filled holes and crevices or long tunnels with glazed lava stalactites, and owing to these hidden dangers we had to proceed with the greatest caution, as on such a terrain the horses would get into most serious danger at the slightest unfortunate movement." I quite agree with THORODDSEN that the landscape is fantastically wild and rough. And as there is an excellent view over it from the surrounding gravel mounds, it gives a more imposing impression than Zone D; it is much smaller, however, nor have the volcanic processes had anything like the same violence. Nevertheless some of the individual phenomena are extremely fine.

Northern Pytlur has an extent of about 4 km. from northeast to southwest, and is about 2 km. wide; to the northeast it is continued in the fissure eruption that has been called Zone A in the foregoing, while to the southwest it continues in Zone C. The longitudinal axis of the system coincides with the longitudinal axis of the whole of this great volcanic Zone A—D.

The pre-eruptive surface within Zone B has practically disappeared, part of it having been covered with lava streams while the remainder — and greater part — has been broken up by the explosive forces. To the southwest and east the field is bordered by mounds 100—150 m. high, falling steeply on the inner side, but less steep on the outer side. These mounds are without doubt the remnants of gravel cones and are thus analogous to the formations at Fossvötn and Fiskivötn. On the south edge of the zone the boundary mound is broken by a large and complicated "maar" which will be described below.

The eruption field itself exhibits a combination of simple "maar"s, complicated "maar"s and explosion pits. There are also traces of an effusive activity, but its lava streams are quite short and have remained in the depressions within the field itself. There is an exception, however, in a small lava tongue which, through a cleft at the complicated "maar" referred to, has advanced to the shore of Litlisjór. Here the lava lakes have undoubtedly been very deep, and their contraction while cooling has brought about large subsidence basins which now contain lakes. Their circumference is very irregular; many sharp points and spits run out into the lakes, and a large number of small and large islands break the surface of the water. There are frequent occurrences of lava-canals and contraction holes whose roofs are as yet unbroken. The situation of the effusive local eruptions is marked by the presence

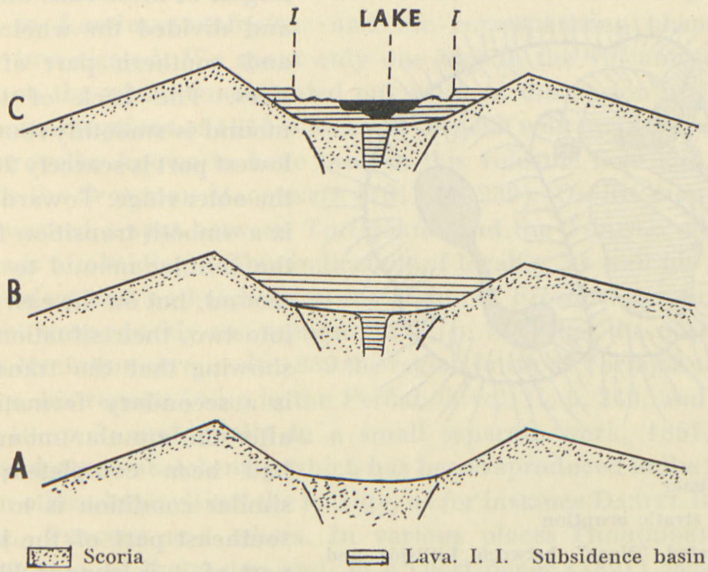

Fig. III. The evolution of a volcanic area at Fiskivötn.

of small craters. At one place on the inner side of the east boundary mound we have observed a superficial covering of lava produced by a lava fountain of about 100 m.

The most characteristic feature of Zone B is the occurrence of large, complicated "maars". As an example of formations of this type — also occurring in Zone D as stated above — a description may be given of the largest, situated in the south edge of the zone. Despite its relatively small height, about 100 m., the surrounding ring mound is widely visible in the terrain because it lies right out on the west shore of Litlisjór. Seen from the outside it gives the impression of being a simple, round, single "maar", but when one climbs up the edge it is discovered that in reality it is most complicated. Fig. IV.

The top of the annular mound is practically circular, and only at one place, on the northwest in towards the rest of Zone B, is it broken by a narrow opening. The material in the mound has partly come from the magma in the form of gravel, adhered slag and bombs, and partly originates from the substratum. Most of the blocks thrown out are of considerable size, up to 10—15 sq. m., which shows that it has been an explosive eruption proper, in contrast to the "maar" type mentioned, whose most pronounced representatives were found at Vatnakvísl and which were distinguished by the fact that the material all through was fine grained and presumably was the product of a blowing-off process. The difference appears from a comparison between fig. 13 and fig. 14.

Within the annular mound is a very complicated eruption basin, fig. IV, which is divided into several secondary basins separated by mounds of gravel. The largest of these runs almost east—west and divided the whole in a northern and southern part of almost equal sizes. The back of the transversal mound is smoothly rounded and at its lowest part is scarcely 20 m. lower than the outer ridge. Towards the west there is a smooth transition from the top of the annular mound to the transversal mound, but on the east the latter splits into two, their situation and direction showing that the transversal mound is a secondary formation, appearing after the annular mound at this spot had been completed; a somewhat similar condition is to be seen in the southeast part of the basin. The east part of it is shaped like two funnels with overlapping edges and their bottoms are occupied by a small S-shaped lake. The western half is more complicated. There is more or less direct evidence of six secondary explosion centres, each of which has formed its own funnel with surrounding mound of gravel, the youngest of them with a fine and regular appearance, whereas the older ones have been disturbed by the subsequent eruptions and can only be recognized fragmentarily. The volcanic activity has concluded with small eruptions of lava, which have been peculiarly placed. The vents — six in all — lie in the west basin but not, as might have been expected, in its deepest parts; the lava has broken out high up on the inner side of the gravel cone a short distance below the ridge. Two streams of lava have run from there down into the deepest parts of the west basin, in which the bottom of the crater-funnel is partly full of lava.

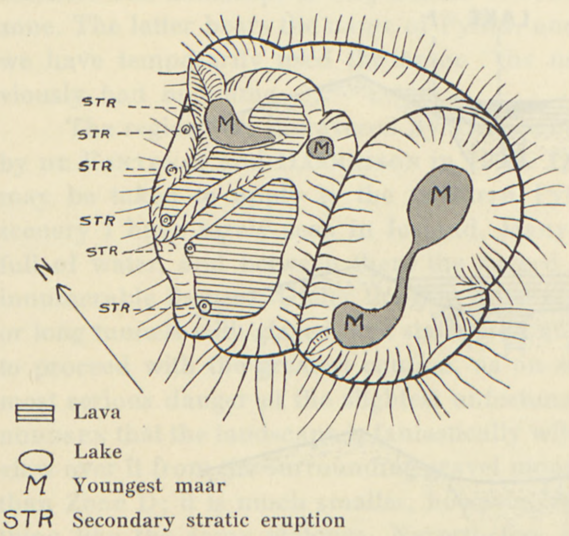

Fig. IV. Complicated "Maar" between Litlisjór and Hraunvötn.

The characteristic feature of this type of volcano is that the explosive forces have predominated. Outwardly it appears like a simple "maar", but its crater basin is very complicated and bears evidence of the activity of at least 14 eruptive centres.

Thus it belongs to another morphological type than the simple "maar", described on p. 35—39, 217—21 and I suggest for this type the name; complicated "maar" formations.

c. Volcanism in Landmannaafrjettur.

In contrast to the volcanic regions so far described, this is relatively easy of access; and, as it furthermore occupies a conspicuous, separate position, it has fairly frequently been visited by investigators. It is outside the scope of this work to give an exhaustive account of conditions there, and I shall confine myself to a brief report of the results of the work of others in order to create a basis for a comparison between the volcanism in Landmannaafrjettur and the corresponding phenomena in the region that we investigated. We spent only one day in the volcano area at Frostastaðavatn, and on the whole concentrated our work in this region upon investigating the two little known eruptions of 1913, which will be dealt with in a separate publication.

The first traveller known to have been in this volcanic field and to have made notes about it is the Scotsman MACKENZIE (1812, p. 239). On his map he has drawn his route and marked a spot between Torfajökull and the Túngná, where he writes: "Here is a stream of obsidian." This indication of locality, as well his whole description, make it evident that he has been in the region of Frostastaðavatn, and SCHYTHE is without doubt wrong in his assumption (1847, p. 137) that the obsidian found by MACKENZIE was Hrafntinnuhraun. In 1889 the region north of Torfajökull was travelled by THORODDSEN, his reports being in the Ferðabók vol. II, p. 240, and also in Geogr. Tidsskrift vol. 10, p. 7; and finally in a small separate work, 1891, he described several details and gave a sketch-map which has been reproduced in the large synopses.

Since then others have visited the locality, as for instance DANIEL BRUUN, SAPPER, RECK, TYRRELL, PEACOCK and others. In various places THORODDSEN published a geological sketch-map of the region and, in a short paper (1891) gave a description of the liparitic lava occurrences. The rocks in the liparitic lava streams, Laugarhraun, Námshraun and Dómadalshraun, have been examined and described by HELGE BACKSTRÖM (1892), and finally SAPPER (1908) published a morphological analysis of the region and also a map — the best in existence both morphologically and topographically. The results of the work of TYRRELL and PEACOCK (1924) have unfortunately not been published yet.

The strangest thing about the volcanic forms of expression is that in post-Glacial times there have been liparitic and basaltic eruptions side by side. SAPPER (1908, p. 35) goes very thoroughly into a description of the conditions, which may be briefly summarised as follows: The eruptions have to some extent occurred along a line running NNE, and thus in so far are typical; but along that line there are: 1) a large explosion crater, 2) a small basaltic fissure eruption with a considerable output of lava, and 3) two liparitic eruption fields. There is scarcely any doubt that we have here a continuous series of volcanoes despite the petrographical differences of the individual parts, and consequently one comes to the conclusion that there must be two magma-containers under this terrain, one basaltic and the other liparitic, and that it is one common cause, having nothing to do with volcanism, that has opened them. The cause is probably to be found in tectonic changes.

To the west of these two liparitic streams is a third one of the same character, Dómadalshraun — post-Glacial like the others. Our investigations of the surrounding mountains have shown that the earlier deposits in the region belonging to the Glacial-volcano formation on the north are basaltic and on the south contain liparites, and the boundary bètween them almost coincides with that of the present day. This observation might mean that the boundary between the two petrographic provinces is rather old and has remained unchanged throughout a considerable period.

Northwest of the liparitic region, between it and the Túngná, is a very productive basaltic, mass-eruption field that hitherto has had no mention in the literature. Lack of time, unfortunately, prevented us from examining it more closely. Its construction is fairly complicated; there are "maar"s and a large number of lava eruptions. The vents are apparently not in linear order and presumably the field may be characterised as a collective area eruption. Productivity has been very great. The masses of lava have spread west and north and fill the country between the foot of the mountain and the Túngná. It is these masses that have caused the intrusion of lava into the Túngná that will be described later and determined its course throughout the whole of the bend to the north until it joins the Þjórsá.

With very few exceptions the Tjörfafell lava forms the left bank of the river from the place where it is overlain by streams from the Hekla region. The relations between the different series of eruptive products from the two volcano fields Tjörfafellsgígir and Hekla as to deposit and age are, however, not known, and it is an extremely difficult, perhaps practically impossible task to find this out; it is probable, however, that these fields have jointly produced the enormous masses of lava that have forced their way through the valley of the Þjórsá right along to the coast of the Atlantic.

d. Hágöngur.

The names Háganga nyrðri and Háganga syðri designate two isolated mountains of truncated-cone shape, standing on the plateaux south of Túngnafellsjökull. We know only very little about them, for to my knowledge they have only been visited by Björn Gunnlaugsson in 1839, when he climbed the most southerly one and there had a topographical surveying station. As was stated in the introduction, several travellers have since passed through the region, but we know of none who have climbed or made any examination of the summits.

As both cones are widely visible and very prominent in the surrounding plateau-land they have been referred to by several writers without attempting any detailed description. Thoroddsen, who has seen them from the heights at Þórisvatn, writes (1905—06, p. 280): "Mitten auf dem Hochlande, in den Ausläufern des Túngnafellsjökull, den sogenannten Hágöngur, sind blaszrote Bergspitzen sichtbar, die warscheinlich aus Liparit bestehen, jedoch bin ich nicht an Ort und Stelle gewesen."

These two mountains are on a low ridge south of the massiv on which Túngnafellsjökull lies. The rocks in situ that are visible in this region belong to the Glacial—volcano formation (the Palagonite formation), but they differ from corresponding rocks in the surrounding areas by a frequent occurrence of liparitic intrusives. The ridge from Túngnafellsjökull runs north—south and thus, together with a mountain range east of Hágönguhraun and a cliff in Vatnajökull, forms a system of north—south lines that are in decided contrast to the southwest—northeast lines that prevail in the rest of the landscape. It is possible that just this zone represents the transition between the two main regions of the great axial fracture system, viz. the great Nordland system and the southwesterly system, of which the former is characterised by fault lines running north—south, whereas the latter is marked by faults running southwest—northeast. As yet, however, these conditions have been too superficially examined to allow of any definite statement on the problem; nevertheless, the transition must be somewhere in this region, as the north—south fracture lines are known to extend a good distance south of Ódáðahraun.

The distance between the two Hágöngur is about 3 km. The one to the south is the highest and also the widest, but otherwise they resemble each other and in their whole appearance are of a peculiarity that contrasts in a most pronounced manner with the mountain forms in the whole of the surrounding landscape. Fig. 18.

At its base Háganga nyrðri has a diameter of about 1 km. and a relative height of about 700 m., whereas Háganga syðri has a base-diameter of about 2 km. and a relative height of about 800 m. The sides are fairly steep, with an incline of about 45 deg., and this steepness increases somewhat towards the summit, where the basic rock is visible, whereas the talus at the foot has produced declivities that do not incline so much and are more varied. The summit of Háganga syðri is a plain of about 1 sq. km., forming a marked contrast to the slope, as everywhere the edge between the two planes is quite sharp. The top surface bears two low, circular domes. Ascent gives no great trouble, except that some care must be taken, especially when descending, because on the surface of the rock there is a very thin coating of loose gravel which must be removed before one can obtain anything like a safe hold. In addition the rock walls are badly weathered, and even large and apparently firm protruberances give no secure foothold, but easily loosen off and fall into the depths.

In the upper half of the mountain wall the rock is visible almost everywhere; but lower down it is also accessible for examination in the deep clefts which the mountain streams have formed in the otherwise thick covering of talus. As Thoroddsen supposed, the material all through proved to be liparitic lava, and the presence of no other material has been established. One prominent feature is a peculiar fluidal structure which seems to be associated with forms of lava with a strong tendency to split into cubic blocks measuring 10—30 cm. along the edges. There are also rocks with a faintly developed porphyric structure produced by the presence of small, angular grains of quartz; and finally there is glassy, black obsidian, although in small quantities only. In the surface of the plateau at the top is an angular, liparitic breccia.

The most astonishing feature of the building of this mountain colossus, whose volcanic origin is indisputable, is that it has not been possible to find any crater, no sign of it, morphological or petrographical, having been discovered. We are therefore compelled to assume that this is a liparitic volcano type not previously known in Iceland, a form corresponding to the "Staukuppe" known in other volcanic regions, as described for instance by SAPPER in his splendid work: "Vulkankunde" of 1927.

Unfortunately, time did not permit of a closer study of these extremely interesting matters, and I would not venture to make any definite explanation of the phenomenon; all I have wished to do was to point out that Háganga syðri seems to be unique among the types of volcanoes hitherto known in Iceland.

5. The tectonic conditions.

There has been this especial difficulty in examining the tectonic structure of this region, that it has not been possible to find a single continuous horizon. The tremendous volcanic activity has resulted in the forming of a collection of elementary phenomena whose morphological association and chronological sequence have been impossible to analyse. In this respect the difficulties are increased by the circumstance that normal humid erosion is lacking, so that in the study of the tectonic conditions one has not the important assistance that is usually given by the profiles cut by the watercourses. As a consequence, one's tectonic studies have mostly to be made on the basis of observations on the terrain, and profile observations in the higher parts of the landscape can only be of a supplementary nature. That it is nevertheless possible to unravel certain of the tectonic problems here is due to the fact that the phenomena are quite recent and not yet blurred by the activity of disintegrating forces.

Briefly, the principal morphological result of the recent volcanic activity in the country west of Vatnajökull may be described in the following way: Throughout the whole of the north part of the area investigated, volcanism has produced a slightly sloping plain, uneven — very uneven — in its details (fig. 8), but in the main having a strikingly constant and slight dip (fig. 3), a surface form that is characteristic of regions where for long periods mass eruptions have been the predominating morphological factor, the volcanic filled up plateau. In the south part of the region, where explosive forces at any rate in recent times have predominated, we do find volcanogenous heights round about the eruption vents, but these gravel cones are only of slight importance in the terrain as a whole. In Vatnakvíslargígir the highest summits have a relative height of 2—300 m., but as a rule they do not exceed 150 m., and in the greatest area of them all, the great Area Eruption Zone D at Fiskivötn, the relative height scarcely exceeds 100 m. In this case, too, the local heaps round the vents are very small. Nevertheless, large masses of loose material have been released. The covering of lapilli stretches over an area that measures at any rate 300 sq.km., and, as far as can be ascertained at the moment, it is relatively evenly distributed, the region with the heaviest deposit of lapilli being at Fiskivötn, whence the thickness decreases smoothly to all sides. The gravel cones referred to are perishable formations, and it is solely due to their youth that today they play any part at all in the terrain.

The forms of erosion that are active at the present time only add to the relief in quite exceptional cases. Water erosion is almost insignificant, and the forms of subaerial and aeolic denudation smooth out and reduce the relief. It has practically been impossible to establish traces of glacial erosion on the present surface between the Túngná and the Kaldakvísl. At one single place, viz. on the northwest side of Snjóalda, I have observed at some height a few hollows that may be read as ice or snow-erosion phenomena; in one, by the way, lies a small mass of ice, a hanging glacier, partly covered with last year's snow. Otherwise on these plateaux, which rise several hundred metres above the predominating high-plateau surface, no trace of glacial radial erosion has been met with, and this must mean that the present terrain form cannot have existed at a time when the snow-line for this part of Iceland was much lower than it is now. On the other hand there is nothing to indicate that this difference in height, formed in recent times, can have been produced by the work of erosive forces; we must assume that this height-difference and peculiarity of relief is of tectonic origin: in other words, that the slopes that occur (ruptures de pentes) are faults. The correctness of this view is confirmed by means of a closer study of the conditions.

Heljargá. The most recent and most pronounced example of a tectonic disturbance is the fissure discovered in 1925 by de Fontenay and named by him Heljargá. East of Þórisvatn de Fontenay and Hannesson in 1926 came across a similar formation, and, by following it towards the northeast, they found that it was a continuation of the same fissure.

It runs from the northeast edge of Vatnsleysuöldur to the region east of Þórisvatn, and thus has a length of about 30 km. The fissure is continuous and straight, and, as the map shows, it runs from southwest to northeast. At its widest part it is barely 1 km. broad, and for the most part it only measures 5—600 m. It is peculiar that the ends do not taper off very much, as the bordering fracture lines if anything run parallel right to the point where the fissure-formation is obliterated. At the ends the depth decreases steadily, and, if one goes along the bottom of it, one comes up an even slope to the unbroken surface both north and south of it. The fault has its greatest depth in the mountain Gjárfjall, where it measures about 100 m., but at the other parts is rarely exceeds 40—50 m. The greater part of the fissure is simple and does not branch off; but at the deepest stretch in Gjárfjall complications occur, there being several small cracks parallel to the main fissure, as well as very short, inclined, lateral fissures running from both the main fissure and the secondary fissures. There the whole of the fractured zone is about 2 km. wide.

The terrain that is cut through by Heljargjá is divisible into three. To the north it runs through an arm, 6 km. wide, of the lava fields of Hágönguhraun, then follows a plateau, Gjárfjall, at a height of about 300 m., and southwest of this is the southern part of the said lava fields, which are cut through along a line about 16 km. long. In this section the fissure passes two "maars", one of which is cut right through, the fissure running like a path through it, whereas the other (the most northerly one) is only slightly disturbed. The fissure has been caused by tremendous force. The fields of lava are cleft as if along a line (figs. 20 and 19), the plateau of Gjárfall, ca. 300 metres high and steeply-walled, is cracked right through along a line 8 km. (fig. 21), and there is nothing to indicate that this obstacle has had the slightest influence on the course of the processes.

Having made a number of detail observations, it is possible to form some idea of what has happened. When one approaches Heljargjá from the side, the fissure is invisible until one is quite close to it, owing to the fact that the two fracture edges lie undisturbed at their original level; the dislocation has only affected the zone lying between the edges. In other words, the movement has been purely local. This becomes particularly clear where Heljargjá passes through fields of lava, because there a thrust can easily be detected. Thus the vertical dislocation has not taken place in the lava fields as a whole but is limited to the long, straight, narrow zone between the fracture lines; the situation is only comprehensible viewed from the standpoint that there has been a subsidence, and that the rest of the terrain has retained its level unchanged. As will be shown in another connection, this peculiarity is of fundamental significance, as a very large number of the dislocations on Iceland have proceeded in a similar manner, and in this respect they are quite different to the forms of vertical dislocation that we know for instance in Central Europe.

Where the fracture has run across a field of block lava, the latter has broken along a straight line and left an almost vertical wall. In sheet lava the lava has been broken into large blocks, some of which lie obliquely with one edge at the level of the undisturbed surface, whereas the other rests upon the bottom of the subsidence. Fig. 20. We know of a similar state of affairs in the famous Almannagjá, at Þíngvellir, which every Iceland traveller has seen. At those places where the thrust has been greatest we find another complication. The vertical movement has apparently been greatest in the middle of the pit, so that we have a kind of terrace-fissure; the subsiding area has split into blocks, of which the middlemost has sunk deepest while the side blocks lie higher up, while at the same time they have been flung in towards the median line of the fissure.

Apart from the two "maars", which are both older than the dislocation, there is no trace of volcanic activity along Heljargjá, and, from what can be judged, the cutting through of these is not due to any cause connected with their volcanic character. On the whole, nothing has been observed to indicate direct connection between the volcanic processes in the region and the forming of Heljargjá.

The edges of the fracture are quite sharp and only very slightly denuded. All the eruptions in Hágönguhraun with the exception of the very youngest series have come to an end before Heljargjá was made, and therefore the process must be of very recent date.

The fracture zone at Túngnárfjöll and the Túngná. Along that part of the Túngná that stretches from Túngnárbotnar to the bend at Kirkjufell the landscape has been disturbed by fractures in recent times. The dislocations are, in fact, so considerable that they set their mark upon the terrain.

The main topographical lines are all straight, running practically parallel from southwest to northeast. One of them, the east Túngná line, may be followed along the southeast bank of the Túngná from Túngnárbotnar to Kirkjufell, i.e. along a stretch of no less than 45 km.; along the west bank of the Túngná, from the north point of Vörðufell to the south point of Snjóalda, there is a parallel topographical border line, the west Túngná line, of 35 km., and a little further to the west is a third main line, the Litlisjór line, likewise 35 km. long in the same direction as the other two. The distance between the lines is constant, two to three kilometres.

These three main lines divide the landscape into strips of different heights, but within the same strip the height is almost constant. Between the east and west Túngná lines is the long, narrow, straight valley in which the Túngná runs, and between the west Túngná line and the Litlisjór line is a mountain ridge, with separate names for its various parts; the northern part as far as a narrow pass at the north end of Litlisjór is called Vörðufell, the middle section is called Túngnárfjöll, and the south part Snjóalda. Northwest of the Litlisjór line comes a basin in which Litlisjór and Fiskivötn lie.

The mountain range Vörðufell-Snjóalda forms a continuous wall, 35 km. long, two to three km. wide and 3—400 m. high, measured in relation to the Túngná. At only one place it is broken by a pass, viz. at the south end of the Vörðufell section; but at one or two other places, opposite Litlisjór and opposite Skálavatn, there are depressions where the ridge can be crossed on horseback.

Seen from a distance this range appears to be a narrow ridge (fig. 11); on ascending it one sees that really it is a long, narrow plateau bordered by two parallel cliff walls. The plateau is not quite continuous; in the north part it has been broken to pieces by fractures, the surface in places being crushed into fragments thrust one against the other. This thrusting has mostly been vertical, but along the walls of the ridge, the west Túngná line and the Litlisjór line, there is often an outward tilting towards the lower planes, northwest and southeast of the ridge. Fig. 23 illustrates this. The picture was taken towards the northeast and shows the cliff facing Lake Litlisjór. In the background is the broken surface of the plateau, appearing as a continuous whole, with step-like blocks on both sides. Fig. 23 shows one of these blocks. On the left of the picture is Litlisjór, to the right of the centre another water that is part of the Túngná. On its top the block bears a remnant of the plateau surface, which has leaned over towards the northwest in towards the Litlisjór basin, so that the surface lies obliquely. This phenomenon is most typical of both cliff walls and can be followed all the way along the 35 km. ridge.

The Túngná valley has been described in the chapter on hydrographic conditions, where it will be seen that between the west and east Túngná lines this valley is about 35 km. long, two to three km. wide and on both sides bordered by continuous, straight cliffs with a height of 3—400 m.

There can be no doubt that the Túngná valley and the range Vörðufell-Snjóalda as well as the basin of Lake Litlisjór are tectonic formations, and that the three main topographical lines indicate the situation of the principal fracture lines. The Túngná valley is thus to be regarded as a tectonic fissure of the same type as Heljargjá, but a little wider; the Vörðufell-Snjóalda range as a region of tectonic resistance, a horst, and the basin in which Litlisjór lies an area of tectonic subsidence.

Unfortunately I know the land southeast of the Túngná only from a distance, but there too is a number of long, narrow ridges separated by fissures and subsidence areas; one of these fissures is occupied by Langisjór. Here, too, the direction of the fracture lines is southwest—northeast.

West of Vörðufell is another mountain running southwest—northeast. It is 12 km. long, about two km. wide and about 150 m. high. The walls are steep, and almost straight; at the top is a plateau surface, broken in places into vertically thrust blocks. In every respect the form of terrain resembles Túngnárfjöll, and there can be no doubt that this, too, is a tectonic phenomenon, or, to be more correct, a region of tectonic resistance.

The landscape between Túngnárfjöll and Þórisvatn. In this landscape, too, southwest—northeast lines are so prevalent that the terrain consists of a number of narrow strips of land at different heights and with parallel borders. The various units in this system are not nearly so large as in the landscape just to the west of it and referred to above, and the height-difference between the various blocks is less too. The border lines between the blocks can rarely be followed more than about ten kilometres, and as a rule the width of the blocks does not exceed 3 km. In most cases the difference in height between two neighbouring strips is less than 50 m., although here and there it is up to 2—300 m. The largest and highest of the ridges bears the widely-visible peak Þóristindur. Travelling the country from southwest to northeast one can pass unhindered through long, flat-bottomed valleys with parallel sides, or along the planes of the intermediate strips of plateau; but were one to proceed in a direction at rightangles to the terrain lines the level would be found to change time after time, and one would be compelled to pass over a long series of ridges and valleys.

This region may likewise be regarded as a fracture area, but it is more complicated than those just described. The fracture lines are not so long, nor have they been formed at the same time. Some of the edges are fairly well concealed by denudation and aeolic deposits, as is particularly the case in the region round Þórisvatn, whereas others are quite recent. Very often the valley floors are covered with temporary lakes, others are permanently so covered, as for instance the large eastern corner of Þórisvatn. Time did not permit of a detailed tectonic mapping of the whole of this fracture area; but by the aid of sketches I have drawn the more important lines. The number of fracture lines is, however, much greater than the map indicates, and I suppose the number of well-individualized fracture lines between Fiskivötn and Þórisvatn is at any rate not under 50.

Southwest of Heljargjá is an area that is interspersed with a large number of quite short, parallel fractures in the usual direction. Fig. 22. One of the thrusts is 10—15 m. high and can be followed for a stretch of some kilometres. The others are quite short and low, but nevertheless very distinct. Very often the distance between the various thrusts is only about fifty metres, the result being that the whole terrain is divided up into blocks and strips, a repetition in miniature of the other two fracture areas at Túngnárfjöll and Þóristindur just referred to. The thrusts have taken place in very recent times and possibly were formed simultaneously with Heljargjá.

In a tectonic sense the whole landscape, from the east side of the upper course of the Túngná to the west bank of Þórisvatn, is thus very richly developed. The number of fracture lines is exceedingly great, so great that the whole area must be called a "champs de fractures" (fig. 22). The course of the fracture lines is conspicuously regular, their direction being for the most part southwest—northeast.

6. Subaerial denudation.

On the whole the landscape west of Vatnajökull lies between 400 and 800 m. above the sea, and consequently the mean temperature for the year and the summer temperature are so low that the chemical disintegration of both inorganic and organic substances proceeds slowly and incompletely. The landscape may be called a desert in a biological sense, the annual quantities of organic matter produced being very small; but where an oasis has been formed for some reason or other, one meets with organically mixed deposits with a thickness that is considerable in proportion to the density of the vegetation. Under the continuous covering of plants at Fiskivötn there is a 10—30 cm. layer of loose, crumbly, dark earth mostly consisting of incompletely rotted vegetation whose organic structure can frequently still be recognized. This layer is to be found on both a lava bottom and a gravel bottom, and sometimes it is carried by solifluction down to the lower levels and forms accumulations of great depth; as a rule, however, on account of the great porosity of the substratum it lies fairly firm and appears as a smooth, evenly distributed carpet. Where this deposit is found on a lava bottom it appears that the surface of the lava is quite unaffected below it, with all the small unevennesses characteristic of lava surfaces that have cooled in the open air. The inorganic part of the covering has thus not been formed by mechanical or chemical disintegration of the surface there, but has been carried, assuredly by aeolic means. This soil type seems to be characteristic of the central Icelandic areas of vegetation, lying on a highly porous substratum and especially well-developed in the oasis-area at Fiskivötn.

Another, and much more varied soil type occurs in some overgrown stretches that form a rather widespread facies in the landscape west of Kaldakvísl; we found its most well-developed specimen in the oasis of Illugaver. In the depression, about 10 sq.km., north and west of Sauðafell the groundwater in summer is just above the surface, and on both sides of the mountain small, slow streams have formed with irregular and shifting beds; their bottom is a morass of saturated sand and mud; although these watercourses are quite shallow they sometimes conceal unpleasant surprises to the traveller, for the elastic layer of mud on the bottom gives way time after time. Whereas the surrounding, higher moraine surfaces are so to say naked, and those running down to the depression are at any rate very sparsely covered with vegetation, the bottom of the depression is almost completely covered. The central part of it is very wet and has the character of a marsh, whereas the peripheral parts are drier and firmer and gradually become mountain heath. The wettest parts have almost a plane surface, on which in summer there are large pools of stagnant water and fairly luxuriant vegetation, so that they represent the type that in Icelandic is called *flói* (MØLHOLM HANSEN 1930, p. 34). Round about the "flói" region is a belt of "*mýri*" vegetation, with a surface-form that has only very few unevennesses. On the transition between this and the surrounding mountain heath, which there takes the form of a very hummocky *jaðar*-ground, we find the surface and vegetation form that is so typical of certain highland regions, in Icelandic called *flá* (NIELSEN 1928, p. 21). In habit it is very like a partly dug peat-bog in a temperate climate with its alternation of peat-pits and balks, i.e. narrow parts of the bog that have not yet been dug and therefore are higher. It is doubtful whether as regards the vegetation the "flá" is to be considered as a unity, as its principal peculiarity lies just in an alternation between swamp-formation of the "flói-mýri" type and large hummocks whose sides bear a chamæphyte vegetation; in addition there is still another type of vegetation, found on the top of these hummocks and, at any rate in certain parts of the highlands, characterized by *Cetraria islandica*. There is also a striking morphological difference between the hummocks and the intermediate flat stretches of swamp. The hummocks, or knolls, (Icel. rústir, i.e. ruins — an analogy from the ruins of turf-built, deserted farms frequently met with in certain parts of the highlands) are usually about a metre high with a diameter of from 2 to 10 metres. They consist on the outside of a layer, 20—50 cm. thick, of incompletely disintegrated plant remains and fine-grained inorganic material, probably brought by the winds; under this is usually a core of coherent ice, usually containing such small quantities of earth that it is not to be presumed that it was formed by the simple freezing of the marsh earth. On the other hand the flat belts of marsh between the knolls is not frozen in summer, and it is easy to stick a pole two or three metres down into the muddy bottom without encountering the least trace of ice or frozen ground.

The knolls in the "flá", the "rústir", are accordingly different from the usual arctic hummock in that they enclose a lump of ice that lasts long, and the obvious conclusion to draw is that they appear by means of a kind of ground-ice formation caused by the freezing of the ground water that rises in winter. Thus the "rústir" phenomenon would be analogous to the Siberian blocks of ground ice that are formed when the ground water in winter is enclosed by the frozen surface, but occasionally breaks out either right up to the surface like a spring or, if not so far, lifting the closed, frozen crust like a dome. In both cases the rising ground water freezes and forms a superficial covering of ice and a lenticular, underground lump of ice. The indications of the formation of the Siberian ground ice are scarcely to be doubted, as the process has been observed repeatedly; but we had no similar intimate knowledge of the Icelandic "flá" formation and a thorough investigation was most desirable. For the present we must thus assume that a certain combination of ground conditions, moisture and winter climate, brings about the formation of lenticular lumps of pure ground ice which, while being formed, raise the overlying frozen earth and make it appear as a knoll, on whose sides the oecological conditions in the subsequent periods of growth become different from those on the flats lying between the knolls. While the flats retain their "flói-mýri" character, chamæphyte families will appear on the sides of the knolls.

We thus see that the knolls in the "flá" can scarcely be regarded as being analogous to those in other Icelandic ground-forms; indeed, on the whole the effects of frost in the Icelandic landscape are very varied and produce many surface types, some of which have been dealt with in a work by HAWKES (1924).

In the outskirts of the oasis Illugaver there is an arctic mountain heath on a hummocky ground, but in the outermost border zone of the overgrown area the covering of vegetation is weaker, and there are no hummocks. There the bottom consists mostly of inorganic material that is slowly carried down by solifluction. Here and there the border zone is broken by large fields of springs lying in elongated hollows — without doubt an example of the special type of erosion that occurs through the excavating activities of spring water flowing over a flat surface. At such places ground and vegetation are naturally very peculiar and in Icelandic are called "*dý*" (MØLHOLM HANSEN 1930).

The chemical disintegration of the rock proceeds very slowly, as already stated. On the other hand the physical disintegration is very extensive and plays a great part in the forming of the landscape. In the snowless period the naked surface, devoid of vegetation, is exposed to very considerable fluctuations of temperature, and, as most of the rocks are brittle and very frangible, their destruction proceeds at a fast rate and is observable in many ways. On many mountain sides stonefall is a common phenomenon, and it is no rare occurrence for blocks of up to several hundred cubic metres to break loose and fall into the valley. The result of the mechanical disintegration becomes very conspicuous, as large parts of the highland have no surface drainage, the consequence being that the loose material is not carried away but remains in the immediate vicinity of where it is formed.

The consequence is that the "original" tectonic and volcanic relief of the landscape is to some extent veiled, the steep slopes are smoothed out, the heights are broken down and converted into rounded ridges, where only here and there it is possible to recognize the permanent substratum, whereas the remainder is concealed under a thick layer of the loose material freed by the mechanical disintegration. An example of the weathering of the substratum will be seen on fig. 24, which represents the peculiar column that is called Tröllið. It stands at the exit of a pass leading from the region round Fiskivötn over Túngnárfjöll down to the Túngná. In the background is the extensive river bed, several kilometres wide here and full of deep and quite impassable patches of quicksand. Some idea of the column will be gained by a comparison with the ice-pick standing in front to the right; its helve is about one metre long. The column is thus about 10 m. high and about two metres thick. Its origin may without doubt be placed in connection with tectonic processes of recent date, and I presume it may be taken to be an analogy to the columns observable in other parts of the same mountain range, see p. 57, 239, fig. 23. At the moment it is undergoing violent attacks of weathering, as the picture shows. The large blocks lying at its foot have fallen out of the cavities that can be seen in the upper part of the column.

Another example of the brisk rate of the mechanical disintegration is shown on fig. 26, where there is a moraine boulder that has been split by the frost into a large number of large and small slabs, some of which are in situ, while others have been carried by solifluction down along an otherwise gentle slope. In the landscape west of the Kaldakvísl, Holtamannaafrjettur, one frequently meets with this phenomenon in various stages of maturity. There are all stages from moraine surfaces with intact, scattered boulders, to surfaces where the boulders have been turned into stone slabs which, by means of solifluction, have been distributed over a larger or smaller area, usually oval in form. Large parts of this landscape are in fact characterised by oval patches of frost-split slabs, separated by belts of ordinary wind blown moraine. Each of these patches originates from one or more erratic boulders, nearly all of doleritic lava. The figured specimen shows the phenomenon at a stage where the process is well advanced, but no more than that the situation of the boulder and its approximate contour can still be recognized.

Subaerial denudation plays a very great part in the shaping of the details of the relief in the Icelandic highlands, but in the long run it also succeeds under certain circumstances in marking the landscape as a whole. Fig. 32. An examination has shown that the figured landscape in Þóristungur has been exposed to the activities of very violent tectonic processes, but the consequent disturbances in the relief have been practically erased by the disintegrating forces, the result being a form of landscape characterized by soft, rounded forms produced by very rapid weathering and piling up of the freed material in the intermediate hollows. As regards subaerial denudation, a landscape like this must be said to represent a mature stage, although, as will later on be shown, it is no subaerial-denudation landscape proper, as both the effects of the wind and a peculiar, temporary water erosion have helped to give the landscape its present form.

Only in regions where tectonic and volcanic disturbances have taken place in very recent times does the relief have an undisturbedly young appearance; the unevennesses formed by tectonic and volcanic forces gradually disappear under a covering of their own products of disintegration, and in this manner the arctic desert produces an analogy to the phenomenon that we know so well, especially in sub-tropical desert regions and named by de Martonne "ennoyage desertique".

7. The æolic processes.

The climate of Iceland is on the whole very windy, and the number of storm days is large, especially in the west and south parts of the land (Thoroddsen 1914, p. 278; Þorkelsson 1924). The frequence and violence of the gales, in combination with the slight biological valence of the landscape, have the result that the effects of storms in the Icelandic highlands become a morphological and oecological factor of the very greatest significance, to which many of the writers who have occupied themselves with the study of Iceland's geography and geology have referred. Thoroddsen, both in his diaries and in his comprehensive works of handbook character, mentions a great many times the violent and destructive effect of the wind in certain parts of the inhabited country and also the grand wind-erosion phenomena that characterize large parts of the desert regions of the interior. The works of v. Knebel, Reck, Spethmann and Sapper also contain valuable contributions to our knowledge of the activities of the aeolic forces, and finally, the Swedish investigator Carl Samuelsson has dealt with these problems in two works which not only contain numerous individual observations, but in addition a reference to the interesting fact that the Icelandic region of wind erosion is the analogy of the North Atlantic to the sub-arctic, wind-erosion regions of the southern hemisphere.

The spreading and intensity of the landscape effects of the gales are limited to a certain extent by the fact that the higher parts of the country are covered with snow for a good part of the year, and of course one of the conditions of rapid wind erosion is that the ground is not snow-covered. But even if this condition is present, it is by no means certain that a storm will have any visible morphological effect. In artic and sub-arctic regions the erosive force of the wind is not only governed by its strength, but just as much by its drying power, for moist winds are only slightly erosive, whereas dry, steady winds are capable of carrying even very considerable masses of earth away.

In this connection it would be of the greatest interest to know the size of the rainfall, especially summer rainfall, in the various parts of the highlands of Iceland;

of this we know scarcely anything, however. According to the measurements made at the farm Mödruvellir we must take it that the rainfall in the northern highland is much less than at the coast, as there it only amounts to 34 cm. a year (Þorkelsson, p. 3). It is also quite beyond doubt that there is a very great difference between both rainfall and the number of rain days in the various parts of the interior. While we were in the regions west of Vatnajökull in July and August it was very striking that the Fiskivötn region had many more rainy days than the landscape to the north of it.

A common and very important type of dry wind occurs in a kind of Föhn. A north wind will usually bring rain over the stretch north of the NW—SE altitude axis of the country, and southerly winds to the south of it, whereas the descending winds on the other side of the axis are frequently dry. It must furthermore be assumed that local barometric disturbances of summer time over the ice-covered regions plays some part in this connection, a circumstance that is particularly noticeable at Vatnajökull, whereas the climatic importance of the smaller glaciers is much less marked.

The decisive factor, however, is scarcely the extent of the rainfall or its distribution, but the physical conditions of the surface of the ground, for, on account of the low temperature, the rainfall is quite sufficient to affect the climate in a humid sense. The surface, however, is in all essentials formed of highly porous rocks which allow of the rapid passage of even large quantities of water. The content of fine-grained constituents and especially of colloids is small, and therefore the ground is only little capable of holding the rain water back, so that the soil, despite fairly large quantities of rain, appears to be very dry. Only at places where the ground water appears in the immediate vicinity of the surface does it appear humid, but on the other hand this humidity is often so pronounced that the landscape assumes the character of a marsh. The transition between this type of ground and the highly porous, dry type is rather sharp, and the degree of dryness that changes gradually with the terrain, so characteristic of humid, temperate soil, is unknown in the Icelandic highlands. We have either the dry ground type or the marshy type. Only in rare cases transition forms play any greater part.

According to Richthofen and Walther the erosive activities of the wind are divided into two types: deflation and corrosion. By deflation is to be understood the removal of fine-grained material by the wind, whereas corrosion signifies the polishing effect of firm particles carried by the wind over large boulders and the naked ground. Both types play a great part in the landscape of Iceland, especially in the land west of Vatnajökull.

Deflation. When circumstances are favourable the gales become very violent, and the wind can then carry away particles of considerable size. Thus Harder (1911) states that a December storm in 1908 threw a stone like a bullet through a window in Sandfell Church, and it has often been observed that the gales roll small stones up slopes and throw them into the air from the ridge. There are, however, no exact measurements of the size of the grains carried by the wind. The deflation processes in the highlands are greatly favoured by the fact that there is no continuous covering of vegetation; as a consequence the wind has free play, its speed over the surface becomes relatively high, and, as there is transportable material almost everywhere, there is a violent sweeping across the surface. Sand storms in the highlands are sometimes most disagreeable experiences, the skin is abraded, tents, sleeping bags, food and instruments are filled with sand, and it is difficult to retain one's sense of direction. In addition there is trouble with the animals. Dogs are quite helpless, horses manage rather better owing to their greater height, but they nevertheless suffer a good deal, and keeping a caravan together in the teeth of a sand storm is a task that requires much energy and care. When conditions are difficult it is worth while tying the whole caravan in a long line, head to tail.

The transportation of the coarser material proceeds in the form of a sweeping across the ground, but the finer particles are carried in another manner, at any rate some of them. In good weather, looking out over the interior of the island from some high point, one often witnesses to the formation of large rotating columns of dust of a height of several hundred metres. Usually there are several together and they sail away at a considerable speed, but retaining their mutual positions and forcing upon the observer an impression of advancing groups of giant soldiers. These phenomena are only to be seen on relatively calm days and are especially fine at the commencement of a sandstorm. As they continue to develop the details become blurred, visibility is reduced, and the whole landscape is enveloped in a fog of dust. If one observes a sand storm from a suitable elevation, it will be seen that the mass of dust is sometimes sharply limited at the top, and in such cases it is possible to obtain a tolerably reliable measurement of its height. In this manner we succeeded in measuring the height of a dust storm south of Hofsjökull at 2—3000 m. over the plateau.

The surfaces of the Icelandic plateaux contain large quantities of material sufficiently fine-grained to be carried away by the wind. Even if the moraine material that covers large parts of the highland is fairly coarse, there is a considerable part of it with a grain that is less than the maximum size for transportable sand. Some of these glacio-fluvial deposits provide a very good working basis for deflation, as the grain varies from very coarse gravel to quite fine clay. The rapid mechanical disintegration of the rocks of the glacial-volcanic formation likewise produces large quantities of fine material (THORODDSEN: palagonite dust), and finally, in certain periods and regions enormous quantities of fine volcanic explosion material are present. There is thus an abundance of material for the deflation process, and this, in combination with the favourable climatic and terrain conditions, makes the region west of Vatnajökull a pronouncedly arctic wind-erosion region, perhaps the most pronounced in the northern hemisphere.

The result of the deflation is that the greater part of the fine material that is accessible to the wind is blown away. In this manner the moraine is converted into a stone-paved surface whose moraine character is still to be recognized owing to the varying size and petrographic composition of the stones. If there nevertheless is any doubt as to the origin of the covering of stones it is easy to ascertain by means of digging, as directly underlying it is the untransformed moraine. Glaciofluvial surfaces are transformed in a similar manner, the fine particles are blown away while the coarser ones remain, and, gradually as the process goes on, there will be a lowering of the surface. The further result in this case is that a clean-swept surface is formed, closely paved with stones; these, however, in contrast to the blown surface of the moraine, are almost uniform in size and usually not more than 5 cm. in diameter. As a rule it is also possible to recognize the pre-æolic relief, as for instance in the wind-blown moraine one can distinguish the undulating surface form that is so markedly in contrast to the glaciofluvial surfaces which, after being swept clean, are practically flat. The volcanic explosion products and weathering material undergo a similar sorting, whereby the fine-grained material is blown off, leaving the coarser particles behind.

In the lowland the effects of sand and dust storms are fainter as a rule, because the surface is more resistant, for one thing on account of the vegetable covering, and also because the strength of the wind in the lower aerial strata is less than in the highlands. In some especially disposed regions, such as the great sands of the south, the Hekla region and certain places in the north, there is, however, a very considerable and fateful sand drift, and over practically the whole country the æolic phenomena play a great part in the forming of the landscape. As has been stated, erosion is especially active in periods of descending winds of a Föhn character, and, as a consequence, the northwest—southeast axis of elevation divides Iceland into two regions which differ as regards æolic landscape-forming, viz. a northern part with south-wind erosion and a southern part with north-wind erosion.

Sand drift is usually a local phenomenon, but the fine dust spreads out over tremendous areas. With dry north winds of ordinary strength there arises a peculiar atmospheric condition in the south and far out over the Atlantic, (Icel.: mistur), characterized by a soft, yellowish-brown gleam as a consequence of the refraction of the innumerable particles of dust. Even with a cloudless sky the light is very diffused, so that the shadows are faint and pale even in full sunshine. When examining objects close at hand nothing unusual is noticed; but at only a few hundred metres away everything is seen as through a fine veil, and the remote distance is shut out entirely. This is when the dust from the plateaux is falling steadily and densely over the whole landscape.

Aeolic ablation is not equally great in all parts of the highlands, however. In certain places the activities of the wind are hampered by moisture or other factors; but in the region between Hofsjökull and Vatnajökull the gales have free play, and I know of no part of Iceland that is so storm-harried. Another significant peculiarity is that sand storms from this region have relatively easy and unhindered access to the lowlands through the large, flat-bottomed, barren valleys west of Hekla. In its mildest forms the drift in the lowlands looks like fig. 28 and 29. These two pictures show the same locality, but photographed in different directions. The person has not moved between the two exposures. Fig. 29 was taken from the south and shows how the surface is covered with an apparently continuous carpet of vegetation, in this case mosses (*Grimmia*), whereas fig. 28, which is taken towards the south, discloses that the carpet in reality is not continuous, but consists of a number of cushions, separated by wind-blown, stony flats. The various cushions display a most asymmetrical structure, with a steep, undermined north side and an evenly sloping plane towards the south. In this locality we thus have an example of the conditions that hold good for the whole of South Iceland, that it is the north winds that ravel out the covering of vegetation, whereas the corresponding processes in the north are due to southerly gales and produce similar results, except that here the erosion is from the south. It is a question whether such a ravelled-out cushion formation is to be regarded as a transitional stage between a continuous type of growth and an entirely clean-blown desert surface, or whether the cushion regenerates on the lee side at such a speed that the growth there keeps pace with the erosion on the other side. In a number of cases it must be assumed that the latter is the case, and that the intensity of growth adapts itself to a certain equiponderance governed by the interplay of the biological valence of the locality and that of the destructive forces — in this case especially the devastating activity of the gales.

In other places there is no such stability at all, and there is no question but that developments have been towards a reduction of the covered area. There is a typical example of a landscape of this kind in the Hekla region, where wind erosion in past centuries has assumed an extent not paralleled anywhere else in the country. A part of the region where this erosion is at present attacking the inhabited country is shown on fig. 30, a view from Skarðsfjall towards the southwest. The foreground is a wind-blown, stony surface which formerly has borne a metre-deep covering of quite fine, wind-deposited loose earth, as near as anything a loess. A remnant of this covering is to be seen on the right in the picture, the dark patch representing the surface before the commencement of the erosion. It has quite a luxuriant covering of grass. The wind attacks the under edge of the loose layer so that the vegetation layer is undermined and falls down. On the figure one can see the quite fresh profile made in this manner, displaying the still recognisable original stratification in the atmospherically deposited material. In the lowland, which forms the background of the picture, two different surface types can be recognized. On the right is a smooth, grass-grown, loess surface attacked from the left, i.e. from the northeast, by the wind, whereby the whole layer of loose earth with its plant covering is being peeled off. This exposes the underlayer, in this case a postglacial stream of lava, whose characteristic unevennesses mark the left side of the background. The loess-covered lava field here is of great industrial importance and forms the subsistence of a very large herd of sheep and cattle; in this locality the erosion is nothing short of a national catastrophe, as a number of farms have been laid waste and others are threatened. The principal agent of the erosion here is the sand that sweeps along the surface, undermining the loose earth; the method of putting a stop to the work of destruction is therefore this, that a number of stone dikes of blocks of lava are built at right angles to the prevailing winds in order to catch and hold the sand. On the picture are two of these dikes, one straight and the other curved.

Corrosion. The violent sweep of the sand along the surface of the land causes greater wear, both on the particles that are swept along and on the substratum, whether this consists of loose blocks or firm ground. This indirect wind erosion, corrosion, is very marked and several writers have referred to it. For instance, v. KNEBEL has observed the triangularly polished stones that are so familiar in other wind-erosion regions, as well as lava blocks with air pockets, whose orifices were of the form of enlarged funnels as a consequence of the corrosion (v. KNEBEL-RECK 1912, p. 133, fig. 15). HARDER (1911) relates a very drastic example of sand-grinding. He says that a flock of sheep one stormy night were driven out into a snow drift, where they froze fast. When they were found next morning most of them were dead, and the others had to be killed, as all that showed up above the snow was bloody flesh, wool and skin having been worn entirely away by the sand and stone drift.

Outcrops are frequently smoothed off by corrosion. There is one example of this kind in a postglacial lava surface on the dome volcano Solkatla, where the uppermost layer, with the characteristic cord structure of such deposits, has been partly removed by wind erosion (NIELSEN 1927, p. 107, fig. 2). It is naturally most marked on prominent edges and often gives rise to curious profile forms, in which with the application of a little imagination one can see human and animal heads and all kinds of fabulous beings. The very heterogeneous rocks are given a character of their own. The glacial volcanic formation so frequent in Central Iceland usually consists of a fairly soft basic mass of a rock that must almost be called a tuff, in which are strewn boulders of harder material. In the course of corrosion the tuff is violently attacked and is smoothed off, whereas the hard boulders are dressed and stand out as protuberances and points which offer convenient but rather unreliable holds when climbing. The landscapes that are least marked by corrosion are undoubtedly the post-glacial lava fields; there loose material to work with is lacking, and, if it should be brought along, it soon settles in the numerous cavities. Only if the surface of the lava is very smooth or the material brought very large is there any actual corrosion.

In the Icelandic wind-erosion regions we thus have a number of surface types that in all essentials correspond to the hamada phenomenon in the temperate, sub-tropical and tropical deserts. Apart from the differences produced by climatic divergences, the main difference seems to be that in the warm deserts the phenomena are frequently mature, whereas the Icelandic hamada-form is of very youthful character. This is seen, for instance, in the fact that the pre-æolic landscape phase is usually easy to recognise. One can differentiate between the moraine hamada and the glaciofluvial hamada and the weathering hamada, and below the stone paving one constantly finds rocks that have not been affected by æolic activity.

Where nothing of an unusual nature interferes, the sand freed by the wind settles in the vicinity of the eroded area. As a consequence of the climatic conditions described above, the transportation is nearly always in a direction away from the axis of elevation of the country, and thus one may expect to find sandy deserts outside the erosion regions, especially below them. But there is no parallel to the sand-dune areas of the sub-tropical desert (Sahara: erg, Asia: kum). THORODDSEN was already aware of this peculiarity, for he writes, for instance in his report from Fiskivötn: "Sand-dunes proper do not exist at all." This entirely conforms with my observations both in the regions west of Vatnajökull and in other parts of the Icelandic highlands. The absence of dune areas is without doubt due to a number of coinciding circumstances. In the first place the Icelandic landscape forms referred to are of fairly young type, and the processes have simply not been allowed to work sufficiently long to form a mature "erg" landscape. Next there is the factor that one of the predominating landscape facies in the Icelandic highlands, viz. the post-glacial lava field, is able to absorb and retain large quantities of æolic-brought sand without becoming "satiated", and this is probably the cause of the apparent disproportion between the thickness of the dust deposits in the lowlands and the corresponding sand deposits both in the highlands and on the outskirts of the wind-erosion areas of the lowlands.

In places, however, we find landscapes that must be said to be marked by wind-blown masses of sand; but even in such cases there is usually no dune formation proper. This is undoubtedly connected with the fact that the æolic activity is a temporary phenomenon, being restricted to a short period of the year, and that throughout the whole of the remainder of the year the surface of the ground is exposed to the workings of other forces which in fact level out the rudimentary dunes formed during the sand storms, a circumstance that is referred to elsewhere in this work, viz. in the hydrographic section and the chapter on the annual morphological cycle.

8. Hydrographical conditions.

We know nothing of the rainfall in this part of the Icelandic highlands, and in fact we know little of the climatic conditions on the whole. It is true that from the north we have continuous observations from two inland stations up in the hills, but a comparison between conditions north and south of the axis of elevation would be untenable, as the coast stations in the north and south return such great differences that we cannot assume that the climate of the Icelandic highlands is marked by any uniformity either.

The summer rainfall in 1927, however, was much greater at Fiskivötn than in the lowlands, which had dry weather for weeks at a time, whereas at Fiskivötn there was rain almost every day. It would seem, however, that the profensity for rainfall varies greatly in the different parts of the highlands; Sprengisandur, for instance, had much less rain than the region round Fiskivötn, and at Illugaver the rainfall was much less than at Tjaldvatn. In the latter part of August snow already begins to fall down to about 1000 m. above sea level, and throughout the whole of the winter half-year the landscape is covered with snow.

The total period when there is no snow is presumably about five months, and in that time a large part of the rainfall must thus be carried away. The output of the glacial rivers falls off very considerably in winter time, whereas the spring-fed rivers, as far as we know from other parts of the highlands, are open and productive throughout the greater part of the winter (Müller 1926, Nielsen 1928, p. 19).

The watercourses are fed with supplies that come from 1) summer rain, 2) melting snow, and 3) glaciofluvial waters. All these factors are very variable; snow melting is a spring occurrence, but it commences at different times in the various parts of the highlands; glacier melting is a high-summer phenomenon and represents a dominating regional factor in the hydrography of the landscape. The fact is that neither summer rain nor snow melting is sufficient to form the basis for the forming of a hydrographic net. In this region this is done by the glaciofluvial waters alone.

This is surprising, in so far as the volume of water produced by both summer rain and snow melting is very considerable, and this, in conjunction with the low temperatures, whose effect is that evaporation is small, ought to favour the development of a well-formed hydrographic net similar to what we normally find in regions with a pronouncedly humid climate. But, as already stated, there is none.

The cause of this peculiarity is the physical nature of the surface of the ground. As was stated in the previous chapter, the following surface forms predominate: lava fields, lapilli surfaces and glacio-volcano formation. In the region between the Kaldakvísl and the Túngná they prevail so to say to the exclusion of all others, but west of the Kaldakvísl we find moraines of relatively young age, and quite young moraines at the margin of the Vatnajökull.

The lava fields occupy about half of the surface and are all very porous. Even in periods of most violent rain there is not a drop of surface water to be seen; probably the snow melt-water also disappears immediately; at any rate in this part of Iceland I have seen no sign of ponds or streams having been formed in the lava fields. Furthermore, arctic lavas are very durable. They are snow-covered for considerable periods of the year so that there is not much subaerial denudation, water erosion nil, while vegetation is lacking. We thus see that a long time elapses before erosion can get to work at all and transform or carry away parts of the lava. All things being equal, the lava fields in these regions will retain their porosity for a long time and thus prevent the forming of a drainage system on the surface.

In the lapilli surfaces we have something of the same kind, but not so stable. They occur especially in the region round Fiskivötn and cover about 140 sq. km. These, too, are highly porous and avidly absorb rainwater and melt-water. The material, however, is not coherent, and as a rule the landscape has not the horizontality that is so typical of the lava fields, but may, all according to the nature of the substratum, be more or less markedly profiled. This favours a removal of material. In summer the lapilli fields are quite dry and usually have no superficially running water. But during the melting of the snows such considerable quantities of water are freed that a number of small brooks are formed, of a purely local character and only leading water down from the ridges towards the nearest valley. The result is that the loose lapilli material gradually disappears from the heights and accumulates in the valleys in the form of stratified deposits of great thickness. Regarding the forming of lakes in these valleys see p. 84, 266 and, as regards æolic forces, p. 63, 245.

The glacio-volcanic formation, too, in these regions is usually very porous, although not so much as the surface forms just referred to. This is probably connected with the fact that there is little chemical disintegration, and that mechanical disintegration is the prevailing form of demolition. In some cases small watercourses are formed on surfaces of this kind, but as in these regions such surfaces only occur in the form of elevated areas, jutting up over the enormous lava or lapilli plains, such small brooks reach no further than to the foot of the height, where they immediately disappear in the highly porous surface.

The least porous of the surface forms in this part of Iceland is the moraine. The fresh moraine contains a considerable quantity of fine-grained material and therefore can very well retain water; otherwise conditions in the very young moraine areas are as a rule so peculiar, hydrographically, that quite other factors predominate. The rather older moraines, such as those in Holtamannaafrjettur, are to a considerable extent subjected to the activities of the æolic forces and are thus transformed into stony plains; in the depressions, however, the water collects in lakes and marshes, from which rise brooks that in certain cases have succeeded in accumulating into a drainage system.

On account of the peculiar conditions referred to here, practically the whole of the landscape between the Túngná and the Kaldakvísl lacks superficial drainage, and thus, despite the markedly humid climate, there are surface forms that are pronouncedly arid both as regards their present condition and morphological development. All surface water percolates away or evaporates, so that there must be a very large transportation of water in the form of ground-water. This is directly observable at the great spring systems, of which the south part of the area in question has a great number, and it also appears for instance from the fact that the Vatnakvísl five kilometres from its source is so big that it can only be crossed at certain fords. It is also to be seen with great distinctness from the way Þórisvatn is fed and drained, p. 80, 262. The few spring-fed rivers that do exist are, although of some volume, quite short and play scarcely any part morphologically. The only rivers that are of any topographical and morphological importance are the two large rivers that drain the northwest part of Vatnajökull: the Túngná and the Kaldakvísl.

a. The Rivers.

The main watershed of Iceland runs in the direction northwest—southeast and divides the country into two main hydrographical provinces, a northern part that is drained into the Arctic Ocean and a southern part drained into the Atlantic. A small province is drained into Denmark Strait, and another into the ocean washing the east coast of the island.

The area that concerns us here is the northeast part of the drainage of the Þjórsá, and thus lies on the boundary of the great southern, main hydrographical province. The main watercourses in this area are the Kaldakvísl and the Túngná, which unite and immediately fall into the Þjórsá at Búðarháls. The drainage area is about 4000 sq.km., but in addition there are the parts of the Vatnajökull whose disburdening of ice takes place down towards the area in question, and of the size of this region we know nothing, no more than of the volume of the masses of melting ice. Both main watercourses have a length of about 100 km., and together they carry so much water that when they join the Þjórsá the latter's volume is almost doubled and thus becomes one of Iceland's largest rivers, if not the largest. Both the Kaldakvísl and Túngná are glacier rivers with the muddy, greyish-white water characteristic of such watercourses, but on their way they both receive large supplies of clear spring water (Icel. bergvatn).

The Kaldakvísl. The northwest part of Vatnajökull is formed of an enormous dome about 2000 m. high, from which large masses of ice glide down towards the north, west and southwest. In summer time the lower parts, up to 14—1600 m. above the sea, are subjected to very violent melting, and a great part of the water thereby freed collects in Vonarskarð into a fair-sized glacial river which must be regarded as the main source of the Kaldakvísl; but it is just as difficult to point to any definite source for this river as for so many other Icelandic watercourses.

In a hydrographical region where the watercourses are fed by the groundwater it is mostly possible to determine the exact position of the source of a fluvial system, and the same can be done with the ice-born rivers in an ice-sheet region of Alpine character, as the subglacial terrain, in conjunction with the abundance of cracks and fissures in the ice, favour the formation of large collective subglacial drainage systems which come to view through glacier ports; as a rule it is said that the river has its source at this spot. At most of the Icelandic glaciers, however, the draining assumes another form. It is true that at ice-margins in the Icelandic highlands there are numerous glacier ports, but their importance as drainage channels is relatively small. For there the freeing of the meltwater mostly proceeds diffusely along the whole of the margin, and as a consequence it collects into an enormous number of small streams which only gradually turn into large watercourses. In such cases we may therefore only say that a watercourse rises in this or that district, but we cannot point to any definite spot. But where the terrain favours it, as at some of the ice-margins in the south there are also examples of the Alpine drainage type.

On its way through Vonarskarð the Kaldakvísl receives a number of tributaries from the Vatnajökull and a corresponding series from the western part of Túngnafellsjökull, and on leaving that pass the watercourse is already of considerable size. There it runs out on to a plateau lying about 800 m. above the sea, called Köldukvíslarbotnar, which is the name of the landscape between the foreland of Vatnajökull and the Háganga mountains. Here the substratum consists of lava, as the enormous mass eruptions to the south have pressed the lava streams northwards right up to the foot of Túngnafellsjökull. It is possible that there have also been eruptions in this area, but we do not know the landscape with such certainty that this can be decided. Thus, as far as is known the substratum in Köldukvíslarbotnar is the extreme northerly offshoot of Hágönguhraun. The eruptions of lava have affected the course of the Kaldakvísl, it having been forced towards the north and west by the advancing masses and in quite recent times been compelled to form a new bed in the edge of the lava field.

In this region the Kaldakvísl receives several large tributaries, all glacial rivers, one of which comes from Túngnafellsjökull. It drains the southern part of the glacier and makes its way through a number of deep gullies down on to Köldukvíslarbotnar where, over a large, flat gravel cone it joins the Kaldakvísl. The draining of the margin of the Vatnajökull proceeds over the lava field, where in the course of time the various rivers have changed their beds again and again. The result has been that the lava is covered with a continuous layer of gravel and sand and the landscape transformed into a fluvioglacial plain, where the underlying lava can only be recognized here and there. In 1927 there were three main watercourses, one from the ice margin just at Vonarskarð and two from that part of the margin that lies behind the great forelands north of Kerlingar. Fig. 33.

The fall in Köldukvíslarbotnar down to Háganga syðri is slight, and, as the surface owing to its origin is almost flat, the watercourses frequently change their beds. This is to be seen on fig. 33, which was photographed from the top of Háganga syðri, i.e. about 800 m. above the plain. In the background there is a glimpse of Túngnafellsjökull and the river coming from it; from the background to the right comes the Kaldakvísl, and from the right edge several small streams which are branches of the three rivers referred to. It will be seen that the Kaldakvísl splits up into a confusion of small arms which join together again further down. Furthermore, the lighter zone to the left of the ramified part of the Kaldakvísl marks a bed that has only recently been left and where the river has formed a system of ramifications corresponding to the present one. Under these circumstances of course a very brisk deposition of sand and clay is proceeding over the whole plain.

At the foot of Háganga the Kaldakvísl receives its last afflux of glacier water, and immediately afterwards it pours down at rushing speed through a narrow ravine which the river has cut out of the foot of the mountain itself. There the lava embankment has been extremely strong, the lava streams have come like waves towards Háganga's slope (fig. 18), where they have been broken and turned to the north and to the west. Just at this point is where the Kaldakvísl breaks through, and the effects are magnificient. The river runs in against the side of the mountain and again out on to the lava field, then it forms two fine falls, after which it continues more smoothly in a deep ravine. Here we have the explanation of the formation of the whole of the great area of deposition in Köldukvíslarbotnar as described above.

The course from Háganga to where it meets the Túngná is much quieter and uniform, though there are certain disturbances too. On the stretch as far as Þórisós the river is in several places intruded upon by offshoots from the great lava fields on the east. At the places where the lava is visible in the valley the course is usually through a ravine and the fall is steep, with whirlpools and small waterfalls; but above such narrows the course is quiet and not uncommonly the bed is ramified. At these places the river is easy to ford. The relation of drainage to lava at Þórisvatn will be dealt with when describing this lake.

On its course from Háganga to the Túngná the Kaldakvísl receives considerable quantities of clear water (Icel. bergvatn), for instance, from Þórisvatn through its outlet Þórisós and from Holtamannaafrjettur. From this landscape run a number of streams, and also along the valley bottom of the Kaldakvísl there is an almost continuous spring horizon which is especially marked on the left bank. It is characteristic of this part of the Kaldakvísl that the flow of water to it varies greatly. In many places ravines and river valleys of insequent character are observable, practically dry in summer but, while the snow is melting, carrying considerable masses of water. They have in fact modelled the relief so much that, when travelling in the direction northeast—southwest, one cannot very well follow the river but must direct one's route at some distance from it, five to ten kilometres. On the stretch from Þórisós to the Túngná the valley is wide and open, with long, gently sloping sides. There the river receives a number of tributaries, of which the largest is the Klifshagakvísl which drains the southern part of Holtamannaafrjettur.

The Túngná. On his journey in 1889 THORODDSEN followed the Túngná from Vörðufell to Botnaver, and in describing that journey he says that the Túngná rises in a plain north of Botnaver, which he calls Túngnárbotnar, and there on his map he indicates the source of the river. When DE FONTENAY in 1925, after a laborious wandering over the wild lava fields of Hágönguhraun, came to Kerlingar, he observed a small glacial stream running southwards, rising in the region north of Kerlingar, which he called Ulfaldakvísl. From all appearances this must run into the Túngná, and on his map of Iceland of 1927 DANIEL BRUUN marked a small stream running from Kerlingar to the Túngná. This was confirmed during a journey undertaken in 1927 by DE FONTENAY and the writer of the present work, and the river coming from Kerlingar proved to be so large that it is justifiable to place the source of the Túngná to the plain in front of Kerlingar.

The Túngná drains the ice margin of the Vatnajökull from a point north of Kerlingar to Gamelsfjöll, i.e. a stretch of 15 to 20 km. Along this stretch the glacier slopes smoothly and almost uncreviced. The subglacial drainage is slight and the glacier ports small. On the other hand there is a parallel system of meltwater streams down over the ice, by which means enormous volumes of water are carried to the ice margin; from the margin itself, too, and the numerous dead blocks of ice in the foreland, much water is freed, and the moraines and glaciofluvial plains in front are consequently saturated and form, at any rate sometimes, an almost impassable, bottomless morass. From this rise numbers of muddy brooks which collect into bigger watercourses.

One of these systems of small streams is formed on the plain before Kerlingar, whence, in the form of a deep river, they pass to the south. Almost midway between Kerlingar and Túngnárbotnar the river passes through a deep, narrow cleft between two mountains belonging to the glacial volcanic formation. There the river's course has been violently disturbed by recent volcanic processes. From the north a thick stream of lava has run down and filled the gully, with the result that the river has had to erode a new bed for itself. This has been done in the manner typical of such processes (fig. V) (Bjerring-Petersen and Nielsen 1925, p. 228, fig. 2). The forming of the new bed has proceeded at the outer edge of the lava, but mostly outside it in rocks from the glacial volcanic formation. From there the river runs in a gully on the edge of the lava field down to the edge of the lava at Túngnárbotnar. At this stretch the river is quite narrow but deep, and very swift with many small waterfalls.

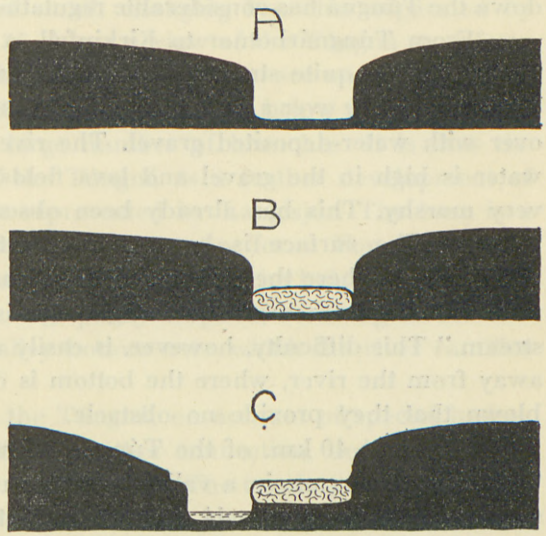

Fig. V. River valley filled up by a lava stream. The river has been forced to erode a new bed at the edge of the lava.

The whole of Túngnárbotnar may be characterized as a moraine morass with a number of ponds, and before it a fluvioglacial plain of clay and gravel, with only a few boulders and craters rising out of it. Numerous meltwater rivers ramify over this terrain. They differ greatly as to volume, strength of flow and bed; some are hard and stony at the bottom, others are full of quicksands and very difficult to cross. The principal water, the Túngná itself, is difficult to ride over at this point, and the fords change from day to day. Normally, however, it is possible to cross the river just a little way below the outlet of the lava-dammed gully at the spot where it begins to branch out, and a little more to the south towards the isolated mountain. Below this place the whole of the mass of water from the Vatnajökull gathers into a wide, quiet, muddy stream, with numbers of quicksands. Like all glacial rivers, the Túngná here is very variable. In cold periods it shrinks, but on warm days, and especially when rain is falling over the glacier, it swells violently and forms new beds in an astonishingly short time. Under such conditions large parts of Túngnárbotnar are under water and are practically impassable. The same oscillations are of course observable in the lower parts of the river, but the amplitudes are less, because further down the Túngná has considerable regulating basins in the form of lakes and swamps.

From Túngnárbotnar to Kirkjufell, a distance of about 50 km., the course of the Túngná is quite straight in a southerwesterly direction. For the first 10 km. the river runs freely over a wide plain, doubtless an old lava field which has been covered over with water-deposited gravel. The river branches a good deal, and the ground water is high in the gravel and lava fields to the west, which to a great extent are very marshy. This has already been observed by THORODDSEN, who writes (1889, p. 15): "The surface is here covered with angular, coarse lava gravel and drift-sand, and, as there the lava lies at the same level as the Túngná, it is saturated with water so that here we have to fight against an unusual obstacle — a swampy lava stream." This difficulty, however, is easily avoided by simply going two or three km. away from the river, where the bottom is dry and firm and the lava fields so sand-blown that they provide no obstacle.

The next 40 km. of the Túngná's course are morphologically very interesting. There the river runs in a valley which must be taken to be a tectonic fissure of the same type as the Heljargjá and others of this kind described elsewhere. The width of the valley is two to four km., the sides are steep, continuous mountain walls of a height of three to four hundred metres. On the side looking northwest the valley is bounded by the mountain chain Vörðufell, Túngnárfjöll and Snjóalda, which form a wall about 35 km. long, 2—3 km. wide and about 300 m. high. Its origin must be placed in connection with the activities of tectonic forces and has been dealt with elsewhere in the present work. In some parts this mountain wall has a pass, viz. between Vörðufell and Túngnárfjöll just opposite the north end of Litlisjór, and also opposite Skálavatn at the remarkable rock (fig. 24) that is called Drangur or Tröllið (i.e. the troll). Several parts of the southeast wall of the valley are broken by water-courses which make their way through gullies to the Túngná; this side of the valley, however, is also straight and steep, and, with the exceptions named, continuous for a stretch of almost 40 km.

Out on the bottom of the valley lie several isolated rocks, and here and there it is interrupted by transversal ridges of a height of about 100 m. Throughout its entire length the valley is dominated by the Túngná. From one side to the other it is covered with soft sands and clay deposited by the river at various times. The transversal ridges have played an important role in the course of developments in the terrain, for they have formerly been dams against the waters of the river and have thus given rise to the formation of at least two lakes. The basins of these lakes have presumably occupied an area about 20 km. in length but only two to three in width, so that there has been a lake formation in every way similar to the Langisjór discovered by THORODDSEN on the east of it. In the course of time the Túngná has succeeded in breaking through these ridges by means of a narrow gate, whereby the water level in the lake above has been lowered; it is still possible, however, to see remains of one of the lakes and there is still an unevenness in the fall of the river. The current in the gates is very swift, whereas the river above spreads over an area two to three km. wide, with thousands of small, changing branches separated by bottomless patches of sand and clay. Fig. 35 shows a view of the Túngná seen from the top of Túngnárfjöll from a height of about 300 m.; one can see one of the transversal ridges with the breach, where the river is very narrow; below it spreads over a considerable area and splits up into a large number of branches. It is thus the obvious thing to do to regard this part of the Túngná as a further development of a system of the same type as nowadays is represented by Langisjór. The base is a tectonically-formed fissure of characteristically long, narrow form. For a time this was filled with glacial water to a height that was governed by the height of the dam; after this had been eroded down the lake was partly emptied, resulting in the formation of a flat sand and mud-covered valley bottom over which the river ramifies in a large number of branches.

Throughout the whole of this stretch the Túngná, on account of special hydrographic conditions which will be dealt with in another connection, does not receive a single tributary from the right, but a few from the left. The two largest of these fall into the Túngná opposite Drangaskarð and at Kirkjufell just by the first bend.

Hitherto the Túngná has run southwest, but at Kirkjufell it runs right into the great mountain region whose highest part is represented by Torfajökull. This forces the river to make a bend of 90° to the right, and in that direction it runs for about one km.; then, however, it meets another obstacle in the form of a volcanic ridge which, from the neighbourhood of Frostastaðavatn, runs up towards Fiskivötn. This compels the river to bend again at right angles, and over a short stretch it now lies in a bed parallel to the course north of Kirkjufell, but running in the opposite direction. Another small complication arises by the fact that the river is nipped in between the outermost offshoots of Snjóalda and a large, elongated "maar", thus forming two right-angled bends; after that, however, the river runs northeast towards Fiskivötn. There it bends again 180° and runs south of the most southerly of the volcanoes in the Vatnakvíslagígir. This mountain's enormous gravel cone has been partly eroded by the Túngná; one side has been completely removed, so that the Túngná and the lake in the bottom of the crater are connected. Thereafter the Túngná describes a wide curve towards the north and west. It follows the edge of the masses of lava that came from the basaltic mass eruptions at Frostastaðavatn and from the northeast eruption centres of the Hekla region. Here the river's course is violently disturbed by lava, and the same applies to a long stretch of the Þjórsá after meeting the Túngná. West of the ford at Bjallar there are several high waterfalls, and the greater part of the river as far as the Þjórsá runs through ravine.

On the stretch from Kirkjufell the Túngná receives large tributaries. The largest is the Námskvísl, which drains a part of Torfajökull and the surrounding mountain region. It is a deep and swift glacial river with a large volume of water, and over some extensive gravel plains it joins the Túngná just at the second bend. From the northeast come two large tributaries, the Vatnakvísl, draining the Fiskivötn region, and the Blautakvísl — very short but conveying a lot of water and, as the name indicates, swampy and soft. These tributaries both bring clear water exclusively.

As has been indicated previously, the Túngná presents rather serious obstacles to the traveller. Throughout the whole of the 80 km. stretch from Botnaver to Þjórsa it is only passable at few places, viz. 1) at Drangaskarð, 2) above Námskvísl and 3) at Bjallarvað. The first two fords are very unreliable and variable; they are full of quicksands and therefore difficult to cross. On the other hand Bjallarvað is constant, as there the river lies permanently on a single bed, the bottom is hard and not too stony, but the ford is rather deep.

During a survey of the course of the Túngná we find a number of the features that are so characteristic of the hydrography of that part of the island where postglacial volcanism and tectonic activity have been the predominating morphological factors. In fact, the various sections of the Túngná each represent a type. At the highest part as far as the south edge of Túngnárbotnar there is a typical glaciofluvial collecting area, then comes the straight course to Kirkjufell, determined by tectonic factors, and finally the lower course from Námskvísl to where it joins the Þjórsá, a stretch that has been influenced by volcanic activity. A glance at the map will show that the difference is also conspicuous from a purely topographical point of view.

b. Lakes and Marshes.

In a terrain where volcanic and tectonic forces have been active right up to the present day, the presence of a large number of closed basins may be expected, and thus in the country between the Kaldakvísl and the Túngná one may expect to find good orographic conditions for the formation of lakes. As moreover we have no hydrographic net and consequently no normal erosion either, these basins will generally not be exposed to having the embanked barriers cut through, so that we may expect to find lakes of fairly stable character.

The principal lake basins in the region may be genetically divided according to the following plan:

Glacigenous lakes	Extra-marginal ice-margin lakes. Lakes in basins from dead ice. Moraine lakes.

Volcanogenous lakes	"Maar"-lakes, simple and complicated. Lakes in explosion pits. Lava-subsidence lakes. Lava-dammed lakes. "Maar"-dammed lakes.
Tectonic lakes.	

We can make another classification if we take regard to the water circulation. Some lakes have ever-running, superficial tributaries, but most of them have none and receive their supplies of water partly from ground water, partly from temporary local tributaries (snow-melting streams). Drainage areas are likewise variable, for some have constant, superficial streams, others temporary superficial streams, and again others (most of them) have no surface outlet. This again involves a difference as to water level. Those with constant outlets naturally have a constant water level, whereas the others are exposed to greater or smaller fluctuations of the level and consequently of their area. The extreme case is represented by the purely temporary lakes, which only exist a short period of every year — after the snow has melted. As the following will show, this type plays a great part in the landscape. This little survey makes no pretence at being complete, and is merely given for the purpose of providing some sort of systematic guide to the following description of a number of typical cases.

Þórisvatn has an area of about 80 sq. km. and thus is the second largest lake in Iceland, much larger than any other in the region now under review. Its basin is in two parts, a main basin of about 70 sq. km. and a branch of about 10 sq. km. The main basin has its longest dimension in the direction of NNE, where it measures 14 km., while the breadth is three to five km. The side basin has its longest dimension running NE, about 8 km., while the breadth is 1 to $1^1/_2$ km. Here and there are small indentations. There are no islands except a few very small ones near the shores.

The shores of the lake are mostly cliff walls rising steeply from the water edge, though part of the west shore is less steep, and on the northeast the basin opens with a gate 3 km. wide towards the great plateaux that are covered by Hágönguhraun. There is not much trace of erosion by the lake on the shores, and as a rule no beach has been formed; here and there are small spits across the coves, but the present water level seems to be a phenomenon of recent date. No earlier, higher shore lines were observed, but it is not precluded that such traces may be found; time did not permit of a thorough examination. Only at one place was there observed a spit of considerable size, near the eastern end of the small basin; from the southeast shore a spit of about 1 km. runs over towards the other shore, so that a small part of the bay is almost entirely shut in.

At most places the shore is so steep that it is difficult to get down to the water edge on horseback. This is connected with the fact that the lake has no superficial tributary; as far as we could see the heights round the lake have no permanent water-course; the only ones we saw were some small brooks rising from springs in the slopes and no wider than that one can jump over them. At some places we also observed unbroken spring horizons. The result is that there are no erosion gullies leading down from the surrounding high land to the lake, such as would normally be the case (fig. 40).

The outlet stream Þórisós is on the north, i.e. towards the normal fall of the land, and forms a fairly big river, about 5 km. long, ending at the Kaldakvísl. This implies that the lake must have fairly large but invisible supplies of water. Experience elsewhere may perhaps justify the assumption that the supply of water mostly comes through the great lava fields which, through the aforesaid northeast gate, stretch right up to the shore of the lake and must be taken to be the subterranean drainage channel for a large part of the water that falls over the extensive lava fields in Hágönguhraun; nor is it impossible that part of the melt-water from Vatnajökull has also made its way there.

In broad outlines the origin of the lake may be taken to be the result of the development sketched in the following. Both basins must have been tectonically formed. As is usually the case in Iceland there is no trace whatever of folding. It is not a volcanic basin, and it is true of at any rate part of the basin that it cannot have been formed by erosion. The small, narrow basin, for instance, cannot be other than a tectonic fissure. Long and narrow, with steep parallel walls, it recalls in every way the fissures of tectonic origin that are so frequently met with in this part of the country. The only kind of erosion that could produce a terrain of similar type is ice erosion, but this possibility must be rejected, as at the side towards the ice the basin is closed by a steep wall, and on the whole there is no trace of this small basin ever having been filled with ice. On the other hand it is possible that ice had some part in the forming of the large basin, but the fact that it is open towards the north and closed by a cliff on the south does not indicate that in this we have to do with a glacially-formed basin.

There is, however, another factor that has helped in the forming of the present appearance of the lake. As has been said, Hágönguhraun runs right down to the northeast shore of Þórisvatn. Lava has forced the outlet aside up against a ridge which forms the partition between the basin and the valley in which the Kaldakvísl flows. Thus we may take Þórisvatn to have been tectonically formed, but with the complication that in recent times there has also been a damming up by lava; erosive forces, on the other hand, have played only a slight part in the formation of the basin.

It is quite curious to see the almost complete analogy which, in a genetic sense, characterises Þíngvallavatn and Þórisvatn. The former is likewise a tectonic lake which at some time or other has been dammed by lava. The two lakes have very much in common in a landscape sense, except that the different height above the sea involves a number of biological differences, especially that the shores of Þíngvallavatn have vegetation whereas those of Þórisvatn are almost sterile.

Litlisjór is the second largest lake in this region, occupying an area of about 9 sq.km. On its longest axis, running northeast—southwest, it measures about 7 km., and its greatest breadth is about 3 km. It occupies a part of the bottom of the great tectonic subsidence area lying just to the west of Túngnárfjöll. Its shores are very different. On the southeast the lake washes the foot of Túngnárfjöll and the shore line is practically the same as the fracture line along which one of the principal movements in the system has taken place. Some large blocks have, however, loosened themselves from Túngnárfjöll and have been flung northwest out into the subsidence area, fig. 23, and in that way have formed a part of the small projections of the shore.

The greater part of the southeast shore is steep, some of it cliff and some steep talus. Only at a few places is there a little flat beach. At the north shore we find a very low and flat sandy beach running smoothly into the extensive sandy plains which, like a wide trough, continue right up to Vatnajökull. The west and southwest shores are mostly of volcanic explosion material, and on this long stretch the lake for the most part washes the outer side of volcanic gravel ridges, of which the most northerly originate from the volcanic region at Hraunvötn, i. e. Zone B of the Fiskivötn region, and the most southerly from Zone D.

We may take it that the basin of the lake was formed in the following manner. The primary cause was the occurrence of the large tectonic basin on the west side of the mountain chain of Snjóalda-Vörðufell. It is to be regarded as a formation analogous to the long tectonic fissure in which the Túngná runs. In the southern part of this subsidence occur a number of complicated volcanic phenomena which have previously been described under Fiskivötn — zones A—D. The explosion phenomena in Zones B and D have created a continuous rampart of tipped substratum and loose volcanic gravel, and this rampart forms the embankment of Litlisjór. Thus genetically it is characterisable as a tectonic lake which in addition is "maar"-dammed.

Litlisjór has neither superficial tributary nor superficial drainage. As a consequence the water level is subject to annual variations which seem to amount to one or two metres, for it is possible to trace numerous systems of higher water marks all round the lake. In the lake itself are several islets. The banks are extremely poor in vegetation and thus form a decided contrast to those of Fiskivötn described below. The cause may be found in the circumstance that the water level is variable and that the whole of the beach (and probably the greater part of the bottom) consists of sand and gravel and not of lava. It is inhabited by numerous families of loons and thus may be assumed to have a stock of fish.

Fossvötn is the name of two small lakes lying southwest of Litlisjór, separated from it by a barrier that has probably been formed by explosive eruptions. Stóra Fossvatn covers about 1 sq.km; its outline is irregularly winding, the sides are steep slopes. There are several peninsulas and a triangular island connected with the shores by two barriers of stone and sand. Over one of these runs a lively stream. Litla Fossvatn is a small, round crater lake in whose steep walls there are traces of secondary eruptions.

The water circulation is very large in proportion to the size of the area. From Stóra to Litla Fossvatn there is a short but deep and swift channel; at the outlet of Litla Fossvatn there is a fall, about 10 m. high (fig. 36) just on the edge of the lake. Fossvötn has no superficial tributary, and the surplus water must thus come to it through subterranean channels. It is possible to observe a little of this up in the lava field which THORODDSEN has called Fossvatnahraun, where in the numerous lava holes the water can be seen streaming slowly down towards Stóra Fossvatn. This water undoubtedly comes from Litlisjór, which thus seems to be drained through the aforementioned barrier of gravel. This explains why Litlisjór has no superficial drainage and why the water from the very small Fossvötn is of such an imposing volume. The shores of Fossvötn have a biological valence that for these regions in considerable; large parts are covered with continuous vegetation of great luxuriance; the lakes abound with life and are particularly well stocked with trout.

Fiskivötn or Veiðivötn. This name signifies a group of at least 50 lakes and ponds, whose situation I have described in another connection, p. 32, 214. The two largest bear the names Grænavatn and Snjóölduvatn and they both have an area of about 2 sq. km. Several cover about 1 sq. km., viz. Ónýtavatn, Skálavatn and the two variable lakes Breiðuvötn on the lower course of the Vatnakvísl. The remainder are smaller.

I have already accounted for a number of the morphological factors which have led to the formation of the lake district, p. 39, 221, but shall add a few details here. As I have stated, the formation of the lakes must be directly or indirectly placed in connection with volcanic activity, but the various lake basins genetically and habitually represent a number of different types.

Grænavatn and Ónýtavatn form a unit by themselves; they lie in a common basin having its greatest length southwest—northeast. This basin seems to form an analogy to the basin in which Litlisjór lies. On the southeast it is bounded by Túngnárfjöll and is cut off from the deeper part of the valley system on the west by the gravel mounds that have been produced by the explosive eruptions referred to on p. 42, 224. Tectonic and explosive eruptions have thus in community formed the basin. Grænavatn runs into Ónýtavatn and therefore has a constant water level. It is not a lava or crater lake with steep shores like most of the others in the area, but is surrounded by flat marshy land with a continuous and luxuriant *Cyperacée* vegetation which provides good grazing. The Ónýtavatn, however, has no superficial drainage and therefore its water level is very variable. It is surrounded by gravelly slopes displaying many water marks, but it has no vegetation and on the whole seems to be deficient in life.

Snjóölduvatn is, as THORODDSEN observed, a complicated crater lake. It is connected with the Túngná by a short channel. North of this lake is a landscape that is given the name of Pytlur. It contains a very large number of small lakes of volcanic origin. Simple and complicated crater lakes, some partly full of lava and thereby reduced to small, crescent-shaped basins, explosion craters with lakes in the bottom, lava-subsidence lakes, and so on, and as these phenomena everywhere overlap, there is a great abundance of forms. Drainage from this part of the group is exclusively subterranean.

A special group is represented by Skálavatn, Tjaldvatn and Langavatn. Their genesis has been referred to on p. 45, 227. They are fed by springs which can be seen in some places. In the north end of Tjaldvatn, for instance, there is a most productive spring area with numerous openings, and in the slopes east of Skálavatn there is another large spring area. Skálavatn is drained subterraneously through the lava to Tjaldvatn, and from there a brook runs down into Langavatn, whence drainage continues through Eskivatn and Kvíslarvatn to the Vatnakvísl. In the first three lakes, bottom and shores consist of lava, which, however, in certain places and in parts of Langavatn and Tjaldvatn is overlain by a thin deposit of gravel and sand. The presence of lava seems to have a very favourable effect upon conditions of life, which here seem to be especially good. The fauna in the lake is rich, the stock of trout large and well nourished, and on the shores, which are covered with a low but continuous vegetation (fig. 43), a number of birds breed.

Eskivatn and Kvíslarvatn are both "maar" lakes whose encircling walls of gravel are broken and eroded by both tributaries and drain-water. The water level has once been higher, and up the slopes one can still see systems of old shore lines on a level with the upper edges of the embankments.

The lower part of the Vatnakvísl, i. e. from Vatnaskarð downwards, is connected with two lakes called Breiðuvötn. They lie at almost the same level as the river and are surrounded by low, extensive stretches of marsh which have probably been formed by deposits from the Vatnakvísl. Their depth seems to be slight and their form and size variable, but the whole terrain is so marshy that movement in it is very difficult. In the edges of the marshes there are very good grazing places.

Other volcanic lakes. In the region of Hraunvötn there is a form of landscape that corresponds to the southern part of Fiskivötn. We find here again the same changes in the terrain, with numerous undrained small basins, many of which contain lakes, p. 48, 230. Thus there are very fine examples of complicated "maar" lakes with gravel shores and very fluctuating water levels; there are also lava-subsidence lakes with the very irregular outline and not very high, but steep shores that are peculiar to such formations. Here as elsewhere it is obvious that the lava lakes offer the best conditions of life. The shores are densely covered with vegetation and the water teems with small animals and fish. In most of the large "maars" in this region there are crater lakes, fig. 11, but their effect upon the landscape is small. In the eruption vents belonging to the mass-eruption types, however, I have not found a single crater lake.

The temporary valley lakes, on the other hand, are an important morphological feature in that part of the landscape which is not covered with lava. As there is no superficial drainage system, the valley structure is discontinuous, i. e. there are no evenly sloping passes from one valley to another, and every hollow forms a separate, closed basin. During the melting of the snow the valley bottoms are turned into lakes, whose water level is determined by the quantity of melt-water. During the course of the summer the water percolates away and evaporates, and thus the level gradually falls. This can be directly read from the shore lines or watermarks, whatever one may call them, surrounding valleys of this kind. In spring these lakes may have an area of several square kilometres, but in the late summer they have diminished greatly and many of them dry up entirely. The difference in the water level may be more than 5 m., and it will be understood that these lakes form an important part in the water circulation of the district. Their shores are always devoid of vegetation, a fact that must be placed in connection with the fluctuating level of the water. For when the water falls the surface comes under the influence of the destructive effects of the wind and any germs are immediately swept away. Shores of lakes having a variable water level are therefore practically sterile, as several examples in this account have shown, whereas shores with a constant water level are overgrown. The same applies as a rule to the edges of the lava lakes where the possibilities of shelter seem to be the condition that is vital.

Especially well developed temporary valley lakes are to be found in the regions round Þóristindur. The largest one observed, lying in the valley west of this peak, seems to have an area of about 10 sq. km. in spring. In the landscape east and northeast of Þóristindur too drainage proceeds in the manner described above.

At the bottom of the lakes proceeds a very lively accumulation of washed-down gravel, which forms finely stratified, horizontal beds of great thickness, at any rate up to 25 m. In addition, considerable quantities of loess, which is caught by the surface of the water and precipitated. This causes a raising of the bottom, while at the same time permeability decreases, and there are various circumstances that argue that such temporary lake basins may under certain conditions develop into a kind of marsh of a type that is for instance to be found in the landscape Þóristúngur, southwest of Þórisvatn. Fig. 45.

Moraine lakes. The recent moraine deposits on the west edge of Vatnajökull are not very large, but, where they do exist, they naturally have lakes. A frequently occurring type is formed when the ice margin on its retreat exposes a hollow between an older moraine and the new margin. There has been just such a retreat in recent times at that part of Vatnajökull that lies between the Túngná and the Kaldakvísl, and therefore we find many of these extra-marginal lakes. In Botnaver there are many traces of dead ice, both in the glaciofluvial plains and in the moraine. This brings about a quantity of small lake basins which, however, generally do not seem to last long as they are quickly filled with sand and clay and are transformed into mud holes.

In those areas where the terrain is characterized by glacial-deposit forms as in Holtamannaafrjettur we have moraine lakes that are not much different to the corresponding lakes in other parts of the Icelandic highlands.

9. Annual cycle of denudation.

The activities of the disintegrating forces in the Icelandic highlands are subject to a very characteristic, annually recurring variation. Winter is signified by a covering of snow — permanent as far as we know — lasting six to eight months, and in this period the morphological changes in the earth's surface must be quite minimal. In the time from May to July inclusive most of the snow melts and in the saturated earth there occurs a lively solifluction which has a very marked, flattening effect upon the relief. The output of melt-water, however, is so great that even highly porous surfaces are unable to absorb it all, and the surplus has to run off in the form of streams. In loose, sterile soil these streams are able to cut furrows a metre deep and they transport large quantities of the loose surface layer down on to the lower parts of the terrain. The meltwater streams, however, are not sufficiently voluminous to form a permanent hydrographic net. They usually end blindly in the depressions, where they give rise to the formation of large, shallow lakes whose water in the course of the summer is greatly diminished or disappears entirely through percolation or evaporation. Patches of snow that last throughout the summer may be met with down to 7—900 m. far below the snow line at places where the winter depth has been especially thick or where melting has been especially slow, as for instance on northern slopes. Year after year one finds summer patches at the same places, and this gives rise to a concentration of the erosive activity of snow-melting, which in the long run produces a very peculiar form of landscape which plays a great part in the Icelandic highlands.

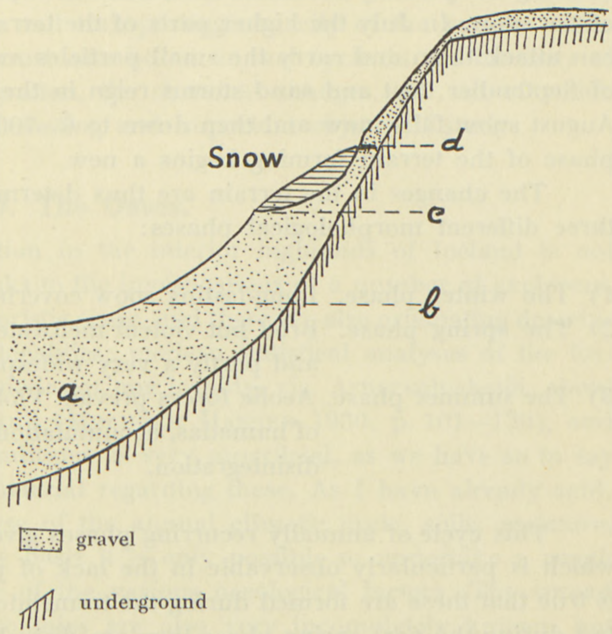

Fig. VI. Slope with an oversummering snow patch.

Fig. VI represents a vertical section through a slope with one of these summer snow patches. Above it the surface is smooth and dry. Below the snow itself a small hollow will form because the bottom is always wet and therefore inclined to shrink downwards. The material thus displaced forms a small mound at the lower edge of the snow patch. On the part of the slope lying below the snow the percolating meltwater will always keep the soil moist and, in periods when melting proceeds quickly, furrows will form in the surface. The total result of the process is that there is a considerable displacing of material under the snow and for some distance below it, thus producing a hollow at the side of the slope. Fig. 42.

After the meltwater has percolated or evaporated away and the surface has attained the necessary dryness, the æolic forces come into play, and, on account of the great porosity of the surface, this takes place shortly after the disappearance of the snow. In July the higher parts of the terrain are already so dry that the wind can attack them and carry the small particles away, and from that time till the end of September dust and sand storms reign in the highland wastes. But at the end of August snow falls, now and then down to 6—700 m. above sea level, and the winter phase of the terrain forming begins a new.

The changes in the terrain are thus determined by the alternating activities of three different morphological phases:

1) The winter phase. Long-lasting snow covering. Slight morphological change.
2) The spring phase. Brief but violent meltwater activity, partly local water erosion and partly a very widespread solifluction.
3) The summer phase. Aeolic forces prevail. Violent deflation and corrosion, forming of hamadas, accumulation of sand and dust, rapid mechanical disintegration.

This cycle of annually recurring phases gives the landscape a special character which is particularly observable in the lack of purely æolic forms of deposition. It is true that these are formed during the tremendous sand and dust flight in summer, but during the next spring phase they are disturbed and obliterated again. The lack of dune formations in the highlands is very typical. Instead we have sandy flats with slightly undulating surfaces. In the lowlands, however, where the climatic conditions in many respects are otherwise, there are numerous examples of dune formations of considerable expanse, whereas the wind-deposited material in the highlands is rebedded by the temporary water and snow erosion in combination with solifluction. These forces by their united efforts push the loose material — both that formed on the spot and that carried there — down into the hollows where it is accumulated in the form of thick, handsomely stratified series.

An important section of the annual morphological cycle is the forming of the aforementioned temporary lakes. For on their bottom it is not only the material brought by the meltwater streams that is deposited, but also a quantity of sand and dust that is caught by the surface of the water during the passage of the sandstorms throughout the summer and gradually deposited on the bottom in fine argillaceous layers which form the arctic analogy to the "Schwemmlöss" that we know in other parts. When during the course of the summer the lake disappears partly or entirely, the bottom appears as a clay flat which, after drying, is subjected to a lively deflation and supplies a voluminous contribution to the dustladen air of the late-summer storms.

Under these conditions the annual variation in the morphological processes is very marked, but it is a question whether one ought, to an extent greater than is now the case, to turn one's attention to the corresponding variations in other climes too. In a temperate, humid region such as Denmark for instance, there must be very important differences in the erosive and transporting capacity of the various water courses at various seasons. There must also be an annual cycle in the intensity of solifluction, the mechanical disintegration, the chemical changes, etc., all of which are questions that embrace most interesting and important objects of study.

10. The Oases.

Our knowledge of the vegetation in the interior highlands of Iceland is not very satisfactory. It is true that, thanks to the investigations of a number of explorers, the country is very well known in a floristic sense, and there are also orientating descriptions of the formations of various localities; modern statistical analyses of the formations, however, have only been made for one locality, viz. Arnarvatnsheiði, about 500 m. above s. l., west of Langjökull (Mølholm Hansen 1930, p. 101—120), and our knowledge of the œcological conditions is very superficial, as we have so to say no complete, reliable observation material regarding these. As I have already said, we know very little about the course of the annual climatic cycle, soils, moisture, snow fall, etc. and on this insecure basis it is only possible to undertake a rough examination of the relative valence of the various oecological factors. The spread and distribution of the vegetable colonies are also very incompletely known, but some of them: a mýri-growth with *Carex* and *Eriophorum* as the predominating families, play so great a part to the traveller, that we must assume we know all the more important occurrences in the Icelandic highlands.

The highlands west of Vatnajökull, as has been stated in the foregoing chapters, bear a plurality of surface types with very profound morphological and genetic differences. Among the recent rocks — which form the greater part of the surface — lava and lapilli fields predominate, whereas moraines and glaciofluvial material are more subordinate. There are also extensive areas where the very varying rocks of the glacial volcanic formation, also called the Palagonite formation, crop out, but we lack — at any rate as a surface layer — the older, striated, doleritic lava streams with a very thin coating of moraine that are so widespread in the other highlands. If all these surface types, despite great differences, nevertheless bear a certain common stamp, it is due i.a. to the fact that they have the common property of being sterile, as the land is practically bare of vegetation.

In the lower parts of the Icelandic highlands earlier lava fields in their hollow shelter an impoverished growth of lichens and mosses, with scattered vascular plants; but throughout the greater part of the lava fields between the Kaldakvísl and the Túngná conditions are so bad that there is practically no macroscopic life unless special conditions prevail, and conditions are at least just as severe on the lapilli surfaces and on the greater part of the moraine and the recent, glaciofluvial deposits.

Only in especially favoured parts are the conditions of such a nature that it has been possible for a continuous vegetable covering to develop, and there oases have formed, with a luxuriance that is only modest, it is true, but still forming a striking — and very pleasing — contrast to the enormous wastes surrounding them.

The area of the ice-free land between the Túngná and the Kaldakvísl is about 1600 sq. km., and of this only about 10 sq. km. is covered with a vegetable growth, distributed in the following oases:

Fiskivötn and Fossvötn....................	circa 5 sq.km.
Northern Pytlur	— 2 —
Botnaver..................................	— 1 —
Þóristúngur...............................	— $^1/_2$ —

In addition there is a small growth at Þórisós, whose size I do not know, and small overgrown patches at Blautakvísl and on the spit that blocks the innermost cove of Þórisvatn. Otherwise the land is practically naked.

According to the surroundings in which they occur these oases represent four types:

1) Oases in lava fields.
2) Oases on lake shores with constant water level.
3) Oases on recent, glaciofluvial plains.
4) Oases on moraine land with high ground water.

When dealing with the morphology of the landscape I have several times referred to the patches of vegetation, as for instance when describing the volcanism at Fiskivötn and in the chapters on subaerial denudation, the aeolic conditions and the annual cycle of denudation; I shall here present some supplementary and summarizing observations.

As a rule the lava oases are associated with the edge of the subsidence basins that are so characteristic of the volcanic regions at Fiskivötn, Fossvötn and Northern Pytlur. At any rate physiognomically the vegetation is dominated by dwarf bushes, especially *Salix* species, and thus is of little value for grazing. The favours offered by nature here seem capable of being summarized in two groups, viz. a suitable ground-water level and protection against the destructive forces of the gales. The deeper parts of the subsidence areas are usually full of water, and in the lower parts of the lava the ground water is near the surface. In itself the irregular relief of the lava offers a fairly effective protection from the gales, and the volcanogenous gravel mounds lying round the fields are certainly of some importance in this respect. On the other hand, as already stated, conditions in the usual lava fields that have come from the great mass eruptions are not sufficiently good, and very few living things succeed in withstanding the destructive work of the hostile elements.

The second type of oasis, the lake oases, have grown on the shores of those lakes that have a constant water level. As a rule they are flat expanses of marsh with continuous vegetation, whose character changes with the conditions prevailing in the various arts of the area. The predominating families there are *Carex* and *Eriophorum*, which provide good fodder. There are examples of this type of growth beside the most easterly of the lakes in the Fiskivötn group, especially at Grænavatn and Breiðuvötn.

The glaciofluvial oases are poorly represented on the west margin of Vatnajökull, as for the present we only know one, viz. Botnaver in the southern corner of Túngnárbotnar. Poor and small is this patch of vegetation, only about 1 sq. km. in extent, but it gives a charming impression to visit this green little vale just under the ice margin, far away from other life. The soil consists of sand, which throughout the summer is soaked by springs and meltwater from Vatnajökull. Most of the area has the character of a "mýri", in which spring-water predominates and which is sheltered from the gales by the surrounding mountains. In several other parts of the highlands this type of oasis is the principal one (NIELSEN 1928), and is especially well developed at the southeast margin of Hofsjökull, where the area of vegetation is at least 100 sq. km. Fig. 46.

Moraine oases are also weakly developed in the land between the Túngná and the Kaldakvísl. In Þóristúngur there is a small patch of this type, but it seems to be perishing. There is a typical example of this form of oasis in Illugaver, just west of the Kaldakvísl. In the chapter on subaerial denudation I have dealt with certain soils and, in connection with them, some peculiarities of vegetation in that locality, which embraces a whole series of vegetation types, various "flói" and "mýri" types, "flá", "jaðar", "mó", and transitions between these.

Conditions throughout the whole of this part of the Icelandic highlands are so severe that, in a biological sense, it must be called a pronouncedly border region; the question is, however, whether this poverty is associated with any one of the oecological factors or whether it must be regarded as a result of a general impoverishment of the conditions. Even without knowing any figures as to the volume of rainfall and its distribution, it may be asserted that the volume of summer rainfall, combined with the water freed by the melting snows, is more than sufficient to maintain a continuous covering of vegetation under the prevailing temperature conditions. Nevertheless it is a fact that the quantity of surface water in great parts of the highlands is very small, and one of the hydrographical and morphological results of this is that drainage almost exclusively proceeds along subterranean channels, whereas there is no normal, superficial, hydrographic net. This is undoubtedly connected with the great porosity of the surface and its poverty in colloids, a peculiarity that stamps many of the polar surface forms. The great majority of Central Icelandic types of vegetation are consequently xerophilous, not only in the localities where the ground is very wet and cold, but also in the comparatively high, well-drained areas of vegetation. Thus both soil and vegetation bear evidence of a dryness that cannot be directly governed by the climate, but must rather be described as a pedologically governed aridity.

Naturally, the temperatures leave their mark upon the intensity of the vegetation, but it is scarcely the failure of the thermal conditions of life that set a boundary to the diffusion of life in the Icelandic highlands. This view is supported by the fact that we find extensive oases, some of the largest and most luxuriant we know — for instance those at Hvítárvatn and the southern margin of Hofsjökull — on high localities just under the ice margin. Naturally, a vegetation living in the conditions prevailing in this region must be poor, but neither rainfall nor temperature are of such a character that the formation of a continuous covering of plants is precluded for that reason, and so the cause of the poverty of the landscape must be looked for in other directions.

The feature common to the oases is that they are associated with localities where the destructive work of the wind is rendered difficult in some way or other. In some of them — as in the lava oases — it is a direct lee-protection, in other cases the moisture of the soil is so great and so constant throughout the summer that the gales do not succeed in pulling the plants up. The desert formation in Central Iceland must thus be regarded from the following angle: Low summer temperature, in combination with the poor water-economy of the soil, makes for slight intensity of vegetation; and yet conditions in these respects are not so bad that the formation of a continuous growth is precluded for that reason, but the vegetative power is too small to withstand the destructive activities of the gales, especially the dry gales. In this part of Iceland the deserts must therefore be called gale deserts.

B. Iceland's Volcanism and Tectonics in the Light of the Wegener Theory.

1. Types of Volcanic Landscapes.

Iceland having for the most part been built up by the activities of eruptive forces, the primary volcanic landscape must be one of the most important starting points for a study of the morphology of the country. As is often stated in the literature, regions characterized by eruptions contain a plurality of surface types whose differences are founded upon an interference between a number of colliding factors, namely:

1) The properties of the magma.
2) The nature of the earth's surface at the place of eruption, and
3) The character of the medium or media that cover the earth's surface at the place in question.

We thus differentiate between mass eruptions with mostly effusive outbreaks of very hot, thin lava, explosive eruptions with a predominating production of loose materials, and eruptions of mixed or stratic character, with alternating output of lava and solid products corresponding to effusive and explosive phases respectively.

The course of volcanic activity is furthermore governed by a number of dimensions such as the shape of the magma container, its size and distance to the surface, and the shape of the vent, which again depends upon a very complicated set of physical factors in the earth's crust. Finally, a volcanic eruption will proceed very differently according to whether the earth at that place is covered with air, water or ice.

In the recent Icelandic volcanic region, mass eruption is the predominating form of eruption, whereas stratic and explosive forms play a subordinate part, and this balance is of vital importance to the line of development in the recent moulding of the relief. The predominance of the eruptive and terrain-forming mass eruption is, however, not only a present day phenomenon, but has, as far as we know at present, extended through by far the greater part of the period of the geological development as to which the now accessible Icelandic series give us any information, and in addition it seems to have been the prevailing morphological factor during the forming of the other parts of the North Atlantic volcanic region (the Thule Region). It is therefore of importance to arrive at an understanding of the direct effect of such an eruption on the terrain.

We often meet with the view that the activity of volcanic forces produces an increase of the unevenness in the terrain in which they work; the validity of this view is, however, very restricted. It is wrong, for instance, when talking of mass eruptions, and as these — not only in the Thule Region but in many other earlier and later volcanic regions — have been and are still predominant, it would perhaps be most correct to allow the view to drop entirely. If a mass eruption takes place in an uneven terrain, the masses of lava will find their way to the lowest parts and wholly or partly fill them, with the result that a smoothing out takes place, simplification of the relief, which tends towards the forming of a plateau. An example of such a process has already been described on page 25, 207 of the present work, and it is there pointed out that, as regards the terrain, the places of eruption mean very little indeed, because the accumulation of material round them is slight, so slight in fact that it is not uncommonly a matter of difficulty to find them. Here and there in recent-volcanic Iceland we find more or less completely formed, recent volcanic lava plateaux, of which the largest and, as regards degree of filling up, most well developed is Ódáðahraun. The stratification in the greater part of the quaternary and tertiary formations shows, however, that there has been an enormous number of these volcanic plateau surfaces in which there have constantly occurred disturbances arising from the activities of non-volcanic forces, but that, parallel with the destruction of the plateaux, there has been a regeneration of them, produced by the filling-up activities of the ever-recurring mass eruptions; Iceland's surface forms have, throughout the greater part of the period in which we know the geological development of the country, been determined by this very cooperation between these two processes. The volcanic filled-up plateau is thus the most important structural basic form in the Icelandic landscape.

During explosive eruptions the greater part of the gravel material is distributed fairly evenly over the landscape, without regard to the pre-eruptive forms; but as soon as erosion, especially solifluction (so violent in arctic and sub-arctic regions) begins to work, we get a lively transportation of loose material towards the lower parts of the terrain and, as a consequence, a flattening out of the relief. Only if the volcanism is concentrated in pronouncedly stratic eruptions will it have much effect in a relief-increasing and mountain-forming direction; but this type of volcano, which elsewhere in the world is so conspicuous that it has been regarded as the paradigm of volcanic activity, plays a very small part in Iceland.

The series dating from the Glacial Ages — the interglacial periods and interstadial epochs — occupy a special position. Interstadial and interglacial eruptions do not differ much from the other subaerial eruptions, and the large sheets of lava thrown up are usually of doleritic character; but the terrain over which they have spread has been affected by the ice sheet in different ways. Subglacial eruptions have played a great part, but so far we know too little about the course of these processes to say anything with certainty about the primary morphological results. It is true that similar processes are going on at the present time, under Vatnajökull and under Mýrdals-Eyjafjallajökull, but they unfold themselves with such violence that it is very difficult to get near them and make the necessary observations, and there is no report of any scientific investigation of such an eruption. That something extraordinary is going on is beyond all doubt when it is remembered that the temperature of the lava must be assumed to be above 1100°, and that large quantities of this material are being pushed up under an ice sheet of very considerable thickness. Part of the ice melts, and the freed water makes it way through and over the ice-masses below, whereas another part of the water sinks down upon the glowing lava and is converted into steam with tremendous explosions; simultaneously the lava is burst into pieces and thrown high into the air in the form of ash, much of which is washed away by the freed water. The whole of this mixture of water, lumps of ice, volcanic ash and gravel then rush down the slopes and spread over the flatter parts. The present-day form of these processes is called volcanic glacier runs, or perhaps better glacier "jumps" (Icel. jökullhlaup), and are among the most violent natural catastrophes which the earth's surface can show at the present time. They have time after time devastated the coast plains in southern Iceland and have stamped this part of the island both morphologically and economo-geographically.

In those periods when the country was covered with ice, processes of like kind must have gone on to a much greater extent, and some of the rocks from the glacial volcanic formation or Palagonite formation were undoubtedly made by subglacial eruptions. We do not know much about the character of the resulting landscape forms, but the extent of the formation shows that there has been a very considerable diffusion of the material produced, even if it is beyond doubt that in certain cases there have been local accumulations of eruptive products to such an extent that increases of the relief — and very pronounced increases — have resulted.

With these deviations — immaterial on the whole as they are — the Icelandic rocks are remarkable for their almost horizontal stratification, and the dominating form of landscape is the plateau.

2. The Tectonic Disturbances.

The whole of the North Atlantic volcanic region, and especially the Icelandic part of it, distinguishes itself by the occurrence of a large number of tectonic disturbances. The most striking peculiarity of the Icelandic tectonic processes is that there is no trace whatever of folding, and that the dislocations have formed themselves exclusively as fractures. The course of the tectonic processes in the earlier part of the country's geological development are unfortunately little known; we know that there have been great and numerous thrusts, but there is no systematic investigation of Iceland's early tectonic development; as a matter of fact it is a very difficult subject for, as stated above, through the constant flattening out of the mass eruptions the unevennesses caused by the fractures have been concealed. On the other hand, Iceland's later tectonic development, especially the recent, is easily accessible and readily studied and has been subjected to examination by several investigators. For the fractures are so large and so recent that in many cases the physiognomy of the country is determined by the course of the tectonic processes, and therefore it is possible to apply purely topographic-morphological methods of investigation.

The distribution of the fracture zones is remarkable for an arrangement in great continuous systems with a conspicuously common stamp.

The more recent Icelandic faults of morphological importance may be divided into a few, perspicuous groups. The earlier systems are more difficult to grasp, because their morphological effects in the neo-volcanic region have to some degree been erased by later eruptions and, in the older part of the surface of Iceland, by the glacial and humid erosion. In the latter region there is for instance a possibility of confusing "ruptures de pentes" of tectonic origin with those produced erosively. The quaternary and post-glacial fracture zones are divisible into two main systems, which one might call the Westerly System and the Axial Southwest—Northeasterly System. The former group is represented by the great depressions in Breiðifjörður, Faxafjörður and the southwest lowlands, all of which are topographically conspicuous. Among the writers who have occupied themselves with the morphology of Iceland there is a fairly unanimous opinion that these three great basins are tectonic and that at any rate the latter two are very recent; the processes have probably not come to an end yet, as for instance appears from the great seismicity of the regions. In all three cases the boundary of the tectonically affected region lies near the present highland boundary, and the fracture areas run into one another only slightly, being separated by two long, narrow areas of resistance, Snæfellsnes and Reykjanes. In a geographical sense their difference is considerable; Breiðifjörður is a large, two-armed gulf, whose innermost part is shallow and studded with islands, Faxafjörður is a wide bay with no great indentations and no islands, and the third fracture area for the greater part lies above the surface of the sea; with a submergence of about 50 m., however, Faxafjörður would be increased by the landscape Mýrar, which would thereby be converted into an archipelago, and with a little more submergence we would have a completely analagous transgression area in the southern lowlands. There are no similar landscapes at all in East Iceland, and thus we have the characteristic asymmetry in the Icelandic coast line and landscape-forming that, in practically every respect, is a prominent geographical feature in the regional division of the country. Probably one formation that corresponds to the three fractures is the large indentation Ísafjarðardjup, which can be followed from the central parts of the great northwest peninsula to a depth of 200 m. on the submarine plateau. This narrow, curved channel is undoubtedly tectonic and probably belongs to the same system of fractures, even if with regard to age and form it may differ somewhat from the other three.

The axial main system of tectonic disturbances is in two sections. It can be followed from the southwesterly corner of Iceland, Reykjanes, across the country to a depth of about 300 metres out in the northern Arctic. The southwesterly zone runs from Reykjanes to a stretch in Central Iceland, almost from the northern margin of Langjökull to a point northwest of Vatnajökull. In this zone the fracture lines are with small deviations orientated southwest—northeast, whereas in the northern part of the system they run north—south, likewise with small deviations. The fault lines of the south land are very distinct on the Danish General Staff's topographical map-sheets of this part of the country; topographically they appear very clearly and in several localities they lie so closely together that the areas concerned may be characterized as "champs de fracture". The fracture lines of the north land are of very different ages and in this they form a contrast to those of the south land, which for the most part are quite recent: late-Quaternary or post-Glacial. In the north country they occur principally in the sides of the great gulfs. Húnafloi, Skagafjörður, Eyjafjörður, Skjálfandi and Axarfjörður are all wide, deep depressions which can be followed about 100 km., sometimes more, into the highland plateaux and at least just as far out into the northern Arctic, whereas the peninsulas lying between them continue as shoals out from the present coast line. These fracture lines are undoubtedly of Quaternary age, as they cut through rocks belonging to the earlier parts of the glacial volcanic formation, and as the situation of the later glacial erosion valleys shows that at that time the fractures already had been formed. Later, and even recent, fracture lines with the same direction exist in the regions east of Eyjafjörður, where they very pronouncedly give character to the terrain.

3. Tectonics and Volcanism.

One peculiarity of the Icelandic tectonics is its close association with the volcanism. On the whole the volcanic processes are lineally orientated, and, even if there are numerous exceptions from this rule, the phenomenon is so consistent that the circumstances are most striking in the landscape. As a rule the volcanic lines are not particularly long, rarely more than 20—30 km.; in some places, however, one sees volcanic zones stretching over wide expanses, but in such cases the lines do not lie in prolongation of one another but in parallel displacement. This feature occurs in nearly all the new-volcanic regions of any considerable output, Reykjanes, Þingvalla-region, Hekla region, the regions west of Vatnajökull and Ódáðahraun. The probability is that the great mass eruptions bring about mass disturbances, which result in a kind of tectonic movement, and indeed we see that a series of mass eruptions in a district is followed by tectonic disturbances; the phenomenon is met with so often that we must assume a causal-connection between the volcanic processes and certain subsequent tectonic changes. The fracture lines then formed in certain cases become determinative of the situation and form of the next series of eruptions in the region, and in that way we have an interference between the volcanic and tectonic processes which seems as if it would continue through long periods.

Observations of this kind have led some writers to the assumption that the tectonic activity is a phenomenon arising out of the volcanism, and that the volcanic activity in this respect too is the fundamental morphological feature.

To this it must be observed, however, that the tectonic movements of Iceland proceed according to such great common main lines that they can scarcely be placed in direct causal-connection with the volcanism, whose tectonic after-effects must be of local extent. There is thus little probability that a volcanic eruption for instance in the Hekla region can have any tectonic after-effect that stretches far beyond the rather limited area in which the eruption takes place. The tectonic processes are, however, much more widely diffused and are not associated with the volcanic regions alone. Nor would there be any reason why the tectonic changes should retain their right-lined course if they were not due to a cause independent of volcanism, or, more correctly, if they were not inter alia under the influence of forces which indicated this right-lined course and which did not directly stand in causal connection with volcanism. On the whole it does not seem to me possible to advance the eruptions as the explanation of the arrangement of the fracture lines; much rather must it be assumed that both groups of phenomena are under the influence of a common, mighty force of regional character. However, before going further into this problem I shall deal briefly with one or two other matters that are important in this respect.

One of the fundamental problems in the creation of forms of the tectonic landscape is: What is the direction of the movements that have involved the forming of the fractures, and how have these movements proceeded on the whole? In advance there are three or perhaps four possibilities that must be taken into consideration: 1) The process may have been this, that the present highest parts (the horsts) were pushed upwards while the other parts have lain still. 2) Both the highest and the lowest parts may have moved, but in opposite directions. 3) The present lowest parts may have sunk and the higher parts retained their position, and finally, there is the possibility 4) that the whole surface has sunk or risen, but unequally.

All that is directly accessible to observation is usually that a once continuous surface has become discontinuous, that "ruptures de pentes" have formed along the fracture lines; but it is rather difficult to fit every single concrete case of tectonic movement into the above system and decide the direction of the movement. And yet, in certain cases it is possible to do it with some certainty. At the forming of the great, recent tectonic fissure Heljargjá, west of Vatnajökull, what has happened is this, that a small right-lined zone with a width of rather less than a kilometre and a length of about 30 km. has sunk, while the surrounding terrain has retained its position unchanged. Similar phenomena are to be seen time after time in the Icelandic landscape, recognizable by the fact that the two edges of a fissure lie at the same level; why should they do so if the movement has not been localized to the fissure and the two sides have remained firm? This has in addition given us a determination of the direction of the movement which, as far as I am aware, in all cases investigated has revealed itself as a subsidence.

Another circumstance may help to clear up this problem, namely, the stratification of the Icelandic horsts. As shown above, the Icelandic series distinguish themselves by a mostly horizontal stratification, signified by a course of mass eruptions with intermediate deposits of tuffs and subordinate, sedimentary series. Now it appears that the positions of the strata in the Icelandic horsts have in a strikingly large number of cases retained their horizontality even after the tectonic disturbances. Early horst formations will naturally be rather severely eroded, and the difference between the orientation prior to and after the tectonic processes can only be determined by the dip of the strata; in the very young horsts, however, we have still another indicator, viz. the terrain. On their upper sides the young horsts have plateau flats which are the remains of the pre-tectonic surface, and in most cases this proves to have retained its horizontality. These young horsts are very common in the south land and in parts of the interior highlands, and they are also to be found in that part of the north land where there are recent tectonic disturbances. As typical examples I may name the Ingólfsfjall, Vörðufell and Skarðsfjall. As the map shows (No. 2), Ingólfsfjall is bounded by steep walls 3—400 m. high, with sharp edges both towards the plain at the foot of the mountain and towards its upper surface, which is in the form of a plateau with slightly rugged terrain forms. Humid erosion has only affected this flat and its edges in the slightest degree and the plateau surface is almost unbroken. Vörðufell (map 4) is exactly the same; on its plateau it bears a small lake whose drainage to the south has formed a very small gully. Both mountains must be very young, otherwise Ingólfsfjall would be cut up by erosion gullies and the little lake on Vörðufell would have disappeared long ago, emptied by the deepening of the erosion gully. A more exact estimate of the age may be obtained by a comparison with the landscape shown in map 5, on the east of Skagafjörður on the peninsula lying between that fjord and the Eyjafjörður to the east of it. The section of the map shows a volcanic plateau land, mostly built up of lava beds; but in between the uppermost of these Helgi Pjeturss has shown moraines and striated horizons, so that we must assume that the lower part of the system is Tertiary, while the upper part is Quaternary. The valley formation at this place must therefore be later than the early ice-sheet. The forms of the valleys, however, display a most distinct glacial erosion, partly in the principal valleys shown in the map section and partly in the form of a number of cirques lying in an almost continuous row along the upper edge of the valley, each of which has eaten away a small piece of the plateau. The principal valley must therefore have existed during the last Glacial period.

There is a type of landscape of somewhat similar origin in the mountain region of Súlur (Botnssúlur) in Southwest Iceland. Pjeturss(on) has explored it geologically and morphologically and has come to the probably incontestible conclusion (1904) that the mountain is the ruin of a strato-volcano, the formation of which has taken place at any rate partly in Quaternary times, as the products of the volcano rest upon ice-striated and moraine-bearing horizons, whereas today the volcano appears as a mass badly broken down by a post-eruptive glacial erosion. Map 6 shows that the mountain is split up into a collection of peaks and ridges with steep walls, leading down to characteristic Botn formations. Photograph No. 51, was taken from the highest summit on the map, Point 1095, and the high pinnacle in the middle of the picture is Point 1035. The two Botn-formations on the right and left side of the picture meet at the rounded ridge whose lowest point on the map bears the Cote 888. The peak in the middle of the picture, Point 1035, is probably an old crater canal. This type of terrain and the land east of Skagafjörður have this in common, that they both contain moraine-bearing material, and that prior to the last great glacial period there has been a difference in the level of the landscape, which has given rise to a violent, glacial erosion under the last ice sheet. That they are so different as the map shows, despite this fundamental likeness, is a result of petrographic differences, Súlur being built by the activity of stratic eruptions, whereas the land at Skagafjörður is a lava plateau which in all essentials has received its form by a long series of Quaternary mass eruptions' having flooded the land with streams of lava.

If we now compare the illustrated and described forms of landscape, we arrive at the conclusion that they represent two main morphological types. One, represented by maps 2 and 4, distinguishes itself by the fact that the terrain forms look young, as there is no trace of a glacial erosion after the occurrence of the difference of level, while the traces of humid erosion are sparse and very faintly developed. The other type, maps 5 and 6, displays landscape forms with a similar difference of level, but this has already existed under the last ice-sheet. We must therefore date the formation of Ingólfsfjall, Vörðufell and many other mountains to post-glacial times, and this assumption is strengthened by one more observation. The plateau surface on Ingólfsfjall and several other similar mountains such as Skarðsfjall and Hrafnabjörg (fig. 50) bear traces of glacial erosion, including striae; these are peculiar in that they run in the direction of the natural fall of the country, regardless of steep slopes and the now-existing difference of level between the plateau surfaces and the lowlands at the foot of the mountains, and they are to be found right out to the edges of the plateaux, in fact on the marginal boulders which in certain cases during the tectonic processes have been loosened from the mass and displaced from it outwards and downwards. The cliffs on these mountains must thus be younger than the striae on the plateaux. Another question is whether these striae date from the last great glacial covering, and this seems to me to be much the most probable explanation, for, if this were not the case, one would find on the edges of the rock traces of local ice movement and small cirques produced by the erosion of ice and snow; as the maps clearly show, there are none.

Conditions at the present time indicate that one must regard the faults not as instantaneous processes but as interrupted movements that take place throughout a short or long period, but whose duration in a geological sense seems to be fairly short. For the present we do not know sufficient about the tectonic processes in Iceland to definitely fix the duration of the various fault systems, but, as shown in the foregoing, one can in certain places arrive at an approximate dating of the processes, roughly as follows: The great fjords in the west country seem to have been formed in Quaternary and post-Glacial times, the north-country fjords are Quaternary, and the principal faults now identifiable in the south country must be taken to have been formed in late-Quaternary and post-Glacial times.

4. The Tectonics of Iceland and the Alpine Foreland.

When considering the forms of movement that have caused these fractures it will not be out of place to undertake a comparison between the Icelandic faults and the corresponding movements in the Alpine foreland, where there is also a system of young — some of them recent — tectonic processes.

According to several writers, the northwesterly Alpine foreland between the Alps and the North Sea is remarkable in that it consists of a large number of blocks of great size (Schollen), each of which turns on its own axis while at the same time an axial change seems to be in process. Certain parts of the blocks are rising, others sinking, and in this manner occur a number of inclined planes dipping in various directions, varying from one block to another. The characteristic morphological feature in this part of Europe is thus that the pre-tectonic horizontality is being broken.

In this respect there seems to be a profound difference between the tectonic processes in the Alpine foreland and the processes in the Icelandic fault region, where we find that the fundamental morphological peculiarity is that horizontality is retained during the tectonic processes. It is true that there are inclined planes in the Icelandic fault country, seemingly caused i.a. by a general subsidence in towards the new-volcanic zone. Another form of inclination occurs at the edges of the tectonic-resistance regions. We see this in recent fractures when these for instance have affected the lava streams, causing the gjá-formations described by several writers, on the borders of which one frequently sees large tilted blocks with one edge resting upon the upper edge of the fault and the other on the sunken surface. We know of a corresponding example on a larger scale on the mountain Esja at Reykjavík (Thoroddsen 1906, p. 209), where the principal tectonic element, the mountain itself, is horizontally orientated whereas the smaller blocks to the south of it have tilted away from the highest part of the fault area. We know of similar conditions in the great fault area west of Vatnajökull, where tilted marginal blocks have played a very considerable part in the forming of the terrain. On fig. 23 is a horst, Túngnárfjöll, in the centre; on the right and left are long, narrow subsidences, one of which is filled by the big lake Litlisjór, which is shown on the picture. On the side towards Litlisjór very large boulders have loosened themselves from the horst and have been flung out towards the subsidence; the process has taken place so recently that it is still possible to recognise remains of the plateau surface on the upper side of these blocks which, on account of their tilting, forms an inclined plane in contrast to the almost horizontal surface of the main block.

In all cases known to me, in which it has been possible to determine the direction of movement during Icelandic tectonic processes, there has been a subsidence of certain parts of the terrain, whereas other parts have remained stationary. We have thus to do with a one-sided movement and not a tilting like that characteristic of the Alpine foreland. The great western fjords have already been assumed to be subsidence areas, and the correctness of this view can scarcely be disputed. The great north-country fjords must likewise be taken to be subsidence areas, whereas the peninsulas lying between them may be regarded as areas of resistance. What it is that brings about this contrast between subsidence and resistance areas, what it is that holds parts of the tectonic units of the landscape up when the other collapse, we can say very little about at present. PJETURSS(ON) (1904, p. 257) was perhaps the first to get the idea that "the volcano itself is often regarded as being less exposed to fracture than its immediate surroundings". HANS RECK later (1922) reviewed this problem and propounded the theory that the regions in which volcanic eruptions have taken place, probably on account of the stiffness of the magma are firmer than the surrounding country and, moreover, anchored so deeply that they get these very peculiarities during a tectonic breaking up of the country. He gives a number of examples, especially for the north country, of landscapes whose formation is explainable on the basis of this theory, and on the whole it seems to me possible to apply this view as a working hypothesis when considering the formation of a number of the Icelandic horsts.

As I have stated above, we find the surprising circumstance that in most cases horizontality has been preserved in the later Icelandic horsts. This would scarcely be imaginable if these horsts had been formed by upheaval processes, at any rate not as a common feature. For in that case what would undoubtedly have happened is that they would have been tilted. There are thus a number of circumstances that argue that the tectonic processes in Iceland have mostly been in the form of subsidences, and that the movements for the most part have been vertical.

5. Iceland and the Wegener Theory.

In explanation of these remarkable features in the Icelandic tectonic region I have gradually arrived at the following theory, which may be of some importance as a working hypothesis in the further exploration of this territory, which contains so many valuable objects of study for tectonic morphology. My theory aims at setting the activity of the volcanic and tectonic forces in association with the theory of the horizontal Contintal displacement as formed by ALFRED WEGENER in his famous work: "Die Entstehung der Kontinente und Ozeane" (Ed. 1, 1915, Ed. 4, 1929) which in so many ways has stimulated geographical and geological science. WEGENER drew attention to the fact that the conspicuous unity in the North-Atlantic basalt region finds an explanation in the westerly movement of the American continental group. Accordingly, the various earlier basalt regions are regarded as parts of a split-up basalt plateau of Middle-Tertiary age, of which the various parts have later on been subjected to transformation by erosive tectonic and eruptive processes.

The foregoing account of the Icelandic tectonics has shown that the great common features are the following: We have a number of great, curved subsidences in the west and a large system of almost right-lined faults in the direction southwest—northeast and north—south. These two systems may be regarded as the result of a pull from west to east which has simply split the land into innumerable fissures. When deeper-lying, firm material is removed, cavities occur, and these collapse, thus providing an explanation of the peculiarity of the Icelandic tectonics that subsidences are the main feature. Where such fissures meet a magma and go so far down that this can make its way out, we get the fissure eruptions and the other linear eruptions; and likewise a magma extending from below upwards will, just through the effects of the constant pull, be inclined to break out along a linear zone at rightangles to the pull. This relieving of the magma containers will then produce new subsidences of secondary character with on the whole the same orientation, governed partly by the situation of the relieving zones and partly by the tendency accompanying the pull to form cracks at rightangles to the pull.

The Swiss Alpine school (ARGAND, STAUB and COLLET, etc.) have earlier placed the Alpine folding and its accompanying formation of faults in the Alpine foreland in connection with the Continental movement and have regarded the whole of this process as a result of a collision between European masses and Gondwana masses. The construction of these ideas has been presented in a number of works of great ingeniousness and beauty. The characteristic feature of the whole of this tectonic unity is the pressure, in the central parts of the geosynclinal region manifested as nappes with gigantic overthrusts, and in the foreland manifested as a breaking up of the land into blocks which tilt and turn about different axes. The whole of this system is a typical example of what with a common term one might call the pressure tectonics. In contrast to this the Icelandic tectonics must be regarded as the result of a tension, a tearing asunder, and in this manner we get a distinction between two forms of tectonic movement that genetically and morphologically are very different: pressure and tension.

It must be regarded as certain that there is a profound difference between these two tectonic types; whether the explanation I have set up is tenable is another matter, but it is to be hoped that future investigations will throw more light over these fundamental morphological problems. For the present I hope that this collective point of view of the variegated crowd of individual phenomena in Icelandic tectonics and volcanism will prove to be fruitful to further research.

BIBLIOGRAPHY

BÄCKSTRÖM, H.: Beiträge zur Kenntnis der isländischen Liparite. Stockholm 1892.

BAILEY, E. B.: Iceland, a stepping stone. Geol. Mag. London 1919.

BJERRING-PEDERSEN, Th. og NIELS NIELSEN: Geomorfologiske Studier i det sydvestlige Island. Geogr. Tids. København 1925.

BRUUN, DANIEL: Sprengisandur og Egnene mellem Hofs- og Vatnajökull. Geogr. Tids. København 1902.

— »Vatnajökullsvegur« samt Undersøgelser ved Vatnajökulls Nord- og Vestrand. Geogr. Tids. København 1925.

— Fjældveje gennem Islands indre Højland. København 1925.

— Kort over Island. 1:850 000. København 1927.

ERKES HEINRICH: Das isländische Hochland zwischen Hofsjökull und Vatnajökull. Peterm. Mitt. Gotha 1911.

— Neue geographische Forschungen auf Island. Mitt. Ver. f. Erdk. Dresden 1925.

— Forskningsrejse. Geogr. Tids. København 1925.

DE FONTENAY, Fr. le Sage: Ferð til Vatnajökuls og Hofsjökuls summarið 1925. Andvari. Reykjavík 1926.

GUNNLAUGSSON BJÖRN: De mensura et delineatione islandiæ interioris, cura societatis litterariæ islandicæ his temporibus facienda. Viðey 1834.

— Uppdráttur Íslands. 1844.

HARDER, POUL: Virkninger af Flyvesand. Nogle Iagttagelser fra Island. Medd. Dansk Geol. For. København 1911.

HAWKES, L.: Frost action in superficial deposits, Iceland. Geol. Mag. London 1924.

HELLAND, A.: Islændingen Sveinn Pálssons beskrivelser af islandske vulkaner og bræer. Norske Turistforenings Aarbog 1881, 82 og 84.

— Lakis kratere og lavastrømme. Kristiania 1886.

JOHNSTRUP J. F.: Indberetning om en i 1876 foretagen Undersøgelsesrejse paa Island. Rigsdagstidende. København 1876—77.

— Om de i Aaret 1875 forefaldne vulkanske Udbrud paa Island tillige med nogle indledende geografiske Bemærkninger. Geogr. Tids. København 1877.

— Om de vulkanske Udbrud og Solfatarerne i den nordøstlige Del af Island. Naturhist. For. Festskrift. København 1886.

KÅLUND, P. E. KRISTIAN: Bidrag til en historisk-topografisk beskrivelse af Island. København 1877—82.

VON KNEBEL, W.: Der Nachweis verschiedener Eiszeiten in den Hochflächen des inneren Islands. Centralbl. f. Min. Geol. und. Pal. 1905.

— Vorläufige Mitteilung über die Lagerungsverhältnisse glazialer Bildungen auf Island und deren Bedeutung zur Kenntnis der diluvialen Vergletscherungen. Centralbl. f. Min. Geol. und. Pal. 1905.

— Studien in Island im Sommer 1905. Globus 1905.

— und RECK HANS: Island. Eine naturwissenschaftliche Studie. Stuttgart 1912.

Koch, J. P. und Wegener A.: Wissenschaftliche Ergebnisse der dänischen Expedition nach Dronning Louises-Land und quer über das Inlandeis von Nordgrönland 1912—13 unter Leitung von Hauptmann J. P. Koch. Medd. om Grønland Bd. 75 I. København 1930.
Mackenzie, G. L.: Travels in the island Iceland. Edinburgh 1812.
Mølholm Hansen, H.: Studies on the vegetation of Iceland. København 1930.
Müller, L. H.: Skíðaferð suður Sprengisand veturinn 1925. Skírnir. Reykjavík 1926.
von Nidda, O. Krug: Geognostische Darstellung der Insel Island. Karstens Archiv. 1834.
Nielsen, Niels: Der Vulkanismus am Hvitárvatn und Hofsjökull auf Island. Medd. Geol. For. København 1927.
— Foreløbig Beretning om den 2. dansk-islandske Expedition til Islands indre Højland. Geogr. Tids. København 1927.
— The second Danish-Icelandic expedition to Iceland. Nature. London 1928.
— Landskabet Syd-Øst for Hofsjökull i det indre Island. Geogr. Tids. 1928.
— Islandske Vulkanformer. Naturens Verden. København 1929.
— Islands Tektonik og Wegener-Theorien. Beretn. 18. Skand. Naturforskermøde. København 1929.
— Tektonik und Vulkanismus Islands unter Berücksichtigung der Wegener-Hypothese. Geol. Rundschau 1930.
Nørlund, N. E.: Rapport sur les travaux géodésiques exécutés de 1927 à 1930. Danemark. Institut Géodésique. København 1930.
Oetting, W.: Neue Forschungen im Gebiet zwischen Hofsjökull und Langjökull auf Island. Deutsche Islandforschung. Breslau 1930.
— Inselberge und Plateaus auf den Hochflächen Innerislands. Mitt. d. Geogr. Ges. München 1930.
Pálsson, Sveinn: see Helland, A.; 1883.
Peacock, M. A.: The geology of Viðey, S. W. Iceland. A record of igneous action in glacial times. Trans. Roy. Soc. Edinburgh 1926.
— The vulcano-glacial palagonite formation of Iceland. The Geological Magazine. London 1926.
— Recent fracture lines in the Faeroes in relation to the theories of fjord-formation in northern basaltic plateaux. Glasgow University, Papers from the Geological Department. Glasgow 1928.
Penck, A.: Über Palagonit- und Basalttuffe. Zeitschr. d. d. geol. Ges. 1879.
Pjetursson, H.: The glacial palagonite-formation of Iceland. Scottish Geological Magazine. 1900.
— Om nogle glaciale og interglaciale Vulkaner paa Island. Vid. Selsk. Oversigter. København 1904.
— Om Islands Geologi. Medd. Geol. For. København 1905.
— Einige Ergebnisse einer Reise in Süd-Island im Sommer 1906. Zeitschr. Ges. Erdk. Berlin 1907.
Pjeturss, H.: Einige Hauptzüge der Geologie und Morphologie Islands. Zeitschr. Ges. Erdk. Berlin 1908.
— Island. Handbuch der Regionalen Geologie. Heidelberg 1910.
Quiring, H.: Die quartäre Hebung und Senkung Westdeutschlands. Peterm. Mitt. 1928.
Reck, H.: Ein Beitrag zur Spaltenfrage der Vulkane. Centralbl. Min. Geol. und Pal. 1910.
— Über Erhebungskratere. Sitz. Ber. d. d. Geol. Ges. Berlin 1910.
— Isländische Masseneruptionen. Geol. und pal. Abh. v. Koken. Neue Folge. Bd. 9. 1910.
— Geologische Studien über die rezenten und glazialen Gletschergebiete Islands. Zeitschr. f. Gletscherk. 1911.
— Über vulkansiche Horstgebirge. Zeitschr. f. Vulkanologie. Berlin 1922.
Samuelsson, C.: Vittrings- och erosionsstudier på Island. Geol. För. Förhandl. Stockholm 1924.
— Några studier över erosionsföreteelserna på Island. Ymer. Stockholm 1925.

Samuelsson, C.: Studien über die Wirkungen des Windes in den kalten und gemässigten Erdteilen. Bull. Geol. Inst. Univ. Uppsala 1927.

Sapper, K.: Ueber einige isländische Vulkanspalten und Vulkanreihen. Neues Jahrb. f. Min. Geol. und Pal. Beilage-Band 26. 1908.

— Über isländische Lavaorgeln und Hornitos. Montasber. d. d. Geol. Ges. 1910.

— Die Vulkanizität Islands. Mitt. d. Islandfreunde. Jena 1929.

— Vulkankunde. Stuttgart 1927.

Schythe, J. C.: En Fjeldreise i Island i Sommeren 1840. Krøyers Naturhistoriske Tidsskrift. Bd. 3. København 1840—41.

— Hekla og dens sidste Udbrud. København 1847.

Spethmann, H.: Der Nordrand des isländischen Inlandeises Vatnajökull. Zeitschr. f. Gletscherk. Berlin 1908.

— Der Aufabu der Insel Island. Centralbl. f. Min., Geol. und Pal. 1909.

— Meine beiden Forschungsreisen im östlichen Inner-Island. Studien an Vulkanen und Gletschern. Mitt. Ges. f. Erdk. Leipzig 1912.

— Forschungen am Vatnajökull auf Island und Studien über seine Bedeutung für die Vergletscherung Norddeutschlands. Zeitschr. d. Ges. f. Erdk. Berlin 1912.

Thoroddsen, Þ.: Om nogle postglaciale liparitiske Lavastrømme i Island. Geol. För. Förh. Stockholm 1891.

— Landfræðissaga Íslands. Reykjavík og København 1892—1904.

— Die Bruchlinien Islands und ihre Beziehungen zu den Vulkanen. Peterm. Mitt. 1905.

— Fra Islands indre Højland. En Rejseberetning fra Sommeren 1889. Geogr. Tids. Bd. 10. København.

— Island. Grundriss der Geopraphie und Geologie. 1—2. Peterm. Mitt. Ergänzungsheft 152—53. Gotha 1905—06.

— Lýsing Íslands. København 1908—11.

— Ferðabok. Skýrslur um rannsóknir á Íslandi 1882—98. København 1913—15.

— An account of the physical geography of Iceland with special reference to the plant life. Botany of Iceland. I. København 1914.

Trautz, Max: Die Kverkfjöll. Sitz.-Ber. d. Vers. deut. Naturf. u. Ärtze zu Karlsruhe. Leipzig 1912.

— Die Kverkfjöll und die Kverkhnukaranar im Hochland von Island. Zeitschr. d. Ges. f. Erdk. Berlin 1914.

Tyrell, G. W. and Peacock, Martin A.: The petrology of Iceland. Trans. Roy. Soc. Edinburg 1927.

Wadell, H.: Vatnajökull. Geografiska Annaler. 1920.

Wegener, A.: Staubwirbel auf Island. Meteor. Zeitschr. 1914.

— Die Entstehung der Kontinente und Ozeane. 1—4 Aufl. Braunschweig 1915—29.

Wigner, J. H.: The Vatnajökull traversed from NE. to SW. The Alpine Journal. London 1905.

Wunder, L.: Beiträge zur Kenntnis des Kerlingarfjöllgebirges, des Hofsjökulls und des Hochlandes zwischen Hofs- und Langjökull in Island. Monatshefte für den naturwiss. Unterricht aller Schulgattungen. Leipzig und Berlin 1912.

Þorkelsson, Þorkel: Um úrkomu á Íslandi. Búnaðarrit XXXVIII. Reykjavík 1924.

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Fig. 1. Old, hardened moraine, Tillit, in Suaðafell. The stones have been graved by the subaerial denudation.

Fig. 2. Hardened, stratified, volcanic tuff that has been broken up by a recent dislocation, Heljargiá, and thereafter eroded by the wind. Among the blocks is wind-borne sand.

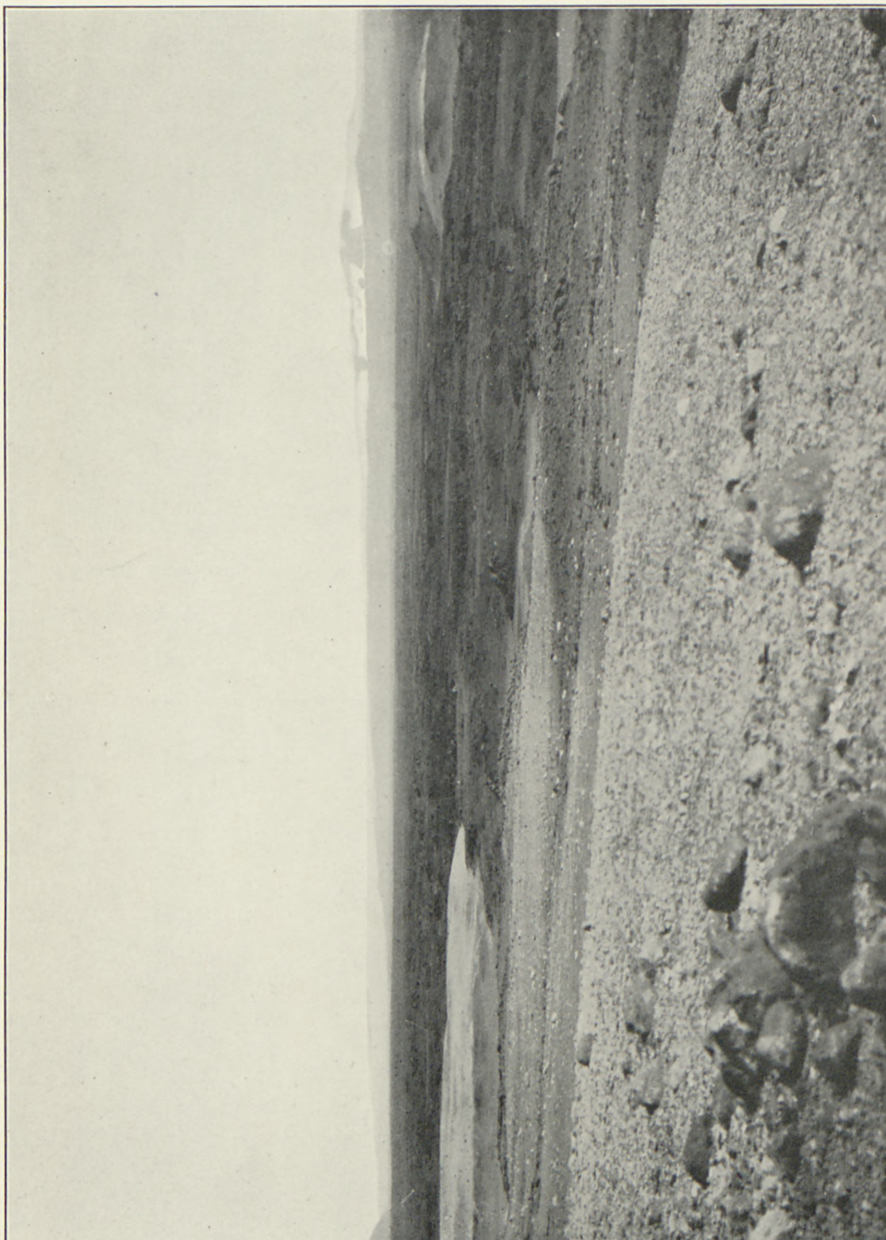


Fig. 3. Hágönguhraun, seen from Ljóshólar. Lava-levelled plane caused by lava eruptions from fissure vents almost in the middle of the lava field. Cf. fig. 4 and 8.

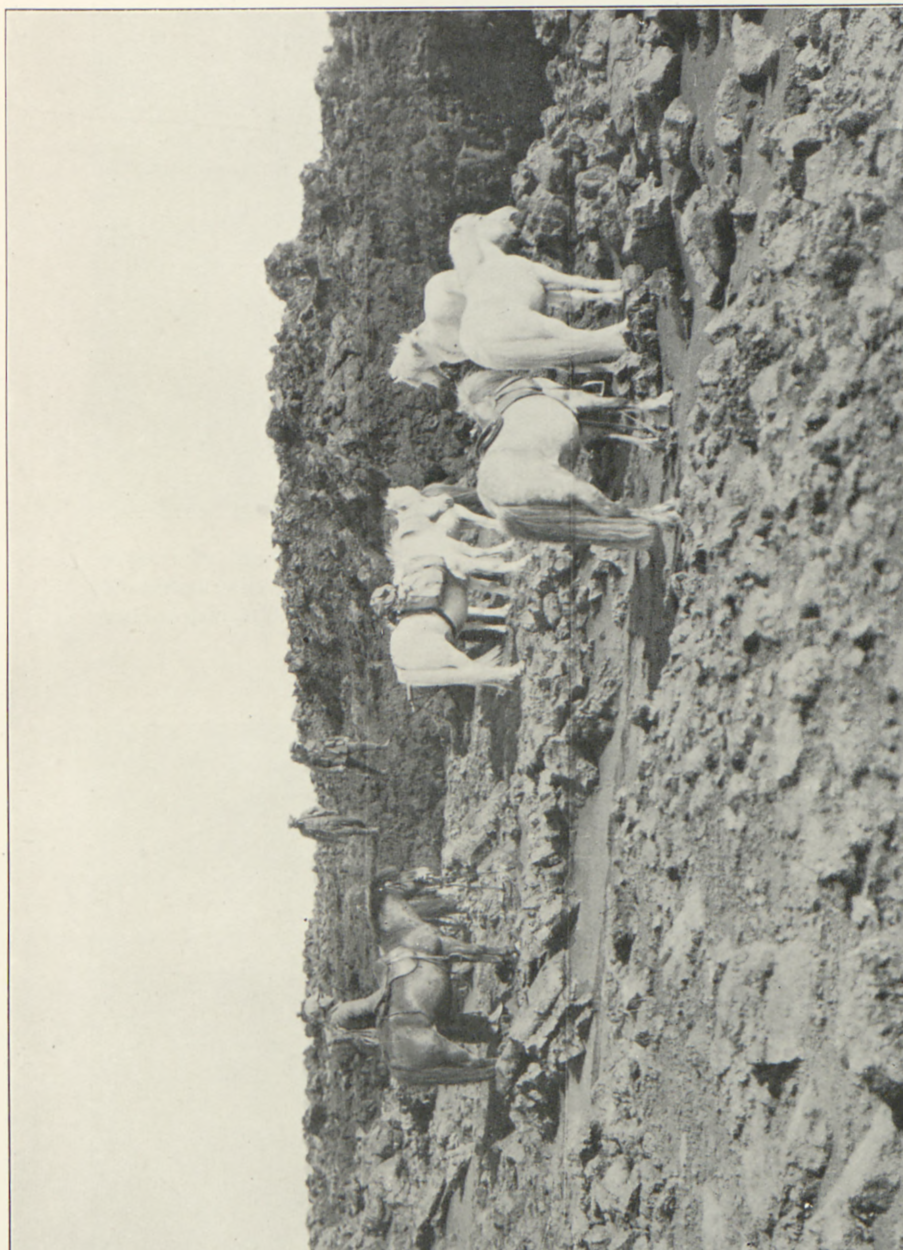


Fig. 4. Terrain details on Hágönguhraun. The horses are standing on a rather sand-swept, older lava surface which has been covered by a very recent stream of block lava. The two men are walking on the later covering, the edge of which is clearly seen in the picture.

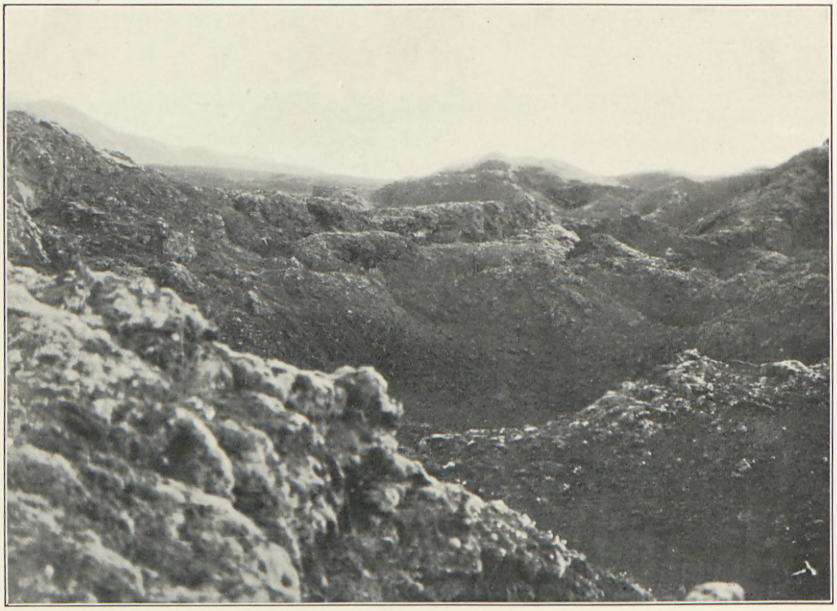


Fig. 5. The vent of a linear mass-eruption, in Zone C of the Fiskivötn region. The fissure itself is full of a chaos of slag mounds, cf. fig. 16. The slag mounds along the edges of the fissure are quite low, rising only about 15 metres above the surrounding terrain.

Fig. 6. "Maar" in Pytlur. After the conclusion of the explosive process a small lava stream has come from an adjacent effusive vent and filled about half of the maar basin. The whole surface of the surrounding landscape is interspersed with explosive areal-eruptions.

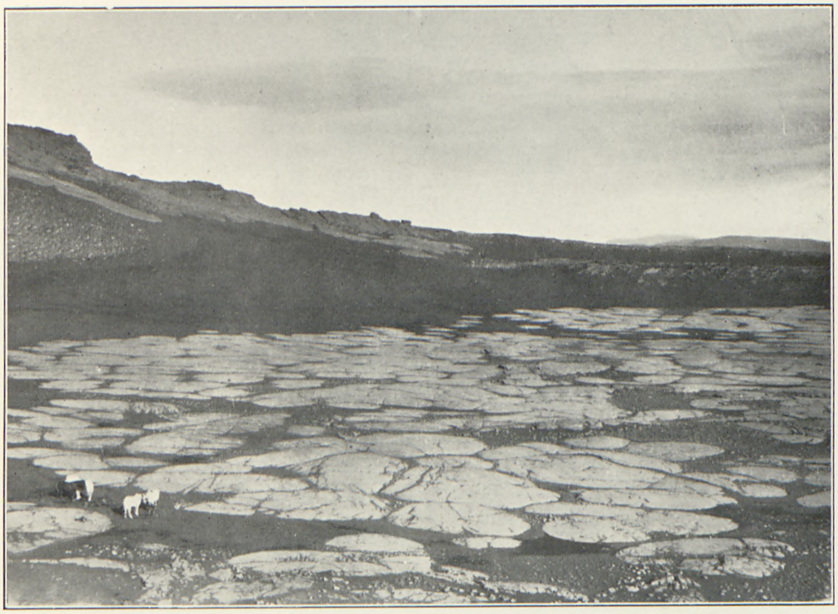


Fig. 7. An explosive volcano, the crater partly full of "foreign" lava which has hardened under very quiet conditions in the form of sheet-lava (Icelandic: helluhraun). The size of the various domes may be estimated from a comparison with the four horses.

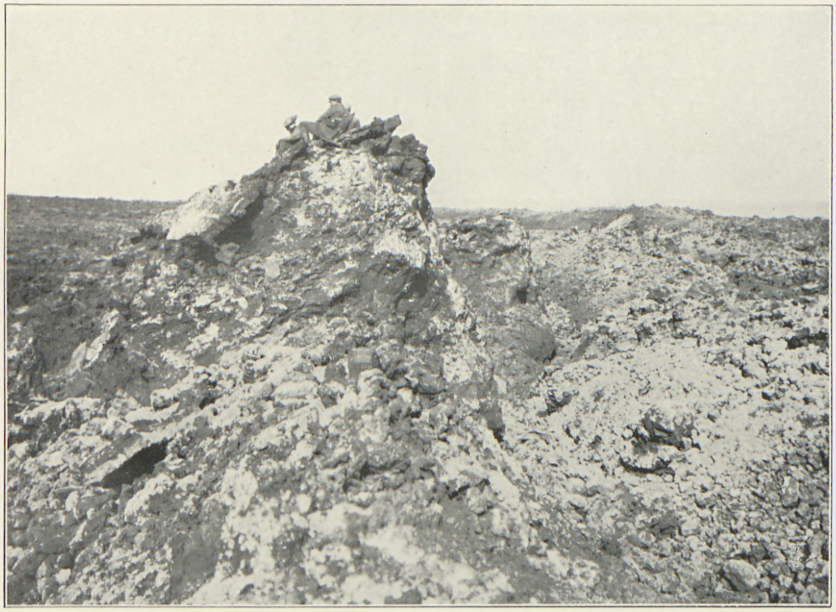


Fig. 8. Terrain detail from Hágönguhraun. Characteristic block lava (Icel. apalhraun). Cf. fig. 3, a general view of the same locality.

Fig. 9. Landscape at Fiskivötn. On the left is Lake Tjaldvatn. The basin in the foreground was formed by the collapse of a deep lava lake, of which a remnant of the surface may be seen in the "shore line", which appears in the right side of the picture and — farther back — in its left edge.

Fig. 10. A corner of Lake Skálavatn, formed in a subsidence basin, on the banks of which are two hornitos of lava fragments. The largest is known as Arnarsetur.

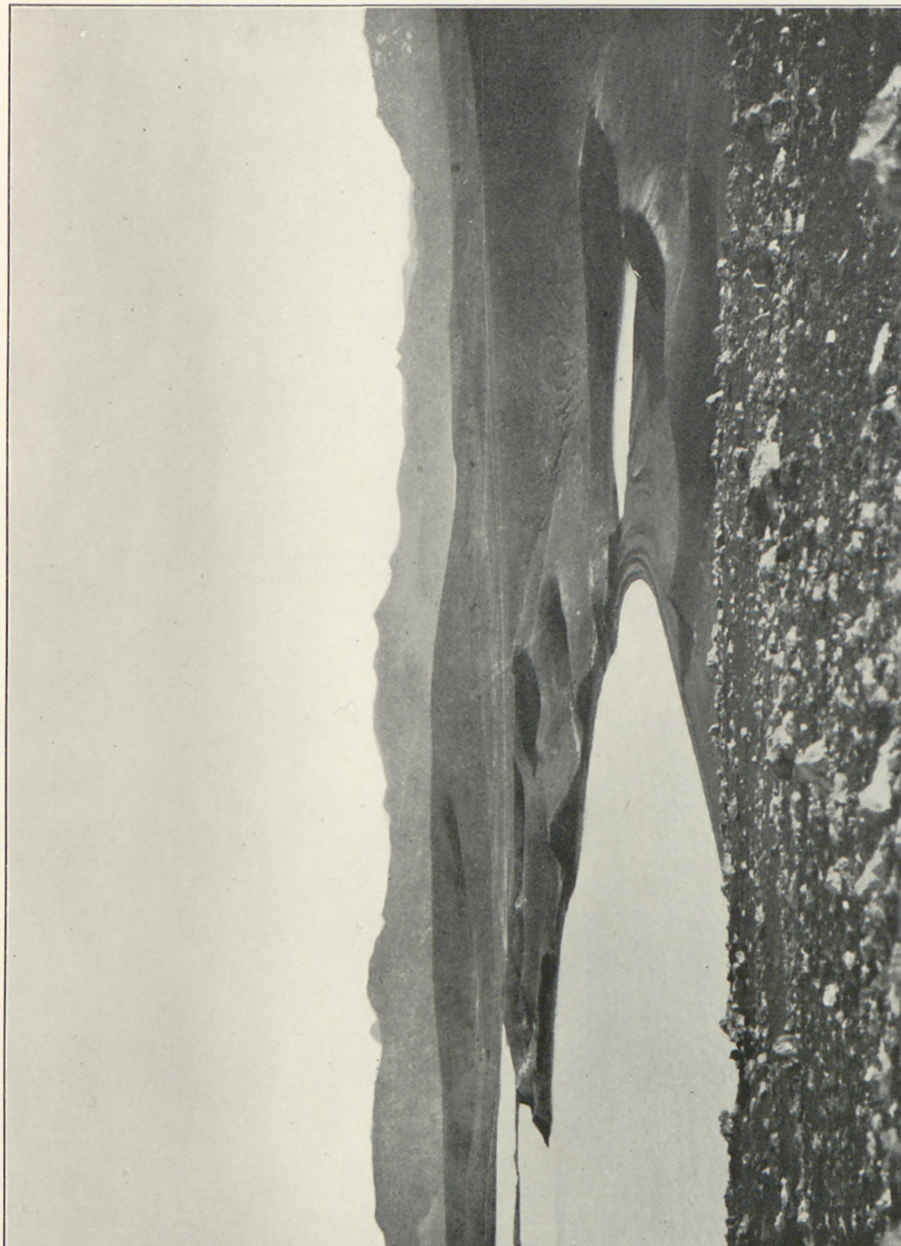


Fig. 11. The southwest end of the large lake Litlisjór. On the shore is an explosive areal-eruption. Note the water-marks which indicate the high water-table when the spring thaw is on. The foreground is of material from an explosion crater. Behind the craters is a landscape with a lapilli surface, converted by solifluction combined with temporary water erosion. In the background is a part of the long, narrow horst Túngnárfjöll.

Fig. 12. Explosion pit in Pytlur, looking along the pit, which is split up by low gravel mounds. After the explosive phase, lava has risen up in the fissure, but only to a certain height, and there have been subsidences during the solidification process.

Fig. 13. A genuine explosion volcano on the banks of Litlisjór, seen from the outside of the gravel cone. Its peculiarity is the presence of large blocks, and thus forms a contrast to the blast crater shown on fig. 14.

Fig. 14. Blast crater in Vatnakvíslagígir, photographed almost from the ridge-top of the gravel cone; in the background are two other volcanoes of the same type and belonging to the same line of eruption. The deepest part of the crater contains a lake, and the cone consists of rather fine-grained material, visibly stratified; cf. fig. 13. The dark, elliptical covering of the inner wall of the cone consists of lava and came from a lava jet which must have been about 150 metres high and which seems to have brought the eruption to a close.

Fig. 15. The edge of the same cone as in fig. 14. Close-up picture of the top of the gravel cone covered with broken up lava from the jet referred to under fig. 14.

Fig. 16. Coherent slag ("Schweiszschlacken") from the innerside of an "eldborg". The splashes of lava have been thrown up on the inner side of the crater in such a state that they have stuck together before cooling, but without losing their individuality.

Fig. 17. Sub-surface canal in the lava at Fiskivötn. The orifice of the canal is seen in the foreground of the picture, the roof having partly fallen in. The lava sheet is covered with a carpet of incompletely decomposed organic remains originating from the characteristic vegetation-covering of moss (Grimmia) and dwarf bush (Salix lanata).

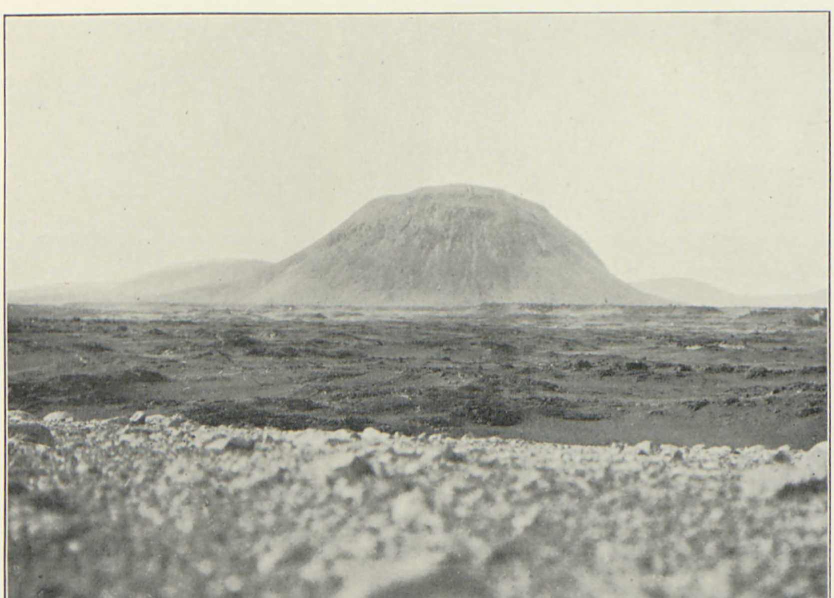


Fig. 18. Háganga syðri, a craterless, liparitic "Staukuppe"?, about 800 metres high. In the foreground is wind-eroded moraine, in the middle distance basaltic lava.

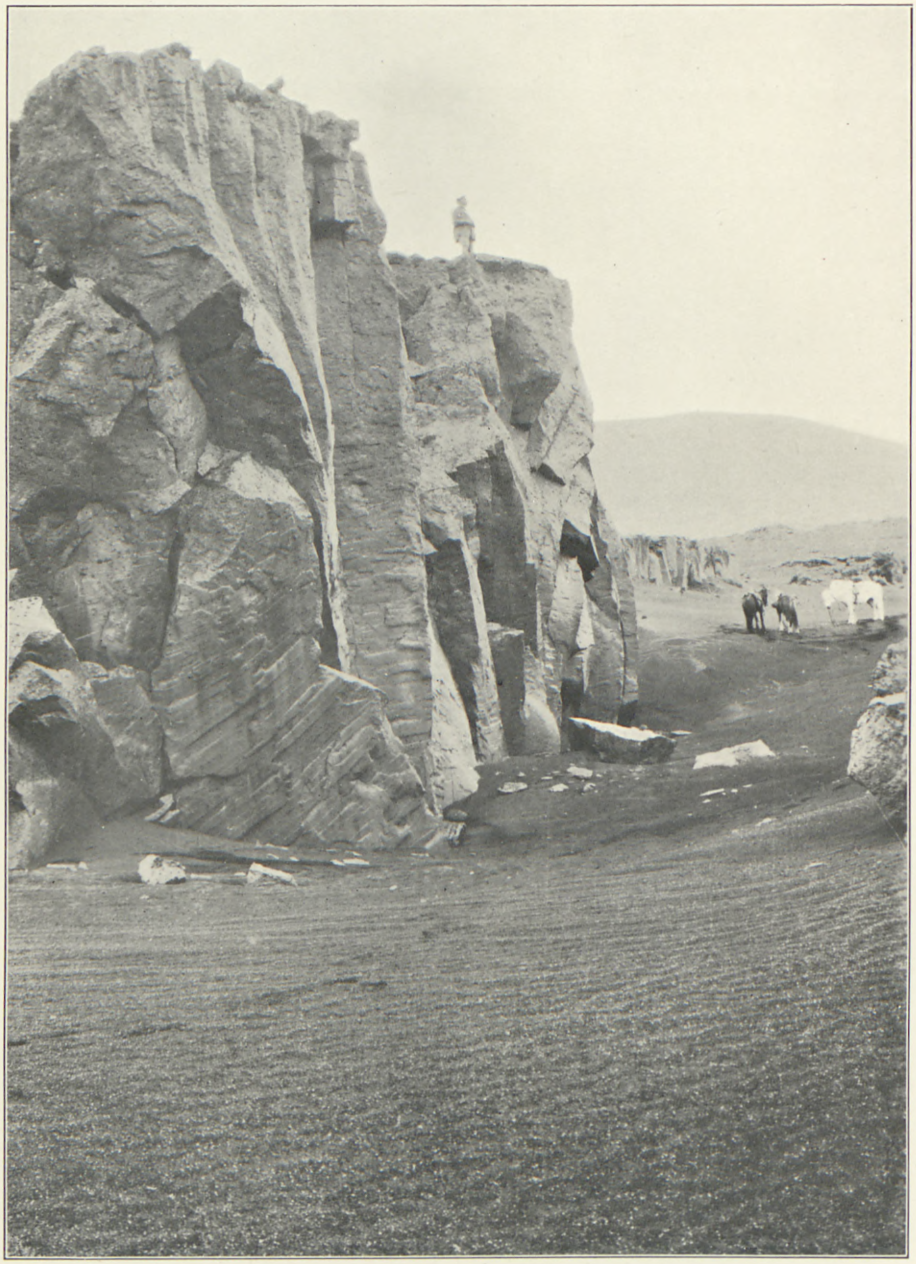


Fig. 19. Heljargjá, a recent tectonic fissure west of Vatnajökull, looking along one edge, which here runs through a field of sheet-lava. The picture is taken from the subsidence depression, the man standing on the extreme edge of the undisturbed lava field. In the foreground wind-borne sand.

Fig. 20. Heljargjá at a spot where the fissure extends through slab lava. The edge of undisturbed lava surface is seen on the right, the subsidence area to the left. During its movement a large slab of lava has tipped over towards the subsidence.

Fig. 21. Heljargjá in Gjárfjall. Here the fault is about 100 metres deep. At the top the edge of the fissure is quite sharp, at the bottom concealed by tipped blocks and later by aeolic material. The wavy line is the track of the caravan, made while descending to the bottom of the fissure.

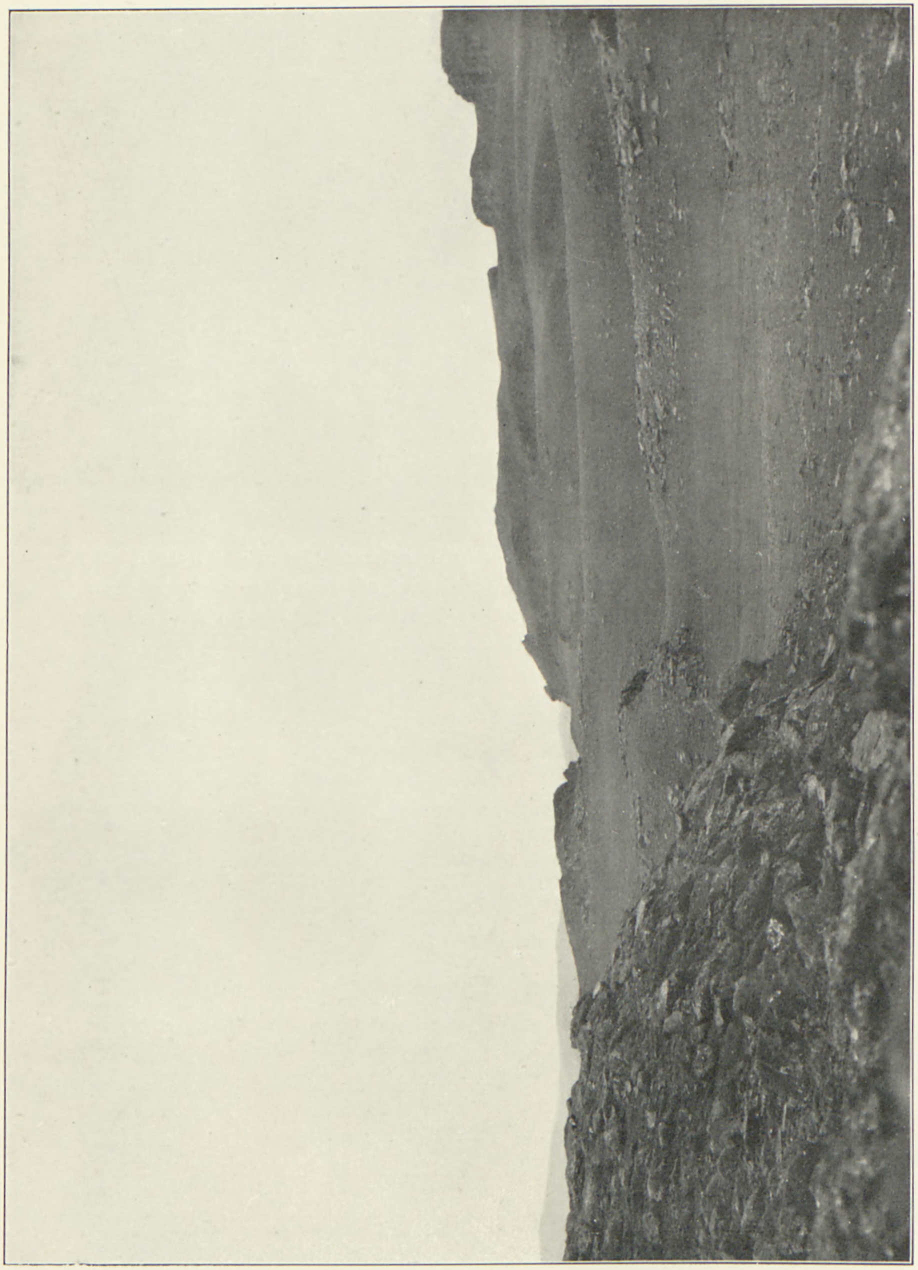


Fig. 22. Recent "champs de fracture" with a close system of parallel fracture lines, which have divided the landscape into narrow, straight-sided strips. The area east of Þórisvatn.

Fig. 23. Túngnárfjöll, photographed towards the northeast. On the left Lake Litlisjór, on the right a part of the bed of the Túngná in a tectonic fissure 2—3 km wide. In between is a view of Túngnárfjöll, a horst about 25 km long, 2—3 km wide, its steep wall forming the right bank of Litlisjór, and its plateau surface distinctly visible. The block in the foreground has on the top an inclined plane: a small plateau surface which has got into its present position through being tipped to the left out towards the subsidence area in which Litlisjór lies.

Fig. 24. A column, over 10 metres high, called Tröllið, probably formed by a combination of tectonic and subaeric processes. The stick in front of the column measures about 1 m. Sterile lapilli surface with an incline of about 12°. Traces of the local and temporary spring water erosion, which has produced a dense, consistent system of melt-water channels 0.3 to 1 m deep. No terracing, cf. fig. 25. In the background Túngná, with one of the transversal barriers (see fig. 35), through which the river has cut a gateway.

Fig. 25. Solifluction surface with terraces at Fiskivötn. Dip about 8°. In the background are steeper slopes with meltwater channels, but without terracing. The landscape is a small part of an explosive area-eruption, the depression on the right being a secondary crater. The material is partly lapilli, but mostly the explosion debris repeatedly referred to in the text.

Fig. 26. Windblown, sterile moraine surface on Holtamannaafrjettur. A doleritic boulder has been split into slabs by the frost; some of the slabs are seen in situ, whereas others have been carried by solifluction down towards the observer. The stick is 1 m high. In the background are several other blocks, similarly disintegrated and split.

Fig. 27. Storm-devastated lapilli surface at Fiskivötn. Almost in the middle of the picture is a small, stunted Armeria in bloom.

Fig. 28. Overgrown lava surface in Þingvallahraun, looking south. Most of the vegetation is Grimmia, its carpet having been torn up by the north gales, which gives the cushions a steep destruction-face towards the north. Cf. fig. 29.

Fig. 29. The same locality as fig. 28, photographed towards the north. The man has not moved between the two exposures. The carpet of moss is apparently continuous and intact, whereas it is actually being torn up by the dry north winds, as fig. 28 shows.

Fig. 30. Wind-erosion from the north-east (the left) in Hekla farming area. View from the southwest end of Skarðsfjall towards the southwest, from a point about 100 metres above the plains. In the left half of the picture is the wind-eroded surface, where the lava has been laid bare; the right half is covered with loess and grass. On the border line between these two surface-forms the local inhabitants have built long dykes of lava blocks, two of which are seen on the picture, one straight, the other curved.

Fig. 31. Wind-erosion in the highland east of Langjökull. In the foreground a patch of continuous vegetation, the edge undermined by the gales. Behind are enormous wind-eroded surfaces, with very sparse vegetation. The surface of the plateau has been raised to the present level by lava of inter-glacial age, eroded by ice during the last glaciation and covered with a thin cap of moraine. The hills in the background, Jarlhettur, appear to be Quarternary volcano ruins. Behind them is a glimpse of Langjökull.

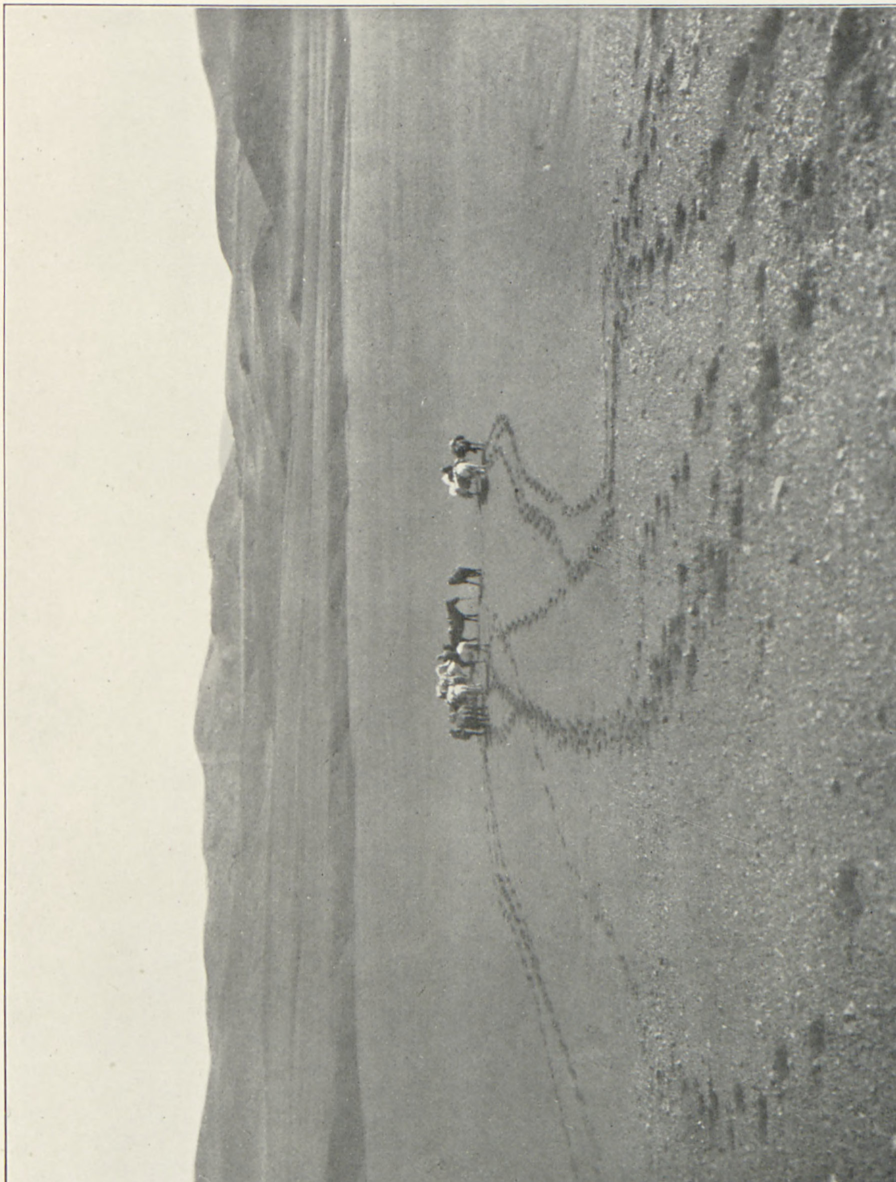


Fig. 32. Polar storm-waste in the high-land west of Vatnajökull. The surface is very modified moraine, the relief is mainly tectonic in origin, but the details are the result of subaeric denudation and aeolic forces in combination with a temporary and local solifluction and snow-melting erosion. A typical example of polar "ennoyage desertique".

Fig. 33. View from Háganga syðri (relative height about 800 metres) over the jökull-river Kaldakvísl's upper course, which is remarkable on account of its great change-ableness. On the left edge of the picture is a recently abandoned bed. In the background Túngnafellsjökull.

Fig. 34. Köldukvíslarbotnar, seen from Háganga syðri (relative height about 800 m). In the background Vatnajökull. The plain is a lava field overlain by recent glaciofluvial deposits. Numerous abandoned river beds.

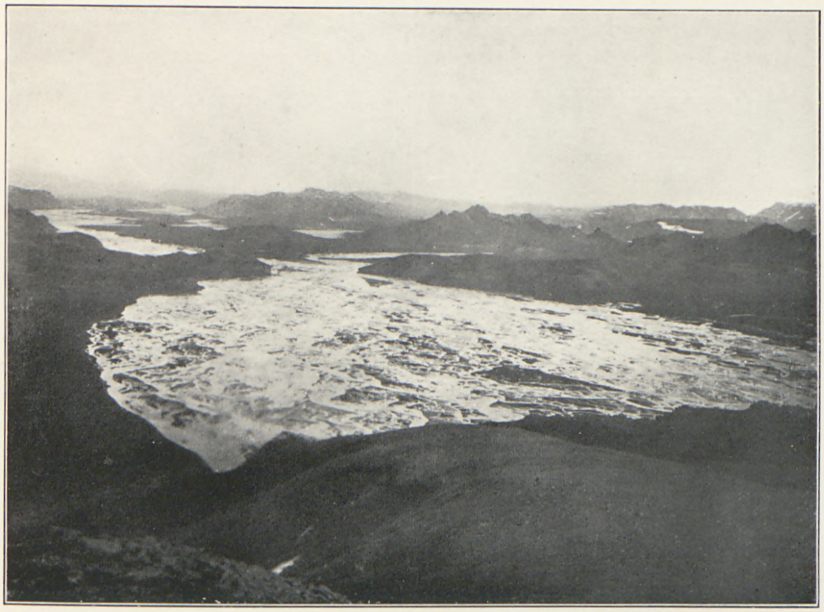


Fig. 35. View over the valley of the Túngná from Túngnárfjöll, showing one of the breaches in a transverse barrier referred to in the text; below it the river spreads out in a large number of arms which enclose very variable quicksands. In the background a region broken up by tectonic processes. The valley is about 2 km wide.

Fig. 36. Outlet from the crater-lake Litla Fossvatn. The waterfall is right in the shore of the lake.

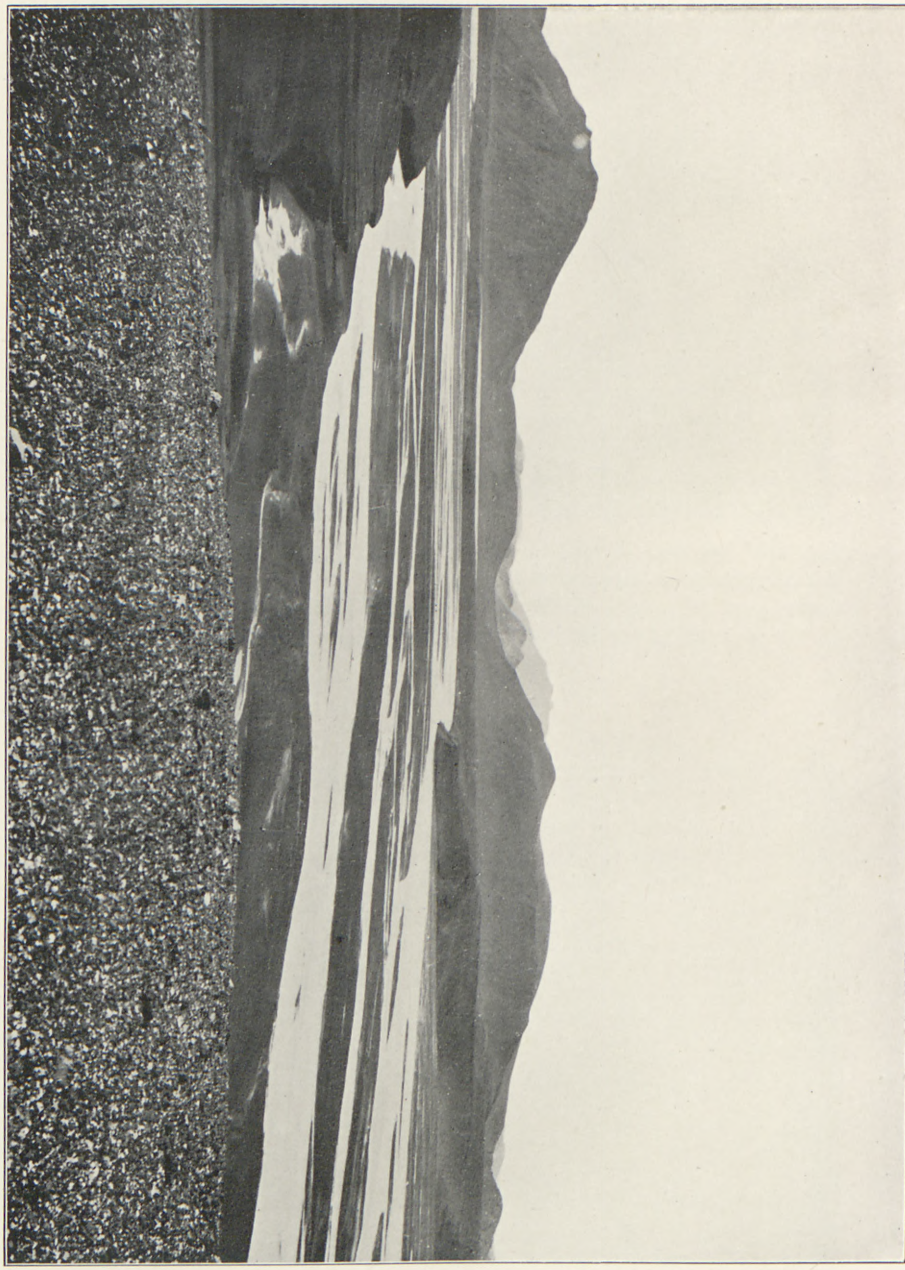


Fig. 37. The Túngná, below where it joins the Námskvísl. The bed is about two kilometres wide. Several arms with intermediate, variable sandbanks. Both the arms and the banks are full of quicksands.

Fig. 38. Hraunvötn west of Litlisjór. The depression is an explosive area-eruption, which has been secondarily filled to a certain height by lava which, while solidifying, has formed numerous subsidence basins which now contain lakes.

Fig. 39. Litlisjór, seen from Túngnárfjöll. The lake has no superficial feed or outlet, and water table is variable and the shores sterile. The basin was formed by the damming up of an explosive eruption in a tectonic basin, one border line of which passes along the mountain foot in the right side of the picture.

Fig. 40. Þórisvatn, seen from the northeast. Only a small part of the main basin is visible; most of the area belongs to the eastern arm, which is a tectonic fissure, its inner part being cut off by a tongue of sand. Almost in the middle of the picture is Þóristindur, and on the right of it Loðmundur.

Fig. 41. Part of Fiskivötn. The foremost lake is Tjaldvatn, and behind it on the left is Skálavatn, on the right Langavatn. The peaks in the background are the great blast craters in Vatnakvíslagígir.

Fig. 42. Snow erosion at Fiskivötn. The snow lies long in the inclined depression which runs from the foreground up to the right of the stick, and thus the bottom is kept moist and moveable untill well into the summer. The mound on which the stick is standing glides down a little every year towards the left edge of the picture.

Fig. 43. Lava oasis at Fiskivötn. Certain lavas provide good shelter, where a continuous covering of vegetation grows, with various forms of growth. The heights in the background are wind-blown and sterile.

Fig. 44. Illugaver, a swampy oasis in a moraine country. A high ground-water table prevents wind-erosion. In the central part of the swamp are many ponds. Drainage to two sides, both right and left in the picture.

Fig. 45. Moraine oasis in Þóristúngur. Purely locally the ground-water table is high enough to prevent wind-erosion. In the foreground is wind-exposed moraine.

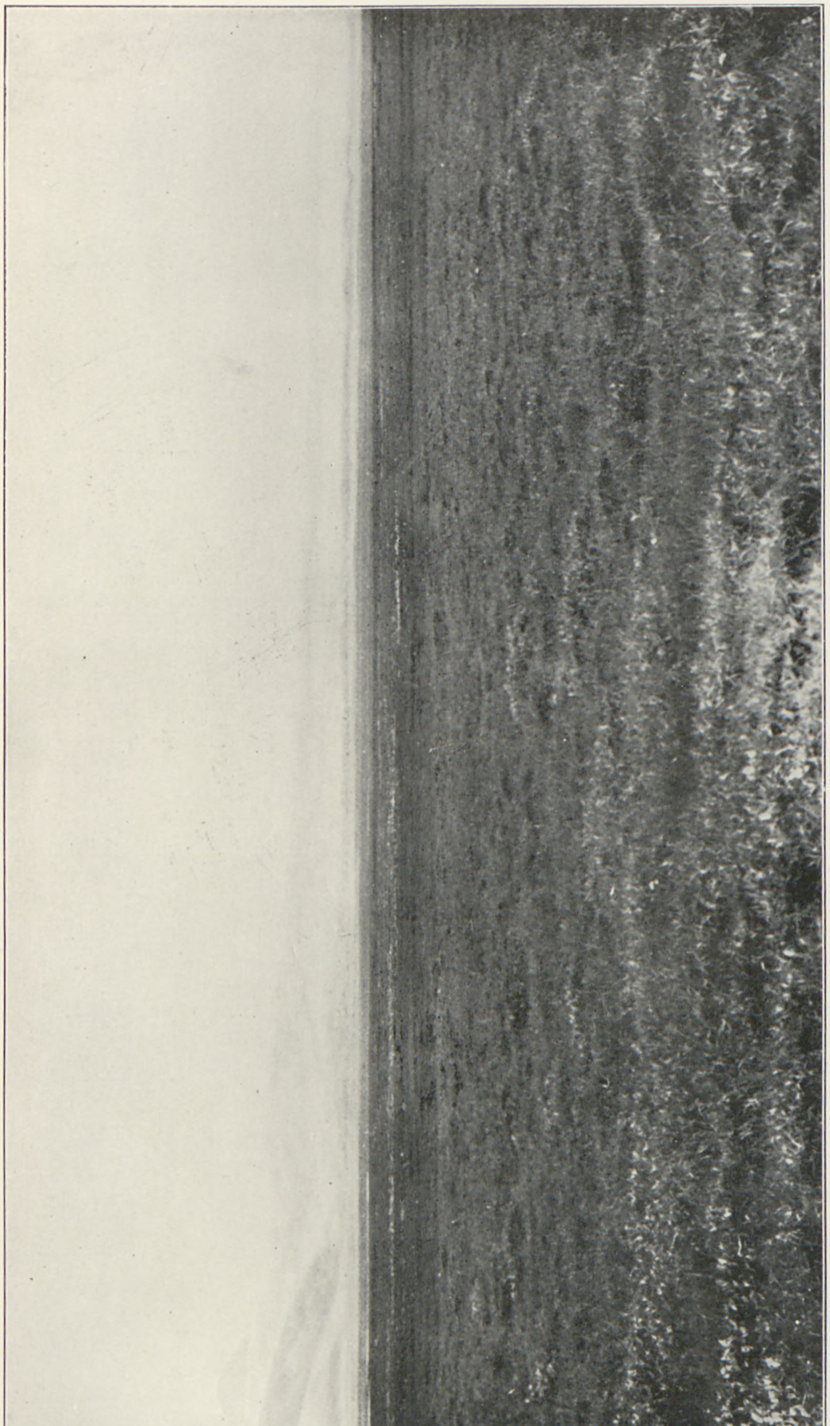


Fig. 46. Glaciofluvial oasis as the south edge of Hofsjökull. High ground-water table, part of it meltwater from the "jökull", prevents wind erosion and creates a possibility for the formation of very large overgrown surfaces. In the background "the jökull" can just be seen.

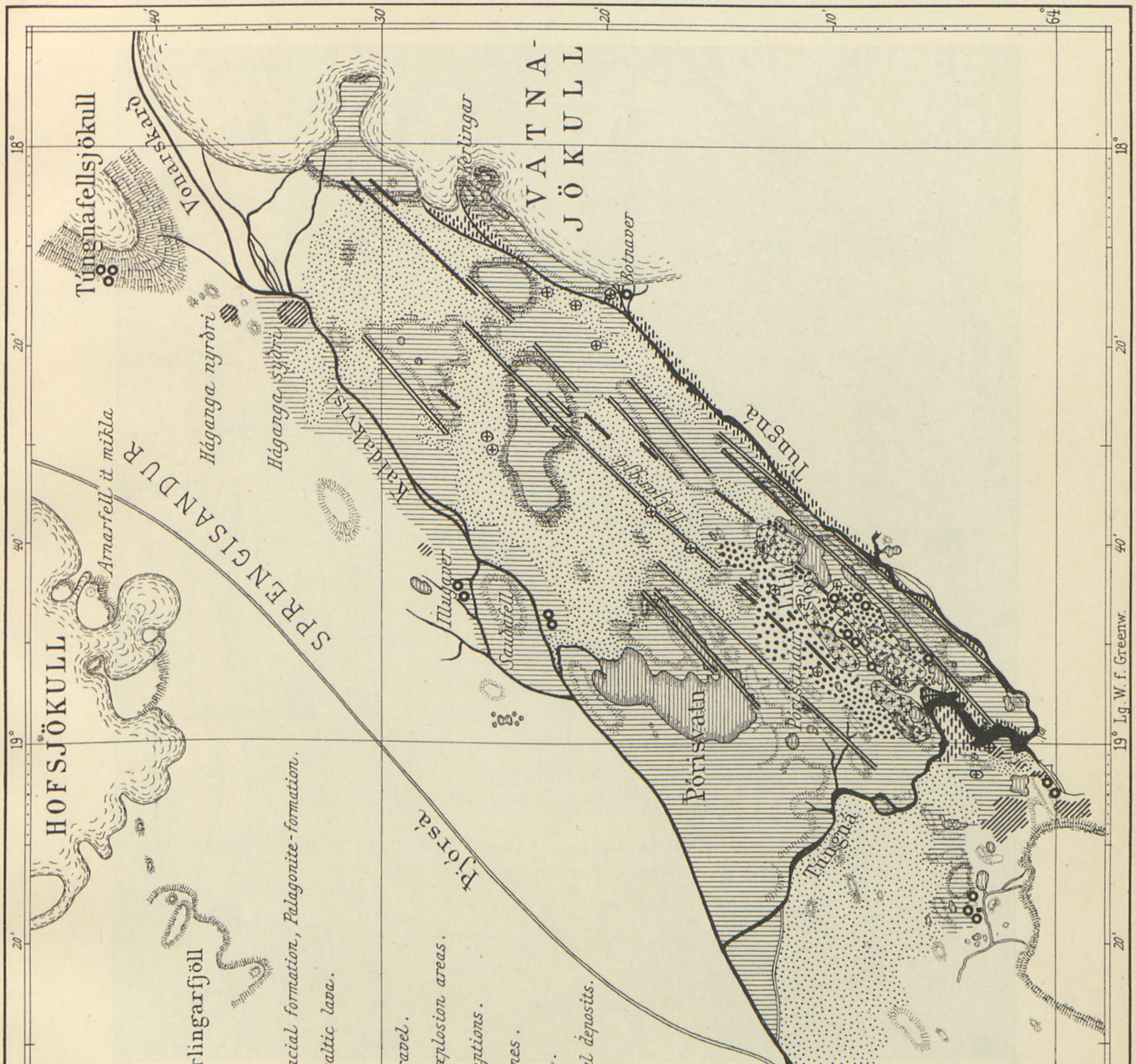
Fig. 47. The mountain Loðmundur á Landmannaafrjetti. Type of a young horst. The walls are steep, not much attacked by erosion, without a trace of glacial erosion. At the top is a plateau. Cf. the following picture, fig. 48.

Fig. 48. The plateau on the top of Loðmundur. An impression of the size is given by the two men on the snow surface.

Fig. 49. View northwards from Hengill in Southwest Iceland. In the right background is þingvallavatn. The surface marked by many straight-lined, parallel faults which have split the terrain into narrow strips.

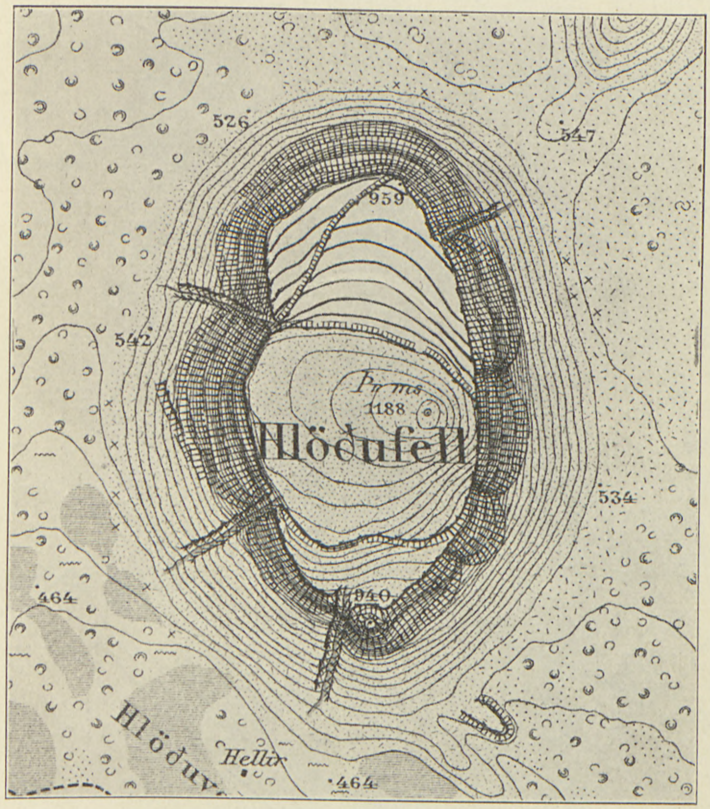
Fig. 50. Hrafnabjörg, NE of Þingvellir. A young, possibly post-Glacial horst, with steep sides and a striated plateau surface on the top practically untouched by erosion. In the foreground post-tectonic lavas.

Fig. 51. The mountain Súlur (Botnsúlur) in Southwest Iceland. Ruin of a Quarternary strato-volcano with strong evidence of glacial erosion. The peak in the middle of the picture is probably an old crater pipe.



Map Nr. 1. Geological map of the region West of Vatnajökull. Topographical survey by Steinþór Sigurðsson, geological survey by Niels Nielsen.

Map Nr. 2. Ingólfsfjall in S.W. Iceland. Scale: 1 : 50000, Equidistance 20 m. Explanation see p. 97, 279.
Reprinted from Nr. 37 Hengill S. A. Geodætisk Institut. København.



Map Nr. 3. Hlöðufell in S.W. Iceland. Scale: 1 : 50000, Equidistance 20 m. Explanation see p. 97, 279 ff.
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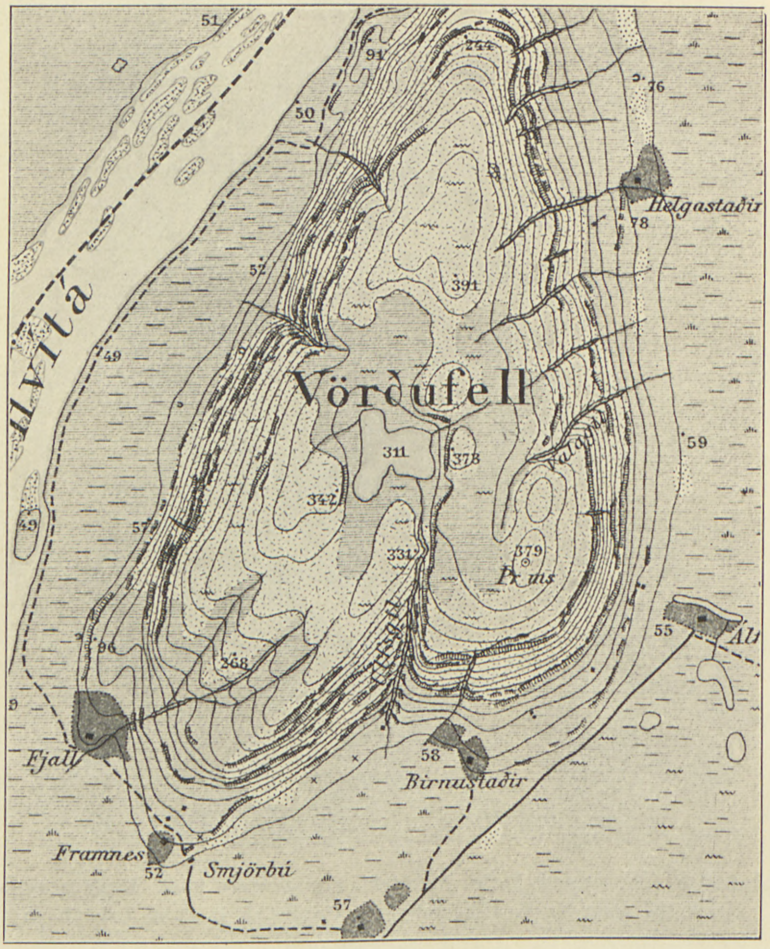
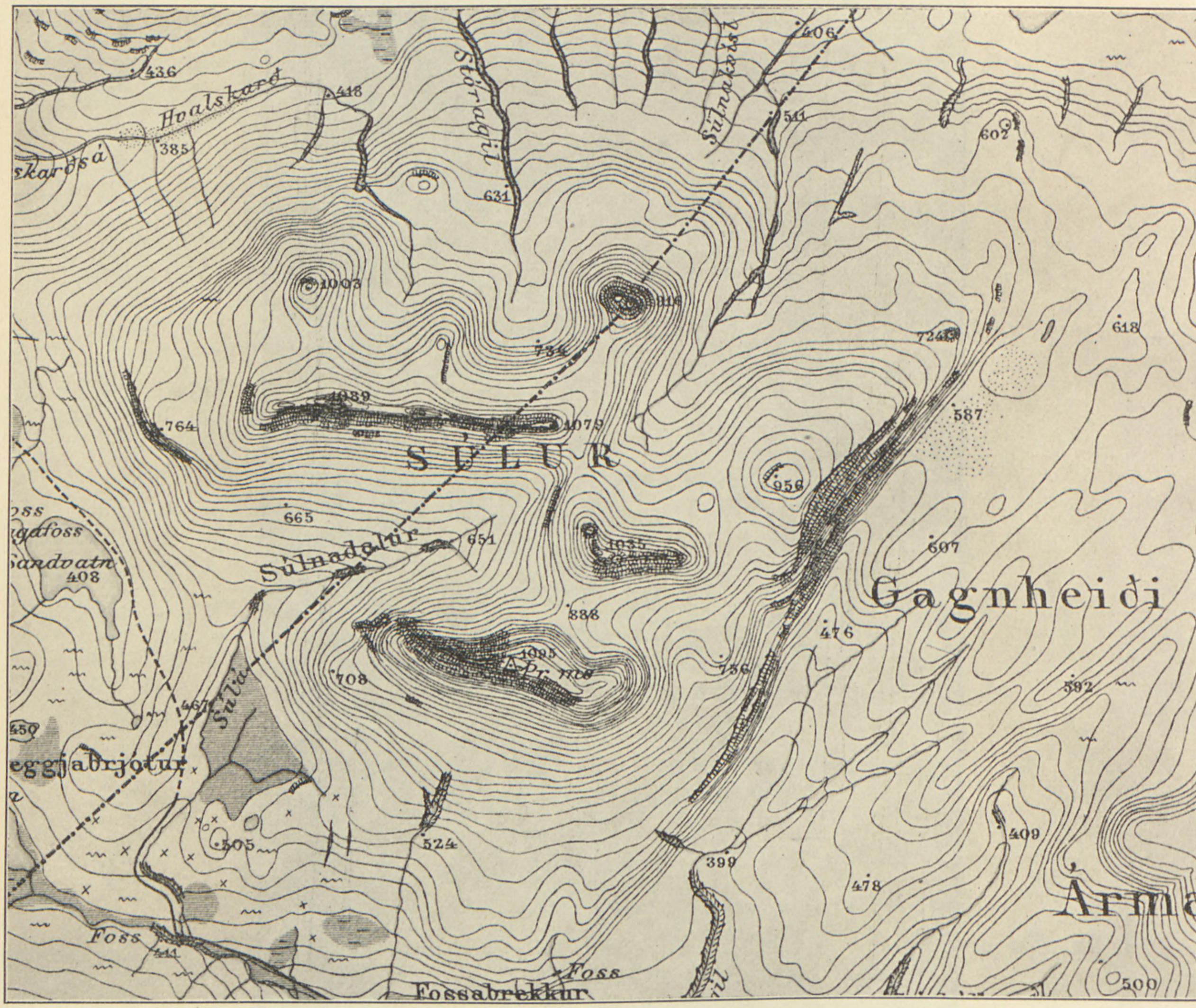


Map Nr. 4. Vörðufell in S.W. Iceland. Scale: 1 : 50 000, Equidistance 20 m. Explanation see p. 97, 279. Reprinted from Nr. 47 Skálholt S. V. Geodætisk Institut. København.

Map Nr. 5. Landscape on the East of Skagafjörður, North Iceland. Scale: 1 : 240 000, Equidistance 20 m.
Explanation see p. 97, 279.
Reprinted from Nr. 52, Skagafjörður. Geodætisk Institut. København.



Map Nr. 6. Súlur (Botnssúlur) in S.W. Iceland. Scale: 1 : 50 000, Equidistance 20 m. Explanation see p. 97, 279 f.
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Map Nr. 7. Hreppar in S.W. Iceland. Scale: 1 : 130 000, Equidistance 20 m. Explanation see p. 95, 277 ff.
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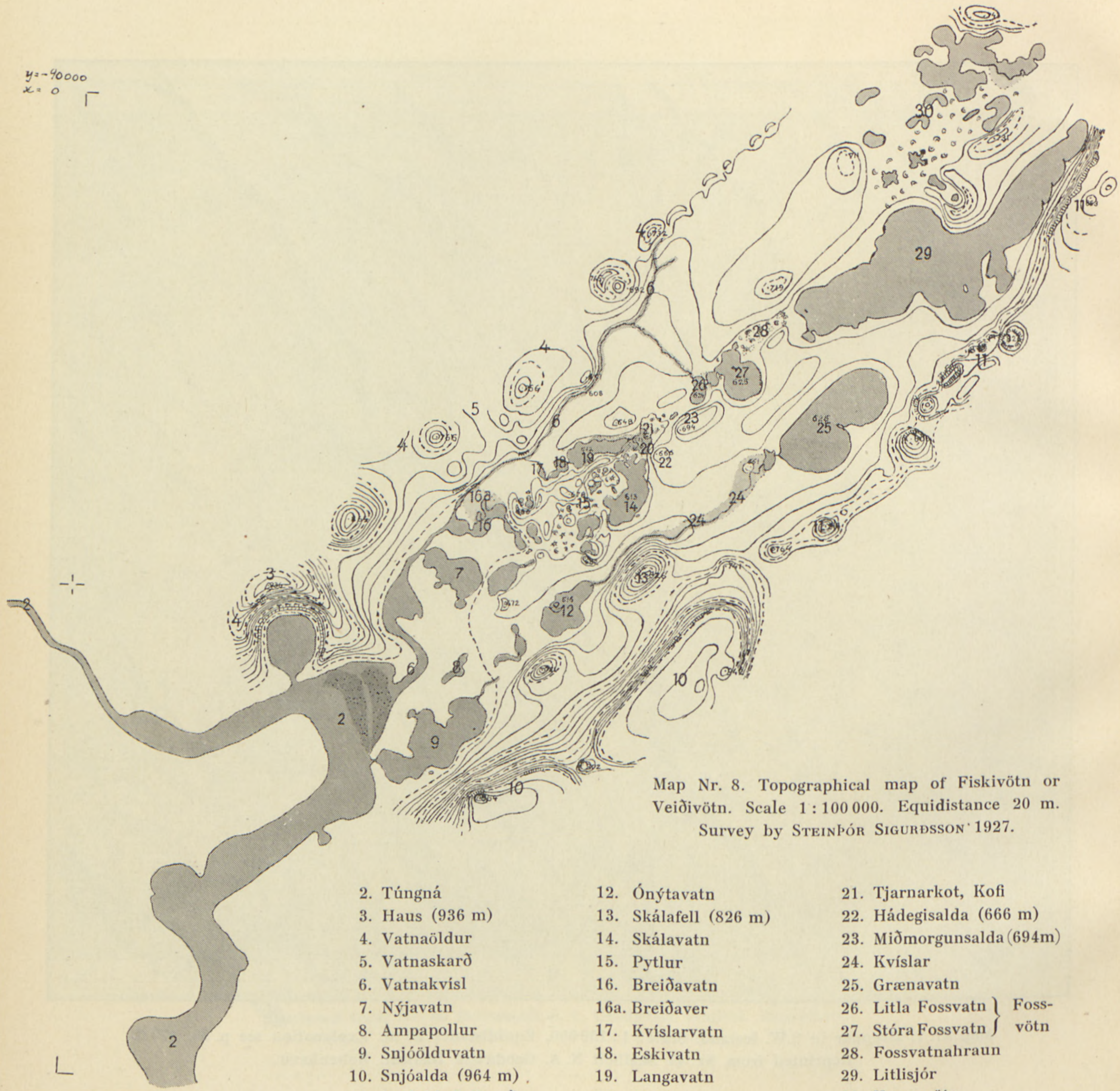
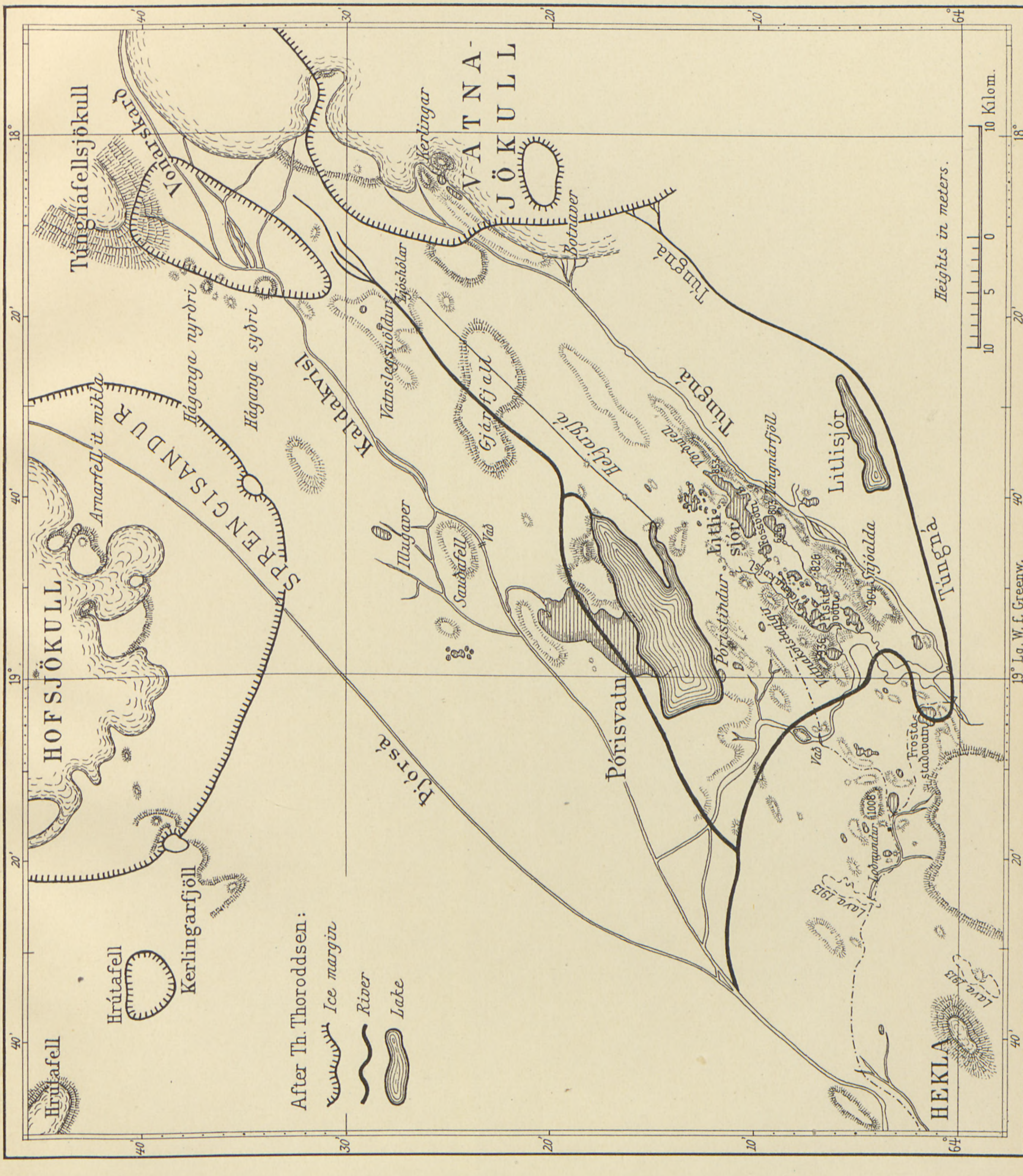


Map Nr. 8. Topographical map of Fiskivötn or Veiðivötn. Scale 1 : 100 000. Equidistance 20 m. Survey by Steinþór Sigurðsson 1927.

2. Túngná
3. Haus (936 m)
4. Vatnaöldur
5. Vatnaskarð
6. Vatnakvísl
7. Nýjavatn
8. Ampapollur
9. Snjóölduvatn
10. Snjóalda (964 m)
11. Snjóöldufjallgarður
12. Ónýtavatn
13. Skálafell (826 m)
14. Skálavatn
15. Pytlur
16. Breiðavatn
16a. Breiðaver
17. Kvíslarvatn
18. Eskivatn
19. Langavatn
20. Tjaldvatn
21. Tjarnarkot, Kofi
22. Hádegisalda (666 m)
23. Miðmorgunsalda (694m)
24. Kvíslar
25. Grænavatn
26. Litla Fossvatn } Fossvötn
27. Stóra Fossvatn } Fossvötn
28. Fossvatnahraun
29. Litlisjór
30. Hraunvötn



Map Nr. 9. Main topographical features of the region West of Vatnajökull as drawn by Steinþór Sigurðsson compared with Thoroddsen's map