The volcanic geology of Vestur – Skaftarfellssysla Iceland

Robson, G. R.

T H E S I S

presented in candidature for the degree of

D O C T O R O F P H I L O S O P H Y

of the University of Durham.

The Volcanic Geology of
Vestur - Skaftarfellssysla
Iceland.

by

G.R. Robson.

Being an account of the work carried out at the Geology Department, Durham University (Durham Division) During the period 1949 - 52 under the direction of Professor L. R. Wager, F.R.S. (1949 - 50) and Professor K.C. Dunham, F.R.S. (1950 - 52).

CONTENTS.

PREFACE.

The writer was introduced to Icelandic Geology as a member of the Durham University Iceland Expedition of 1949.

The expedition consisted of eight members, and was committed to an extensive programme of topographical surveying and meteorological and glaciological work. The object to be studied was the Kotlujokull glacier; the largest of the outflow glaciers of Myrdalsjokull.

The expeditions' programme of work was severely hampered by very poor weather and the major part of the programme was abandoned as the summer wore on. The Expeditions' two graduate geologists were thus allowed more time to study the geology of the area than had at first seemed probable, and it was possible for them to move about the area with relative freedom, albeit in poor weather, by making use of the camps and dumps of food established by the expedition on and around the ice cap. During this expedition the Katla lavas, the Sandfell trachybasalts and the Myrdalsjokull rhyolites were discovered and partially mapped.

The area appeared to offer scope for geological research and so, with the help of Professor Wager and the University Exploration Society, and expedition was organized in the summer of 1950 and the writer returned to Iceland in the company of Mr. P.B. Robinson and Mr. E.A. Timothy of the Durham Colleges Department of Geology. It was decided to extend the work northeastwards from the area studied in 1949, into the country on the eastern border of Myrdalsjokull and into Skaftartunga. A base camp was established on the eastern bank of the Holmsa river near the mountain Einhyrningar. In spite of determined efforts it was found to be impossible to ford this river and gain access to the country to the west except at Maelifellsandur in the extreme north of the area. The base camp was moved to Maelifellsandur from where the whole of the area to be studied was accessible. Because of the remote situation of the base camp it was now necessary to establish subsidiary camps from time to time in the southern part of the area and this involved the movement on foot, by the three members of the expedition, of a considerable part of the expeditions' equipment, food and specimens, of which there was about half a ton.

In spite of these difficulties the lavas of Holmsadalur and the eastern part of the Eldgja fissure were mapped, and the Myrdalsjokull rhyolites on Kotlukollar were visited for the first time. During this expedition the unique features shown by the craters of the Eldgja volcano had engaged the writer's attention, which came to be directed more and more towards the modern volcanics of the area.

In order completely to describe the Eldgja fissure and its lavas a second expedition was organized in 1951 with the help now of Professor Dunham and the University Exploration

Society. The same area was visited with Mr. B.W. Pace. In order that the extensive lava flows of Eldgja could be mapped, horses were bought, and, travelling on horse-back from two bases, one in the north of the area at Alftavotnskrokur and one in the south at Hrifuness, the whole of the Eldgja fissure and its extensive lava flows on Myrdalssandur and Methallandssandur were mapped.

The writer is indebted to many individuals and organisations for their help during the course of this work. In Iceland, to Mr. Jon Eythorsson and Mr. Agust Bothvarsson of Reykjavik, and to Mr. Ardni Johsson of Hrifuness, and to the Icelandic National Research Council for permission to undertake the work.

In England, to Professors Dunham and Wager for their help and encouragement throughout the work; to Dr. E.A. Vincent for instruction in the methods of chemical analyses, to Mr. R. Phillips for kindly undertaking the partial analysis of an Icelandic rock, and to Dr. F.H. Stewart and the laboratory staff of the Durham Colleges Department of Geology for help in the final stages of the work and during the preparation of the manuscript.

The work was made possible through the kind help of the Durham University Exploration Society and by various grants of money from The Royal Society, The Shell Petroleum Company, The Durham Colleges Research Fund and the Durham Colleges

Exploration Society, to which bodies gratitude is expressed for their assistance.

INTRODUCTION.

The Geology of Iceland.

Iceland is formed entirely of volcanic rocks of which the oldest are the Tertiary plateau basalts of the East and West coasts. In the centre of the island basalt lavas, tuffs and breccias, termed collectively the Palagonite Formation, overlie the Tertiary basalts and fill a graben sunk in the basalt plateau, which is between 100 and 200 km. in width, and trends north and south. The Palagonite Formation rocks are themselves overlain in the centre of the island by Post-Glacial basaltic extrusives and pyroclastics.

There is some controversy over the age of the two older groups of rocks and of the graben faulting which intervened. Hawkes (1938) gives the following provisional dates.

1. First Volcanic Period.
   Outpouring of the Thulean plateau basalts, Eocene (Oligocene?)
2. Tectonic disturbance - uplift along a Barthardal fault. Miocene (Oligocene?).
3. Deposition of marine sediments at Tjornes within the central graben. Pliocene.

4. Second volcanic period - Accumulation of Palagonite Formation and later of Post-Glacial extrusives.

Pliocene - Present Day.

5. Glaciation. Quaternary - Present Day.

The Region Studied.

Vestur - Skaftarfellssysla is that part of Iceland between the two ice caps Myrdalsjokull and Vatnajokull. It is bordered to the south by the north Atlantic and to the north by the inland desert. It lies within the Central Graben and thus the oldest rocks exposed are those of the Palagonite Formation. Vestur Skaftarfellssysla is roughly bisected by the river Skafta which flows southward from the northern desert to the Atlantic. It is the western part, that lying between the Skafta and Myrdalsjokull, with which the following account is mainly concerned.

The Geography of the Region.

The region is divisible into three physiographic provinces:-

The Coastal Lowlands. - have been formed by the coalescing of river deltas. These lowlands are a flat sandy waste, some 20 km wide, extending along the entire coastline of Vestur Skaftafellssysla.[1] On to this plain the Laki and Eldgja flows have spread, until now almost half the sandy plain or 'Sandur' has a lava cover 10 - 20 metres thick. This lava has formed a firm foundation for soil formation and has rendered the region, in places, habitable. Periodically the catastrophic melt-water floods from the ice-covered volcano Katla sweep across the south western part of Sandur, depositing fresh layers of sand and gravel and pushing the coastline seawards.

The Highlands. - lie to the north west of the coastal lowlands, and are bounded to the south east by a line of old sea-cliffs which form an abrupt division between the two regions. These cliffs are not present north of Myrdalssandur where the broad, lava-flooded Holmsa valley reaches the Sandur, but are conspiciously present to the north east, where with few breaks they culminate in the magnificent vertical cliffs of Lomagnupur, more than 600 metres high. Behind the old sea cliffs lies an undulating plateau region 400 - 600 metres in height, which forms the drainage basins of the Hverfisfljot, Skafta and Hólmsa rivers. These rivers flow, for the most part, in broad, shallow valleys flooded by recent lava which has made its way through them to the Sandur. The tributary streams, however, have everywhere cut deeply into the soft tuffs, forming picturesque gorges and canyons. The higher parts of the plateau are sparsely vegetated with an intermittent cover of mosses and lichens, growing on a loose pavement of basalt and tuff fragments. The lower and wetter parts, however, support a vegetation of grass and, in sheltered places, a beautiful and varied alpine flora. To the north west this vegetation becomes less and less continuous, finally existing infrequently only in the more favoured localities; the 'Oases' of the central desert. Roughly 60 km. from the coast, to the north west, the topography loses its undulating plateau - like character and becomes much more rugged, as a north east - south west trending range of higher mountains is reached. These hills seem to have been formed by block faulting of the tuffs; the faults lying in a north east - south west direction. The soft tuffs weather rapidly producing rocky crags and peaks on the upper parts of the mountains, which contrast with the smooth, debris-laden lower parts, into which the rivers have cut deep valleys. These mountains form the natural boundary between the vegetated and semi-vegetated plateau of Vestur Skaftarfellssysla and the cold desert to the north.

The two great fissure volcanoes Eldgja and Laki lie along the south eastern border of these mountains. Laki lies within the northern part of the Skafta drainage plateau and stretches, from Vatnajokull in the north east, a distance of 20 km. to the south west. Unlike Laki, however, Eldgja lies within the southernmost mountains, cutting through them from Gjatindur, one of the highest peaks, a distance of almost 30 km. to disappear under the ice of Myrdalsjokull in the south west.

<u>The Ice Caps.</u> with their barren outwash plains, form the natural south western and north eastern boundaries of Vestur Skaftarfellssysla. Though the summer snow line is 1000 metres above sea level and the maximum height of the ice cap only a little over 1400 metres, the annual precipitation is large enough to maintain a stable ice cover down to 700 metres, and glacier tongues to between 100 and 200 metres. The Myrdalsjokull ice cap is a low, broad dome of ice covering a high mountainous mass of tuffs capped in the south east by liparite. The ice cap has only two major outlet glaciers, now almost stagnant. These are Solheimajokull to the south west and Kotlujokull (or Hofthabrekkujokull) to the south east. It is from these two glaciers that the floods pour out which accompany the eruption of Katla. Though Katla has erupted fourteen times since the year 900, there has always been some

uncertainty about its exact position because of its ice cover. However, observations on the ash column from Katla were taken by the people of Vik in 1918, and recently rediscovered by the Icelandic glaciologist Jon Eythorsson, which makes it possible to place the volcano with reasonable accuracy. (This position is marked on Maps 1 and 11). It is significant that Katla lies on the line of the southern section of Eldgja.

PART 1.

THE VOLCANO ELDGJA.

HISTORICAL.

The colonisation of Iceland was begun in the tenth century by members of the Norwegian aristocracy with their families who, for political reasons, were forced to flee their native land. The colonists preserved their cultural traditions in Iceland, part of which was the recording and and preservation of the clan history as narrative poems or sagas, and hereby much of Iceland's early history has been preserved. While the sagas are for the most part a record of clan feuds, where natural events disturbed the lives of the colonists, these have been recorded. Thus in the Landnamasaga (The Saga of the Settlers), dating from the tenth century, the author says in verse 373 - "Hrafn hafnarlykill was a great viking; he went to Iceland and claimed the land between Holmsa and Eyjara. He called his farm Dynskogar. He foresaw the coming of an eruption and moved to Lagey. And in verse 375 - "Molda - Gnupr ... claimed land between Kuthafljot and Eyjara and the whole of Alptaver. At that time there was a big lake and good swan-hunting. Molda - Gnupr sold land to many people from his claim and the district was thickly populated until an earth-fire came. Then they fled westward to Hofthabrekka and camped there in a place called Tjaldavollur".

These early settlements have been long since abandoned and there is some uncertainty about their exact position; it is certain however that both were on Myrdalssandur. Recently an attempt has been made by Sveinsson (1948) to trace the history of the first settlers. He states that these events probably took place between the years 900 and 930; he suggests that Eyjara may be an older name for the (river) Blautakvial; he points out that part of the Sandur is called Dynskogar even today and believes that this is where Hrafn had his farm. Eyjara and Dynskogar are marked on Map 1 and from their position it appears that it was the southern part of the Holmsa valley and the northern part of Myrdalssandur that Hrafn owned. Hrafn apparently took flight before an impending eruption and moved westward. The place of refuge, Lagey, is not known but is thought to be on the western part of Myrdalssandur.

Molda-Gnupr probably owned all of Myrdalssandur south of Hrafn's land "between Kuthafljot and Eyjara and the whole of Alptaver." It is significant that his land became thickly populated, for it shows that southern Myrdalssandur was good grassland, this in turn implies that at that time there had been no flood from the sub-glacial volcano Katla for a considerable period of time. Apparently Molda-Gnupr had less foresight or greater hardihood than Hrafn, for it was not until lava, "earth-fire", approached, that he fled, like Hrafn, to the westward and established himself at Tjaldavolur in the hills on the western border of Myrdalssandur.

There are only three volcanoes which, if they erupted, could have caused the flight of the settlers, these are, Laki, Katla and Eldgja. An eruption of Laki is most unlikely to have caused the flight, for the latest of its pre - 1783 flows pre-dates the Methalland flows of Eldgja. Katla is unlikely to have caused the flight because, while both Krafn and Molda-Gnupr lived close to the eastern border of Myrdalssandur, both chose to cross it and fly to the west, and the floods which inundate Myrdalssandur when Katla is in eruption would have prevented this. Probably, then, an eruption of Eldgja was responsible.

Some of the above arguments are those of Thoroddsen (1925) who, however, applies them in much more detail in the belief that there has been only one major eruption of Eldgja and that this took place early in the tenth century. The author's mapping in Skaftartunga has shown, that there have been at least four major extrusions of lava from Eldgja into the Holmsa valley, and that at least four lava flows have reached Myrdalssandur, south of Sandfell, after flowing over the ice-cap from Katla. There is good reason for supposing that the successive extrusions from both volcanoes were separated by considerable periods of time. Thoroddsen (1925) states that both Myrdalssandur and Methallandur had been settled by the 12th century, and, as there is no record of eruptions in Skaftartunga, other than those of Katla, in the later sagas, and no record of lava from any volcano, it is very probable that the four Katla lavas were erupted long before the tenth century and that it was the last flow from Eldgja which caused the flight of Hrafn and Molda-Gnupr.

The evidence suggests that both Eldgja and Katla have been erupting for several thousands of years, and that the last eruption of Eldgja occurred not later than the tenth century.

EARLIER WORK.

It was Thoroddsen who discovered the volcano in 1893. Impressed by the sight of the Gjatindur crater, he described the fissure as cutting through the mountains as though they were made of cake, and gave the volcano its name Eldgja or Fire-Rift. Thoroddsen spent some time working on the volcano that year and published a description (Thoroddsen 1906) in which the main features of the fissure are described; its length, trend and crater forms. He particularly comments on the frequent differences in height between the opposite sides of the crater walls and on the unusual southward dip of the palagonite tuffs of Svartahnuksfjoll, which dip into the fissure. He states his views on the origin of the fissure as follows. "It seems almost as though the cleft was formed in several steps, first it was small and the lava flowed out quickly to either side along its length, then on the occasion of a new earth-quake the cleft was widened considerably, and then, from the sunken magma level, streams of lava flowed out through breaches in the walls." Thoroddsen correlates the lavas of Myrdalssandur, Methalland and Landbrot with Eldgja, estimating a total area of 693 sq.km. and a volume of 9.3 cub.km. for them, and finally states that his historical researches lead him to believe that the date of the eruption was about 930 - 950 shortly after the first Norwegian settlers landed in Iceland.

In the year following the publication of Thoroddsen's paper, Sapper visited the volcanoes Laki and Eldgja. Sapper travelled on foot along almost the whole length of Eldgja and his paper (Sapper 1908) contains a description of the features of each crater in turn. His descriptions are based on an interpretation of the fissure as a line of explosion craters. It is possible that Sapper was influenced in his views on these crater forms by the explosive eruption of the fissure Tarawera (to which he later refers) in New Zealand, which had occurred in 1886, and whose craters resemble those of Eldgja. Thus in discussing the Svartafell craters he says - "It is clear that these formations can only have been formed by explosions; that these explosions can only have taken place at the end of the volcano's history is proved by the crushing of the lava scoria layers; but where the vents are from which the lava and bombs came, I was unable to determine; as the recent layers of ash obscures their exact position."
In discussing the great crater on the northern shoulder of Axlir he says - "Lava flows and masses of slag extend over the breccia on either side, in parts about 20 m. thick. It is clear that these cover a strongly eroded basement. As these lavas are to be seen even high on the hill summit they must have been extruded before the beginning of the eruption of Eldgja, from vents which are no longer recognisable or not yet recognised." Finally when discussing the Gjatindur crater

" ... broad bands of smooth lava have flowed down from above over ... (the crater) ... slopes to the bottom. Thus proving that these have been outpourings of lava after the explosions. In one case I could see from afar that to one side of the fissure, on the plateau, lavas had been poured out, and, from their shape, that they had flowed down into the fissure. In all other places the source of the flows was unrecognisable." Sapper refutes Thoroddsen's suggestion that the floor of the great Gjatindur crater is of basalt thinly covered by alluvium saying "Thoroddsen says that the floor consists of lava but is largely covered by boulders and sand, but I did not succeed in finding any lava there apart from the hornitos. Besides, the structure of the ditch corresponds to that of the other explosion craters and ditches, i.e. tuff and lava lying on breccia and breached by explosion." Sapper identified the fault continuing the line of Eldgja to the northeast, saying "There seems to be a remarkable fault stretching to the north east as a continuation of Eldgja, at least I could distinguish the dislocation which faults of small throw usually cause."

Commenting on the views of Thoroddsen already quoted, Sapper says ... "I agree with Thoroddsen in his supposition that the formation of these structures took place in several stages, and in part, the extrusion of the first lavas may have taken place as Thoroddsen imagines - from a cleft which was small at first and situated where now the ditches and crater rows occur. In other parts, however, this is impossible as at V"(Axlir)" or P"(Morauthavatnshnukar)" or K"(Svartafell)" where the lavas resting on the breccia basement slope upwards as well as downwards from the edge of the fissure. In this case the lava must have been extruded from vents above and apart from the fissure." Sapper does not state his conclusions in detail but they appear to be that the lavas along the fissure which dip away from the crater are pene-contemporaneous with the craters while those which have an apparent inward dip are later extrusions from other fissures.

Further work on Eldgja by Thoroddsen was published posthumously, (Thoroddsen 1925). Though he refers to Sapper's paper he does not insist on his own interpretation, but deals at length with the question of the age of the Eldgja lavas.

GENERAL FEATURES OF THE ELDGJA ERUPTIVE PRODUCTS AND CRATERS.

The Ejecta.

The ejecta are those eruption products which were thrown out with more or less violence by the escape of magmatic gases from the craters. Following Stearns and Macdonald (1946) they are placed in three groups.

1. Essential Ejecta. These are the ejecta which were expelled in a fluid state and are derived from the erupting magma. They are of two kinds - ash, and pahoehoe slag.

The ashes occur as loose, shifting deposits of black, highly vesicular basalt glass. The compenents grade in size from fragments 2 cm. in diameter to the finest dust. They occur extensively over much of Skaftartunga, principally as secondary deposits in the Holmsa and Skafta valleys and also in enormous quantity on the coastal plain, which is formed primarily of basaltic ash transported from the interior.

The ashes of Eldgja and those of the neighbouring basaltic volcanoes can not be distinguished in the field and it has been impossible to determine the distribution and volume of them.

The present wide distribution of the ashes, their glassy nature and their high vesicularity, show that they have been thrown from the craters to great heights and have been very rapidly cooled. It is suggested here that such ashes are formed as clots of highly gas-charged magma from the lower levels of the conduit and are thrown violently upwards by the gases escaping from the craters. As the gases within the clots expand, the basaltic liquid is violently inflated and finally fragmented, producing highly vesicular sideromelane ashes.

The ashes which, together with pahoehoe slag, form the fragmental deposits between the crater walls are unusual in two respects. They are usually red in colour and are formed dominantly of opaque tachylite and not sideromelane. These peculiarities are thought to be the result of the re-heating of sideromelane glasses by the simultaneous accumulation near the craters of hot pahoehoe slag. This re-heating having allowed the iron ores to separate within the glass in sub-microscopic particles rendering it opaque, and the oxidation of the outer parts of the heated glass converting the iron ores to haematite.

Pahoehoe slag is found most commonly in the craters in several related types of deposit. Its chief characteristic in the field is a smooth, rounded, outer surface and a highly vesicular, cellular interior. It is formed of tachylitic basalt with few immature crystals. The most common deposits are those in the crater walls between the older lava flows. These are poorly bedded accumulations of ashes, of the type described above, and of pahoehoe slag. The slag assumes a great variety of shapes; from rounded pancake-like masses to elongated entrail-like and ribbon forms. The slag masses are discrete and not interconnected and are almost always flattened vertically and elongated horizontally. They are usually less than twenty centimetres in length, though larger masses up to 0.5 metres in length do occur rarely. While the upper surface of individual masses ise smooth and rounded, the lower surface commonly fits closely over the underlying ash and slag and not uncommonly is welded to them. The outer surface of the slag fragments of the crater walls is normally red in colour, occasionally this colour penetrates the entire slag mass, and rarely layers of entirely black slag occur.

Deposits of this type occur in Hawaii and have been recognised there as the products of "fire-fountaining" in the active vents. The interpretation placed upon these deposits here is that the magmatic gasses escaping from the craters throw out clots of liquid magma from the uppermost layer of the conduit where the basaltic liquid is only moderately rich in volatiles. The expansion of the volatiles is not sufficient to cause the clot to disintegrate and a cellular inner surface structure is assumed. During the flight through the air the smooth, rounded outer surface is preserved and the hot plastic masses fall on the outer surface slopes of the craters to form deposits of the type described. Where accumulation is rapid the deposits maintain a high temperature and oxidation and reddening proceeds throughout the entire accumulation. Less rapid accumulation produces a surface reddening only, and slow accumulation a relatively rapid cooling and an absence of reddening.

A thick accumulation of slag and ash with some interbedded lava in Crater Q, is shown in Plate 17.

Where, as in the senile stage of the activity of Eldgja fire fountaining occurs on a small scale and from small vents, walls or cones of pahoehoe slag are built up around these vents. The materials of which these walls and cones are built is very similar to that interbedded with the older lavas in the walls of the craters, but it is not usually reddened and has little or no ash content. Typical minor accumulations of ash and slag are shown in Plates 1, 4 and 5, and 21 and 22.

Where the influence of escaping gases from minor vents is small, driblets of gas-charged lava ooze from the vents and build up driblet cones or spiracles over the vents. One such is shown in Plate 2. The material of which the spiracles are formed is very similar to that forming the minor cones already described, but in this case miniature flows of lava mingle with the isolated clots. This type of accumulation marks the transition between pahoehoe slag and pahoehoe lava; between the Ejecta and the Flows.

2. Accessory Ejecta. These are those ejecta which were erupted in a solid state and were torn from older rocks related to the erupting magma from the walls of the conduit. They are relatively rare among the Eldgja ejecta. Occasional reddened and angular fragments of basalt occur with the essential ejecta in the crater walls, but these form a very small proportion of such deposits (not more than 3 or 4 per cent). Only one deposit, which forms the upper layers of Crater O, contains important quantities of accessory ejecta. The deposit consists principally of black glassy ash and tachylitic basalt fragments, a few centimetres in diameter, with occasional angular blocks of fine grained basalt 20 or 30 centimetres in diameter. Somewhat larger blocks of Palagonite Formation tuff also occur. This deposit is believed to be a breccia deposited by explosive activity in Crater O. That this is the only deposit of its kind

seen at Eldgja, and that Crater O is one of the smallest of the Eldgja craters, suggests that explosive activity has not been an important factor in the formation of the Eldgja craters.[1]

3. Accidental Ejecta. These are those ejecta, erupted in the solid state, which are unrelated to the erupting magma and formed part of the basement through which the eruptions occurred. These ejecta too are very rare at Eldgja. Apart from the deposit at Crater O described above, only one other occurrence of accidental ejecta is known, and this is at Crater D. Here, overlying the older volcanics of the crater walls, a few composite bombs, with cores of Palagonite Formation tuff within a thin skin, of basalt, occur. It seems likely that these bombs resulted from the crumbling of the walls of this high crater as the lava level within it fell, due to overflow at lower levels on either side. These bombs are associated with pahoehoe slag and their eruption probably accompanied fire fountaining before this crater became inactive.

The Lavas.

The lavas are those fluid products of the eruptions which have flowed quietly away from the craters in spite of the liberation of enormous quantities of volcanic gas within the c. raters themselves. This relatively tranquil extrusion shows that, within the craters at least, the liquid lava had very low viscosity. The great distances (up to 50 kilometres) over which some of the lava has flowed shows that this low viscosity was retained for a considerable time afterwards.

The low viscosity of the lavas implies that the confining pressure tending to maintain the gasses of the lava in solution can not greatly have exceeded atmospheric pressure, and as the solubility of these gases (principally water vapour) in silicate liquids is very low at atmospheric pressure it follows that the lavas left the craters with a very low gas content, which must have steadily fallen to even lower values as long as the low viscosity was maintained. These theoretical considerations find some confirmation in the structures shown by the lavas.

For descriptive purposes the Eldgja lavas are best divided into two groups; the crater lavas and the major flows and valley lavas.

<u>The Crater Lavas.</u> These are all relatively thin flows; usually less than five metres in thickness. They occur in two groups; in the crater walls and on the

crater floors. The lavas of each group differ in structure.

The lavas of the crater walls are in their upper parts very similar in structure to pahoehoe slag. A thin and fairly level surface layer occurs, which is commonly smooth in the thinner flows but may be much contorted in the thicker ones. Beneath this thin skin is a highly vesicular layer exactly similar to the inner parts of pahoehoe slag; this layer varies from a thickness of a few centimetres in the thinnest flows to a few tens of centimetres in the thickest. These upper layers are commonly reddened. The vesicular layer passes downwards quite abruptly into the main body of the flow which is a dense, fine grained, greyish-black basalt with rare spherical vesicles, usually in the upper part. The thickest flows appear to show the greatest uniformity in structure in this part of the flow. The thinner flows on the other hand occasionally show streaks and lenticles of darker basalt in lighter, and the reverse. A few thin flows are porous with innumerable very small cavities of irregular shape distributed throughout them. Some of these may show streaks of dense basalt in porous basalt and the reverse and some thin flows show common vesicles in the inner part of the flow. It is worth noting that the pore spaces and vesicles of these Eldgja basalts, and of those to be described, never contain mineral infillings, in fact amygdales are entirely absent from the modern lavas of Skaftartunga.

The lower surface of these flows is similar to the upper. The fine grained basalt core gives place downwards, and again quite abruptly, to a highly vesicular layer similar to the inner part of pahoehoe slag. This layer is thinner than the corresponding upper layer and rarely exceeds a few centimetres in thickness. A thin skin corresponding to that of the upper surface is rarely present, however, and the vesicular lower layer commonly passes downwards into a jumble of broken highly vesicular basalt fragments and ash, through a thickness of a few centimetres. Like the upper layers the lower vesicular layer is normally reddened.

Jointing is common in the thick flows but less so in the thinner ones. The jointing tends to be vertical, or normal to the flow surfaces, but is irregular and never approaches in character the columnar structures which are found in other Eldgja flows.

The lavas of the crater floors are markedly dissimilar in structure from those of the walls, and their upper and lower surfaces never resemble pahoehoe slag and are very rarely reddened. Their upper surfaces are almost perfectly horizontal - often for several hundred metres. The surface texture is much coarser than the very smooth pahoehoe surface and is often pitted by the bursting of vesicles. Occasionally the surface has been wrinkled to form typical 'ropy' structures. Sections through these lavas are rare, but those examined suggest that these lavas are relatively thin; only a few tens of centimetres in thickness, and are commonly vesicular throughout. The vesicles themselves are large and often streaked horizontally. Where this occurs the greater axis of the vesicle is rarely more than three times the smaller.

There is no marked differentiation of structure at different levels in units of these lavas and they pass uniformly from a sharp upper surface with no concentration of vesicles and no reddening to a sharp lower surface without concentration of vesicles and without reddening. These lavas may follow one another without intervening fragmental deposits of any kind; the upper lava fitting closely and uniformly over the lower, though occasionally thin deposits of black ash occur between them.

The jointing in these lavas is irregular and vertical. The writer believes that the difference in structure shown by these lavas is due essentially to differing gas content. It seems likely that the lavas of the crater walls were highly fluid at the time of their extrusion and such volatiles as they contained quickly separated to form a basaltic froth on the outer, principally the upper, surfaces. A dense, relatively dry, silicate liquid remained in the centre of the flows insulated by the frothy upper and lower surfaces. If this simple hypothesis is near the truth the approximate quantity of volatiles in the lava at the time of their extrusion can be estimated from the relative thicknesses of the vesicular layers and the dense central layers. If the volume of the vesicles is about one tenth of the total volume of the flow, the volume of the volatiles contained in the lava must have been about ten per cent of the volume of the lava, that is, if they consisted principally of water vapour, 0.003% by weight. This low value is not surprising in view of the low solubility of water vapour in silicate liquids at low pressures. It implies that, if the erupting magma contained 4% by weight of water, 99.9% of this escaped from the craters, and that for each cubic metre of lava extruded about one hundred cubic metres of water vapour were liberated from the craters.

The lavas of the crater floors appear to have been much less rich in volatiles than those of the crater walls, and it seems likely that they were derived from the upper levels of the magma conduit whence nearly all the volatiles had been lost. It is fairly clear that while the volatiles were lost this lava was maintained at a high temperature for it has been fluid enough to cover the crater floor as a succession of thin and extensive sheets.

Though these lavas are characteristic of the craters and occur most frequently in them, they are not confined exclusively to them. On Maelifellsandur for example they are found overlying the major flows, where they have flowed through breaks in the walls of craters A, B and C.

The Major Flows. These are the voluminous extrusions of lava which have flowed southwards through the Holmsa and Skafta valleys and ultimately spread widely over the coastal plains. Unfortunately these lavas are greatly obscured by secondary accumulations of modern volcanic ashes. Good sections through them are found only in the Holmsa valley, and the upper surfaces are exposed only occasionally where, for some reason, ashes have not accumulated.

Unlike those of the craters, the valley lavas end somewhat abruptly in steep lava 'fronts'. These lava fronts are conspicuous even when the lavas are ash covered and much reliance has been placed on them in deciding the limits of individual flows.

Because of the relatively poor exposures it has not been possible to examine the structure of a single flow over the whole of its length. However, in the occasional exposures which are available, it is possible to see a systematic change in the structure of the flows as their distance from the craters increases.

Near the craters and in the Holmsa and Skafta valleys the major flows appear to have an average thickness of about 20 metres. In structure they appear to resemble closely the lavas of the crater walls. Immediately south of the craters, on Maelifellsandur, Alftavotnskrokur, and in the Nythri Ofaera valley, only the upper part of the highest lava can be seen. It consists of highly vesicular reddened basalt very similar to the upper layers of the crater wall lavas, but up to five metres in thickness. This layer passes abruptly into massive basalt with few vesicles and irregular vertical jointing below. Above the upper vesicular layer the lava carries a layer of debris a few metres thick, which consists principally of black vesicular ash and black and red pahoehoe slag. In addition, scattered extensively over the flows, are blocks of coherent red pahoehoe slag which occasionally include layers of lava about a metre in thickness. The largest blocks are ten or more metres in diameter and up to seven metres in thickness. They occur only on the surface of the major flows at distances up to five kilometres from the craters. Some of these blocks are seen in Plate 29. The material of which they are formed resembles exactly the slag and lava of the crater walls and there can be no doubt that originally they formed part of these deposits. Thus an explanation for their present wide distribution is required. It is most unlikely that blocks as large as these and with, relatively, such slight cohesion could be distributed by explosion and have survived the explosion and impact. It should be noted too that they occur only on the surface of the major flows. It is much more likely that they have been transported from the craters on the surface of the major flows. The major flows together have a volume of over ten cubic kilometres and it would not be surprising if some disintegration of the crater walls had taken place as this great quantity of lava flowed from the craters. The blocks clearly mark the major flows as later extrusions than the lavas of the crater walls.

It seems likely that much of the loose slag on the lava surface may also be derived from the crater walls but it is also possible that it has been deposited directly on the lava surface, if fire fountaining accompanied the extrusion. Part of the ash too, may be a primary deposit but much of it appears to be a secondary accumulation. Three small spiracles of pahoehoe slag were seen on the Maelifellssandur lavas, and are thought to have been formed by gasses escaping from the surface of the upper flows.

Good sections through the major flows are seen in the Holmsa gorges, a few kilometres south of Maelifellssandur. The structures are similar to those shown on Maelifellssandur, but here the flows have been constricted as they passed through the narrow valley and the upper surfaces are thrown into large folds five metres or more from crest to trough. The jointing of the flows is well seen and is of the entablature and collonade type described by Tomkeieff (1940) in the case of the Antrim lavas. The lower vesicular surface is usually only a few centimetres in thickness.

On Myrdalssandur and Methallandssandur the lava is often much eroded and the surface seen only occasionally beneath the secondary ash cover. In general the upper vesicular layer appears to be thinner, relatively, than in the lavas nearer to the fissure. Lavas occur with only moderately vesicular upper layers and without reddening. Broad, level pavements of ropy lava similar to those of the crater floors occur and also areas in which this type of surface has been broken to form a blocky surface. These coastal plain flows are thinner than those in the Holmsa valley and show only irregular vertical jointing. Both on Myrdalssandur and Methallandssandur the lava gives way in places to massive accumulations of basaltic scoria. These consist of contorted fragments of porous or slightly vesicular basalt with rough clinkery and reddened surfaces, together with reddened and angular fragments of dense basalt, and occasionally angular non-vesicular fragments of sideromelane. On Methallandssandur the accumulation is penetrated by steep pit-like craters often fifteen metres deep, while on Myrdalssandur the upper surface shows a rash of cones, about five metres in height, with small central craters. It is thought that these unusual structures are the result of the escape of steam, generated from water trapped beneath the flow, through the partly liquid lava.

The slag, which makes up these deposits is poor in, or lacks, vesicles and is quite unlike the pahoehoe slag of the craters. The near absence of vesicles in the slag confirms that the gas content of the lava was very low at this distance from the craters.

In one of the Myrdalssandur cones several small, rounded, masses of glass were observed cemented to the surface of normal basaltic scoria. The largest was ten centimetres in length and had a smooth outer skin in which a few basaltic scoria fragments were embedded. The interior was highly vesicular. The glass had a refractive index close to 1.5 and is thought to be a remelted xenolith of Myrdalsjokull liparite squeezed out from the interior of the lava at the time of formation of the cones.

Generally speaking, the major flows tend to change systematically in structure from a type similar to that of the crater walls near the craters to a type similar to that of the crater floors on the coastal plain. It seems likely that as the lavas were extruded the dissolved gasses separated quickly to form a semi-solid upper vesicular layer which served to insulate fresh material beneath which was flowing towards the front of the flow. As the flows grew longer, material, still hot but less and less rich in gas, would reach the front until, as on Myrdalssandur, the lavas assume structures which show them to have been very poor in gas.

The major flows provide little evidence of their effect on the underlying materials at the time of their extrusion. Where sections through them occur, the upper lavas usually rest upon the reddened vesicular upper surface of an earlier Eldgja flow and have produced no change in this material. In the Middle Holmsa gorge and on the north eastern part of Myrdalssandur at Hrifuness flows are seen overlying banded soils. The upper surface of these soils has been altered from a dark brown to a light reddish brown, to a depth of about 20 centimetres. This effect is thought to be due primarily to the oxidation of the organic constituents of the soil.

The Craters.

The fissure through which the Eldgja volcanics were erupted cuts through rocks belonging to the Palagonite Formation. In Skaftartunga these rocks form three groups, and it is the rocks of the Lower and Middle Groups, consisting of coarsely bedded tuff and conglomerate, which form the lower part of the walls of the craters.

The Eldgja craters vary in depth from 30 metres to nearly 200 metres, in width from 70 metres to 500 metres and in length from 100 metres to 5 kilometres. The walls are characteristically steep sided and show lava and reddened interbasaltic layers of the type already described. The ash and slag layers show no evidence of weathering or erosion between eruptions. The volcanics of the crater walls vary in thickness from two metres to seventy metres and, except on Maelifellssandur where the base of the series is not exposed, can be seen to rest upon Palagonite Formation rocks.

The eruptives appear to have had little effect upon the underlying rocks, In the sections examined, even when the lowest member was a lava, the underlying palagonite tuff was unaltered. It may be that the crater wall lavas, which are only a few metres thick, cooled too rapidly to cause alteration. An additional factor which may have contributed to this effect is the vesicular and rubbly base of the flows which would tend to inhibit the transfer of heat downwards.

The Palagonite Formation rocks which form the walls beneath the early volcanics also lack any sign of alteration, but it is clear from the thick mantle of scree on the lower parts that there has been much erosion since volcanic activity ceased.

One inclusion of Palagonite tuff in a lava, in the wall of crater Q, was seen. The tuff had not been fused and appeared in the field to have suffered only an alteration in colour from light brown to dark red. The petrography of this rock will be described later.

In the smaller craters the scree slopes from either wall meet on the floor, and nothing is seen of the lavas which may be present in the bottom of these craters. In the larger craters, however, particularly those of the Eastern and Western fissures, the central parts of the crater floors show a nearly level expanse of lava, sometimes with slag cones and spiracles on its surface. These rocks have already been described.

The Origin of Craters in Basaltic Volcanoes.

It has been seen that Thoroddsen and Sapper held divergent views on the origin of the Eldgja craters. During the course of the field study special attention was paid to this question and it has been concluded that explosive activity was a subsidiary feature of the activity of Eldgja and that the craters originated in some other way. The views of other geologists on the origin of craters in basaltic volcanoes are presented below.

Dana (1891, P.149) says, of the Hawaiian Volcanoes, - "The preceding remarks about the permanence of craters apply to other kinds of volcanoes as well as the basaltic; but in the form of the crater the basalt volcano has peculiarities, owing to the mobility of the lavas and the paucity of cinder discharges. The ordinary crater of the basaltic volcano is pit-like, with the walls often nearly vertical, and the floor may be a great, nearly level, plane of solid lavas. The liquid material of the extremity of the conduit works outward from the hotter centre, through the fusing heat and the boiling and other cauldron-like movements; and hence, where the mobility favours freedom of action in these respects, it tends to give the basin or crater a nearly circular form with steep sides. Besides, when the discharge takes place, there is usually a fall of the walls, which is still another reason for vertical sides and the pit-like form. Such pit craters are normally circular; but where there is a large fissure beneath the crater they may be much elongated."

Jaggar (1947, P.347) discussing Judd's theory of volcanoes (1881, P.170) says "Circular form, terraced slopes and precipices all occur in the Hawaian volcanoes and generally without steam-blast explosion. These features afford no evidence whatever of explosive action. The great known explosion craters such as Tarawera, Krakatoa, Pelee and Bandaisan are chiefly remarkable for the absence of circularity and regularity and for definite accompanying engulfment."

Whenever active lava occupies the crater of a basaltic volcano the walls are probably being continually undermined and broken down in the manner described by Dana above, occasionally however, events lead to vary rapid enlargement of the crater.

The great collapse of May 1922 at Kilauea is described by Jaggar as follows(Jagger 1947. P.155) - "The crisis in Halemaumau began May 13th, 1922, and in a week the lake level had dropped 300 ft ... the craggs and lava lakes were enveloped in debris slope, though still identified, more than 600 ft. down on May 26th. In the early afternoons of May 26th, 27th and 28th spells of general caving of the pit wall sent up brown and salmon coloured cauliflower clouds hundreds of feet high and made a thunderous roar. All surveying stations, signs and portions of the trail around Halemaumau caved in. The tunnel south west and the two rift walls fell in, making a smoking canyon that extended as a bay in the Halemaumau rim 500 ft. in that direction. On the other sides the rim caved in for a width of about 100 ft. The new pit was, therefore, a pointed oval in plan, with the point directed toward the Kau Desert and was roughly circular, with a maximum diameter of 1400 ft ..... The bottom of the pit, a mass of convergent talus, later proved to be 961 ft. below the rim July 6th, 1922. " This great collapse and enlargement of the crater was produced simply by the withdrawal of the lava column to a depth 900 feet below the crater rim. Two years later the lava column again withdrew, this time to a depth 1300 feet below the rim. Ground water admitted to the vent caused explosions, throwing large rocks up to 3,000 ft. and cauliflower clouds up to 6,000 ft. The pit was enlarged by 750 ft. on all sides, 202 million cubic metres were lost from the crater walls and 793 thousand cubic metres of rock thrown out.

In Hawaii, then, three processes have been recognised which operate to form the craters of basaltic volcanoes.

1. The presence of active lava in the crater undermines the walls causing piecemeal collapse.
2. The withdrawal of the lava column causes collapsing, probably proportional in magnitude to the depth of withdrawal.
3. Very deep withdrawal of the lava column may admit ground water and result in phreatic eruption and extensive collapsing of the walls.

It is believed that the first two processes were responsible for the formation of the Eldgja craters. The second process has produced in Eldgja, a fissure volcano, a result somewhat different from that in Halemaumau. Because of the absence of explosion breccias the third process is believed to have been absent in Eldgja.

Crater Evolution in Eldgja.

A uniform pattern of events in the formation of the craters can be seen along the whole length of the Eldgja fissure. This pattern is described below and will serve as an introduction to the description of the craters which follows.

The first phase in the evolution of the Eldgja craters was the gradual piling up of lava and slag along the fissure to form a low ridge with a slope of about 6°. These materials form the edge of the present craters. It is possible to reconstruct the early form of the volcano by reference to the less active parts of the fissure which have suffered little modification.

While the volcanic ridge along the fissure was being built up, the craters were beginning to grow in size. The vigorous activity of the lava in the vent, shown by the slag deposits, must have undermined the crater wall and caused slow collapse of the walls. It is unlikely that any major extrusion of lava took place at this stage, for few of these flows exceed one or two metres in thickness.

In many parts of the fissure the development of craters did not progress beyond this phase, but in those parts from which the great flows were extruded this simple form has been modified by the collapse into the fissure of huge blocks of the country rock. The collapse is thought to be the result of a temporary withdrawal of the lava column, perhaps following the extrusion of one of the great flows. Further activity followed the collapse; new craters were formed in the collapsed material, and further large flows were extruded. If, as the writer believes, all the major extrusions of lava occurred at this time, then this, the mature, phase of the volcano has been of much greater duration than either the preceding or following phases.

Following the mature phase, the activity of the volcano gradually waned, thin flows were extruded onto the floors of the craters and slag cones were formed.

The history of the volcano can be divided into three phases -

1. The Juvenile phase, when minor flows were extruded, to the accompaniment of vigorous fire fountaining. A low ridge of lava and slag was formed along the fissure in which craters soon developed. These slowly increased in size as activity continued.
2. The mature phase, when extreme fluctuations in the height of the lava column caused extensive lava flows and the collapse into the fissure of huge masses of the country rock.
3. The senile phase, when minor flows were extruded and slag cones built on the crater floors.

Plate I

Part of Crater A seen from the northern lip. The crater here is four hundred metres wide. The slag cones, the nearest of which is fifteen metres high, represent the waning stages of the activity of the crater, and stand on a flat floor of lava. Beyond the southern lip of the crater lies the Alftavotnskrokur plain and, three kilometres away, the Kerlingarhunkar Mountains.

DETAILED DESCRIPTION OF THE ELDGJA CRATERS.

The Eldgja volcano is formed of three separate, sub-parallel lines of craters. The western fissure extends from Myrdalsjokull to Svartahnuksfjoll and its lavas flowed through the Holmsa valley onto Myrdalssandur. The Central Fissure runs from Svartahnuksfjoll to Strangakvisl, and is connected to the Western Fissure by a fault-graben across Svartahnuksfjoll. The Eastern Fissure lies about half a kilometre to the south east of the Central Fissure, and runs from Axlir to Gjatindur. The lavas of the Central and Eastern Fissures flowed through the Skafta valley onto Methalland and Landbrot.

The Western Fissure.

The Western Fissure is a little over eight kilometres in length from the easternmost crater (Rauthibotn) to Myrdalsjokull. The fissure certainly extends for a further two kilometres beneath the ice of Myrdalsjokull, for a shallow trough can be seen on the surface of the ice cap. Probably the ice becomes too thick to reflect variations in the underlying topography beyond this point.

Crater A. - Between this crater and the ice the fissure is very indistinct; a thick cover of Katla ash and glacial debris makes a detailed examination impossible. Little trace remains of the north-western wall, and only where the fissure

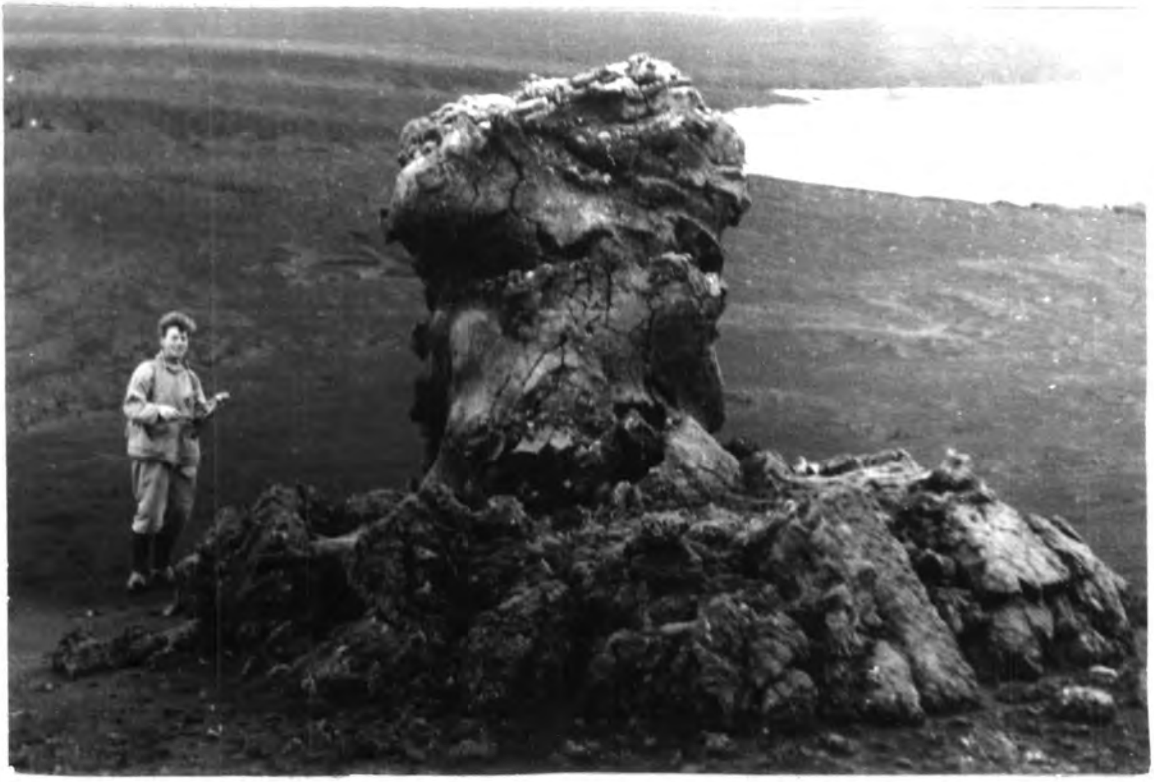


Plate 2

Shows a curious driblet cone in Crater A, formed of concentric layers of smooth-coated vesicular pahoehoe.

enters the ice does the south eastern wall take on any distinct form; here deposits of slag can be seen beneath the moraine.

Crater A lies about two kilometres from the ice-edge and is about one and a half kilometres long. The width of the floor varies from two to three hundred metres. The crater is open at both ends along the line of the fissure. The walls have an average height of thirty or forty metres and slope steeply into the fissure, and gently, at about 7°, away from the fissure.

The materials of the walls, the early volcanics, are everywhere obscured by a thick ash cover. The crater lip is below the summit of the ridge and the zone between the lip and the summit is normally cut by several curving cracks along the line of the fissure.

The floor of the crater is covered by a continuous layer of young lava with the form of very shallow, interlocking domes. Two lines of spiracles and slag cones occur in the central part of the fissure; roughly parallel with the fissure and about one hundred metres apart. The central part of the crater is shown in Plate 1. The cones vary in height from ten to twenty metres and are formed of pahoehoe slag, and occasionally of thin vesicular lava flows. The largest spiracle is shown in Plate 2.

Plate 3

A mass of bulbous entrail-like pahoehoe in Crater A. Though the outer coat is smooth and unbroken the core is highly vesicular.

Between craters A and B the walls are irregular and low, twenty metres or so high, and cut by numerous arcuate cracks roughly parallel to the fissure. The walls slope down into the fissure steeply in some places and gradually in others. The south eastern wall has been breached and through this gap the younger lavas have poured onto the plain to the east. In the vicinity of the gap the younger lavas are covered by blocks of lava and slag from the crater walls. Because of the ash cover, no sequence can be seen in the crater wall. Much of the floor of the fissure is obscured by ash, but here and there the lava is exposed, and occasionally broken slabs of lava project. No well formed slag cones exist, but irregular heaps of slag show that small spatter cones may have been formed and since destroyed. Plate 3 shows some typical pahoehoe slag from one of these piles.

Crater B. - This crater is seven hundred metres long and has a maximum width of four hundred and fifty metres. The crater walls are nearly straight for half a kilometre but converge rapidly at each end. The walls are about thirty metres high, and slope steeply into the crater and gently away from it at about 8°. No sequence of the older volcanics is visible.

Crater C. - This crater joins the north eastern end of crater B, and is much smaller than either of the preceding

Plate 4

The double slag cone north east of Crater C built during the senile stage of the volcano. The two hollow cones are formed entirely of pahoehoe slag. The outer ring is sixty metres wide a nd the inner ring ten metres wide and seven high. These rings have been built by spatter or fire-fountaining from an active lava vent inside. The mountain Svartafell is seen in the background with Crater D breaking the skyline to the right. The left hand snow patch lies within the shallow crater leading to Crater D. The snow patch to the right marks the line of the fault described in the text.

craters. It is roughly circular in shape and has a radius of about two hundred metres. The walls are highest when they are parallel to the fissure and decrease in height and disappear as the line of the fissure is approached and crossed. The northwestern wall is roughly ten metres high, and a steep ash-covered slope dips into and a gentle slope dips away from the fissure. The south eastern wall is twenty metres high and drops in a steep craggy slope to the crater floor. Here the only sequence of the early volcanics on Maelifellsandur is exposed.

The sequence of the older volcanics in Crater C is:-

5. Lava, vesicular	0. 5m.
Slag and ash.	1. 3m.
4. Lava, vesicular	0. 6m.
Slag and ash.	5. 0m.
3. Lava	1.0 m.
Slag and ash.	2. 6m.
2. Lava	1. 3m.
Slag and ash	1. 0m.
1. Lava	2. 0m.
Base not seen.	

Between Crater C, and the Svartafell craters the covering of ash is intermittent. Here, isolated in a plain of young lava, stand crags and pinnacles of the early volcanics. Overlying the young lava are accumulations of slag and lava

Plate 5

The large slag cone close to the base of Svartafell. It is roughly fifty metres in diameter and fifteen metres high. The cone was formed during the last waning stage of the activity of Eldgja. The southern shoulder of Svartafell is seen in the background, the snow patch marks the position of the fault to the south of the fissure.

such as those shown in Plates 4 and 5.

<u>Crater D.</u> - The Svartafell craters, of which D is the largest and most important, are twelve hundred metres in length. On the south-western side of Svartafell is a line of small craters six hundred metres in length, from Brennivinskvisl to the crater D. They begin at the foot of the mountain with four horse-shoe shaped slag cones, each five metres high, and continue up the slope as a shallow trench varying in width from ten to seventy metres, and about seven metres in depth. Pahoehoe slag and one or two lava flows form the older volcanics of the walls.

The sequence of older volcanics near the top of Svartafell is:-

	Slag and ash	1. 0m.
2.	Lava	1. 3m.
	Slag and ash	1. 7m.
1.	Lava	0. 6m.

resting on Palagonite Formation tuffs.

The south eastern edge of the fissure has been down-faulted three or four metres, the fault running obliquely up the hill from the lower part of the fissure. There are no young lavas in this part of the fissure.

Crater D itself begins just below, and to the southwest of, the summit of Svartafell. The floor of convergent talus

Plate 6

The basin between Svartafell and Rauthibotn;taken from Rauthibotn along the line of the fissure with the Svartafell crater behind. In the lower left corner can be seen some of the older volcanics of Rauthibotn. The basin to the right of the fissure is the result of a major collapse of the country rock into the fissure. The river Holmsa winds through much eroded horizontal younger lavas.

slopes steeply, and the walls diverge,to the north east. The crater is roughly two hundred metres wide and about 50 metres deep. To the north east it opens into the basin through which the Holmsa flows.

The older volcanics of the crater walls consist of two flows with interbedded slag and ash.

The sequence of older volcanics in Crater D is:-

2.	Lava	1. 0m.
	Slag and ash	5. 0m.
1.	Lava	1. 6m.
	Slag and ash	1. 0m.

resting on Palagonite tuffs.

The older volcanics extend as far as the summit of Svartafell, which lies one hundred metres to the north west, and now dip inwards towards the fissure. Apparently step-faulting has taken place on this side of the fissure, increasing in degree as the fissure is approached. The south eastern side of the crater lip is at least twenty five metres below the level of the north western side. This difference in height may be accounted for by assuming some slumping of the south eastern lip, and the collapse of an earlier and higher lip, into the crater.

Younger volcanics are not exposed in this crater but around the crater several blocks of Palagonite tuff, up to

Plate 7.

A low broad slag cone about ten metres in diameter at the foot of the Crater D between Svartafell and Rauthibotn. This was the last product of the waning activity in this part of the fissure.

30 cm. in diameter, were found encased in a shell of basalt. These shells are probably the only representatives of the younger lavas.

Between Craters D and E there is a basin through which the river Holmsa flows from the lake Holmsarlon to Maelifell-sandur.

The older basalts in this basin are exposed only at the lake outlet (See Plate 9). The exposures at the lake edge show the basalts dipping away from the fissure, but, as the outlet channel is followed towards the fissure, the lavas become broken and cracked and as the Holmsa plunges into the basin, the dip of the basalts is reversed. The younger volcanics of the basin have been greatly eroded by the Holmsa, which winds its way amongst them, but remnants of a series of horizontal flows are seen which must originally have covered the whole basin floor. Plate 6, shows the basin and Crater D in the background. On the floor of the basin is a small crater, thirty metres in diameter and fifteen deep, in the centre of which is a low slag cone. (See Plate 7).

<u>Crater E.</u> - This Crater is almost perfectly circular. It is 300 metres in diameter and 140 metres deep. The south western wall is broken and the crater opens into the basin through which the Holmsa flows (See Plate 8).

The older volcanics of the walls are formed of slag

Plate 8

The Rauthibotn crater, three hundred metres wide and one hundred and fifty metres deep. The older volcanics can be seen to form the upper lip of the crater. Above the lake the fracture, caused by the Svartahnuksfjoll fault graben cutting the older volcanics, can be seen. On the skyline is the slight depression caused by the graben on Svartahnuksfjoll.

and ash with one major and a few minor lava flows.

The sequence on the north eastern wall is as follows:-

Slag and ash with five regularly spaced vesicular flows	20 m.
Slag and ash	18 m.
Lava	5 m.
Slag and ash	19 m.

resting on Palagonite Formation tuffs.

The edges of the crater show numerous curving cracks, especially on the south eastern side, and it can be seen that in some places the edges of the walls have slumped down a few metres into the crater.

On the north eastern wall of the crater the two faults of the Svartahnuksfjoll fault-graben can be seen to cut the older volcanics of the crater wall. The displacement is probably not more than two or three metres. No younger volcanics are exposed in Crater E.

The Activity and Evolution of the Western Fissure.

The Maelifellsandur Craters. - The fissure is simple in form where it crosses the Maelifellsandur plain, for here the topography has exerted no influence on the development of the craters.

In its juvenile phase the Eldgja fissure on Maelifellsandur

Plate 9

Holmsarlon. The valley in which the lake lies can be seen to narrow as the outlet is reached. The lip of the lake is formed of older volcanics and the Holmsa cascades over broken, inward-dipping older lavas into the basin between Svartafell and Rauthibotn.

must have resembled the Threngslaborgir and Laki fissures as they are today. Probably a row of small coalescing vents formed a sharp ridge along the line on the fissure, which stood on a level plain of early lava. With continued activity, in the form of alternate extrusions of lava and vigorous fire-fountaining, a gently sloping ridge was built up consisting of alternating lavas, slag and ash. This ridge was probably about one hundred metres above the Sandur at its summit and sloped outwards at about eight degrees. With continued activity came a widening of the craters to produce eventually, not a series of closely spaced craters, but a single long crater.

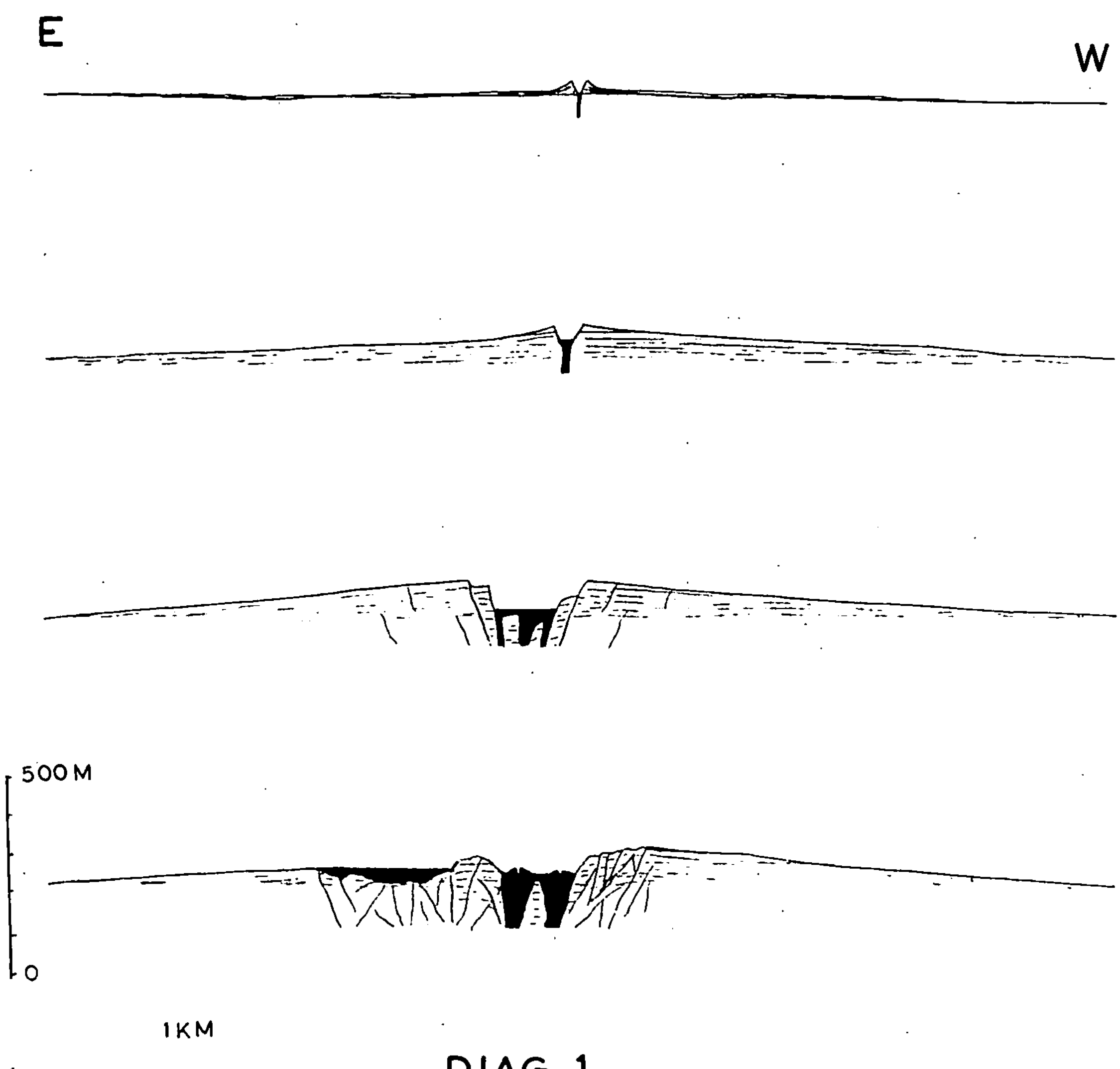
During the mature phase, periodic recession of the lava column may have produced a rapid and uneven widening of the craters by the wholesale collapse of the walls. Subsequent extrusions of great volumes of lava no doubt broke down the already weakened walls in places. In places these two processes have completely destroyed the crater wall; for example between craters C and D.

As activity waned the lavas of the crater floors were extruded and finally slag cones and spiracles were formed on the surface of these lavas.

This sequence of events is shown in Diagram 1.

<u>The Svartafell and Rauthibotn Craters.</u> - In reconstructing

THE MÆLIFELLSANDUR CRATERS



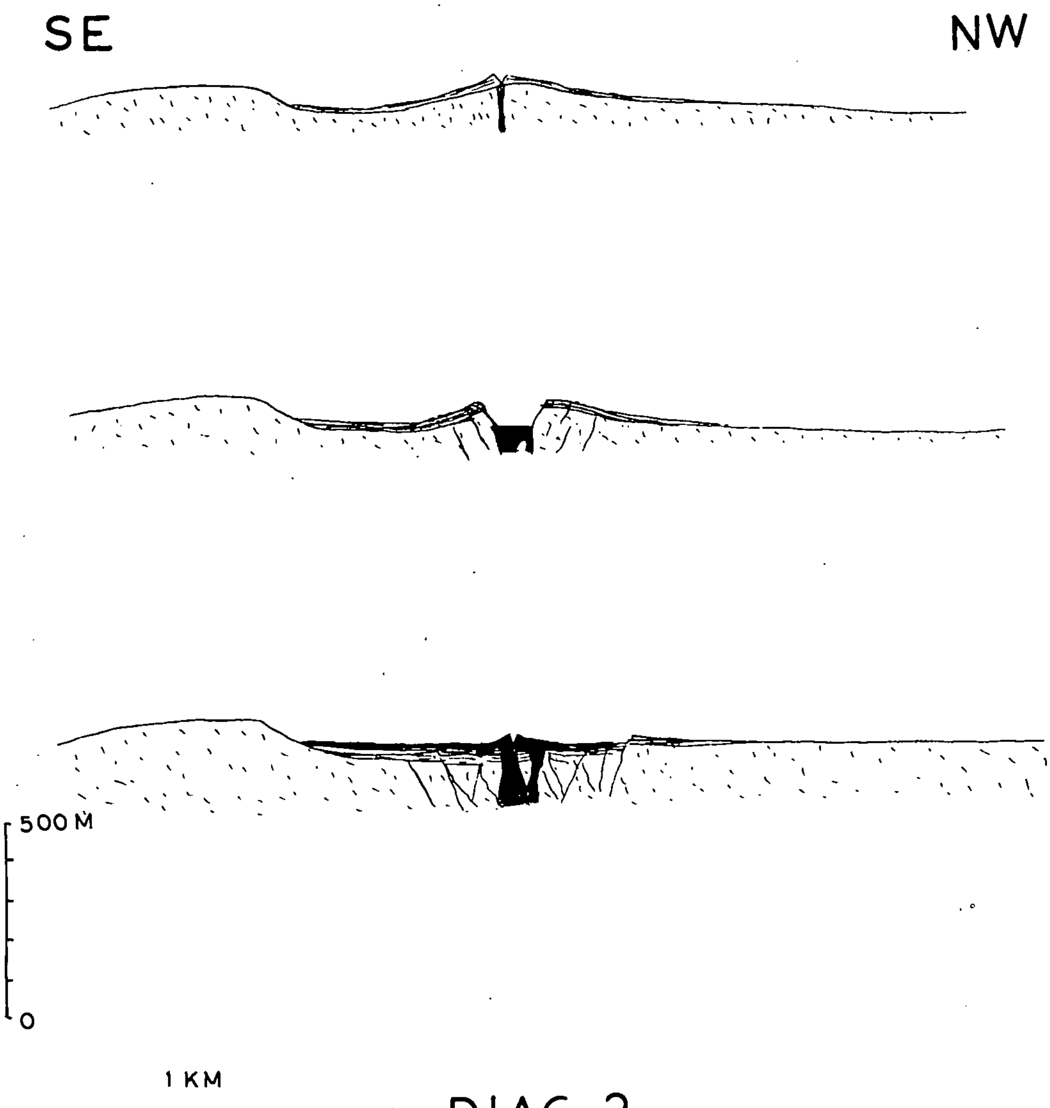
DIAG. 1.

the early stages of the fissure the present situation of the older lavas is of great importance. These occur in three groups, - on Svartafell, on Rauthibotn, and at the outlet of Holmsarlon. None of these lavas could have flowed to their present positions from the present craters. The Rauthibotn and Svartafell lavas are high in the crater walls, and both of these craters are completely open, down to their floors, to the basin between them; the basin in turn is open to the south. It is obvious that great changes have taken place since their extrusion.

During its juvenile phase the fissure must have been very constricted. Had this not been so, lava could hardly have been extruded on Maelifellsandur, and, simultaneously, some two hundred metres higher, on the summit of Svartafell. Had craters been present they could only have acted as channels to divert the lava down the flanks of the mountain. This evidence suggests that the two lava flows of the Svartafell summit are the earliest extrusions, and occurred at a time when the conduit had not widened at this, or any adjacent, point and when craters had not had time to form.

The older flows of Rauthibotn certainly could not have reached their present positions with the present break in the crater walls to the south west. The considerable thickness of the volcanics, sixty two metres, and the presence

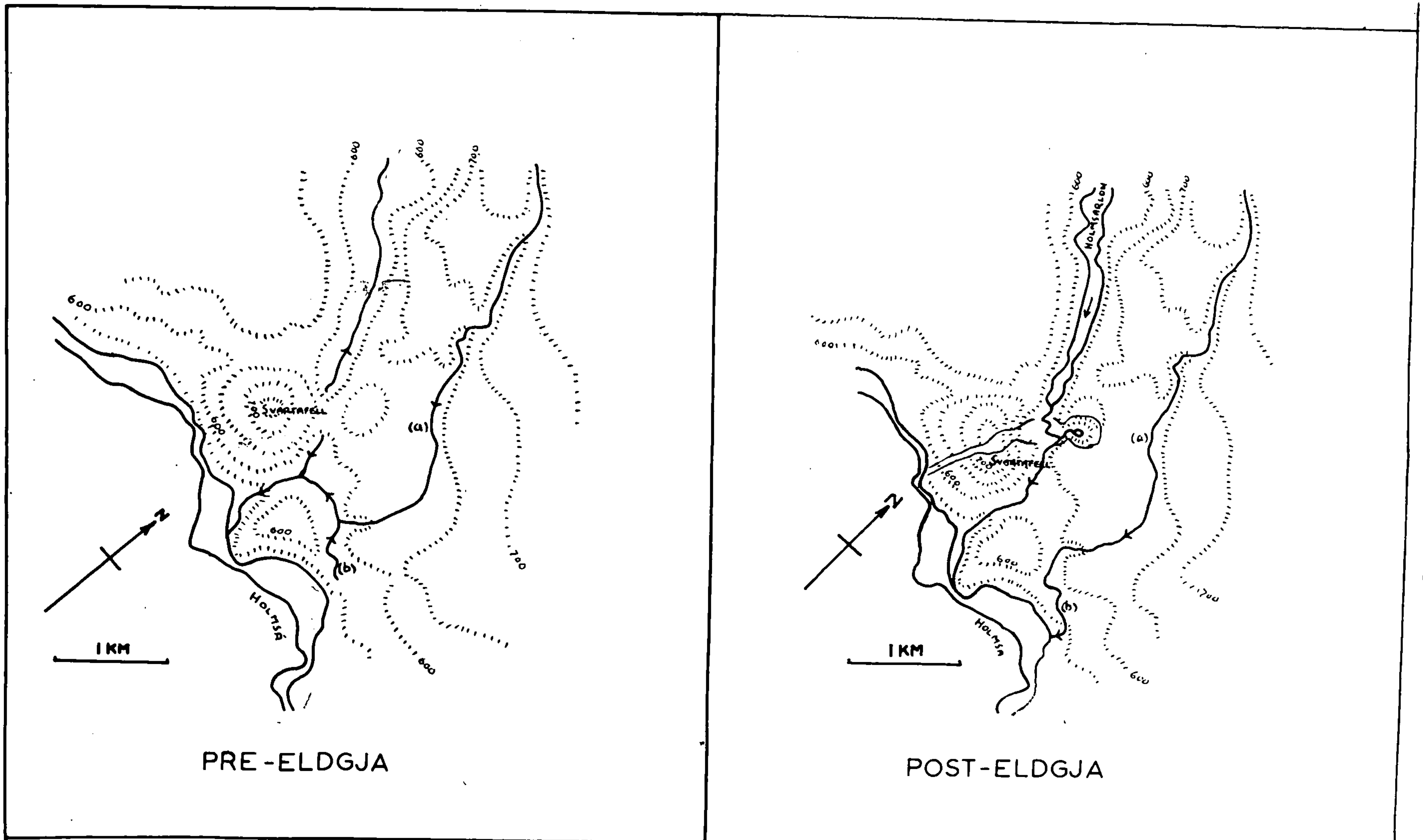
THE HOLMSA BASIN



DIAG. 2.

of five thin lavas in the uppermost volcanics, shows that the vent was active and extruding lava for some considerable time. It would be unreasonable to assume that Rauthibotn had remained isolated from the craters to the south west during the period of accumulation of the volcanic materials of its walls. Some obstacle then, must have prevented the lava within the crater from escaping at lower levels to the south west. It is suggested that this obstacle was a broad ridge of country rock between Rauthibotn and Svartafell, which was cut through by the fissure and down the northern slopes of which, early lavas flowed to a position at the present outlet of Holmsarlon. Probably this ridge was destroyed as the fissure widened at a later stage in the activity of the volcano. This sequence of events is summarised in Diag. 2.

If the basin is volcanic in origin, it becomes necessary to find some alternative outlet for the waters of the Holmsarlon valley. This is easily accomplished, as the head waters of the Holmsa and Sythri-Ofaera are separated only by a broad shallow divide, indeed, the present shape of the Holmsarlon valley, which becomes progressively narrower and with steeper walls as the outlet is reached, suggests that it was formed by a river draining to the north and not to the south as at present. The present drainage direction


PRE-ELDGJA
Svartafell
Holmsá
(a)
(b)
1 KM
N
600
700
POST-ELDGJA
Svartafell
Holmsá
Holmsárlon
(a)
(b)
1 KM
N
600
700

DIAG. 3.

is probably the combined result of three factors; a probable tilting of the surface to the south; the collapse of the high ground between Svartafell and Rauthibotn which provided a low exit to the south; and the silting up of the northern end of the valley by glacial detritus from Torfajokull. Unless the Holmsarlon valley did originally drain into the upper part of the Sythri-Ofaera it is very difficult to explain the origin of the low divide between the two river systems. Further interesting changes seem to have taken place in the course of the small stream (stream a) (See Diag.3) which flows to the east of, and parallel to Holmsarlon. The stream flows in a southerly direction and, after crossing the Eldgja fault graben, turns abruptly west to reach a small valley close to the Holmsa. Here, instead of flowing into the Holmsa, it is deflected by a mass of Eldgja lava which blocks this exit, and it flows to the south down on alluvium-filled and rapidly narrowing valley, finally to reach the Holmsa through a deep gorge cut in the Palagonite tuffs. The shape of the alluvium filled valley suggests that originally it drained to the north and contained a stream (b) which joined stream (a) and flowed into the Holmsa below Svartafell.

Diagram 3 shows the drainage pattern before and after the formation of the subsidence basin.

The activity of this part of the fissure may briefly be summarised as follows:-

1. Early juvenile phase, with preliminary eruptions from the fissure; the early drainage system as in Diag. 2; the extrusion of the Svartafell, Holmsarlon and lower Rauthibotn flows.

2. Late juvenile stage, with the widening of the vent and the beginning of crater formation; activity continuing in the Svartafell craters but no further extrusions there; further extrusions from Rauthibotn and possibly others into Holmsarlon valley.

3. Early mature stage, with major extrusions southward down Holmsa valley; the damming of the small eastern stream by these lavas; the formation of large craters.

4. Late mature stage, with collapse of the ridge between Svartafell and Rauthibotn to form the present basin, continued extrusions of major flows.

5. Senile stage, with the formation of small slag cones in the subsidence basin together with the extrusion of later flows in the basin; possible tilting towards the fissure of a large block of the country rock causing the spilling over of the Holmsarlon waters through the subsidence basin, aided by a silting up of the northern end of the valley.

The Svartahnuksfjoll Fault-Graben.

A shallow fault graben lies between Crater E, the

Plate 10a

The Svartahnuksfjoll fault-graben seen from Rauthibton. The graben is here two hundred and fifty metres wide and about ten metres deep. The conspicuous scarp on the horizon is caused by the southern fault.

easternmost crater of the Western Fissure, and Crater F, the westernmost crater of the Central fissure. The graben is formed of three sub-parallel faults lying in the direction of the fissure, the distance between them varying from four hundred to two hundred and fifty metres. The downward displacement of the inner block appears to be about ten or fifteen metres along the whole length of the graben.

The graben is widest at its highest point close to Crater F and slowly narrows until the lowest part is reached near Crater E. This difference in width suggests that the down-faulted block is wedge shaped, the apex pointing downwards, At each end the faults cut the older volcanics of Craters E and F, while the younger volcanics near Crater E are undisturbed. Thus the graben was formed after the extrusion of the early lavas and before the extrusion of the youngest lavas, or, in other words, at some time during the mature stage of the volcano. Plate 10 shows the graben as it is seen from Crater E. It is here about two hundred and fifty metres wide and about ten metres deep.

The Central Fissure.

The Central fissure is a little more than nine kilometres in length. It starts on Svartahnuksfjoll at a height of seven hundred and fifty metres above sea level and runs north eastwards into the valley of the Sythri-Ofaera to a height of about five hundred metres. From here the fissure cuts through the southern flank of Morauthavatushnukar, rising again to a height of seven hundred metres, and ends on the northern shoulder of Axlir at a height of five hundred and fifty metres. The Central fissure is formed of eleven main craters, but Crater F and the four craters north east of Morauthavatushnukarr have extruded relatively little lava, and may have been inactive, or only intermittently active, during a large part of the volcano's history.

Crater F. - This, the westernmost and highest crater of the Central Fissure, has been one of the least active. The crater is cut into two parts by the Tungufljot. The western part has been greatly modified by a small stream which flows through it, though inward-dipping layers of slag and ash may be seen. This part of the crater is roughly one hundred metres in both length and width. On the eastern side of the Tungufljot, the crater is a broad oval three hundred metres long, two hundred wide, and about thirty metres deep. The walls consist mainly of Palagonite tuff but at the lip of the crater about five metres of older volcanics are exposed.

Section of older volcanics of Crater F.

Slag and ash	2.0 metres
Lava	1.3 metres
Slag and ash	1.2 metres

Resting on Palagonite tuffs.

Plate 11

Crater F, from the east on Svartahnuksfjoll. The crater is two hundred metres wide and thrity deep. The five metres of volcanics and the single lava flow can be seen on the crater edge. On either side of the crater close to the edge of the photograph, the faults cutting the older volcanics can be seen.

Faults which are probably continuations of the Svartahnuksfjoll fault-graben cut through the older volcanics north and south of the crater; both have a throw of about five metres.

No young volcanics are exposed in Crater F. The crater and faults are shown in Plate 11.

Crater G. - This, the greatest of the craters of the Central Fissure, lies four hundred metres to the east of Crater F. The crater has a length of seven hundred metres and a maximum width of about two hundred metres. The southern edge of the crater is formed by the horizontal plateau of Svartahnuksfjoll, capped by early volcanics, with a precipitous drop of one hundred and fifty metres to the crater floor below. The northern edge of the crater lies some hundred metres lower, only fifty metres above the crater bottom. Behind the northern lip of the crater, older lavas, now dislocated and broken by numerous sub-parallel cracks, rise slowly up the slopes of Svartahnuksfjoll to reach a height corresponding to that of the older volcanics high on the southern lip of the crater.

The following sequence of older volcanics is exposed on the southern lip of Crater G.

	Slag and Ash	2. 0 m.
4.	Lava	2. 1 m.
	Slag and ash	2. 1 m.

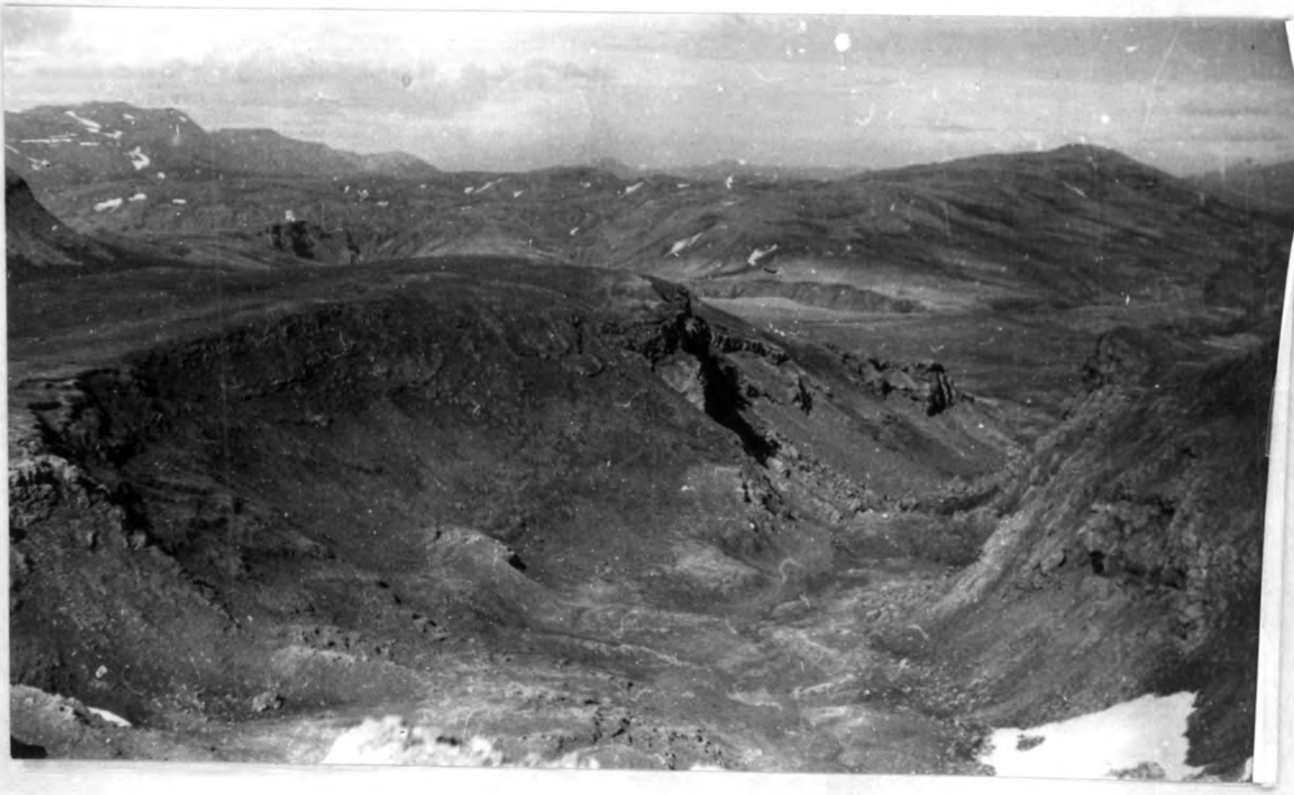


Plate 12

Crater G is seen in the foreground. The photograph is taken from the southern lip of the crater which is roughly two hundred metres higher than the northern lip. Older volcanics, slumping into the fissure can be seen on the facing crater wall. Crater H can be seen following Crater G. In the distance close to the right hand edge of the photograph Crater K is seen.

3.	Lava	2. 0. m.
	Slag and ash	2. 2. m.
2.	Lava	1. 2. m.
	Slag and ash	3. 2. m.
1.	Lava	4. 0. m.
	Slag and ash	6. 0. m.

resting on Palagonite formation tuffs.

These flows vary considerably in thickness from place to place along the exposure, and there are two further thin flows, exposed above the cliff section, which may belong to the upper part of this sequence. Their exact relationship, however, is obscured by the faulting along the rim of the crater.

The slumping of the northern edge of the crater is later than the old volcanics, and takes the form of "step-faulting," the movements of individual faults being of the order of a few metres, but the total downward movement amounting to more than one hundred metres. This type of movement has led to the formation of the irregularly terraced slopes of the early lavas, a characteristic of the larger Eldgja craters, and this is the feature which led Sapper to believe that these (early) lavas post-date the craters and had flowed downwards into the fissure. There are no young volcanics exposed in this crater. Crater G, is shown in Plate 12.

<u>Crater H.</u> - This crater, lying immediately to the north

east of Crater G, is seven hundred metres in length and two hundred in width. The maximum depth of the crater from the lip to the floor immediately below is roughly one hundred metres. The crater itself slopes downwards to the north east, the floor falling from six hundred and seventy metres to five hundred and sixty metres.

The sequence of volcanics exposed on the northern wall of Crater H is as follows:-

	Slag and ash	3. 0 m.
4.	Lava	1. 5 m.
	Slag and ash	2. 0 m.
3.	Lava	1. 5 m.
	Slag and ash	2. 5 m.
2.	Lava	1. 0 m.
	Slag and ash	3. 5 m.
1.	Lava	4. 0 m.
	Slag and ash	1. 0 m.
	Palagonite formation.	

On the northern side of the fissure a smooth lava covered slope extends to the foot of Svartahnuksfjoll and, except near the crater rim, this side of the fissure has been virtually undisturbed by the later slumping movements. On the southern side of the fissure, however, the lavas slope smoothly away from the fissure for a short distance, but then

Plate 13

Crater H, seen from the southern edge of Crater G. In the foreground is the faulted surface of the older lavas south of the fissure. On the northern side of the fissure, pronounced sagging causes the older lavas to dip inwards towards the fissure. Crater I can be seen on the plain below on the right of the photograph.

are broken by a series of sub-parallel faults, roughly in line with the fissure, which break the lava and slag into a confused mass of tabular ridges. These rise steeply and step-like away from the fissure. The amount of the slumping caused by these faults is difficult to estimate but is not less than thirty metres. No young volcanics are exposed in this crater. The crater is shown in Plate 13.

Between Craters H and I the fissure is a shallow depression, three hundred metres long, and one hundred metres wide. No complete section of the older volcanics is exposed. To the north the ground slopes upwards exposing broken fragments of the older volcanics until, at a height of sixty metres above the fissure floor, a rounded southward-facing scarp of older volcanics is reached, from here the surface slopes gently downwards towards Svartahnuksfjoll. On the southern side the low fissure walls are further depressed to form a broad V which has provided an exit for the later lavas. The younger lavas, however, are obscured here by a thick cover of alluvial sand.

Crater I.- This crater is four hundred and fifty metres long, with a uniform width and depth of seventy metres and twenty five metres respectively.

The sequence of the older volcanics in Crater I is as follows:-

4.	Lava	1. 5 m.
	Slag and ash	2. 0 m.
3.	Lava	0. 5 m.
	Slag and ash	1. 0 m.
2.	Lava	1. 0 m.
	Slag and ash	1. 5 m.
1.	Lava	3. 0 m.

resting on Palagonite formation tuffs.

To the north a broken surface of older lava rises slowly to a low ridge three hundred metres from the fissure and then slopes smoothly downwards. To the south the ground slopes irregularly down to the lava-filled basin of Alftavatnskrokur.

At the north eastern end of the crater a small slag cone, about one hundred metres in diameter and twenty metres high, has been built which must post-date the slumping suggested by the changes of slope and surface described above. No other young volcanics are exposed.

Crater J. - This crater begins one hundred metres to the north east of Crater I. It is nine hundred metres in length and bends slightly to the east and then later resumes its old north easterly trend parallel to the other craters. The crater has a uniform width of roughly one hundred metres and is about thirty metres deep.

The following succession of older volcanics is exposed in the crater walls:-

5.	Lava	0. 6 m.
	Slag and ash	1. 2 m.
4.	Lava	1. 0 m.
	Slag and ash	1. 3 m.
3.	Lava	1. 3 m.
	Slag and ash	1. 6 m.
2.	Lava	1. 3 m.
	Slag and ash	2. 0 m.
1.	Lava	4. 0 m.

Underlain by Palagonite Formation tuffs.

As in the case of Crater I, irregular broken lava surfaces slope upwards, away from the fissure on either side. On the northern side of the fissure, though traces of arcuate fractures do exist, and though slumping into the fissure has undoubtedly taken place, no simple explanation of the surface features is possible. On the southern side, however, two well-marked arcuate fault scarps may be seen running roughly parallel with the fissure. The downthrow has been of the order of fifteen metres.

In this fissure two groups of slag cones represent the younger volcanics. Each group is represented by a cone approximately twenty metres in diameter and ten high, with smaller associated slag mounds. All are formed of highly vesicular pahoehoe slag.

Crater K. - This crater follows immediately after Crater J but is displaced slightly to the north west. It is four hundred and fifty metres long with a width of one hundred and fifty metres at its widest point. The crater rim slopes downwards to the south west falling from six hundred metres above sea level, where the crater has a depth of sixty metres, to a little over five hundred metres, where the crater has a depth of thirty metres.

The complete succession of older lavas represented at the south western end of Crater K is as follows:-

6.	Lava	0. 6. m.
	Slag and ash	1. 6 m.
5.	Lava	2. 0 m.
	Slag and ash	1. 6 m.
4.	Lava	1. 3 m.
	Slag and ash	0. 3 m.
3.	Lava	1. 3 m.
	Slag and ash	1. 0 m.
2.	Lava	1. 0 m.
	Slag and ash	0. 6 m.
1.	Lava	1. 6 m.

Resting on Palagonite tuffs.

The northern lip of the crater lies about ten metres higher than the southern. There are no signs of major slumping in this crater. No younger volcanics are exposed.

Crater L. - This crater, four hundred metres long, one hundred wide and forty deep, is divided from Crater K only by a more shallow floor and a slight constriction of the walls between the two craters.

The older lavas of this crater appear to be continuations of the flows of Crater K, but with the upper three flows missing at the south western end. The northern side of the crater has slumped downwards about fifteen metres. There are no young volcanics exposed in this crater.

In line with this crater is a further small crater one hundred metres long, thirty wide and ten deep. The walls are formed of older volcanics. Two small slag cones follow, and the fissure is then represented by a small fault down-throwing about two metres to the north west. This fault can be traced for five hundred metres north eastward, from the hornitos. Running parallel with this fault is a further fault one hundred and fifty metres to the north west, this fault downthrows to the south west by about ten metres, and it too is roughly five hundred metres long, beginning opposite the hornitos, running north eastwards over the shoulder of Morauthavatnshnukar until it gives place to several small slag cones, finally leading to Crater M.

<u>Crater M.</u> - This crater straddles the depression between the two hills which together form Morauthavatnshnukar. The crater is eight hundred metres long and has a maximum width

of two hundred metres. The crater is deepest at either end becoming progressively more shallow as the centre is reached. The floor is a flat layer of alluvial sand and it is clear that this crater is, at some seasons, the site of a small lake.

The following section of older lavas is exposed at the north eastern end of the crater:-

	Slag and ash	1. 0 m.
7.	Lava	0. 3 m.
	Slag and ash	0. 6 m.
6.	Lava	1. 0 m.
	Slag and ash	0. 7 m.
5.	Lava	0. 1 m.
	Slag and ash	0. 3 m.
4.	Lava	0. 1 m.
	Slag and ash	0. 3 m.
3.	Lava	1. 0 m.
	Slag and ash	0. 2 m.
2.	Lava	0. 6 m.
	Slag and ash	0. 2 m.
1.	Lava	0. 6 m.
	Slag and ash	0. 6 m.
	Base not seen.	

The older lavas slope upwards for a short distance away from the fissure to the north west, showing that some minor

Plate 14

Craters M and N from Axlir, above Crater O. Two smaller craters lie in the foreground. South of the rounded hill Morauthavatnshnukar is Crater N. The norther wall with its six metres of volcanics can be seen to lie about fifteen metres above the down-faulted southern wall. A displacement in the old volcanics of two metres can be seen at the western end of the crater. Crater M can be seen indistinctly behind, and in line with, Crater N. Almost ten kilometres away on the far horizon the shallow Svartahnuksfjoll fault-graben can be seen to break the line of the hill.

slumping has taken place. The south eastern lip of the crater, however, is some twenty metres lower than the north western; the surface of the south eastern flank of the fissure does not suggest local slumping as a possible explanation. It seems probable, therefore, that some slight faulting, which post-dates the older volcanics, has taken place along the line of the fissure. There are no young volcanics exposed in this crater.

Five hundred metres north east of Crater M is a series of five slag cones, the south westernmost is perfectly preserved and shows six lava flows with intercalated slag and ash layers, the other four, however, appear to have been affected by the faulting along the line of the fissure described from Crater M, and their original cone-shape has been lost. The slag cones are followed by Crater N.

Crater N. - This crater, five hundred metres long, one hundred wide and thirty five deep, is the last of the large craters of the Central Fissure.

The older volcanics exposed in the crater walls comprise four flows, each roughly two metres in thickness, with equal thicknesses of ash and slag between. At the north eastern end of the crater, however, at least ten flows are present, though many of them are less than one third of a metre thick, with a roughly equal thickness of ash and slag between.

Plate 15

One of the line of small craters at the north eastern end of the Central Fissure. Built of slag and a few thin lavas these craters belong to the late mature stage of the volcano and have been comparatively inactive.

The fault already described from Crater M can be seen to cut the older volcanics at the south western end of the crater; the displacement at the surface is not more than two metres but the warping of the surface maks a movement probably of the order of ten metres. There are no signs of large scale slumping in this crater. No young volcanics are exposed. This crater and Crater M are shown in Plate 14½.

Between Craters N and O are three small cone shaped craters, all are built of slag and ash lava layers, sub-circular in shape and roughly one hundred metres in diameter. They have suffered little modification by slumping or faulting and this suggests that they have been comparatively inactive. One of these is shown in Plate 15.

Crater O. - Though one of the smallest of the Eldgja craters it is one of the most significant, in that lying on the normal red slag and lava layers is an explosion breccia of black ash with angular fragments of basalt and Palagonite tuff. The basalt fragments are less than twenty centimetres in diameter but the Palagonite tuff fragments reach one metre in length.

The crater is a rough D in shape, three hundred and fifty metres long and two hundred wide. The north western edge is straight and slopes down fifteen metres to the floor. The south eastern side, however, has been cut into the steep, northward facing shoulder of Axlir and the height of this wall increases from each end of the crater to reach a maximum of seventy metres at the centre of the crater. No volcanics have been deposited on this side of the crater.

The following succession is exposed on the north western side of Crater O: -

	Black explosion breccia	3. 0 m.
	Red Slag and Ash	3. 0 m.
2.	Lava	0. 4 m.
	Red slag and ash	1. 0 m.
1.	Lava	0. 3 m.
	Base not seen.	

There are no younger lavas exposed in this crater.

Between Craters O and P is a small, shallow crater fifty metres in diameter and ten metres deep, no volcanics are exposed in the walls.

<u>Crater P.</u> - The last of the craters of the Central Fissure, this crater is two hundred and fifty metres long, seventy wide and fifteen metres deep.

The following succession of older volcanics is exposed:-

	Slag and ash	2. 0 m.
3.	Lava	0. 6 m.
	Slag and ash	1. 0 m.
2.	Lava	1. 3 m.
	Slag and ash	1. 0 m.

1. Lava 1. 0 m.

Slag and ash 1. 0 m.

Base not seen.

No younger volcanics are exposed in this crater.

Two small slag cones follow close after Crater P, neither has extruded lava.

<u>The Activity and Evolution of the Central Fissure.</u>

The Central Fissure shows considerable differences from the Western Fissure, in part these differences may be accounted for by the very different topogrpphy which the two fissures traverse, but the major difference is one of size.

The Maelifellsandur craters of the Western Fissure reach five hundred metres in width, and yet no crater of the Central Fissure has a width greater than two hundred metres; the Western Fissure craters tend to be large and confluent, those of the Central Fissure small and discrete. After the extrusion of the early lavas large-scale slumping is quite absent, excepting Craters G and H, along the whole of the Central Fissure. The succeeding major extrusions must have been small in comparison with those of the Western Fissure and have taken place from only two points along the whole Fissure. Though the older volcanics are well represented, exposures of the younger volcanics are limited to two small slag cones in Crater J, though doubtless in other craters young lavas are covered by debris from the crater walls.

The impression produced by the Central Fissure is of a vigorous juvenile stage, followed by a mature stage of considerably less activity than that of the Western and Eastern Fissures.

<u>Crater F.</u> - Though this crater is now divided into two sections by the Tungufljot, which has cut a deep cleft through it, the identical heights of the alluvial floors of the two parts imply that it was once a single crater straddling the Tungufljot gorge. With its floor at a height of over seven hundred metres, this is the highest of the Eldgja craters, It is significant, therefore, that less than five metres of volcanics and only one flow, are to be found in the crater walls.

These volcanics are cut on either side by faults parallel with the fissure, which may be continuations of the Svartahnuksfjoll fault-graben, and are clearly older volcanics.

The activity of this crater seems to have been analogous to that of the Svartafell Crater; during the juvenile stages of the volcano, when the fissure was everywhere narrow, this crater was established and the small amount of volcanics erupted. The crater remained active sufficiently long to be enlarged to its present size, but without the extrusion of much lava. During the mature stage of the volcano, when activity tended to be concentrated in the lower craters, Crater F must have shown little or no activity.

Craters G and H. - These two craters together form the largest crater group of the Central Fissure. It is not easy to see why these craters, ending high on the eastern shoulder of Svartahnuksfjoll, should have become the largest of the Central Fissure, but it will be seen that this, to some extent, is explained by the topgraphy of the region. The southern edge of Crater G is one hundred metres higher than the northern, yet both sides show a roughly equal thickness of older volcanics. It seems very unlikely, if the present topography had existed before the volcano, that any flows at all could have been extruded on to the southern side of the fissure, and quite impossible that the two older southward flowing lavas could have been extruded from Crater G. The pre-volcanic topography in the neighbourhood of the fissure, must have been a fairly flat surface sloping northeastwards almost parallel to the fissure. The succeeding modifications are all volcanic in origin.

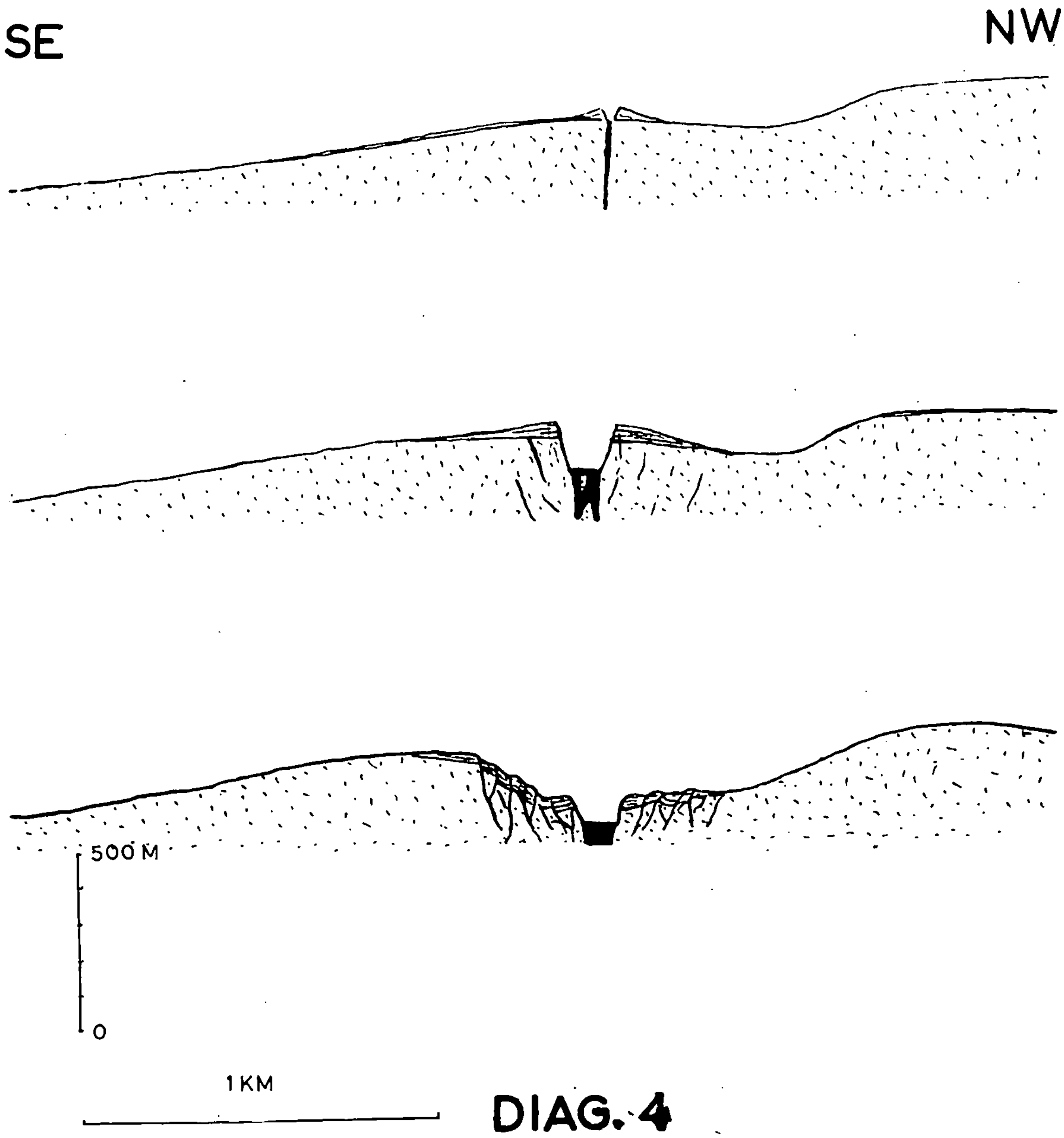
At Craters G and H at least twenty metres of volcanics have been erupted, while at Crater F, a mere four hundred metres distant and at a similar height, only five metres are present. It must be assumed, then, that the original fissure was wider at G, or for some other reason offered less resistance to the upward passage of lava, than at Crater F. The considerable thickness of volcanics at Craters G and H implies that at the end of the juvenile stage large craters had been developed. There is no field evidence which directly supports the existence of large craters at this stage, but the presence of twenty metres of volcanics round the crater rim, more than half of it slag (spatter from fire-fountaining), points to vigorous activity in the craters with only intermittent lava extrusion. With continued activity, the accompanying widening of the conduit and joining of the craters must have created a state of affairs such that the lava level in Crater G could at no time be much higher than that in Crater H. The lower lip of Crater H, even at this stage, cannot have been much higher than six hundred metres above sea level, so that at no time can the lava level in the two craters have greatly exceeded this height. The rim of Crater G, however, is more than seven hundred and fifty metres above sea level at its highest point, so that it follows that Crater G at this, the early mature, stage of the volcano can never have been less than one hundred metres deep and may, at times, have been considerably more. In this way the topography, combined with the high level of activity in the craters, produced an over-deepened crater at G and to a lesser extent at H. Lava outflow from these craters during the remainder of the volcano's history can only have taken place southward onto the Alftavotnskrokur plain.

As a result of the excessive widening of the craters and conduit a series of down-slipping movements followed which greatly altered the crater shape. The greatest vertical movement took place north of Crater G. Here, where the crater lip must originally have been one hundred and fifty metres above the crater floor, it is now at its lowest point only fifty metres high. The surface, which slopes smoothly down to this point from behind and on either side, suggests that the movement here was a simple sagging of the country rock with no considerable movement along any fault surface. The joints or cracks in the lava surface are arranged concentrically with respect to the lowest point on this side of the crater.

The northern side of Crater H seems to have suffered little faulting, but at its north eastern end a fault begins which continues along the line of the fissure, parallel to Craters I and J. At Crater H the movement appears to be of the order of ten metres but here, too, sagging into the fissure seems to have taken place and caused the walls to disappear between Craters H and I.

South of Craters G and H the slipping has taken place along consecutive and well-marked fault planes, the outermost begins in Crater G and has determined the straight northward facing scarp of this side of the crater. Leaving the crater,

CRATER G.



DIAG. 4

the fault runs north eastwards, diverging slightly from the line of the fissure, until it is lost beneath the younger lavas of the Alftavotnskrokur plain. Two other fault lines can be traced between this fault and Crater H. These faults have caused the down-slipping of the southern edge of Crater H by thirty or forty metres. Between Craters H and I on the southern side of the fissure sagging has occurred and through this gap the younger lavas have reached Alftavotnakrokur. These lavas, though poorly exposed, seem to have been small in amount and are heavily laden with debris from the crater walls. The younger lavas, which may form the floor of Craters G and H, are everywhere covered by scree fans from the crater walls. The crateral modifications are shown in Diagram 4.

Craters I and J. - These two craters lie in a shallow basin in a low ridge of older lavas. The remains of the ridge are best shown north of the fissure, where a smooth slope of older lavas slopes gently upwards towards the fissure until the shallow basin which surrounds the craters is reached. During the mature stage of the volcano this part of the fissure must have been only moderately active so that large craters, like A and B of the western fissure, were not formed.

During the mature stage, the early ridge was modified by a sinking of the crest until the present form was established.

The present craters must have been established after the sinking. Their small size implies that there was no great activity following the sinking, though at the north eastern end of Crater I a large slag cone has been built by fire-fountaining. There is no evidence to suggest that any large quantity of lava was extruded from this part of the fissure. The senile phase is represented by two small slag cones in Crater J.

The remainder of the Central Fissure has suffered very little modification. The modification which has taken place has been the enlargement of the craters by piece-meal slumping, and some minor faulting along the line of the fissure. Craters K and L have been modified only by some slight sagging of the northern crater walls. North East of Crater L the fissure resumes its trend after being displaced by one hundred metres to the north west. The two larger craters M and N, of this smaller appendix to the main Central Fissure, have been modified only by faulting along the line of the fissure. The movement has been relatively small, probably of the order of twenty metres, and belongs to a time between the extrusion of the early lavas and the formation of the present craters. A line of small cone-shaped craters follows Crater N. It is unlikely that the lava lying to the north of these craters was extruded from the craters as they are today. The lavas probably belong to the juvenile or early stage of the volcano and the present craters post-date them. The absence of any large craters suggests that this part of the fissure has been comparatively inactive.

It is significant that the only explosion breccia found in Eldgja should occur in one of the smallest craters (Crater O). It seems conclusive proof that explosive activity has played a negligible part in crater formation in Eldgja.

The activity of the Central Fissure may be summarised briefly as follows:-

1. Early Juvenile stage; eruption along the whole length of the fissure; considerable fire-fountaining and intermittent extrusion of lava.

2. Late Juvenile stage; activity waning in Crater F and the three north eastern craters, vigorous activity in Craters G and H, with the beginning of crater formation.

3. Early Mature stage; little activity in Crater F and the three north eastern craters; large craters formed at G and H, possibly fairly large lava extrusions onto the Alftavotnskrokur plain.

4. Late Mature stage; probably no activity in Crater F and the three north eastern craters; collapsing and sagging at craters G and H; and perhaps also at I and J; down-faulting of south side of fissure at craters M and N; slight slumping in other craters; further fairly large extrusions

onto the Alftavotnskrokur plains.

5. Senile stage; slight activity in the craters; formation of the slag cones of Crater J.

The Eastern Fissure.

The craters of the Eastern Fissure are more impressive than the others and it was this part of Eldgja that Thoroddsen had in mind when he wrote - "I had ridden over the southern outflow of the Skaelingar range, when suddenly I discovered this great cleft which has, as Sapper says, 'with sovereign acorn', torn straight through mountains and ridges and stretches southward as far as the eye can see. This great cleft offers a most picturesque appearance, with its perpendicular tuff and lava walls, torn rocks and chasms, and the clear waterfalls which, here and there, rush down the perpendicular walls. If one stands at the bottom of the cleft one can imagine the mighty power which breaks through so many metres of rock as though they were cake." (Thoroddsen 1925, P.67).

Though the Eastern Fissure is eight kilometres long it contains only four main craters, including the greatest Eldgja crater, the northernmost, which is five kilometres in length. In all probability the crater development which has taken place in the Eastern Eldgja Fissure is unique among fissure volcanoes.

Crater Q. - Crater Q and the Eastern Fissure begin six hundred metres to the south east of the Central Fissure, on the northern shoulder of the mountain Axlir. The crater is a little more than a kilometre and a half in length and has a fairly constant width of about two hundred metres. The precipitous southern wall of Crater Q reaches a height of almost one hundred and seventy metres above the crater floor, and is nowhere less than eighty metres high. At its greatest height the southern wall is formed of roughly one hundred metres of Palagonite tuffs overlain by seventy metres of volcanics. These volcanics are inaccessible, but the following table gives approximately the sequence.

Older Volcanics of the southern wall of Crater Q.

	Slag and Ash	3 m.
5.	Lava	2 m.
	Slag and Ash	3 m.
4.	Lava	2 m.
	Slag and Ash	2 m.
3.	Lava	4 m.
	Slag and Ash	10 m.
2.	Lava	5 m.
	Slag and Ash	20 m.
1.	Lava	14 m.

Resting on Palagonite formation tuffs.

Plate 16

Crater Q, from the north. The southern wall has a maximum height of one hundred and seventy metres. The broken and irregular northern wall is less than fifty metres high for most of its length. The step-faulting of the older volcanics on the southern wall is very clearly seen in this photograph at the eastern and western ends of the crater. In the left foreground, on the northern bank of the Strangakvisl river, the broken, older, lava surface is seen.

The southern wall of the crater has suffered considerable slumping and faulting into the fissure. Movement along numerous parallel cracks in line with the crater has resulted in stepped or terraced slopes and inward dipping lavas close to the crater lip. The greatest movement seems to have taken place in two small sections, at the extreme south western end of the crater, and near the north eastern end. The faulting is particularly well shown in Plate 16.

The northern wall contrasts with the southern in being, for most of its length, less than fifty metres above the crater floor. At its north eastern end the northern wall is fifty metres high, but as it is followed south westward the general height falls towards the centre of the crater to thirty metres and in one place to only ten metres. From the centre of the crater, the northern wall gradually gains in height until, at the south western end of the crater, it joins the southern wall at a height of eighty metres above the crater floor. The older volcanics of the northern wall are considerably thinner than those of the southern and it appears that except at the north eastern end, the upper members are missing. The sequence at the north eastern end is as follows:-

	Slag and Ash	1. 0 m.
5.	Lava	0. 5 m.
	Slag and Ash	1. 5 m.

Plate 17

Crater Q, from the north. The seventy metre thick, older volcanics can be clearly seen on the southern crater wall, and, at the left side of the photograph, the step-faulting and resulting terracing. Pronounced sagging of the older volcanics can be seen in two places to the right. The very irregular and fractured slope of the northern wall is well shown.

4.	Lava	0. 5 m.
	Slag and ash	2. 0 m.
3.	Lava	2. 0 m.
	Slag and ash	2. 0 m.
2.	Lava	0. 3 m.
	Slag and ash	3. 0 m.
1.	Lava	0. 6 m.
	Slag and ash	2. 0 m.

Resting on Palagonite Formation tuffs.

The surface of the older lavas is cracked and broken on the north side of the fissure, dips steeply northward and disappears beneath the alluvium of Strangakvisl, (See Plate 17). North of Strangakvisl, however, the valley side, which rises northward away from Strangakvisl and Crater Q, is covered by Eldgja lavas. These lavas rise at least fifty metres above Strangakvisl and the crater floor and, like the lavas of the northern wall of Crater Q, are broken and fractured.

The floor of Crater Q is formed of younger lavas broken here and there by small vents with surrounding mounds of slag. The most perfectly preserved of these is at the south western end of the crater and is a vertical-walled pit about ten metres deep and forty in diameter. The vent-walls are covered by a thick coating of lava with horizontal jointing which has broken away in places, revealing a sequence of five thin flows with no intercalated slag. These form the floor of Crater Q

Plate 18

The southwestern vent of Crater Q, from the vent floor. In the foreground lie large blocks of older volcanics from the northern wall of Crater Q can be seen in the upper right side of the photograph. One of the blocks rests on a small dome of pahoehoe, the last eruptive product. Behind, the younger lavas of the floor can be seen surmounted by a tabular remnant of the once continuous encircling wall of slag.

at this point. To the south and west this vent has been covered by screes from the high crater walls, but on the other two sides the surrounding high rim of slag has been preserved. The rim is about ten metres high with an almost vertical inner wall and a thirty degree outer slope. In the centre of the pit is a small slag cone two metres high. This vent is shown in Plate 18. Two hundred and fifty metres north east on the crater floor is the second vent of Crater Q. It is about seven metres wide and ten long. Little can be seen of this vent, apart from the irregular slag walls. Half way along Crater Q the largest of the vents occurs. It is imperfectly preserved, but the remains of a circular slag wall one hundred and fifty metres in diameter can be seen. The inner part of the vent is overgrown with mosses and grass but there are, here and there, low slag mounds and a small slag cone in the centre. North eastwards from this vent the crater narrows and the screes from opposite walls have joined to obscure any younger volcanics present. (Crater Q is shown in Plates 19 and 20). Between Craters Q and R the northern wall has sagged and disappears beneath the younger lavas and it is through this gap that Strangakvisl flows. The southern wall of Crater Q is continued north eastwards as a semi-circular fault scarp which forma a quarter circle round Crater R, falling in height as it does not

Plate 19

The interior of Crater Q, from the northeast. The continuity between the older volcanics on both sides of the crater can be seen from this photograph, and the pronounced dip to the north. In the foreground is a remnant of a young slag cone. In the distance, on the floor of the crater, the slag walls of the well-preserved south western vent can be seen.

Between Crater Q and Crater R is a flat floor of younger lavas. Several irregular slag mounds suggest that small late-stage vents existed here, but their form has been destroyed by Strangakvisl, which cuts deeply into the younger lavas, showing 1.3 metres of massive lava overlying a series of ten flows which average 0.25 metres in thickness. The younger lavas continue eastward, between the arcuate scarp described above and Crater R.

Crater R. - This crater begins three hundred metres from, and in line with, Crater Q. The crater is just over two hundred metres long and a little less than two hundred metres wide. The northern wall is fifty metres high of which the upper seven metres are formed of older volcanics. These older volcanics slope upwards away from the fissure and can be traced nearly two hundred metres from the crater edge. The southern wall of Crater R is forty metres high with the following, probably incomplete, succession of older volcanics:-

	Slag and Ash	1. 0 m.
3.	Lava	0. 6 m.
	Slag and Ash	1. 5 m.
2.	Lava	4. 0 m.
	Slag and ash	3. 3 m.
1.	Lava	1. 0 m.
	Base not seen.	

Plate 20

The interior of Crater Q, from the south western end of the southern wall. In the foreground, on the floor of the crater, lies the south western vent, behind, on the crater floor, less distinct slag mounds mark the site of vents now obscured by debris. Strangakvisl is seen to the north of the crater; the slopes to the north of Strangakvisl have a cover of older lavas. In the distance Craters R and S are seen.

The broken upper surface of the older volcanics slopes south eastward and disappears beneath the younger lavas which have flowed eastward between this crater and Craters Q and S on either side.

The floor of Crater R is paved with young pahoehoe lava. Between Craters R and S slumping of the southern wall of the fissure has taken place and through this gap younger lavas have made their way eastward.

Crater S. - This crater follows immediately after Crater R. It is four hundred and fifty metres long and one hundred and fifty metres wide. The northern wall is sixty metres high and shows fifteen metres of older volcanics. The older lavas, which are broken by cracks parallel to the fissure, slope upwards away from the crater for a distance of two hundred metres.

The southern wall of the crater is fifty metres high and shows the following succession of older lavas.

5.	Lava	0. 7 m.
	Slag and Ash	2. 3 m.
4.	Lava	0. 8 m.
	Slag and Ash	1. 5 m.
3.	Lava	0. 7 m.
	Slag and Ash	1. 8 m.
2.	Lava	1. 2 m.
	Slag and Ash	2. 7 m.

Plate 21

Part of the basin between Craters S and V, from the north east. In the foreground an isolated tabular block of older lava is seen. Behind, on the extreme left of the photograph, is the main central mass of older lavas, and, partially superimposed on this, the large slag cone T, two hundred metres in diameter. Through a break in the walls, the vent within the cone can be seen. Behind the slag cone is Crater S and on the southern slope the marked hump produced by the V faults described in the text.

1. Lava 2. 4 m.

Resting on Palagonite formation tuffs.

The southern slope of Crater S is broken by two intersecting faults which form a broad V, the apex of which points up the slope, and both of which downthrow towards the fissure. The inner undisturbed part of the V has an unbroken, though somewhat eroded, surface, but the downthrown blocks are irregular and broken. South of the faults these older lavas disappear beneath the younger lavas in the valley of the Nythri Ofaera which flows between Crater S and the lower slopes of the Skaelingar hills.

Crater S has a flat floor of younger lavas. Between Crater S and Crater V the fissure is of considerable interest. Here, any early craters which may have existed have been destroyed, and only a broad and shallow basin remains. The basin is roughly circular and approximately four hundred metres in diameter, bordered to the south, east and west by broken and tilted masses of older lavas. Isolated remnants of older lavas occur with their basement of palagonite tuff, notably in the north western part of the basin, where later activity has formed a new crater, Crater U, within the older lavas. The isolated masses of older lavas are surrounded by the younger lava which forms the floor of the basin, and on which stands the large vent T. See Plates 21 and 22. This

Plate 22

The vent T, from the east. Within the broken slag walls the inner vent is seen. To the right of the cone lie the isolated older lavas of the basin. To the left of the vent the northern wall of Crater S is seen. A small section of the older lavas can be seen to have slumped downwards, by about ten metres, at the eastern end of the wall.

vent is very similar in form to those of Crater Q. An inner, pear-shaped vent, roughly fifty metres long and pointing east, has been cut through a series of this younger lava flows, of which two metres are exposed. The floor is covered with debris from the walls but two small slag mounds can be seen.

Surrounding the younger lavas and the vent is a slag wall now completely broken through at two points, but reaching twanty metres in height between. The slag wall is roughly circular and one hundred and twenty metres in diameter, with the vent at its centre. A small slag cone lies thirty metres to the north west of the vent T; it is forty metres in diameter with low walls roughly four metres high. The Nythri Ofaera flows southward from Crater V through the open northern side of the basin (See plate 23) and makes an exit through the older lavas of the south eastern side to join Strangakvisl, south of Crater S. Plate 24 shows the Craters Q, R, S and U and vent T, from the south eastern wall of Crater V.

<u>Crater V.</u> - This crater is almost exactly five kilometres long and runs from Crater S to the southern flank of Gjatindur. Close to its open south western end the crater widens to six hundred metres, but a kilometre to the north east, narrows again to three hundred metres and remains at this width for

Plate 23

The Nythri Ofaera, flowing from Crater V towards the camera. The flat floor of alluvium is broken only by small slag cones and rings. One is seen in the immediate foreground.

roughly half a kilometre. North eastward from this constriction the crater increases in width once more and remains at a roughly constant width of five hundred metres for the remaining three and a half kilometres of its length. There is no great variation in the height of the crater walls. One of the lowest sections, where the Nythri Ofaera plunges over the northern wall, (see Plate 25) is roughly one hundred and sixty metres above the crater floor. The highest section of the walls, where the crater narrows, must be at least two hundred and fifty metres above the crater floor. The older volcanics, which everywhere form the lip of the crater, vary in thickness from twenty to seventy metres. Only two lava flows are seen, forming roughly thirty percent of the volcanics, the remainder being slag and ash. Accurate sections are difficult to obtain because of the large distance between opposite walls and the inaccessibility of the volcanics themselves.

Slumping and sagging on a small scale has taken place along the crater lip, and this is well seen in Plates 25 and 26.

The remarkably flat floor of the crater (well seen in Plate 26) suggests that beneath the present cover of alluvium there is a floor of younger lava similar to that of Craters Q, R and S. The alluvium is broken here and there by small

Plate 24

Craters Q, R, S and U and the vent T, from the southern end of Crater V. In the foreground is seen the irregular, ridged slope produced by slumping of the older volcanics. The Nythri Ofaera is seen flowing through the basin between Craters S and V. On the extreme right is seen the Crater U cut through collapsed older volcanics, and to the left, just above the river, more older volcanics. The vent T lies behind; behind the vent is seen the northern wall of Crater S. The contrast between the inner faulted and the outer unfaulted southern slope of Crater S is well shown. In the distance is seen Crater Q, The semi-circular scarp mentioned in the text, with its steep and very broken slope, is seen to the left of the crater.

groups of slag cones and rings less than three metres high and which represent the waning stages of the activity of the crater.

The Activity and Evolution of the Eastern Fissure.

The craters of the Eastern Fissure contrast with those of both the Western and Central Fissures. Though the eastern craters have been superimposed on a topography similar to that of the Central Fissure, they are much larger in size, comparing in this way with the craters of the Western Fissure, but differing from them in complexity.

Crater Q. - There are three features of this crater which need to be explained. (1) the high southern wall, with its thick cover of early volcanics, (2) the much lower northern wall, with its shattered and incomplete cover of early volcanics, and (3) the older volcanics on the northern slopes of the Strangakvisl valley. It is quite impossible, with the present shape of the crater and its surroundings, for lava flows from the crater to have reached the northern slopes of the Strangakvisl valley. If these lavas were extruded from Crater Q it follows that at the time of the extrusion the Strangakvisl valley did not exist. It follows too, that unless the northern wall corresponded in height with the southern, it is impossible for the seventy metres of early volcanics, including lavas, to have been poured out above the

Plate 25

Crater V from the south. Three and a half kilometres of the crater are shown until it terminates on Gjatindur. The opposite walls are roughly two hundred metres above the crater floor. Where the Nythri Afaera plunges over the wall in a double fall, a large mass of older volcanics has subsided and now forms the lip of the lower fall.

hundred metre high wall. The southern crater wall now falls as low as eighty metres in places but this is the result of sagging and faulting of the crater lip after the extrusions of the early volcanics. The present distribution of the early lavas requires that at the time of their extrusion the walls should have been equal in height and, further, that they should have been nowhere much less than one hundred and fifty metres above the present crater floor. The early volcanics of the northern wall, though probably incomplete, are individually comparable in thickness with the lower members of the southern wall volcanics. It follows, then, that the slope leading down to the north from the northern wall of the fissure, cannot have been of great steepness. It was down this comparatively gentle slope that the lavas flowed, which are now on the northern side of Strangakvisl.

During the early stages of the volcano it is probable that a series of cone-shaped slag craters were developed. The great thicknesses of slag interbedded with, and exceeding in thickness, the older lavas, however, show that vigorous and prolonged activity in the form of fire-fountaining was taking place. As this activity continued, large craters must have been formed by piecemeal collapse of the walls, and this process continued until a single crater was formed equal to, or exceeding in size, the present Crater Q. Excessive

Plate 26

Crater V, from Gjatindur. In the left foreground the older volcanics can be seen to wedge out away from the fissure. In the left middle distance the older volcanics are faulted and sagging at the crater lip. The crater floor is quite flat and probably underlain by younger lavas; two small slag mounds are seen on the crater floor. Almost in line with the fissure is a low conical hill set against the ice of Myrdalsjokull; this is the mountain Svartafell at the eastern end of the Western Fissure.

enlargement of the crater and conduit, may alone have caused the whole-sale collapse of the northern crater wall, though a temporary withdrawal of the lava column may have contributed. At this stage the crater had taken on the essentials of its present day appearance, with early lavas lying to the north of, and above, the early lavas of the collapsed northern wall, and separated from them by a fault zone which is now the lower Strangakvisl valley. It seems likely that the faulting and slumping of the southern wall also belongs to this time.

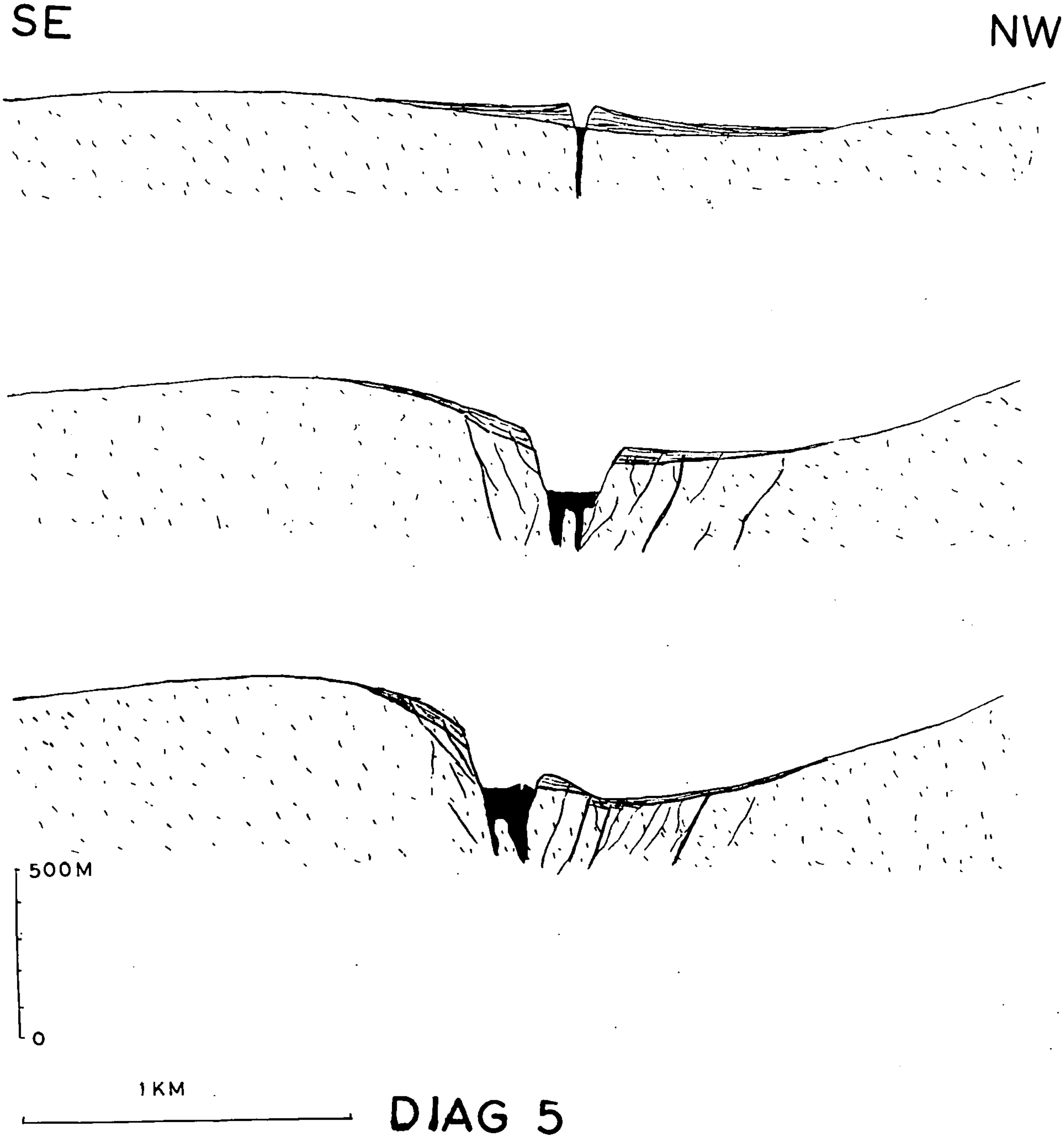
After the collapse, further activity must have cleared away debris from the present crater, and extruded the series of younger lavas which now form the floor. During the last stages of activity the vents and slag cones of the crater floor were formed.

This probable evolution of Crater Q is shown in Diagram 5.

Craters, R, S and U. - The Eastern Fissure as a whole presents the anomalous features of a thick series of volcanics, including lava flows, high on the walls of deep craters, and all with outlets at floor level.

The great thickness of the volcanics of the present crater walls shows that at the time of the extrusion of the upper members the feeding conduit must have been widened and small craters, at least, formed. At this stage it is unlikely that the uppermost of the older lavas could have been extruded, for example from Crater Q, if a gap one hundred and fifty

CRATER Q



DIAG 5

metres lower had existed between Crater Q and Crater R, for it has been shown that at Svartafell, under these circumstances, only two early flows were extruded from the summit crater. The gaps, then, between Craters Q and R and R and S and the basin between Craters S and U, are clearly not features of the original topography and must be volcanic in origin. They clearly belong to the general subsidence of the mature stage of the volcano.

Before and during the early phase a shallow trough probably existed between the Skaelingar hills and Axlir, and through this trough the Nythri-Ofaera and Strangakvisl flowed. The general level here cannot have been much less or much greater than the present height of the northern walls of Craters R and S, for early lavas were extruded onto the northern hillside from both craters, but reached no great distance from the fissure. The general pattern of events then closely followed that of Crater Q. With continued activity the conduit and craters were enlarged until Craters R and S must have coalesced, and these craters, in turn, may have been joined to Craters Q and V. Further activity may have led to over-widening and the crater walls became unstable. A fall in the lava level in the crater may have precipitated the collapse. The southern wall of the fissure subsided, along an arcuate fault zone, which forms the scarp already described round Crater R and along the faults which cut the southern slope of Crater S. Probably some movement took place along a fault zone between Craters R and S, causing Crater R to move downwards relative to Crater S. Probably also the northern walls of Craters R and S suffered some slight sagging causing the older lavas to dip gently inwards towards the two craters. It is difficult to estimate the total downthrow, but the movement of the southern wall of Crater S was not less than fifty metres, and probably a few more metres in the case of Crater R. The sagging of the northern walls of the two craters was a little more than ten metres in the case of Crater S but may have been as much as thirty in the case of Crater R.

Between Craters V and S little now remains of the older volcanics and nothing of the early craters. It is unlikely that the height of the oldcrater lip was lower than at Crater S. The material originally forming the crater walls has presumably fallen below the level of the younger lavas which now floor the basin. It is probable that this subsidence took place at the same time, and for similar reasons, as the collapse of the other craters of the Eastern Fissure.

Following the general collapse of Craters R and S, and the fissure to the north east of S, further activity re-established the craters and the young lavas which form their flows were extruded. Later activity in the basin between Craters S and V resulted in the establishment of a new crater, U, cutting through a collapsed, inward-dipping mass of older lava on the northern side of the basin. During the waning stages, activity tended to be concentrated between the new Crater U and Crater S, and resulted in the formation of the vent and slag cone T.

Crater V. - The early fissure probably formed in a shallow valley draining to the southwest; slowly the early volcanic deposits of slag and lava built up a low ridge. Lava extrusions took place only through the natural outlet of the valley to the south west, except for one small flow which almost reached the Skafta valley from a shallow saddle on the Skaelingar ridge. Subsequent activity in the crater resulted only in its enlargement to its present dimensions. This seems to have been accomplished by piecemeal collapse of the walls. The crater almost everywhere shows signs of marginal slumping. The results of one of the largest of these movements can be seen at the Nythri Ofaera water fall, where a large tilted mass of older lavas, fifty metres high, dips inwards at thirty degrees and disappears beneath the crater floor.

The youngest lava from the crater solidified to form the present floor and the dying activity produced the few scattered slag mounds and cones of the crater floor. The formation of this very large crater is puzzling. No other Eldgja crater approaches it in size, and yet the largest of the other Eldgja craters have all been subject to subsidence on a major scale. It would seem that the length of this large crater is the result of the local uniformity of the topography, which allowed the outflow of lava only at the extreme south western end of the crater. The present depth of the crater must be due to the collapse of the southern wall of the fissure at Craters R and S, which allowed the lava from all the interconnected craters of the Eastern Fissure to overflow from this low breach in the southern wall, and provided a low maximum height above which the lava in the craters could not rise. But Crater Q in its early mature stage could only overflow from its extreme north eastern end, and it too had a low maximum lava height fixed by the collapse of the south wall, and yet, though the height of the southern wall of Crater Q approaches the height of the walls of Crater V, it is less than half as wide, and has suffered a major collapse of the northern wall. The explanation of these anomalies may be that Crater Q is now narrow because of the collapse of its northern wall, and that originally it, and the other large craters of Eldgja (G, H, Q, R and S), may have approached, if not exceeded, Crater V in width, and have been reduced in size when their collapsing walls moved downwards and inwards. Crater V, then, owes its size to an activity which was vigorous enough to enlarge the crater to its present dimensions, but not vigorous enough to produce an over-widened conduit and crater.

The activity of the Eastern Fissure may be summarised as follows:-

1. Early Juvenile stage; the establishment of the fissure and extrusion of the early older lavas; rows of slag cones formed along the line of the fissure by fire fountaining but no true craters.

2. Late Juvenile stage; continued extrusion of older lavas and deposition of slag and ash by fire fountaining; craters beginning to form.

3. Early mature stage; continued activity producing very large craters, and over deepened craters; beginning of major extrusions.

4. Late mature stage; collapsing on a major scale in Craters Q, R and S; continued extrusion of major flows now through breaches in the walls.

5. Senile stage; majority of lava in the craters solidified; activity concentrated in one or two minor vents in crater Q and the large vent T; waning stages producing the small slag mounds and cones.

DETAILED DESCRIPTION OF THE ELDGJA LAVA FIELDS.

The Eldgja lavas fall into two distinct groups. Those from the Central and Eastern Fissures which flowed down the Skafta valley onto Methalland and Landbrot, here called the Eastern Lavas, and those which flowed from the western Fissure and from the Ice Cap down the Holmsa and associated valleys to Myrdalssandur, here called the Western Lavas.

The Eastern Lavas.

The Eastern Lavas are exposed in four localities; in the valley of the Sythri Ofaera, where they originate from the Central Fissure; in the valley of the Nythri Ofaera, where they originate from the Eastern Fissure; in the north western part of Methallandssandur, here called Methallandshraun; and in Landbrot, here called Landbrotshraun.

The Central Fissure flows. - As a rule the early lavas from Eldgja have been covered by the later, larger flows. Along the higher parts of the Central Fissure, however, and to a lesser extent the Eastern Fissure, the early flows have been preserved by the diversion of the later lavas to the lowest parts of the larger craters. Thus at the south western end of the Eastern Fissure, three of the early flows are well exposed. The easternmost of these, originating in Crater F, has flowed south eastward down the eastern branch of the Tungufljot. The flow is roughly six kilometres long, and is joined after three kilometres by the second of the older flows, which seems to have arisen from both Crater F and Crater G. The two flows have an average width of about ten metres, though they reach thirty metres in width in places. Their average thickness is about three metres.

The third flow is only two kilometres in length and has flowed southward along the top of the plateau which borders the southern end of the Alftavatnskrokur plain. This flow has a roughly constant width of two hundred and fifty metres and is about two metres thick.

At the northewestern end of the Central Fissure older lava flows can be seen to have flowed southward from Craters M and N and northward from Craters N, O and P. The flow from Crater M has flowed through the gorge of Thorsteinsgil for two kilometres until it disappears beneath the younger lavas to the south. Only at the southern end is the flow more than ten metres wide, its thickness is uncertain but may be four or five metres. From Crater N a similar, but much wider, flow runs parallel to the one just described. This flow is two kilometres long, forty metres in width and between one and two metres thick. It too disappears beneath the younger lavas in the Sythri Ofaera valley. Only a rough estimate can be given for the thickness of the lavas north of Crater N, but it is unlikely that they are more than three or four metres in thickness. In the central part of the Central Fissure, north of Alftavatnskrokur plain, no early flows are visible. North of the fissure, it is a matter of uncertainty (because of overlying ash) where the older volcanics cease, but from the topography, they seem to stretch uniformly about fifty metres north of the fissure. South of the fissure the older lavas have been overwhelmed by the younger lavas from Craters, H, I, J and K. These lavas have flooded out over the shallow basin. They are now unfortunately, much obscured by alluvium from the Sythri Ofaera and its tributaries. It is unlikely that an average thickness of thirty metres will be an overestimate for these lavas. From Alftavatnskrokur the younger lavas converge into the steep sided narrow valley of the Sythri Ofaera below the plain. Thoroddsen (1925 P.70) has stated that here "the visible lava is a younger smaller stream which has flowed over a broader stream". While this is probable, no field evidence could be found which supported the statement. Close to Alftavotn the lava flow towers in places twenty or thirty metres above the adjacent valley sides. This phenomenon may have been caused by the squeezing together of the solid and semi-solid upper layers of the flow as it flowed from the broad plain into the narrow valley and gorge. The younger lavas follow the narrow valley of the Sythri Ofaera for five kilometres from Alftavotn until they disappear under the Laki lava of the Skafta valley. Over this distance the flow exhibits what can only be described as a macro-ropy structure. Whenever the flow narrows, the surface has been thrown into great folds ten metres or so in height. The folds stretch across the flow from side to side, but have been bowed downstream by the central, faster moving liquid.

At no point in the lower valley of the Sythri Ofaera, has the river cut through the upper flow to expose an underlying lava, though an underlying flow or series of flows is probably present. The thickness of the lava in the lower valley is unlikely to be less than fifty metres.

The Eastern Fissure flows. - The older lavas of the Eastern Fissure have formed only two well-defined flows. The minor flow, already described, has flowed southward from a shallow saddle high on the Skaelingar range. It is less than two kilometres in length, about thirty metres in width and perhaps four metres in thickness. The other major flow, or flows, have flowed down the valley of the Nythri Ofaera. These flows are now covered by younger lavas, but they seem to have been more than a kilometre in width, and their depth

Plate 27

Younger lavas and Craters R and S, from the north Skafta feeder. In the foreground are seen the younger lavas with a smooth platy surface. In the centre of the photograph, with the northern hills behind is seen Crater S and to the left, with a broken lava surface, Crater R.

may be, perhaps, twenty or thirty metres. In other parts of the Eastern Fissure, the older lavas do not form well defined flows but extend as a more or less regular zone of lava and slag on either side of the fissure. Doubtless this zone consists of many individual flows but the present cover of ash and slag prevents any examination.

The younger lavas of the Eastern Fissure are found only in the southern part of the valley of the Nythri Ofaera. After they passed through the narrow breach in the southern wall of the fissure they spread out to a width of a little less than a kilometre. The Nythri Ofaera reveals the following section as it plunges over the northern boundary of these flows:-

5.	Lava	0. 5 m.
	Black Ash	0. 3 m.
4.	Lava	0. 3 m.
	Black ash	0. 2 m.
3.	Lava	0. 6 m.
	Black ash	0. 4 m.
2.	Lava	0. 7 m.
	Black ash	0. 5 m.
1.	Lava	7. 0 m.

Resting on a series of banded soil and ash layers.

Plate 28

The north Skafta feeder from the same place as Plate 27 but facing down the flow. The upper smooth surface can be seen to become much more broken as the distance from the fissure is increased.

This section is found at the extreme northern margin of the Nythri Ofaera lavas. There may, therefore, be older flows underlying the thick lower flow. The total thickness, and probably number, of the flows must be expected to increase as the centre of the valley is reached. It seems reasonable then to propose an average thickness of twenty metres for these lavas.

A group of large blocks of bedded slag up to five metres in height lie at the eastern side of the lavas. The blocks lie outside the lavas marked on Map 111 as 'younger' but the ash and soil in the vicinity obscure the relationship of the blocks with the exposed lavas. It is certain, however, that these blocks come from the crater walls and have been carried to their present position on one of the lava flows during or after the collapse of the fissure walls. The blocks are shown in Plate 29.

The surface of the youngest lava, which is smooth near the fissure, becomes progressively more and more broken as the distance from the fissure is increased. This is doubtless due to the breaking up of the solidified upper layer of the lava, as it flowed along. The flow is shown in Plates 27 and 28.

The total area occupied by all the lavas of the Central and Eastern Fissures up to the point where they disappear under

Plate 29

Tilted blocks of stratified slag, on the surface of the north Skafta feeder, from the crater walls. The mountain Gjatindur is seen behind the Skaelingar hills.

the Laki lava of the Skafta valley, is 30.6 square kilometres. Roughly half of this area is comprised of younger lavas with an average thickness of about thirty metres. It is more difficult to estimate the average thickness of the older lavas round the craters but an average thickness of ten metres is a conservative estimate.

The total volume of these volcanics then is roughly 612 million cubic metres.

If the lavas of Methallandshraun and Landbrotshraun have been extruded from the Central and Eastern Fissures it follows that a considerable volume of lava now buried by the Laki lava, must lie between the two localities. The area of this lava is estimated at 198.7 square kilometres and, with an average thickness of twenty metres, it will have a total volume of 3,974 million cubic metres.

Landbrotshraun. - Landbrotshraun is the Eldgja flow with the greatest exposed area; 112. 5. square kilometres. The flow probably has an average thickness of twenty metres, though this increases considerably at the north eastern border where the lava proper is replaced by a confused mass of slag cones. These slag cones comprise about a third of the area of the exposed lava. They form a broad band round the northern, and part of the eastern boundaries. The cones

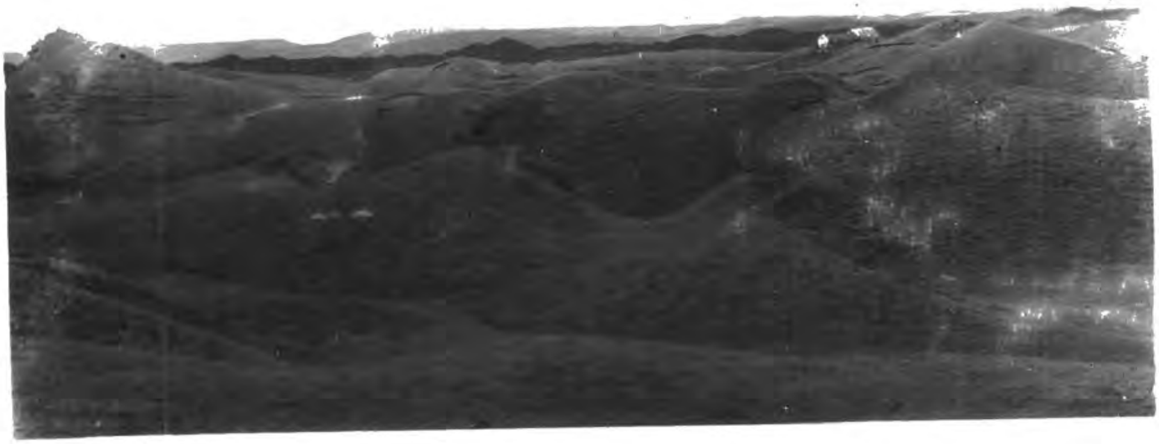


Plate 30

The densely packed, coalescing slag cones of Landbrotshraun. The flow in its eastern part is completely replaced by these mounds of slag formed after the lava had overrun an area of waterlogged alluvium. The huts on the right provide a scale and it will be seen that some of the vents have attained a considerable size but, except in rare cases, their cones have coalesced and a perfect form is not developed.

have been formed by the lava overrunning an area of waterlogged sand. The heat of the lava must have vapourised the water beneath which escaped upwards, more or less violently, through the still liquid lava, blowing out the liquid lava as it did so. The rapid cooling effected by the steam and the air, would cause the lava to vesiculate and so form the vesicular slag of the present cones. The great size of the majority of the cones suggests that the dehydration of the underlying sand was a lengthy process and the lava has been completely replaced by the existing slag mounds. In addition to vesicular slag, the material of the cones includes angular fragments of basalt, and also basalt fragments with a thick glassy selvidge; these have undoubtedly been formed by the abrupt chilling of the liquid lava by water or steam.

There is nothing to suggest that these slag cones have been formed by a process of 'a real eruption' as proposed by Rittman (1938 p.18) for the similar craters of Myvatn in Northern Iceland. The Landbrot cones are not distributed along fissures, form an irregular crescent shaped area bordering the normal lava and, perhaps most important, contain fragments of quickly chilled glassy basalt. There can be little doubt that these craters have an origin similar to that outlined above and also suggested by Thorarinson

(1951, p.67) in his reinterpretation of the Myvatn craters. The Landbrotshraun craters are shown in Plate 30.

The volume of the Landbrot flow from the data given above is 2,250 million cubic metres.

Methallandshraun. - This lava is now extensively drifted over by wind-blown sand and comparatively little can be seen. Along the eastern margin, a series of gorges has been cut through the flow and here some fine sections are exposed. The sections do not show the base of the flow, so that it is impossible to say whether or not other lava underlies it. The lavas have an area of 41.9 square kilometres and, if a thickness of twenty metres is estimated, a volume of 838 million cubic metres.

It is of interest to note that between Methallandshraun and the 1783 Laki lava a few mounds of vesicular slag project through the general cover of alluvium which occurs south of the lavas. This slag is crowded with white felspar phenocrysts which are so characteristic of the 1783 Laki lava, but as they lie more than a kilometre to the south of that lava, are clearly unconnected with it. This evidence suggests that an older Laki lava may underlie both the 1783 lava and the Eldgja lava.

The total volume of the Eastern Lavas as a whole is 7,674 million cubic metres, or a little more than seven and a half cubic kilometres. The area covered by them is 383.7 square kilometres.

<u>The Western Lavas.</u>

For descriptive purposes the Western Lavas will be divided into three groups; the Valley Lavas of the Holmsa and associated valleys, lying north of a line between Sandfell and Atlaey; the Myrdalsjokull Lavas, on the Eythorsson nunatak and in the valley south of Sandfell; and the Myrdalssandur Lavas, lying on Myrdalssandur south of the line between Sandfell and Atlaey.

<u>The Valley Lavas.</u> - The lavas which have been extruded from the Western Fissure were prevented from flowing for any distance to the north west by a low ridge which crosses Maelifellsandur four kilometres to the north west of the fissure. The relatively small volume of lava which did flow north westward is now covered by a thick deposit of fluvio - glacial sand, deposited as a result of the barrier which the ridge of the fissure forms as it crosses Maelifellsandur. The vast bulk of the extruded lava flowed southwards in two main streams on each side of the Kerlingarhnukar mountain mass. Before reaching these two valleys the lavas completely flooded the southern part of the Maelifellsandur to a depth of at least fifty metres. These lavas too are, unfortunately, thickly covered by outwash sands and gravels from Myrdalsjokull,

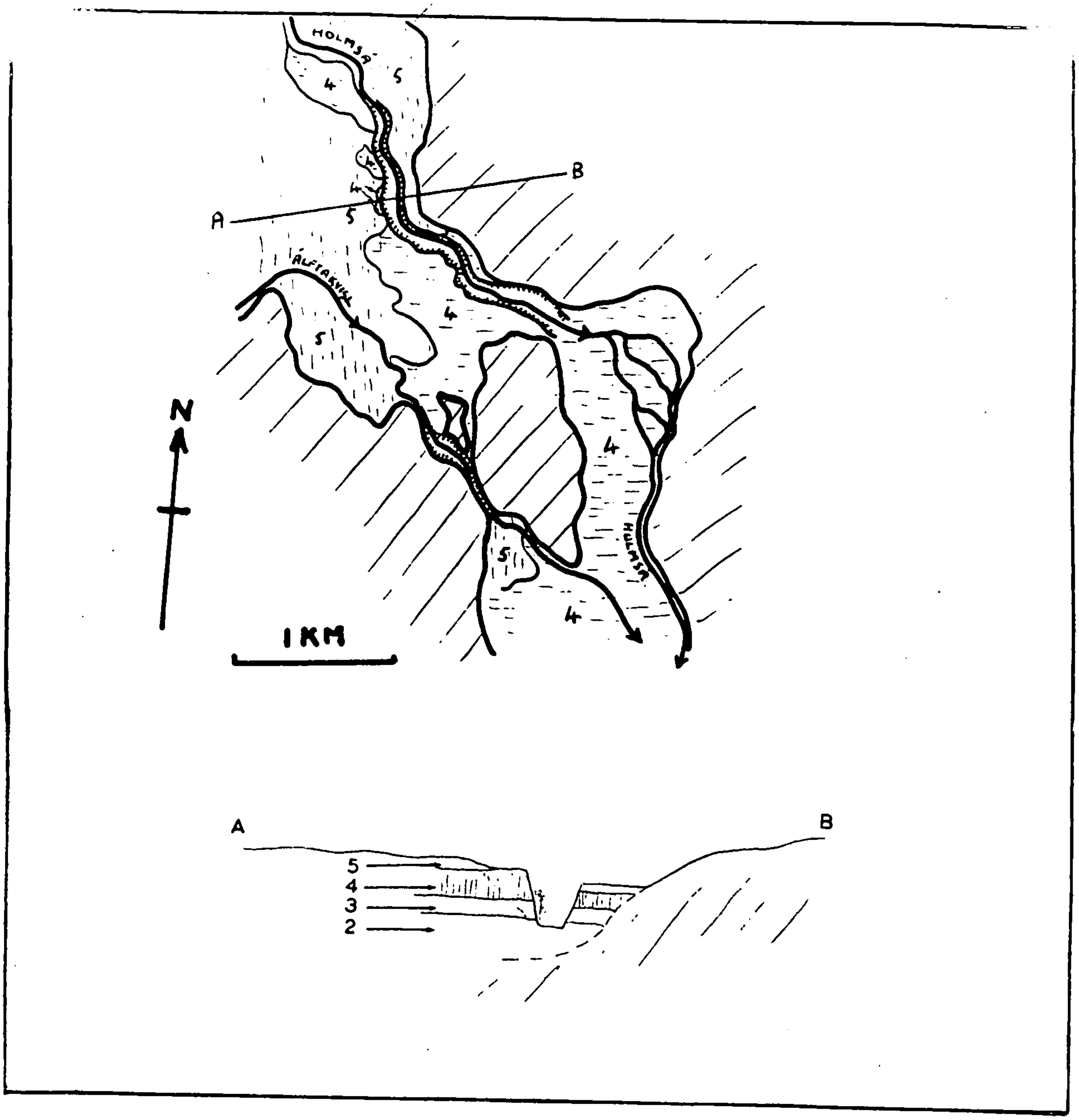
Plate 31

A small slag cone on the surface of younger lava, on Maelifellsandur, three kilometres south of the fissure. Presumably formed by gas escaping from the still liquid interior of the flow through a crack in the solidified surface. The hammer is half a metre long.

but it is possible to map approximately the boundary between the older lavas of the fissure walls, and the younger lavas which have poured through the later breaches in these walls. In all other places the older flows have been completely covered by the younger lavas. One of the most conspicuous features of the lavas of Maelifellsandur is the numerous blocks of older volcanics which are scattered over the surface of the younger lavas around the breaches in the southern fissure wall. These blocks are mainly composed of bedded slag and ash, but not uncommonly have interbedded layers of some of the early lavas too. Like the similar blocks of the Sythri Ofaera valley, these blocks must be debris from the collapsing of the crater walls and have been carried to their present position on the surface of the later flows.

Close to the lake Brytalaekir there are several, small, slag cones on the surface of the youngest lava. These cones may have an origin similar to those of Landbrot but, as they are small in size and number, they may equally well be merely the result of the escape of gas from the lava itself. One such cone is shown in Plate 31.

Of the two main valleys used by the southward flowing lava, Holmsa dalur is the more interesting, for here a sequence of five Eldgja flows is revealed. The river Holmsa, in



DIAG. 6.

flowing down the valley, has cut three gorges. The Upper, northeast of Kerlingarhnukar, the Middle, east of Einhyrningar, and the Lower, east of Atlaey.

The Upper Holmsa gorge reveals the upper four of these flows. It seems probable that the river had cut a gorge here before the existence of Eldgja, for the lavas, instead of spilling over the edge of the low platform which divides Maelifellsandur from the Holmsa valley proper in a uniform sheet, have converged and poured through a narrow gap, less than four hundred metres wide, over the site of the present gorge. As this channel became blocked with solidified lava, the upper two flows have also flowed through a yet narrower gorge, less than one hundred metres wide, eight hundred metres to the west. A sketch map and section of the lavas of the Upper gorge is given in Diagram 6.

The thicknesses of the exposed lavas in the Upper gorge are given below:-

5.	Lava	3 m.
4.	Lava	25 m.
3.	Lava	15 m.
2.	Lava	10 m.
	Base not seen.	

The Gorge and its lavas are seen in Plate 32.

Plate 32

Eldgja lavas in the upper Holmsa Gorge. The fall is roughly twenty metres high. On the right of the fall the youngest lava, flow number five, can be seen about three metres thick and with collumnar jointing. Below, on the right and also on the left, is flow number four, about thirty metres thick on the left. The lip of the fall is formed of flow number three, which is about fifteen metres thick; below this lies flow number two.

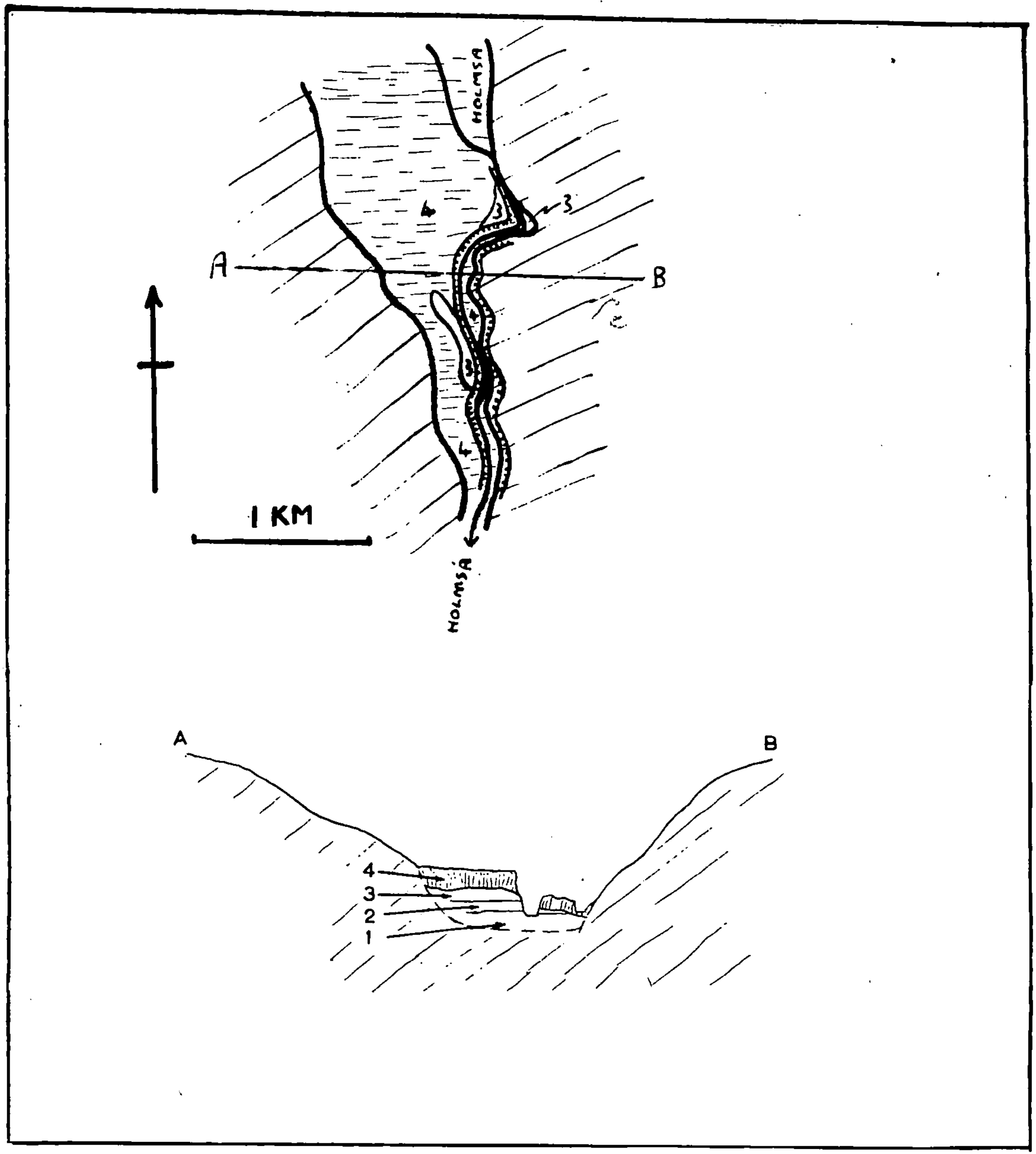
The walls of the gorge are, for the most part, inaccessible and little of the history of the gorge can be learned from the exposures along its length. The present gorge, however, is later than the youngest lava, through which it cuts, but as the youngest lava is found at a lower level on the east of the gorge than on the west, a comparatively shallow gorge may have been in existence at the time of its extrusion.

The youngest lava (No.5) is absent in the lower part of the gorge and, though present in the smaller western gorge, a small lava-front at the foot of this gorge seems to indicate the limit of its southward progress.

Following the lavas southward, exposure is ppor until the Middle Holmsa gorge is reached. Here too the Holmsa valley narrows, from more than a kilometre to four hundred metres in width, and the flows have converged before passing through to the broad valley below. Four flows are revealed in the gorge out by the Holmsa. Though they vary in thickness from place to place along the exposure, their average thicknesses are given below:-

4.	Lava	20 m.
3.	Lava	10 m.
2.	Lava	15 m.
	Banded soils	1 m.
1.	Lava	10 m.

Base not seen.



DIAG. 7.

The flows are numbered to correspond with their equivalents in the Upper Gorge.

The three lower flows are fairly uniform in thickness along the whole of the gorge but the upper flow (No. 4.) is not everywhere present. It appears that the present gorge was already in existence at the time of the extrusion of Flow 4 and that this flow did not completely cover Flow 3 but cascaded over the walls into the gorge where they were lowest. A sketch map and a section of the lavas of the Middle gorge are given in Diagram 7.

As the lavas are followed southward from the Middle Gorge two ridges of lava and slag, up to fifteen metres in height and roughly four hundred metres apart, run down the length of the flow. These ridges may represent debris deposited on either side of Flow 4, the liquid lava between them having subsided and flowed to the south. About seven kilometres south of the gorge, and almost opposite the Kofi, or hut, of the Alftaver farmers, Flow 4 ends in a well defined lava-front. Its average thickness here is roughly five metres. The upper part of Flow 3 is exposed beneath it and it is this lava that forms the waterfall just south of the Kofi. Three hundred metres south of the Kofi Flow 2 is exposed beneath Flow 3, which is here about four metres thick. Two kilometres south of the Kofi Flow 3 ends, it is here only two metres thick. This flow has been cut through by the river and a small outlier of Flow 3 occurs on the western bank of the river. Flow 2 may continue as far south as Atlaey but a great thickness of alluvial sand deposited here by the Holmsa and Jokullkvisl rivers completely obscures the southern part. Flow 1 is exposed only in the Middle Holmsa gorge. It is quite possible that other Eldgja flows underlie Flow 1.

It will be seen, then that five flows are exposed in the Holmsa valley and, of these, the upper three end before the southern outlet of the valley is reached, only the lower two* remain as possible feeders for the great lava areas to the south on Myrdalssandur.

The other valley used by the lava lies to the west of Kerlingarhnukar, between the ice cap and the Kerlingarhnukar, Eimhyrningar, Axlir chain of mountains.

One kilometre south east of Oldufell a cliff section adjacent to the ice cap reveals the following succession of Eldgja lavas.

Upper lava	4 m.
Middle lava	5 m.
Lower lava	15 m.

Base not seen.

The upper lava does not extend as far as the southern limit of the exposure, and this may be the natural limit of the flow, but the thick cover of glacial debris, which everywhere surrounds the ice-cap, makes a definite statement impossible. This western valley is higher than the Holmsa valley and, in consequence, at three points, lava has flowed down adjacent east-west valleys into Holmsadalur.

The northernmost of these flows has been very small, little more than ten metres wide for most of its length and one or two metres in depth, but the two southern flows have been quite large. The northernmost of the two large flows is thickly covered by sand and while it is not possible to correlate it with the Holmsadalur flows, it appears to be older than Flow 4. The lava of the southernmost of the east-west valleys is also covered by sand but appearances suggest that a small flow overlies a larger in the upper part of the valley, but that only the lower flow reached and joined the Holmsadalur flows. This flow, in Holmsadalur, appears to be overlain by Flow 4 and is tentatively correlated with Flow 3.

The majority of the lava of the western valley, however, must have spilled over a small scarp to the south into the broad valley east of Olafshaus.

It is not possible to correlate the Holmsa and Western Valley flows with any certainty, but the most reasonable interpretation is that of the three flows south of Oldufell, the upper does in fact end at the exposure and thus in both length and thickness corresponds to Flow 5 of Holmsadalur. Of the two flows of the southern east-west valley the upper must correspond with the middle Oldufell lava; it must also correspond with Flow 4 of Holmsadalur, as the flow below it has been correlated with Flow 3 of Holmsadalur.

In the valley east of Olafshaus the thick cover of moraine and ash allows only occasional glimpses of the lava beneath. There are, however, two lavas exposed, the upper about two metres in thickness and the lower at least three metres. The upper lava does not quite cover the lower in the south eastern part of the valley. These flows may correspond to the middle and lower Oldufell flows.

West of Atlaey a pronounced lava front occurs, roughly fifteen metres in height. The lava front faces to the north and east and this suggests that it had been moving in a north easterly direction before it was finally halted. If this were so its source may have been on Myrdalsjokull, or it may have been a lateral extension of a southward-moving flow from the valley east of Olafshaus. Correlation of this flow with the ones north and south of it is prevented by the alluvial deposits of the Jokullkvisl and Leira rivers which lie respectively north and south of the flow. It has been tentatively correlated with the upper flow of the valley east of Olafshaus.

The Valley lavas comprise approximately one third of the total area of the Western Lavas and must have an average thickness of at least thirty metres.

The Katla Lavas.- The lavas occur in two restricted localities. The smaller exposure occurs 1,000 metres high on the ice cap, on the Eythorsson nunatak. The lava occurs at the southern end of the nunatak about twenty metres above the present ice level, and is two metres in thickness. It has reached its present position by flowing over the surface of the ice cap which at the time of the extrusion must have been twenty metres above the present level. The lava rests on a metre thick layer of ash, with liparite below.

The other occurrence of Katla lava is south of Sandfell between this mountain and Kotlujokull. The lavas here dip to the east at roughly one hundred metres per kilometre. These lavas are extensively covered by moraine and outwash gravels. There are four lavas exposed, though these may be merely the upper members of a much thicker succession. The occurrence of these lavas suggests that some of the flows of Myrdalssandur may have been extruded from Katla. Unfortunately the lavas are covered by alluvial sand to the east and no connection with the Myrdalssandur lavas has been established in the field. The Katla lavas are discussed in more detail in a later chapter.

The Myrdalssandur lavas. - The lavas of Myrdalssandur may be divided into five groups; the lavas of Hrifuness and the south Holmsa valley; the lava south east of Rjupnafell; the Skalmabaejarhraun lava; the lavas of Hruthalsar; and the lava of Alftaver, Bolhraun and Selhraun.

There are two lavas exposed at Hrifuness, the lower is at least fifteen metres in thickness and the upper about four metres. Their relationship with the southern lavas is obscured by the alluvial deposits of the Leira which occasionally used to flow to the south of these lavas.

The lava lying to the south east of Rjupnafell ends in a well defined front ten metres high and is probably the youngest lava of the Sandur.

Skalmabaejarhraun, lying to the east, projects into the estuary of the Kuthafljot and is ten metres in thickness. The absence of any higher ground to the north or south to prevent spread in those directions suggests that this lava is not the same flow as the lavas which occur to the north and south. It seems more likely that this lava is a later flow which crossed the eastern boundary of the older lavas and

Plate 33

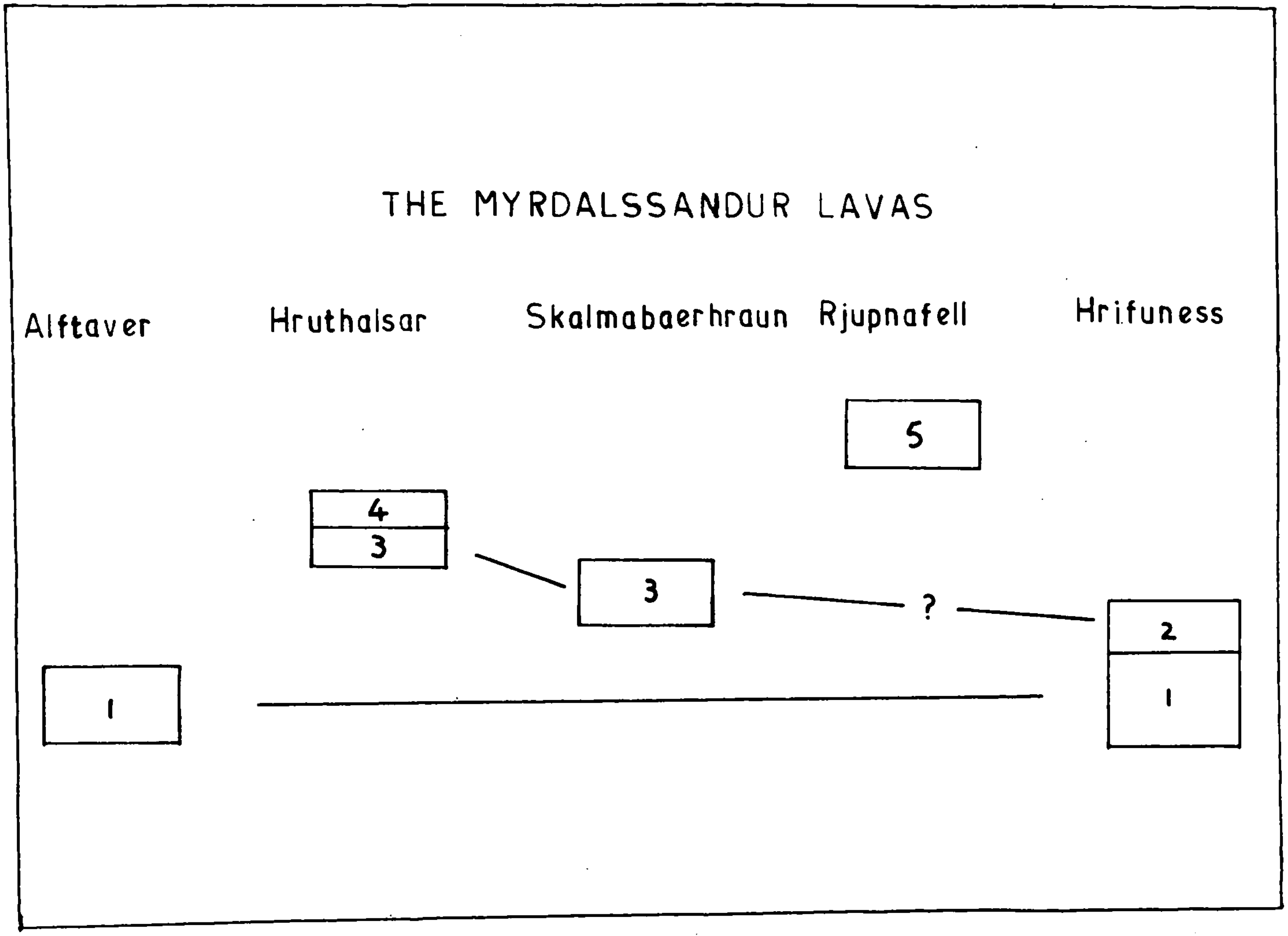
The slag cones of Alftaver, the cones here are much less densely packed than in Landbrot, and each has adopted a more or less perfect cone-shape with a central summit crater. As in Landbrot, these cones have been formed by lava overrunning waterlogged alluvium but the alluvium in this case is less extensive, and probably much thinner, than in Landbrot.

then spread out to the east. This hypothesis is supported by a step in the surface of the lava to the east, along a roughly north-south line, which may represent an old lava front buried by the more recent Skalmabaejarhraun. This buried lava front might then connect the lower lava of Hrifuness with the lava of Alftaver.

South of Skalmabaejarhraun, the lavas of Alftaver, Bolhraun and Selhraun are very poorly exposed; they seem to be about ten metres in thickness and appear to preserve this thickness to their exposures on the southern coast. The relationship of these lavas with those lying to the north is obscured by the alluvium of the river Skalm which flows between the two localities. A small group of slag cones occurs at Alftaver and a smaller group near Hruthalsar, three kilometres to the north. These cones must have an origin similar to those of Landbrot. Some of the cones are shown in Plate 33.

Two flows are exposed at Hruthalsar and form a scarp facing eastward. The thickness of the upper flow is four metres and that of the lower three metres. A third flow of unknown thickness appears to underlie them. These flows may overlie the lava of Skalmabaejarhraun.

A tentative correlation of the Myrdalssandur flows is given in Diagram 8.


THE MYRDALSSANDUR LAVAS
Alftaver
Hruthalsar
Skalmabaerhraun
Rjupnafell
Hrifuness
5
4
3
3
?
2
1
1

DIAG. 8

The Western Flows of Eldgja have a minimum total area of 450.22 square kilometres, a conservative estimate of their average thickness is fifteen metres, making their total volume 6,453 million cubic metres, or a little less than six and a half cubic kilometres.

The total area occupied by both the Eastern and Western Eldgja lavas is 813.9 square kilometres and the total volume of erupted lava, approximately fourteen cubic kilometres.

THE PETROLOGY OF THE ELDGJA ROCKS.

Microscopic examination shows all the Eldgja volcanics to be very similar in petrography. Very little variation in the composition of constituent minerals occurs and that which does occur is not systematic in character. The old and the young crater lavas, the valley lavas and the sandur lavas are all very similar both in chemistry and mineralogy. Wide variations in texture occur, however, and these reflect the varying conditions of cooling to which the basaltic liquid has been subject. The most quickly cooled materials are hypocrystalline-microporphyritic in texture, and the more slowly cooled holocrystalline-microporphyritic, while within the holocrystalline rocks the groundmass texture varies from equigranular to intergranular, depending upon the size of the groundmass felspar laths.

The Pyroclastics.

Petrographic work on the pyroclastics has been confined to the examination under the microscope of powders prepared from the ashes, and of a small number of thin sections of pahoehoe slag. No precise mineralogical determinations have been made.

The Ashes. Extensive deposits of loose volcanic ash occur near Eldgja but it is uncertain whether they are products of this volcano or of Katla. However the lavas of the two volcanoes are so similar in chemistry and petrography that it seems likely that these ashes are at least very similar to those of Eldgja. The component fragments consist of highly vesicular sideromelane, the refractive index of which varies between 1.619 and 1.625. Vesicular tachylite glass fragments occur but are subordinate in quantity to the transparent glass.. The sideromelane is not altered to palagonite. Microphenocrysts of basic labradorite 0.3 mm long and of rather smaller grains of augite and olivine occur somewhat sparsely within the glass.

The ash which is interbedded between the old lavas of the crater walls is very similar to that described above, but in these rocks the glass is opaque tachylite. Both the red and the black ashes are similar in appearance in transmitted light, but in reflected light the red ashes are a rusty brown in colour and the black ashes are black.

<u>Pahoehoe slag.</u> The slags resemble the tachylitic ashes of the crater walls in petrography, but here glomeroporphyritic groupings of the microphenocrysts are seen and the tachylitic base is crowded with small laths of medium labradorite about 0.01 mm. in length and with very small grains of olivine and pyroxene.

<u>The Lavas.</u>

More than one hundred thin sections of Eldgja lavas have been examined. Determinations, by refractive index methods, of the composition of some of the constituent minerals have been carried out in twelve of these rocks. All the Eldgja lavas are very similar in petrography. Apart from the presence of very rare olivines, which may reach 1 cm. in length and are magnesium-rich chrysolites, phenocrysts are absent. The groundmass is formed of olivine, ranging in composition from medium chrysolite to medium hyalosiderite, diopsidic augite, plagioclase, ranging in composition from limerich to limepoor labradorite, and iron ores. Some interstitial tachylite and felspathic material may be present. There is considerable range in the size of the constituent minerals, both within the individual rocks and in the lavas generally, and accordingly textures vary from intergranular to equigranular. None of the rocks exhibits ophitic texture.

Where the range in size of minerals of the groundmass is greatest the texture beomes microporphyritic and for convenience the larger crystals are referred to as microphenocrysts, though there is, in some rocks, a continuous grading in size from the largest to the smallest crystals; all of which appear to have crystallized continuously.

The larger pyroxenes and felspars congregate to form glomeroporphyritic groupings of one or both minerals. The larger olivines always occur singly. The textures present

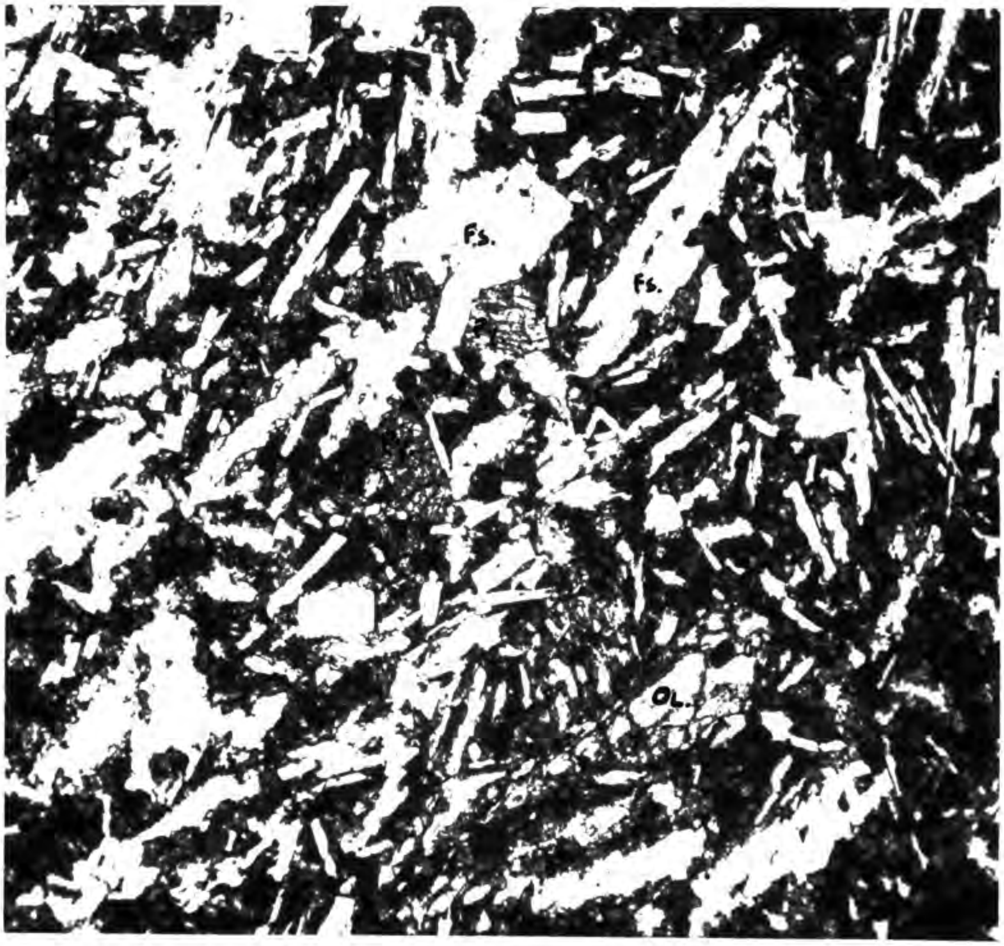


PLATE 34.

Photomicrograph of Eldgja lava. Specimen No. 202, Valley Lava, Flow 2, Middle Holmsa Gorge. (Magnification X350).

no evidence of an order of crystallization; all minerals appear to have crystallized sumultaneously and continuously. There are no alteration products present in the Eldgja rocks, and the only accessory mineral present is apatite which occurs as slender needles in the interstitial felspathic material.

Olivine. This mineral occurs very rarely as large stumpy prisms up to 1 cm. in length both in the old lavas of the crater walls, and in the younger valley lavas. Only five such phenocrysts have been seen in the field and they are not represented in hand specimen or in thin section. Refractive index determinations on material collected from the crystals shows the composition to vary between Fa_{12} and Fa_{15}.

In the groundmass olivine varies in size from long needle-like crystals 1 mm. in length to grains 0.01 mm. or less in diamter. The larger crystals are always slender prisms with sub parallel sides often indented by adjacent felspara and pyroxenes. The prisms terminate commonly in spiked or forked skeletal forms. Rounded inclusions of pyroxene, felspar and tachylite occur. Where the needles are cut across, a diamond shaped cross section is revealed which often contains a central rounded inclusion.

The composition of the microphenocrysts ranges from

PLATE 35.

Photomicrograph of Eldgja lava. Specimen No. 357.
Youngest lava, Crater Q. (Magnification X500).

Fa_{26} to Fa_{42}. Olivine determinations are shown in Table I.

Pyroxene. This mineral varies in size from subhedral crystals 0.5 mm. in diameter to very small grains. The microphenocrysts occur as rather rounded polygonal crystals, colourless or very slightly brownish in colour. Glomeroporphyritic groupings with or without felspar are fairly common. (See plate 35). The cleavages are often slightly curved and very few crystals do not show undulatory extinction. The optic axial angle 2 V/Z appears to vary between 47 and 51, though determinations are made difficult by the poor extinction shown by most crystals. The values indicate a wollastonite content close to 40%. Ny varies from 1.692 to 1.701 indicating a ferrosilite content between 20% and 25%.

No pidgeonitic or orthorhombic pyroxene occurs.

Pyroxene determinations are shown in Table II.

Plagioclase. This mineral occurs as subhedral laths varying in length from 1 mm. or more to less than .01 mm. The larger laths (the microphenocrysts) usually present a very ragged appearance in thin section caused by irregular inclusions of fine grained material of the groundmass, and the projection of groundmass material into the outer parts of the laths. (See plates 34 and 35). All the felspars except the very smallest show some zoning though it may be

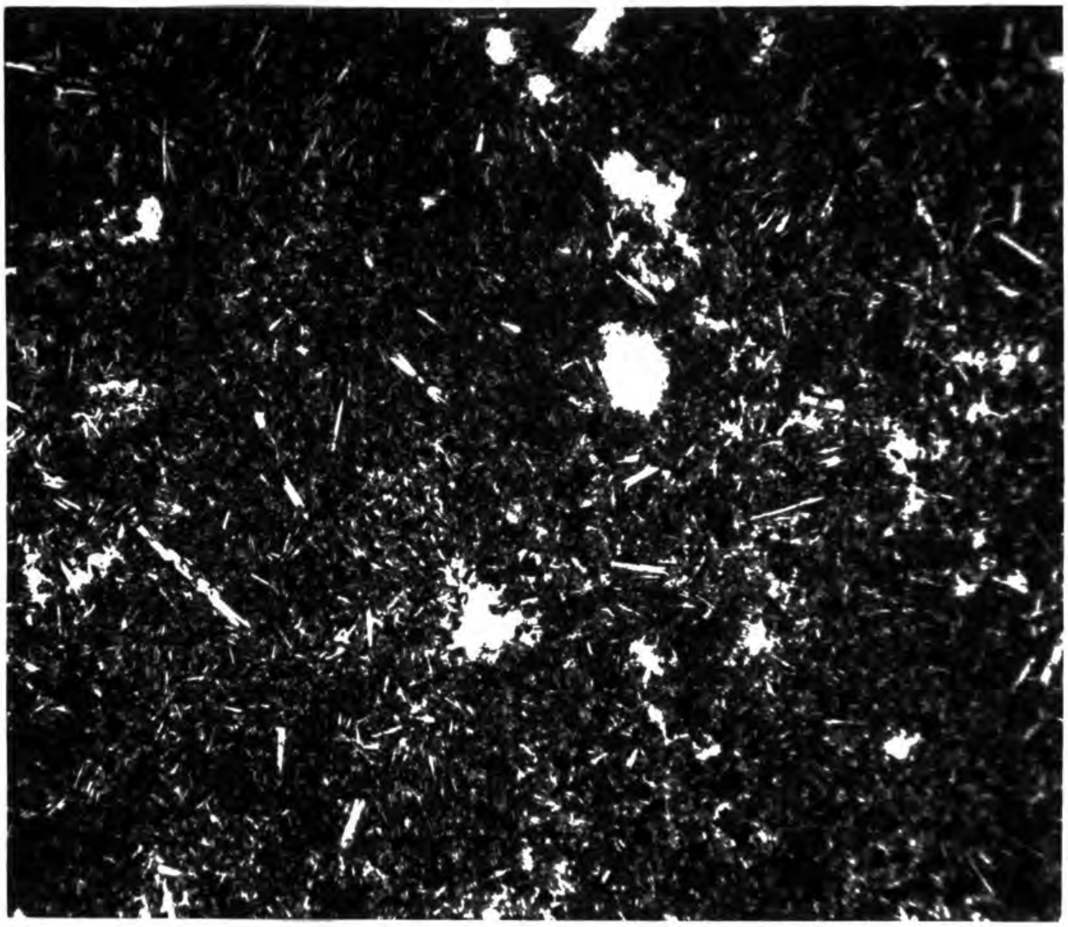


PLATE 36.

Photomicrograph of Katla lava. Specimen No. 21.

Modern lava from Nunatak on Myrdalsjokull.

(Magnification X350).

present only near the borders. The composition of the microphenocrysts varies from An_{73} to An_{58} and that of the smaller groundmass felspars from An_{65} to An_{50}. In all lavas the felspars may show a tendency to form fluidal structure. Felspar determinations are shown in Table III.

Iron Ores. These occur as subhedral grains rarely more than 0.5 mm. in diameter. Inclusions in the microphenocrysts occur but are rare and most of the ores occur as small grains amongst the more fine grained materials of the groundmass. In the more coarse and slowly cooled rocks the ores tend to become interstitial in habit.

Textures. In the thin flows of the crater walls, which have been relatively rapidly cooled, the microscopic textures shown by the slaggy upper and lower surfaces are very similar to those of the pahoehoe slag already described. Microphenocrysts of basic labradorite and of pyroxene and olivine occur, up to 0.5 mm. in diameter, in a groundmass of opaque glass which contains laths of medium labradorite, and very small grains of pyroxene and olivine.

In the inner parts of these flows the groundmass loses its hypocrystalline character and becomes holocrystalline. The microphenocrysts are similar in size and in amount, but the groundmass crystals are rather larger than in the glassy rocks. The groundmass is composed of stumpy laths of felspar, and of grains of olivine, pyroxene and iron ore, with each mineral varying in size from about 0.02 mm. to 0.005 mm. or less, though a few felspar laths intermediate in size between the microphenocrysts and the bulk of the groundmass felspar do occur. The felspar laths are not sufficiently large to break up the other groundmass minerals into wedge-shaped masses and the texture is equigranular. (See Plate 36), Fluidal structure is common in these rocks.

In the thicker valley lavas which have cooled more slowly, the microphenocrysts reach 1 mm. in size. The groundmass minerals are much larger the bulk of them ranging from 0.5 mm. to .05 mm. in length, though larger and smaller felspars are fairly common. In these rocks the distinction between the microphenocrysts and the groundmass minerals tends to become artificial and it is often impossible to decide within which group individual minerals should be placed. The larger groundmass felspars are now large enough to break up the intervening grains of olivine, pyroxene and iron ore and the texture becomes intergranular. In these rocks small interstitial patches of felspathic material make their appearance, often crowded with slender needles of apatite.

On Myrdalssandur, at the surface of flows of the type just described, the smaller grains of the groundmass are displaced by opaque interstitial glass and the texture once more becomes hypocrystalline, but this texture is much coarser than that in the glassy pahoehoe slag and in the similar rubbly surfaces of the crater wall lavas, Crystals quite as large as those in the inner parts of these flows are found within the glass.

Xenoliths in the Eldgja Lavas. A Xenolith of palagonite tuff was found within one of the older lavas in the wall of Crater Q. The zenolith is a sub-angular block about 20 cm. in diameter. The light brown colour characteristic of the palagonite tuffs has been lost and replaced by a dark brick red. The rock shows no sign of remelting in hand specimen. In thin section the rock is seen to consist of vesicular fragments of opaque glass, apparently welded together. There is no palagonite and no zeolite or calcite. Within the tachylitic glass unaltered subhedral phenocrysts of labradorite, pyroxene and olivine occur. None of the palagonite tuffs which have been examined has consisted entirely of opaque glass and none has been without some palagonite. It is probable therefore that the original sideromelane and palagonite have been converted by the heat of the lava to tachylite, but that this heat was not sufficient to melt the tuff appreciably or to destroy the original vesicular character. The phenocrysts within the tuff are quite unaffected.

The occurrence of rounded highly vesicular masses of acidic glass in the slag cones of Myrdalssandur has already been described. It was at first thought that the glass might be an acidic residuum squeezed from the inner parts of the flow during the formation of the cones. However, Mr. R. Phillips kindly made a partial analysis of the glass, and it is clear from its chemical composition that it is a remelted xenolith of Myrdalsjokull rhyolite. The glass has a refractive index of 1.510 and is crowded with microlitic needles of felspar. The partial analysis is compared with corresponding constituents from an analysis of rhyolite from Myrdalsjokull, quoted in full in Table XXVI.

	Xenolith.	Myrdalsjokull.rhyolite.
SiO_2	70.5	70.22
Na_2O	5.0	5.42
K_2O	3.0	3.43
N	1.510	N 1.505 - 1.513

Discussion.

Six of the Eldgja lavas have been chemically analysed by the writer. These six rocks include; one of the older of the wall of Crater Q (No.362); three of the valley lavas from Holmsadalur (Nos. 202, 201 and 440); one of the Myrdalssandur flows (No.273) and one of the younger lavas from the floor of Crater Q (No. 357). The analyses are listed in Table IV, and the normative constituents in Table V. The analyses show the Eldgja lavas, whatever their age and situation, to be very similar in chemistry.

It is evident from the structures shown by the Eldgja basalts that the lava contained a small amount of crystalline material at the time of its extrusion. This material consisted of an extremely small quantity of large olivine crystals, of composition Fa_{12}; and a much larger quantity, perhaps one or two percent by volume, of small crystals of olivine, of composition Fa_{25}, of plagioclase, of composition An_{70}, and of pyroxene, of composition $Wo_{40}En_{42}Fs_{18}$.

The circumstances of the occurrence of the large olivines, as very rare and very large crystals, and the absence of any olivine of composition intermediate between that of the large crystals and that of the microphenocrysts, strongly suggests that the large olivines were not in equilibrium with the basaltic liquid at the time of its extrusion. Their presence can be explained in two ways - as xenocrysts derived from a deep-seated body perhaps of peridotitic composition, or as early products of the Eldgja magma, perhaps crystallized at depth under conditions of pressure, and perhaps of temperature, much greater than those at the surface.

The microphenocrysts appear to have been in equilibrium with the erupted liquid; none shows traces of corrosion and an uninterrupted trend in composition is seen from that of the microphenocrysts to that of the fine grained material of the groundmass.

The textures shown by the lavas reflect the speed with which cooling occurred. In the thin crater wall lavas the surfaces of the lava quickly solidified to tachylitic glass without allowing the microphenocrysts to grow or allowing more than a few small crystals of felspar and ferromagnesian minerals to form. In the inner parts of these flows cooling was rapid enough to prevent the growth of the microphenocrysts, but not sufficiently rapid to prevent the development of crystallization nucleii in great number, from which a fine grained holocrystalline equigranular groundmass formed.

In the more slowly cooled valley lavas the formation of crystallization nucleii and the growth, both of the microphenocrysts and the new crystals, proceeded slowly and continued steadily until the liquid was entirely solidified, A texture resulted in which a continuous range in size is found from the largest to the smallest crystals. When, in these lavas, partly solidified material was chilled at the surface of the flow, the remaining liquid was chilled to form tachylitic glass, but this glass contains more and larger crystals than similar glasses from the surfaces of the crater wall lavas.

It will be observed from Table III, that even the outer soda-rich portion of the microphenocrysts is always less rich in soda than the smaller groundmass felspar. This effect is thought to be the result of the increasing viscosity of the liquid as cooling and crystallization proceeded, which prevented the migration of sodic material within the liquid and favoured its aquisition by the more common smaller felspars.

The normative minerals, calculated from the data in Table V, are all appreciably more salic than those which have been determined in the lavas.

The average normative plagioclase is An_{44}; the composition of that determined ranges from An_{50} to An_{73}. The average normative pyroxene is $Wo_{44}En_{28}Fs_{28}$; that determined varies roughly between $Wo_{40}En_{42}Fs_{18}$ and $Wo_{40}En_{36}Fs_{24}$. The average normative olivine is Fa_{50} and that determined varies from Fa_{26} to Fa_{42}.

These data make it clear that the composition of the fine grained material of the groundmass which is too small to be determined, and which even in the coarse grained rocks must account for nearly half of the total volume, is very salic in character. The data above suggest that in this fine grained material the plagioclase is a sodic andesine, the pyroxene a ferro-augite and the olivine a magnesian ferro-hortonolite.

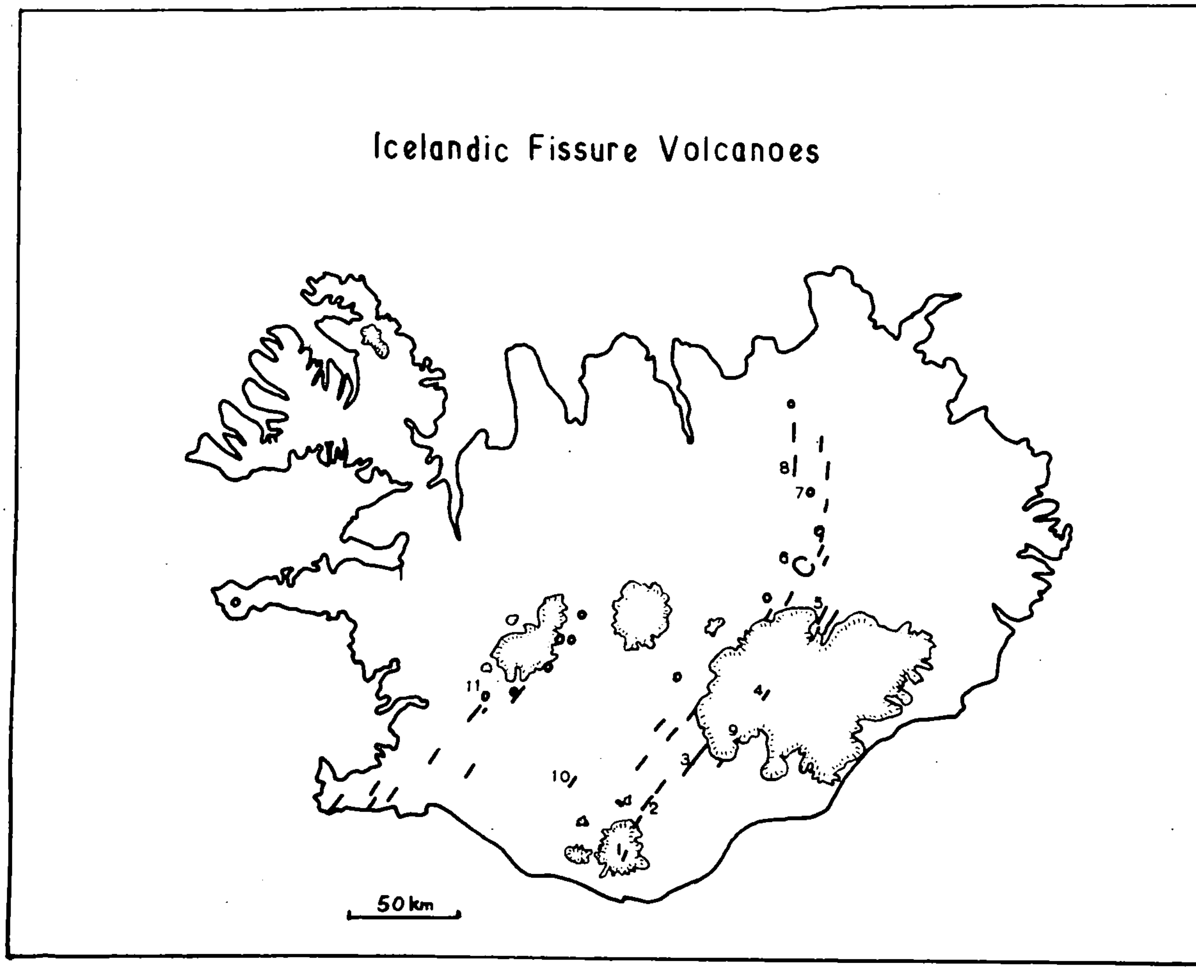
It is interesting to compare the minerals of the Eldgja lava with those which first crystallized from the second liquid of the Skaergaard Intrusion, the composition of which has been estimated by Wager and Deer (1939). The Skaergaard liquid is listed with the average of the Eldgja analyses in Table Xlll; there is a close similarity. The minerals of Wager and Deer's rock No. 4077 were among the first to crystallize from the second liquid; their composition is as follows. Plagioclase An_{56}; Augite $Wo_{47}En_{34}Fs_{19}$; Hypersthene Fs_{45}; Olivine Fa_{37}. The modal values given by Wager and Deer show that hypersthene formed about one fifth of the total bulk of pyroxene in the rock. When the augite and hypersthene are recalculated on this basis, to augite, the composition becomes $Wo_{39}En_{36}Fs_{25}$. This value and the value given for plagioclase and olivine fall near to or within the range of values, An_{50-73}, $Wo_{40}En_{42-36}Fs_{18-24}$, Fa_{26-42}, determined in the Eldgja rocks.

THE RELATIONSHIP OF KATLA TO ELDGJA.

The site of the crater through which Katla erupts is not known precisely, but it is known that it lies close to a line extending south-westward in continuation of the Western Fissure of Eldgja. The volcanic products of Katla are more completely described in Chapter 17 of the second part of this work. A modern lava which has been erupted from Katla was found on Myrdalsjokull in the course of the present work. In petrography the lava closely resembles the thinner, more quickly cooled, lavas of Eldgja. Microphenocrysts of labradorite, zoned, with an inner core An_{71} are found somewhat rarely. The groundmass consists of an equigranular mass of stumpy labradorite, pyroxene, olivine and iron ore. The rock has been analysed, and in Table VI this analysis is compared with an analysis of the ash erupted from Katla in 1918 (from Lacroix 1923), and with the average of the Eldgja analyses. Normative constituents for the three rocks are also quoted. It will be seen that the values of the average Eldgja and Katla lavas are extremely close for both chemical and normative constituents. The 1918 Katla ash differs significantly from the other two only in the values for alkalies and alumina, which lead to the appearance of quartz in the norm; for the other constituents there is close agreement.

Apparently the two volcanoes not only probably lie upon the same fissure, but erupt lavas which are nearly identical in chemistry.

It is suggested that Katla and Eldgja comprise a single volcano system.



1 KATLA
2 ELDGJA
3 LAKI
4 GRIMSVOTN
5 KVERKFJOLL
6 ASKJA
7 KETILDYNGJA
8 THRENGSLABORGIR
9 HAGONGUR
10 HEKLA
11 SKJALDBREITH

DIAG. 9

MAGMA TYPES IN ICELAND.

Thirty chemical analyses of modern Icelandic lavas and ashes have been assembled. It is found that the analyses can be separated into four types, the members of which show a close chemical affinity to other members of the same type and differ more or less markedly from members of other types. Within each type, one volcano is particularly well represented by analyses and the types have been named after these volcanoes. At each volcano lavas of one type only are found.

The Eldgja Magma Type.

The Eldgja magma is represented by the lavas of Eldgja and Katla only. These have already been described in detail. Briefly their petrographic characteristics are, intergranular groundmass, showing olivine Fa_{26-42}, plagioclase, An_{50-73}, and pyroxene, $Wo_{40}En_{42-36}Fs_{18-24}$ with much interstitial microcrystalline material. Analyses are listed in Table VI.

The Grimsvotn Magma Type.

The volcano Grimsvotn lies in the centre of the Vatnajokull ice cap, unlike Katla, however, it appears to maintain a permanent crater through the ice. Four analyses of Grimsvotn rocks are available and are listed in Table V11 together with the average of the four analyses. In Table V111 this average is compared with analyses of lavas erupted in the vicinity of Kverkfjoll, on the northern border of Vatnajokull, and from the volcano Eldgigur on the south western border of Vatnajokull. There is close similarity between the rocks of the three localities. Petrographic data for these rocks is rather poor. Noe Nygaard (1951) records microphenocrysts of olivine, plagioclase and clinopyroxene in the Grimsvotn materials erupted in 1934. The optic data given suggest the following approximate compositions; Fa_{36-48}, An_{70-81}, $Wo_{40}En_{40}Fs_{20}$.

Tyrrel (1949) records the presence of microphenocrysts of plagioclase An_{50}, augite and olivine in a rock of intergranular texture from Kverkfjoll.

Noe Nygaard (1952) records microphenocrysts of plagioclase, An_{75-65}, augite and olivine in the Eldgigur rock.

These data available suggest that the Grimsvotn-type rocks are similar in petrography to those of the Eldgja type. The Grimsvotn and Eldgja averages are compared in Table XII; there is close similarity between the two averages, except that the Eldgja rocks are about two percent lower in silica and about one percent higher in alkalies and titania than the Grimsvotn rocks. Only the persistance of these slight differences throughout the groups justifies their separation into two types.

The Skjaldbreith Magma type.

Skjaldbreith is the well-known shield volcano, south of the Langjokull ice cap, in south western Iceland. The lavas have been the subject of a study by Trygvasson (1943).

Seven analyses are available and are listed in Table 1X together with their average. This average is compared in Table X with analyses of lavas from the volcanoes Ketildyngja, a shield volcano, and Threngslaborgir, a fissure volcano, in the Myvatn district in Northern Ioeland, and with analyses of two lavas from the volcano Askja in central Iceland. The analyses are closely similar. They differ markedly from those of the Eldgja and Grimsvotn type in showing low values for total iron and alkalies, which are respectively close to ten and less than three percent in the Skjaldbreith rocks in contrast to fourteen and more than three percent in the other two groups. In addition, the Skjaldbreith type rocks show a high content of magnesia and lime; the values of seven and twelve percent respectively contrast with five and ten percent in the Eldgja and Grimsvotn rocks.

The Laki rock has been placed with the Skjaldbreith-type rocks because of the high content of magnesia and lime and the rather low alkalies. It differs from the other lavas of this type, however, in showing low values for alumina and high values for total iron.

The optical data given by Trygvasson show that the Skjaldbreith rocks contain olivine, Fa_{11-13}, plagioclase, An_{73-85}, and augite, $Wo_{36}En_{42}Fs_{22}$ in a microcrystalline groundmass.

Thorarinsson (1951) describes the Threngslaborgir lava as containing large phenocrysts of plagioclase An_{85-90} and also olivine and pyroxene.

The Ketildyngja lava is not described by Thorarinsson. Van Bemmelen and Rutten (1955) give no petrographic data for the two Askja rocks for which they quote analyses.

The Laki lava contains common bytownite phenocrysts, together with olivine and pyroxene.

These data suggest that Skjaldbreith-type rocks are more femic than the rocks of the other groups; the plagioclase is a little more calcic and the olivine appreciably more magnesian than those in the Eldgja and Grimsvotn rocks. This difference in petrography is consistent with the differences in chemistry between the Skjaldbreith type and the other types which have already been described.

The Hekla Magma Type.

Hekla is perhaps the best known of the Icelandic volcanoes. This volcano and Katla have produced a long series of eruptions throughout historic time. The volcano lies in southern Iceland roughly midway between Skjaldbreith and Katla. Analyses are available from Washington (1922) and from Thorarinsson. (1950). They are quoted in Table X1, together with the average of the two more basic rocks, and with an analysis of a rock similar in chemistry, from the volcano Hagongur on the south western border of Vatnajokull, which is described by Noe Nygaard (1950).

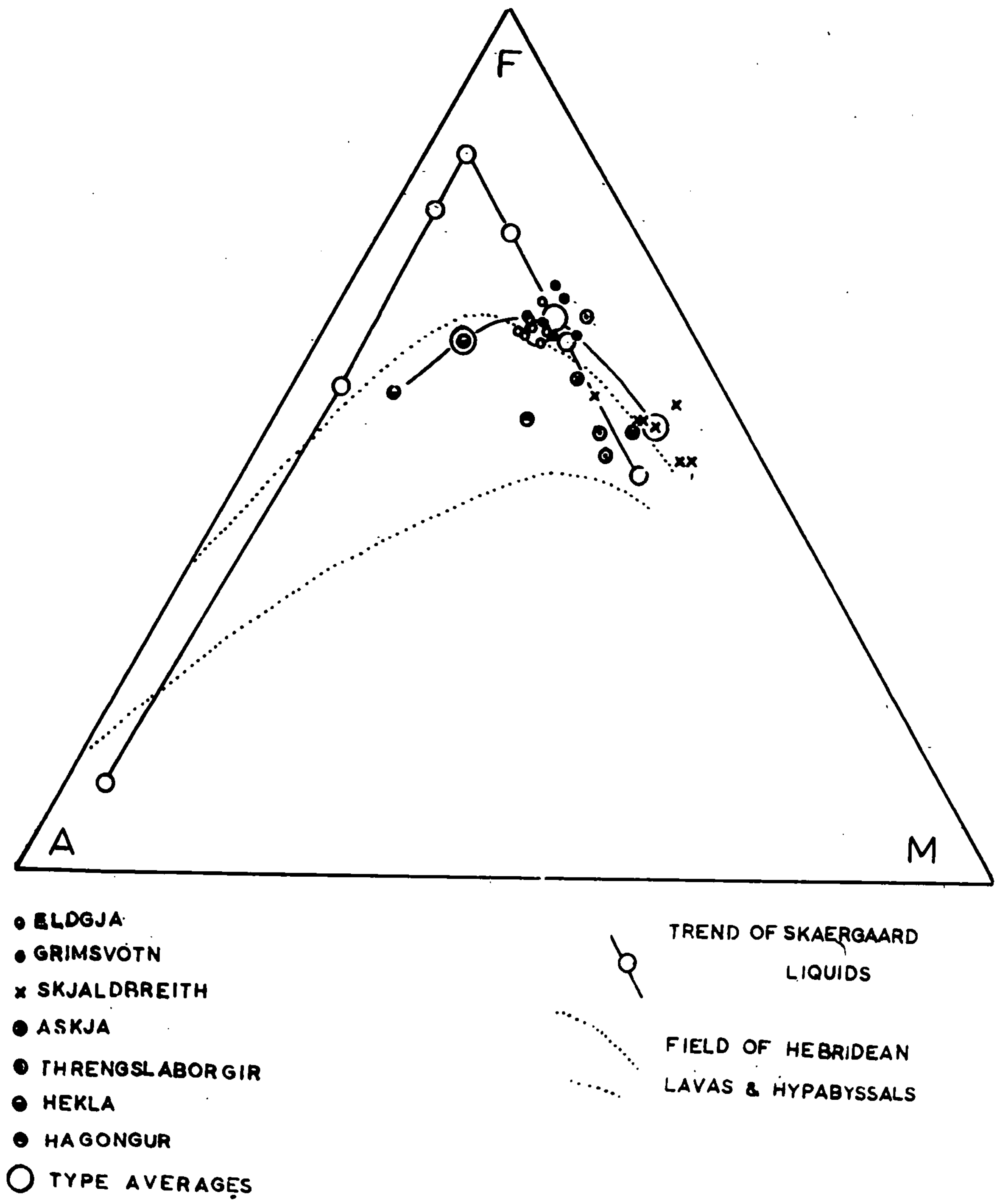
These rocks differ in chemistry from those already described in showing more than 50% silica, less than 10% lime and less than 5% magnesia.

Petrographic data for these rocks are poor. The plagioclases of the Hekla lavas have been the subject of a special study by Sorensen (1950). He found the common zoned phenocrysts of plagioclase to vary in composition from An_{70} to An_{37}. The groundmass minerals include plagioclase, pyroxene and, occasionally, olivine.

The Hagongur rocks are described by Noe Nygaard as containing phenocrysts of plagioclase, which range in composition from An_{85-32}, of olivine of composition Fa_{20}, and of augite, in a groundmass of similar materials. Both Sorensen and Noe Nygaard record inverse zoning and reaction rims in the plagioclase phenocrysts. Noe Nygaard reports that plagioclase phenocrysts with cores of bytownite and andesine, co-exist in the rocks from Hagongur.

The dacitic ash listed in Table XI is that erupted during the early stages of the eruption of Hekla in 1947. It was followed by the extrusion of the 1947 andesitic lava also listed in the table.

The data suggest that the Hekla rocks are more salic than the other types; contain plagioclase appreciably more sodic than the rocks of the other types; and may not contain olivine.


F
A
M
ELDGJA
GRIMSVÖTN
SKJALDBREITH
ASKJA
THRENGSLABORGIR
HEKLA
HAGONGUR
TYPE AVERAGES
TREND OF SKAERGAARD LIQUIDS
FIELD OF HEBRIDEAN LAVAS & HYPABYSSALS

DIAG. 10.

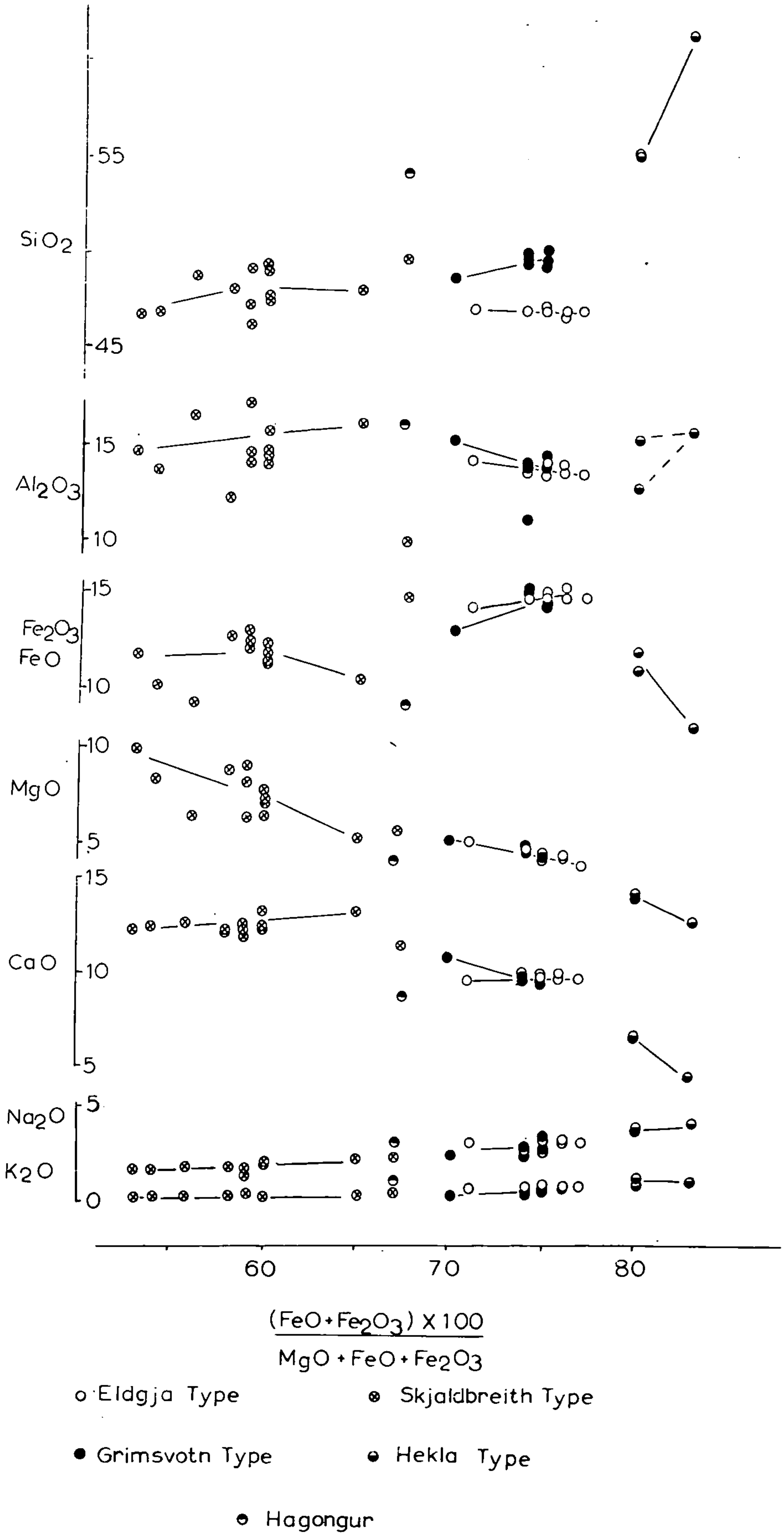
Relationships between the Magma Types.

The modern Icelandic lavas have been plotted on two variation diagrams. In Diagram 10 the total alkalies, total iron and magnesia have been plotted on a ternary A.F.M. diagram. In Diagram 11 the main chemical constituents have been plotted against the ratio total iron/ferromagnesians.

The type averages, which are assembled in Table X11, are also plotted on the ternary diagram. They show a trend, beginning, from the Skjaldbreith average, with enrichment in iron and very little enrichment in alkalies. This trend persists until the Elgja and Grimsvotn averages are reached when it becomes one of enrichment in iron and alkalies equally, until the Hekla average and the Hekla dacitic ash are reached.

The Hekla, Grimsvotn and Eldgja rocks are grouped fairly closely near the type averages and the trend line, but the Hagongur and Skjaldbreith-type rocks are scattered fairly widely and their distribution does not support the suggested trend line.

These features are shown more clearly in Diagram 11. Here the Skjaldbreith-type rocks, with the exception of the Laki rock, have values for the iron/ferromagnesians between 53 and 65, and show a wide scatter for all constituents except lime and alkalies. The Laki rock has a value of 67 and is reasonably close to the other Skjaldbreith type rocks except in the content of iron and alumina for which there is wide divergence.



55
45
SiO_2
15
10
Al_2O_3
15
10
Fe_2O_3
FeO
10
5
MgO
15
10
5
CaO
5
0
Na_2O
K_2O
60
70
80
$\frac{(FeO + Fe_2O_3) \times 100}{MgO + FeO + Fe_2O_3}$
o Eldgja Type
Skjaldbreith Type
Grimsvotn Type
Hekla Type
Hagongur

DIAG. 11

Perhaps the most remarkable features of the diagram are the well-defined trends shown by the Grimsvotn-type and Eldgja-type rocks, and the very close agreement in value, and the general agreement in trend, shown by all the constituents except silica, for which a difference both in value and in trend occurs.

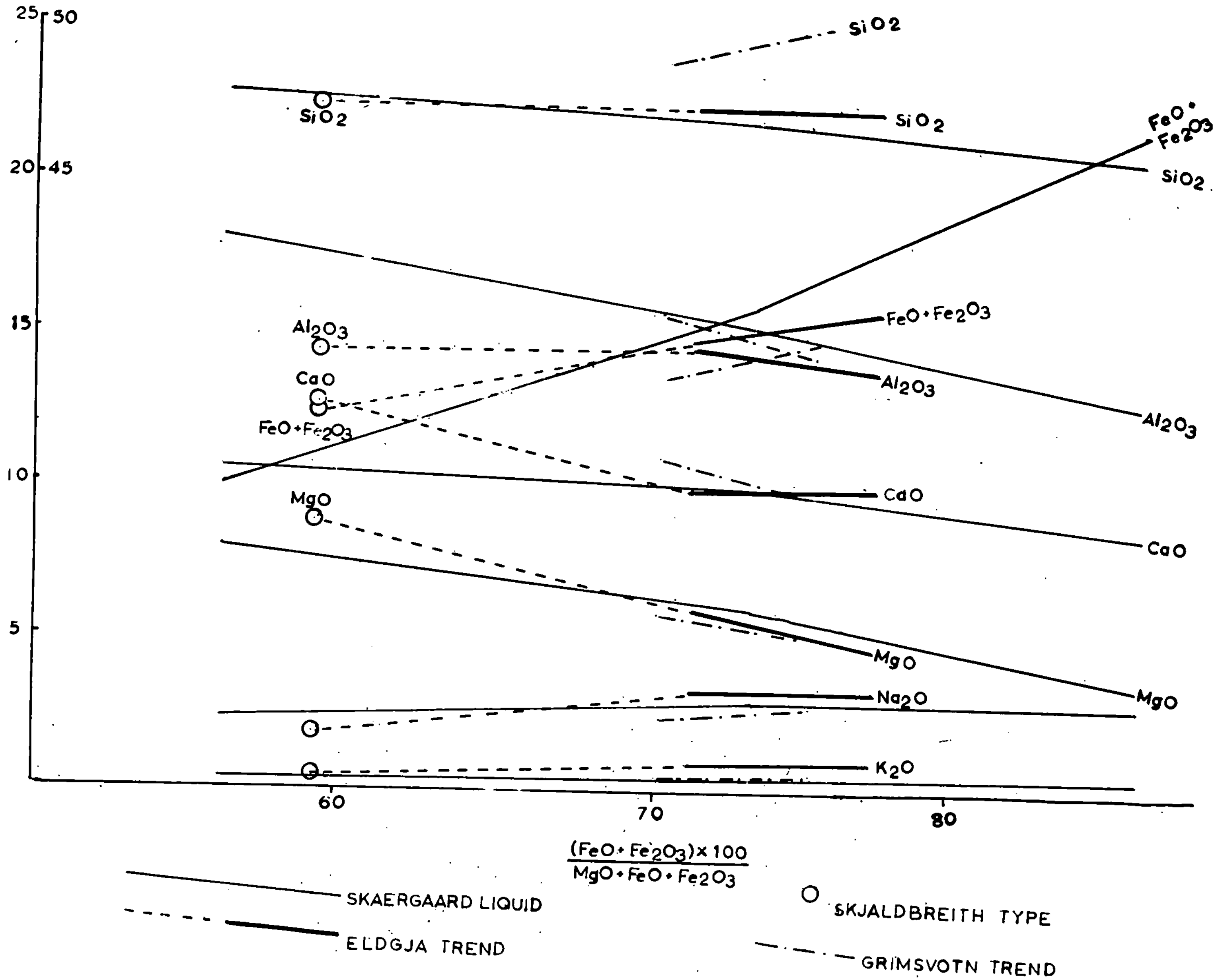
The Hekla andesites show values for iron/ferromagnesians of 80 and the dacitic ash a value of 83. The Hagongur rock is anomalous in showing a value for iron/ferromagnesians of 67 together with a silica content of 54%.

The diagram lacks convincing evidence of a general trend through the entire series. Some suggestion of a uniform trend can be seen for alkalies, which progressively increase, and for lime and magnesia, which show an opposite trend, but for total iron, alumina and silica the values are widely scattered.

These features support a conclusion, suggested by more general evidence, that the lavas are not derived from a single differentiating magma chamber. The fact that the lavas have been extruded nearly simultaneously from volcanoes which are widely spaced, and the fact that lavas of one type only are known from any one volcano first suggest this conclusion.

<u>The Eldgja type rocks</u>. The well-marked trend shown by the rocks of the Grimsvotn and Eldgja types has already been

DIAG.12



DIAG.12

DIAG 12

commented on. In the case of the Eldgja-type rocks the values and the trend of the major constituents are similar to those of the layered series of the Skaergaard intrusion. The two trends are compared in Table XlV.

It is probably more apt however to compare the extrusive rocks with the liquids of the Skaergaard intrusion. Accordingly the major constituents of the Skaergaard liquids have been plotted against their iron/ferromagnesian ratios in Diagram 12. On the same diagram the trends shown by the Eldgja and Grimsvotn type rocks are shown, together with the composition of the Skjaldbreith type average. There is close correspondence in both the composition and the trends of the Skaergaard liquids and the Eldgja basalts. It can hardly be supposed that this correspondence is accidental. It is most reasonable to suppose that the factors which determined the composition of the Skaergaard liquids have also determined that of the Eldgja lavas. The Skaergaard second liquid was derived by fractional crystallization from an initial first liquid. In Table Xlll this liquid is compared with the Skjaldbreith average; there is fairly close agreement, except in the value for alumina. In the same table the Eldgja type average and the second Skaergaard liquid are listed; here there is remarkably good agreement for all constituents. On the basis therefore of the similarity between the trends of the Eldgja basalts and the Skaergaard liquids; the close similarity between the Eldgja average and the Skaergaard second liquid, and the general similarity between the Skjaldbreith average and the Skaergaard first liquid, it is suggested that in Iceland basalts of the Eldgja type may have been derived by crystal fractionation or a similar process from basaltic material similar in composition to the Skjaldbreith type rocks.

In Diagram 12 the trend lines of the Eldgja rocks have been joined to the appropriate constituents of the Skjaldbreith type rocks. It will be seen that these extended trend lines are close to those of the Skaergaard liquids.

It is, of course, most unlikely that the Skjaldbreith rocks themselves are related in any direct way to those of Eldgja, but they establish that modern magma is present in Iceland which is similar in chemistry to the first Skaergaard liquid.

It is of incidental interest to note that if the Eldgja basalts are arranged in sequence, on the basis of the iron/ferromagnesian value, the sequence is also roughly one of age. The basalts are so listed below.

Eldgja Basalts.

Age.	$(FeO + Fe_2O_3) \times 100/MgO + FeO + Fe_2O_3$
1. 357 (youngest crater lava)	1. 357 (71).
2. 440 (valley lava)	2. 201 (74)

3.	201	(valley lava)	3.	440	(75).
4.	202	(valley lava)	4.	202	(76)
5.	362	(oldest crater lava)	5.	362	(76)
6.	273	(age unknown but known to be older than the valley lavas)	6.	273	(77)

These data support the assumption that the slight variation in composition discussed is not random in nature. It should be noted that the first liquid extruded is the one most rich in iron, and it is followed by liquids progressively, is slightly, less rich in iron.

<u>The Grimsvotn type rocks.</u> If the Eldgja basalts are derived by fractional crystallization of Skjaldbreith type magma the question arises; What is the origin of the Grimsvotn type rocks, which are similar in all respects except silica content? There appear to be two possibilities. They may be derived by a process of fractional crystallization of the Skaergaard type, similar to that giving rise to the Eldgja type rocks, but leading to an increase in the content of silica in the residual liquids. Or they may be the result of the contamination of magma of the Eldgja type by acidic material. The first process might arise when the initial magma is somewhat richer in silica than the Skaergaard first liquid. It is one which Wager and Deer, by implication, consider to be possible. They say (Wager and Deer 1939, P.298) ... "The trends shown by the Skaergaard rocks which are most

likely to be true for the majority of basalts undergoing similar fractionation seem to us to be the increase in FeO, Fe_2O_3, Na_2O, K_2O, TiO_2, P_2O_5 and the decrease in MgO ".

The Icelandic data are too poor to permit a firm conclusion. The trends shown by the Grimsvotn type rocks in Diagrams 11 and 12 suggest a progressive increase in silica with increasing iron/ferromagnesian value and this systematic effect is more likely to be the result of crystallization differentiation than of contamination, but the trends shown depend upon the single analysis with an iron/ferromagnesian value of 70. This is a rock from the Kverkfjoll and it cannot be assumed that it is derived from exactly the same magma source as the Grimsvotn rocks. The trend may therefore be accidental and the effect a random one.

The discovery of late Quaternary rhyolites on Vatnajokull by Noe Nygaard (1952) suggests a possible deep-seated source of adidic material which might have contaminated a Grimsvotn magma initially less rich in silica.

In Table **XV** ten percent of the rhyolitic material has been added to the Eldgja average and the sum reduced to equal the original total of the Eldgja analysis. It will be seen that there is close similarity in composition between the mixed rock and the Grimsvotn average.

From the evidence available, then, it appears that rocks of the Grimsvotn type may result either from differentiation by crystal fractionation of a magma of the Skjaldbreith type, or may result from the contamination of magma of the Eldgja type by acidic material.

The Skjaldbreith type rocks. The question may be asked; if the Eldgja and Grimsvotn type rocks show a well-marked trend in composition and are derived by crystallization differentiation from magma of the Skjaldbreith type why do not the rocks of the latter type show a similar trend? It is impossible to give a conclusive answer, but a scatter similar to that of the variation diagram would be produced if crystallization with random fractionation were proceeding rapidly within the magma at the time of the extrusion of the lavas. In other words, if there were random accumulation of the solid and liquid phases in the magma. The suggestion receives some support if a comparison is made with the Skaergaard intrusion. In Plate 27 Wager and Deer (1939) give curves showing the composition of successive liquids and of the solid phases separating from them. In the table below the percentage differences between the composition of liquids and solids as the first half of the Skaergaard liquid crystallized are compared with the scatter of the Skjaldbreith constituents shown on the iron/ferromagnesian diagram. (Diagram 11).

	Scatter of Skjaldbreith constituents.	Difference between liquid and solids. Skaergaard.
SiO_2	6%	3%
Al_2O_3	10%	6%
FeO Fe_2O_3	7%	7%
MgO	6%	4%
CaO	3%	2%
Na_2O	2%	1%
K_2O	1%	1%

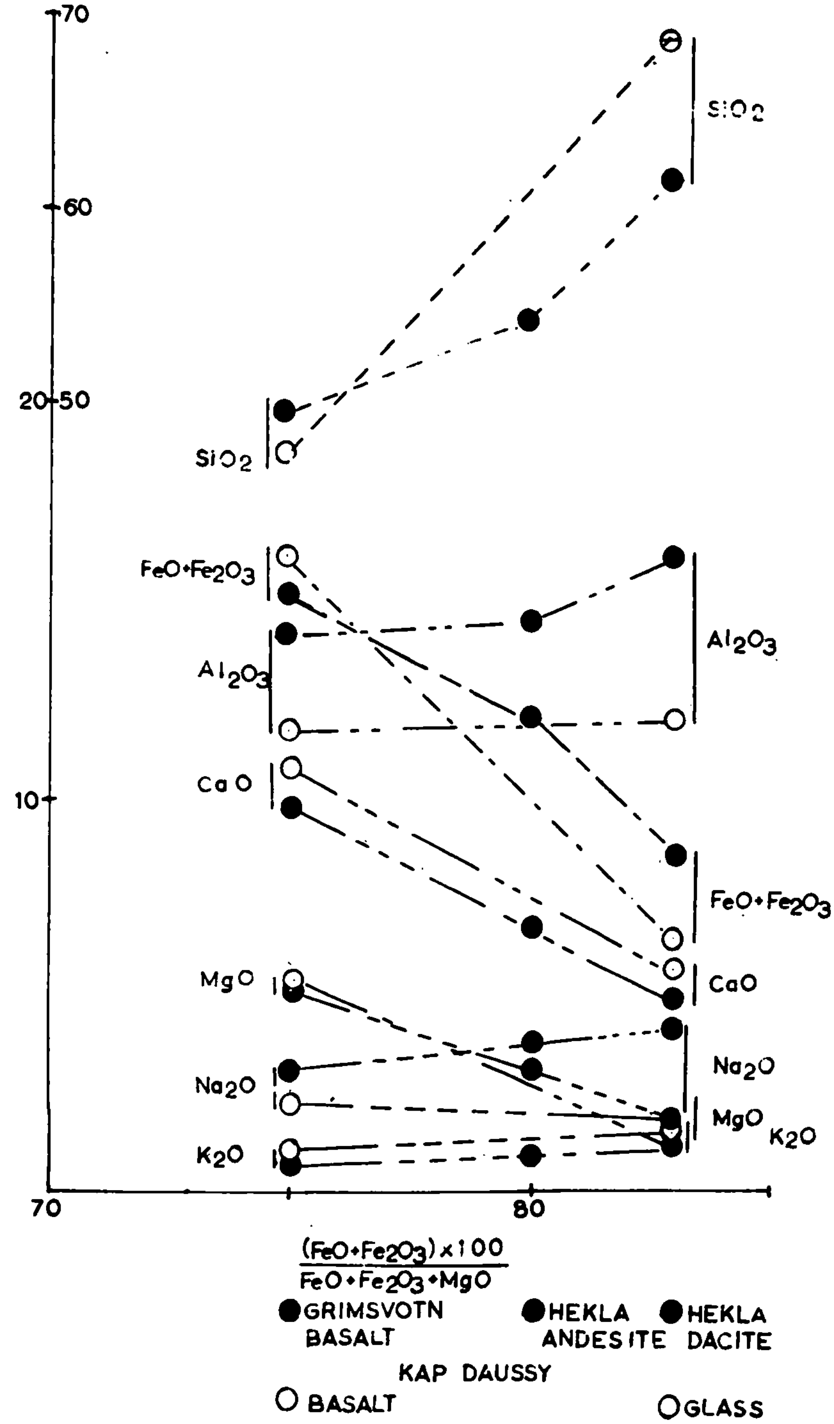
The values are of the same order of size for each constituent. It is suggested that if the liquids and the solids separating from them were mixed in varying degree and extruded, the resulting lavas would show scattering of the same sort as that of Diagram 11.

The Hekla type rocks. The unusual combination of a low iron/ferromagnesian value and a high silica content in the case of the rock from the Hagongur, on the south west border of Vatnajokull, suggest that it may be hybrid in origin. This suggestion is supported by Noe Nygaard's observation that phenocrysts cored both with bytownite and andesine co-exist in the rocks. A rock very similar in composition can be produced by taking one part of Vatnajokull rhyolite and three parts of Eldgja type basalt. The Hagongur rock and the mixed rock are shown in Table XVl. There is very close agreement for all constituents except titania, alumina and ferric iron.

The rocks from the volcano Hekla itself are consistent in the values shown for silica and the iron/ferromagnesian value and the petrographic evidence does not suggest a hybrid origin for them. The available data with which to discuss their origin are few. It is clear, however, that the dacitic ash and andesitic lava quoted in columns 1 and 2 of Table X1 are related genetically, for they were erupted within a few days of one another from the same volcano; a small quantity of the dacitic ash preceding the andesitic lava.

The variation shown by the constituents of increasing silica, alumina and alkalies and decreasing total iron, magnesia and lime, from the andesite to the dacite, is of the type generally recognised to be the result of crystallization differentiation. In the case of the Hekla rocks however both rocks are known to have been liquid originally, and it is not easy to see how the more acid could have been derived from the more basic without the crystallization of the latter. The explanation may be that the more acid rock is derived by crystallization differentiation of a part only of the andesitic magma, perhaps that part left within the volcano conduit after an earlier eruption.

If the trends shown by the constituents of the Hekla rocks in both Diagram 10 and Diagram 11 are continued in the


70
60
20 50
10
70
80
SiO2
FeO+Fe2O3
Al2O3
CaO
MgO
Na2O
K2O
SiO2
Al2O3
FeO+Fe2O3
CaO
Na2O
MgO
K2O
(FeO+Fe2O3)x100
FeO+Fe2O3+MgO
GRIMSVOTN
BASALT
HEKLA
ANDESITE
HEKLA
DACITE
KAP DAUSSY
BASALT
GLASS

DIAG. 13

direction of increasing basicity, values are reached which are very similar to those of the Eldgja and Grimsvotn rocks, and this suggests that the Hekla rocks may be derived from rocks of the latter type. Evidence from Iceland bearing on the question is lacking, but the evidence of similar rocks elsewhere suggests crystallization differentiation as the most probable mechanism in the formation of the Hekla rocks.

Vincent (1950) has described the occurrence of a residual glass, approximating to dacite in composition, in an olivine tholeiite from East Greenland. The Kap Daussy rock is very similar in composition to Grimsvotn type basalt. Analyses of the rocks are compared in Table XVll. The only significant difference in composition lies in the higher content of alumina and silica in the Icelandic rock type. The Kap Daussy rock and its residual glass, the Grimsvotn type average, the Hekla type average and the Hekla dacite have all been plotted in Diagram 13. The diagram shows several interesting features. The Iceland and Greenland basalts have the same iron/ferro-magnesian value and so too have the residual glass and the dacite; the lines which join the constituents of the Grimsvotn type, the Hekla andesite and the Hekla dacite are straight lines for all constituents except silica, alumina and total iron, and for these divergence is slight only. The changes shown by the constituents of both the Greenland and the Iceland rocks are of similar kind and degree, except for soda which in one rock shows a slight increase and in the other a slight decrease in quantity.

There can be no doubt that the residual glass of the Greenland basalt was derived by a process essentially equivalent to crystal fractionation from a liquid of the bulk composition of the Kap Daussy basalt.

It appears to be reasonable then to suppose that the Hekla dacite derives ultimately from magma similar in composition to the Grimsvotn type basalt by a similar process and that the Hekla dacite represents an intermediate stage.

Summary and Discussion. The modern Icelandic lavas have been divided into four types; the Skjaldbreith, Eldgja, Grimsvotn and Hekla types. Their chemical constituents have been plotted on variation diagrams and on the basis of the features shown by the diagrams and on other evidence it is concluded that the modern lavas are not a homogeneous group; in particular, it is concluded that they are not the products of a single differentiating magma chamber.

Among the rocks of the Eldgja type, those which have been erupted from Eldgja show a strong resemblance, both in the quantity and in the variation of their chemical constituents, to the Skaergaard liquids. This variation is shown to be related to the age of the lavas. It is suggested that the Eldgja basalts are derived by crystal fractionation, or by a similar process, from basaltic material similar in composition to the lavas of the Skjaldbreith type, which are themselves similar in chemistry to the first Skaergaard liquid.

The Grimsvotn type lavas are closely similar to the Eldgja type except in their higher content of silica. It is considered that they may be derived from magma of the Skjaldbreith type which was rather rich in silica or may be the result of contamination of Eldgja type magma by rhyolitic material.

The rocks from the volcano Hekla appear, from the variation diagrams, to show affinity to the Grimsvotn type rocks, and after comparisons with the Kap Daussy basalt and its residual glass it is suggested that the Hekla rocks are derived from Magma similar to the Grimsvotn type.

The Hagongur rocks are thought to be hybrid in origin and to result from the mixing of Eldgja type magma and granitic material.

The mutual relationship now proposed between the Skjaldbreith, Eldgja, Grimsvotn and Hekla type rocks may seem to contradict an earlier conclusion that the series is not homogeneous and that it is not the product of differentiation in a single magma chamber. There is also the apparent anomaly that while differentiation of the Skaergaard kind is suggested to explain the derivation of Eldgja type rocks from material of the Skjaldbreith type, differentiation of a different kind, that observed in the Kap Daussy rock, is suggested to explain the derivation of the Hekla rocks from material of the Grimsvotn type.

In Table XVlll the Skaergaard second and third liquids are compared with the Kap Daussy basalt and its residual glass. It will be seen that there is a close resemblance between the basalt and the second liquid. There is, however, little resemblance between the residual glass and the third liquid.

In the glass, iron, magnesia, lime and alkalies have fallen, while silica,has risen and alumina has remained nearly constant in amount.

In the third liquid, magnesia, lime, alumina and silica have fallen while iron and alkalies have risen in amount.

There can be little doubt that the Skaergaard third liquid has been derived from the second, and that the Kap Daussy residual glass has been derived from the basalt, by crystallization differentiation. The close similarity between the basalt and the second liquid appears to rule out an explanation of the very different results of the process in terms of a difference in chemistry between the two original liquids. It is clear, however, that the Skaergaard liquid has been cooled extremely slowly, while the Kap Daussy basalt dyke has been cooled much more rapidly; it is possible that these very different conditions of cooling have influenced the course of the differentiation process.

It is suggested that when basaltic magma is rapidly cooled the crystallization points of the more refractory components of solid solution series are passed without these phases being precipitated, that is, "overcooling" takes place, and that, when, at lower temperatures, the crystallization power is strongly developed and rapid crystallization begins, the composition of the solid phases is determined not by the composition of the liquid but by its temperature. In this way the composition of the early solid phases will be appreciably more rich in iron and in alkalies than when slow cooling occurs. It follows from this that, although the iron/magnesium ratio will increase in the late liquids, and solids, whatever the manner of cooling, when rapid cooling occurs the quantity of iron and alkalies precipitated with the early solid phases may be sufficient to cause a reduction of these components in the late liquids, while under slow cooling the very small amounts precipitated with the early solid phases will cause an increase of these components in the late liquids.

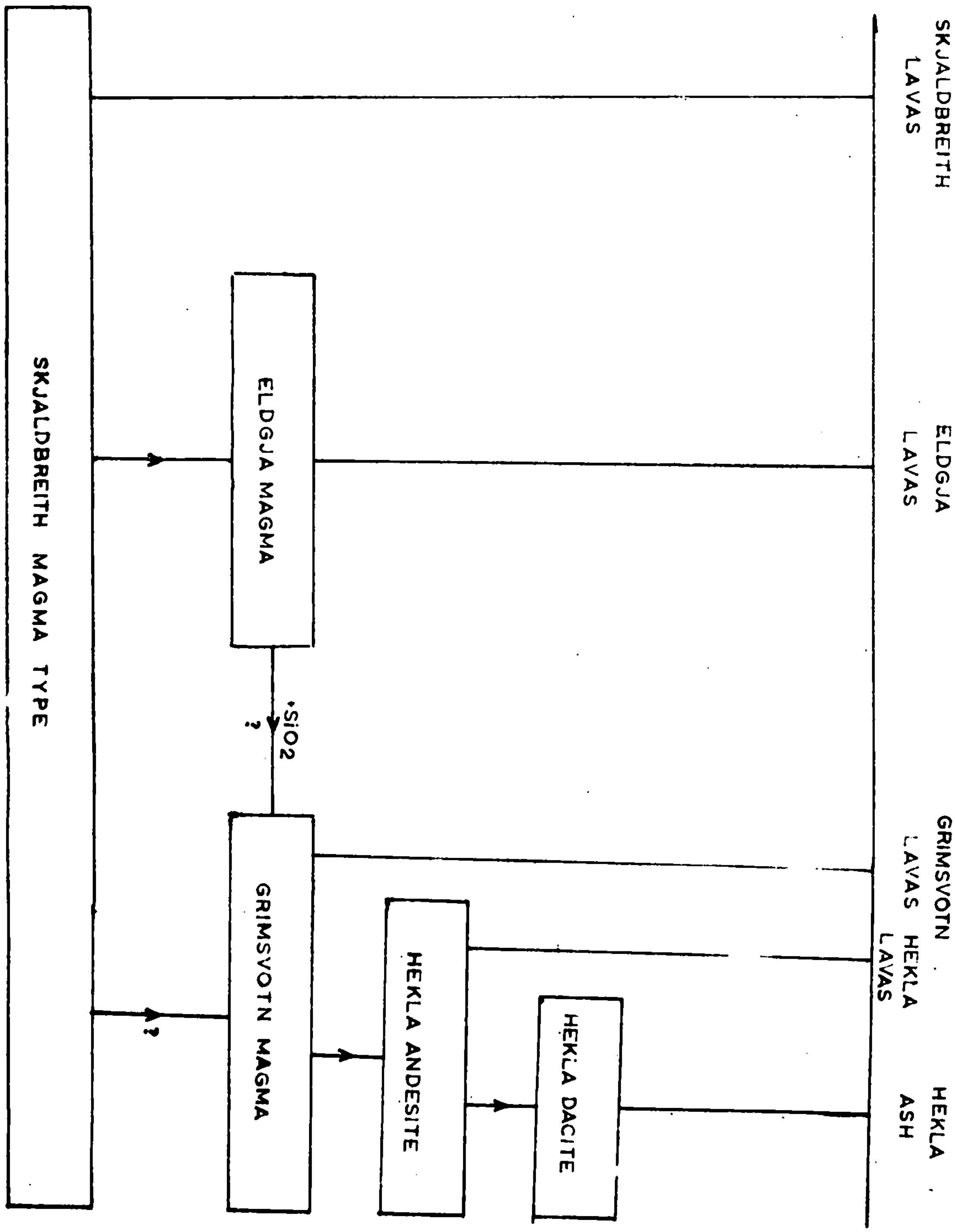
It is believed that these effects will explain the different courses taken by the late liquids of the Kap Daussy and Skaergaard rocks, except for silica, which in one rock increases markedly and in the other decreases slightly. It should be noted in this context, however, that the Kap Daussy basalt contains two percent of quartz in the norm while the Skaergaard second liquid is slightly undersaturated.

An excess of two percent of quartz in the basalt will become an excess of ten percent in the residual glass, while the presence of three percent of olivine among the early crystallization products of the basalt will further increase the excess silica in the residual glass. By these means three quarters of the total increase in silica in the Kap Daussy rocks can be accounted for.

Returning now to the Icelandic rocks, it is suggested that crystallization differentiation of the Skaergaard type under conditions of slow cooling at moderate depths in the crust has led to the formation of magma of the Eldgja type from magma of the Skjaldbreith type, and that under conditions of rapid cooling at shallow depths crystallization differentiation of the Kap Daussy type has led to the formation of magma of the Hekla type from magma of the Grimsvotn type.

It is of interest at this stage to note that if 80% of a magma of the Grimsvotn type crystallized with a bulk composition 50% An_{44}, 25% $Wo_{50}En_{30}Fs_{20}$, 20% Fa_{60}, 5% magnetite, the residual liquid would be very close in composition to the Hekla andesite. If 80% of a magma of the Eldgja type crystallized in a similar form the residual liquid would be

DIAG.14



DIAG.14

DIAG 14

closely similar except that the silica content would be lower than in the original liquid. In other words the differentiate would be trachytic. However modern rocks of this kind have not been described from Iceland.

The proposed relationships are shown schematically in Diagram 14. It is imagined that at considerable depth within the crust a primary source of magma exists. From this source liquids are derived which may vary somewhat in composition but approximate to the Skjaldbreith type. This magma may be extruded directly at the surface; with rapid crystallization during the process. It may also be extruded into the upper layers of the crust where at moderate depth it may differentiate to form magmas of the Eldgja, and possibly Grimsvotn, types.

Migration of magma of the Grimsvotn type to yet shallower depths in the crust leads to the formation by differentiation of magma of the Hekla type (andesitic), and isolated pockets of this magma may then differentiate further to produce dacitic liquids (the Hekla dacitic ash).

Comparisons with Other Volcanic Provinces.

The Hawaiian Volcanics. MacDonald (1949) distinguishes two types of volcano in Hawaii. The first type characterized by the chemical uniformity of its lavas, is comprised of the volcanoes Kilauea and Mauna Loa. The second type characterized by lavas ranging in composition from picrite basalt to oligoclase andesite or mugearite, is comprised of the volcanoes Mauna Kea and Kohala.

Macdonald considers that, in the volcanoes of the second type, the variation in composition of the lavas is the result of crystallization differentiation, and that this has taken place in two ways; by the settling of olivine crystals from and olivine basalt magma in the principal magma chamber, when picrite basalts rich in olivine are formed in the lower layers, and basalts poor in olivine in the upper layers, and by the crystallization differentiation of olivine basalt in small pockets, isolated from the main magma source, when andesine and oligoclase andesites are formed.

Macdonald's general scheme of the migration of magma, its isolation and differentiation, is similar to that proposed by the writer to explain the features of the modern Icelandic lavas. There is a similarity between the modern Icelandic lavas and the Hawaiian lavas generally, but this similarity is best shown in the case of the lavas of Kohala volcano.

The Kohala lavas are divided by Macdonald into two series; a lower Pololu series and an upper Hawi series.

The Pololu series consists dominantly of "primitive" basalts and variants of them. Among these, representatives similar to the Skjaldbreith, Eldgja and Grimsvotn types can be found. Selected basalts from the Pololu series are compared with their Icelandic equivalents in Table XlX. The analysis in Table XlX, Column 1 is very similar to the Skjaldbreith type, but it is not typical of the more basic Pololu lavas which generally show higher values for alkalies and lower values for silica. The analysis in Table XlX, Column 3 is typical of the less basic of the Pololu series and is similar to the Eldgja type. The analysis in Table XlX, Column 5 is a transitional type intermediate between typical lavas of the Pololu and Hawi series. It shows similarity to the Grimsvotn type, but the alkalies are rather higher in the Hawaiian rock.

The Hawi series is composed dominantly of andesine oligoclase andesites - differentiation products of the "primitive" lavas. In Table XX selected representatives are compared with the Hekla rocks. It will be seen that there is a general similarity, but that in the Hawaiian rocks silica is a little lower and alkalies are much higher than in the Icelandic types.

The trend in composition shown by the Hawaiian rocks as they are traversed from primitive basalts to oligoclase andesite is very much the same as that shown by the Icelandic rocks from the Skjaldbreith, through the Grimsvotn, to the Hekla rocks; with the difference, however, that in the Hawaiian rocks the silica content rises relatively slowly while that of alkalies rises steeply and in the Icelandic rocks silica rises steeply and alkalies relatively slowly. It is suggested that the differentiation process has been similar in both cases and that the difference in the end products is due to the higher content of alkalies and lower content of silica in the Hawaiian primary magma.

It is of interest to note that the Icelandic lava type which most closely resembles a typical Hawaiian rock in content of silica and alkalies is the Eldgja type and it has already been suggested that if this magma had undergone crystallization differentiation a trachytic product would have resulted.

The Hebridean Volcanoes. The authors of the Mull Memoir (Bailey etc. 1924) have subdivided the Hebridean volcanics into two principal magma series; a normal series and an alkaline series.

The normal series contains four magma types - the Plateau type, the Non-Porphyritic Central type, the Sub Acid type and the Acid type.

The alkaline series was not subdivided into magma types by the authors. It contains mugearites, syenites and trachytes. There are no modern equivalents of these rocks in Iceland.

When the Icelandic magma types are compared with the

Hebridean it is found that they can be fitted into the Hebridean classification remarkably well.

The Skjaldbreith magma type corresponds to the Plateau magma type of the Hebrides. In Columns 1 and 2 of Table XXl a selected analysis of a lava of Plateau magma type is compared with the Skjaldbreith average. There is good agreement generally, though lime is higher and alkalies are lower in the Icelandic rock.

The Grimsvotn magma type corresponds to the Non-Porphyritic Central magma type of the Hebrides. Analyses are compared in Columns 3 and 4 of Table XXl. Here, too, the correspondence is very close. The Hebridean rock showing only slightly more potash and less total iron and titania.

The Eldgja magma type also corresponds to the Non-Porphyritic Central magma type of the Hebrides. Analyses are compared in Columns 5 and 6 of Table XXl. Here correspondence is very close for all constituents.

The Hekla magma type corresponds to the Sub-Acid magma type of the Hebrides. There are no extrusive equivalents of the Icelandic andesites in the Hebrides but equivalents are found among the minor intrusives. In Columns 1 and 2 of Table XXll the Hekla andesite is compared with the variety of andesite termed Craignurite by the Mull authors and in columns 3 and 4 of the same table the Hekla dacitic ash is compared with the variety of andesite termed Leidlite by the same authors. In each case there is close correspondence chemically between the rocks compared.

The authors of the Mull memoir considered that both the Normal and the Alkaline magma series were probably the result of differentiation of magma of the Plateau type. The Acid line of descent being, Plateau type basalt - Non Porphyritic Central type basalt - Sub Acid type andesites - Acid type rhyolites. The Alkali line of descent also began from Plateau type basalt continuing through Mugearite to trachyte.

This view was later modified by Kennedy (1933) who concluded that there were two world-wide primary parent magmas, the Plateau type and the Tholeiitic type (Non Porphyritic Central type) giving rise respectively to alkaline and acid differentiates. There has been much subsequent discussion of the question of the origin of Plateau type and Tholeiitic type magmas; it has variously been supposed, that the Tholeiitic has been derived from the Plateau by differentiation; and also by contamination with sialic matter, and that the Plateau is derived from the Tholeiitic by differentiation; however Kennedy's original concept has persisted, that Plateau magma is the parent of the alkali line of descent and Tholeiitic magma the parent of the acid line of descent.

If the Icelandic rocks discussed in earlier chapters have any bearing on this question at all they suggest that the authors of the Mull Memoir were correct in their conclusion that magma of the Non Porphyritic Central type is derived from magma of the Plateau type by crystallization differentiation. It should be noted, however, that the ba salts of the Eldgja type strongly resemble Tholeiitic basalts, and there can be little doubt that they would be so classified by the authors of the Memoir. Yet there is evidence that crystallization differentiation of magma of this composition would give rise to an Alkaline differentiate. This leads to the conclusion that Tholeiitic magma, being derived from Plateau magma, is itself the parent of both alkaline and acid lines of descent.

This is a conclusion which most petrologists would find unacceptable. Yet the writer believes that early members of the alkaline line of descent may be present among the lavas classed by the Mull authors as tholeiitic. It is doubted, however, whether direct comparison of analyses, from province to province is a useful guide to petrogenesis. Its usefulness appears to depend upon two assumptions; first, that the primary magma or magmas from which the differentiates are derived show world wide uniformity of composition, this is a premise of Kennedy (1933) and it appears to be open to doubt, and second, that the differentiation process follows always the same course, and this assumption is at variance with modern evidence.

It is suggested that members of a differentiation series might be distinguished on the basis of their iron/ferromagnesian value, which present knowledge suggests will rise in a liquid undergoing crystallization differentiation whatever the composition of the primary magma and whatever trends the chemical constituents may follow, and that the two lines of descent might be distinguished by the presence or absence of quartz in the norm. Investigations of volcanic provinces on this basis might lead to a useful definition of Plateau and Tholeiitic types or might suggest suitable alternatives.

TABLE I.

ELDGJA OLIVINES.

	Microphenocrysts.	Phenocrysts.
362	Z 1.735 Fa_{33}	Y 1.678 Fa_{12}
202	Y 1.720 Fa_{32}	
201	Z 1.745 Fa_{37}	
440	Z 1.727 Fa_{29}	Y 1.681 Fa_{15}
357	No determination.	
273	No determination.	
208	Z 1.745 Fa_{37}	
209	Z 1.758 Fa_{42}	
210	Y 1.705 Fa_{26}	
154	No determination.	Y 1.680 Fa_{13}
367	No determination.	Y 1.679 Fa_{12}

362	Old Lava, lowest flow Crater Q.	Analysed.
202	Valley lava. Flow 2 Holmsdalur.	"
201	" " Flow 3 "	"
440	" " Flow 4 "	"
357	Young lava, vent, floor of Crater Q.	"
273	Sandur lava, Selhraun, Myrdalssandur.	"
208	Valley lava. Oldufell ? equivalent to flow 1 Holmsdalur.	
209	Valley lava. Oldufell ? " " " 2 "	
210	Valley lava. Oldufell ? " " " 3 "	
154	Young lava, south of Crater C.	
367	Old lava, upper flow Crater Q.	

TABLE II.I

ELDGJA PYROXENES.

Microphenocrysts.

363	2V	Ny	
362	48	1.698	$Wo_{39}En_{37}Fs_{24}$
202	48	1.701	$Wo_{39}En_{36}Fs_{25}$
201	51	1.700	$Wo_{41}En_{38}Fs_{24}$
440	47	1.692	$Wo_{40}En_{42}Fs_{18}$
357	51	1.695	$Wo_{42}En_{39}Fs_{19}$
273	48	1.700	$Wo_{39}En_{36}Fs_{25}$
208	47	1.701	$Wo_{38}En_{36}Fs_{26}$
209	49	1.695	$Wo_{40}En_{40}Fs_{20}$
210	48	1.692	$Wo_{40}En_{42}Fs_{18}$
153	48	1.695	$Wo_{40}En_{40}Fs_{20}$

362	Old Lava, lowest flow, Crater Q.	Analysed.
202	Valley lava. Flow 2, Holmsdalur.	"
201	" " Flow 3, "	"
440	" " Flow 4, "	"
357	Young lava, vent, floor of Crater Q.	"
273	Sandur lava, Selhraun, Myrdalssandur.	"
208	Valley lava. Oldufell, ? equivalent to Flow 1 Holmsdalur.	
209	Valley lava. Oldufell, ? equivalent to Flow 2 Holmsdalur.	
210	Valley lava. Oldufell, ? equivalent to Flow 3 Holmsdalur.	
153	Valley lava, Flow 1, Holmsdalur.	

TABLE III

ELDGJA PLAGIOCLASE.

	Groundmass.	Microphenocrysts.
362.	Nz' 1.565 An_{58}; Nx' 1.555 An_{52}	Nz' 1.572 An_{71}; Nx' 1.561 An_{6}
202.	Nz' 1.566 An_{60}; Nx' 1.554 An_{50}	No determination.
201.	Nz' 1.565 An_{58}; Nx' 1.555 An_{52}	No determination.
440.	Nz' 1.564 An_{57}; Nx' 1.554 An_{50}	Nz' 1.566 An_{60} N.D.
357	Nz' 1.567 An_{62}; Nx' 1.554 An_{50}	Nz' 1.570 An_{67} N.D.
273	Nz' 1.569 An_{65}; Nx' 1.557 An_{53}	Nz' 1.573 An_{73} Nx' 1.565 An_{67}
208	No determination.	Nz' 1.572 An_{72} N.D.
209.	No determination.	No determination.
210.	No determination.	Nz' 1.568 An_{65}; Nx' 1.559 An_{58}

362.	Old lava, lowest flow Crater Q.	Analysed.
202.	Valley lava. Flow 2 Holmsdalur.	"
201.	" " Flow 3 "	"
440.	" " Flow 4 "	"
357.	Young lava, vent, floor of Crater Q.	"
273.	Sandur lava, Selhraun, Myrdalssandur.	"
208.	Valley lava. Oldufell. ? equivalent to Flow 1 Holmsdalur.	
209.	Valley lava. Oldufell.? " " " 2	"
210.	Valley lava. Oldufell.? " " " 3	"

TABLE IV

New Chemical Analyses of the Eldgja lavas.

	362	202	201	440	357	273	A.E.
SiO_2	46.92	47.25	47.11	47.48	47.37	47.12	47.20
TiO_2	4.33	4.29	4.27	4.06	3.76	4.56	4.21
Al_2O_3	13.87	14.46	14.04	14.07	14.57	13.90	14.15
Fe_2O_3	4.38	2.31	2.73	3.65	2.26	1.89	2.87
FeO	11.08	12.89	12.47	11.56	12.55	13.31	12.31
MnO	0.15	0.16	0.16	0.10	0.13	0.21	0.16
MgO	4.97	5.00	5.47	5.08	5.93	4.72	5.20
CaO	9.97	10.06	10.06	9.88	9.64	9.94	9.93
Na_2O	3.18	3.02	2.84	3.51	3.19	3.08	3.14
K_2O	0.72	0.81	0.77	0.84	0.87	0.75	0.79
H_2O+	0.07	0.09	0.11	0.09	0.04	0.08	0.08
H_2O-	0.11	0.16	0.16	0.12	0.05	0.10	0.12
P_2O_5	0.10	0.14	0.11	0.11	0.12	0.13	0.12
TOTALS	99.85	100.65	100.32	100.61	100.48	99.79	100.28

362 Oldest Lava, Crater Q.

202 Flow 2 , Middle Holmsa Gorge.

201 Flow 3 , " " "

440 Flow 4 , " " "

357 Youngest Lava, Crater Q.

273 Selhraun, Myrdalssandur.

A.E. Average of Eldgja lavas.

TABLE V

C. I. P. W. Norms of Eldgja rocks.

Rock	362	202	201	440	357	273	A.E.
or	4.5	5.0	4.5	5.0	5.0	4.5	4.7
ab	27.7	25.7	24.1	28.8	26.7	26.2	26.5
an	21.4	23.4	25.4	20.0	23.1	21.7	22.5
ne				0.5			0.1
wo	11.4	10.8	11.1	11.7	10.0	11.3	11.0
en	9.3	6.2	8.7	5.8	5.2	6.8	7.0
fs	8.5	7.1	8.6	5.7	5.4	8.7	7.4
fo	2.1	5.0	3.5	4.8	6.7	3.0	4.2
fa	1.4	5.7	4.1	4.7	7.5	5.1	4.8
mt	6.3	3.3	3.9	5.3	3.3	2.8	4.3
il	8.2	8.1	8.1	7.8	7.1	8.7	8.0
ap	0.3	0.3	0.3	0.3	0.3	0.3	0.3

362	Oldest lava, Crater Q
202	Flow 2, Middle Holmsa Gorge
201	" 3, " " "
440	" 4, " " "
357	Youngest lava, Crater Q
273	Selhraun, Myrdalssandur
A.E.	Average of Eldgja Norms.

TABLE VI.

Chemical Analyses and Norms, Eldgja Type.

Rock	AE	21	A		AE	21	A
SiO_2	47.20	47.70	47.68	Q			3.0
TiO_2	4.21	4.19	5.01	or	4.7	6.1	5.0
Al_2O_3	14.15	13.67	12.54	ab	26.5	26.7	20.4
Fe_2O_3	2.87	2.09	3.44	an	22.5	19.2	20.9
FeO	12.31	12.97	12.34	nĕ	0.1	0.9	
MnO	0.16	0.10		we	11.0	11.8	10.4
MgO	5.20	5.14	5.25	en	7.0	5.3	13.2
CaO	9.93	9.72	9.58	fs	7.4	6.5	11.4
Na_2O	3.14	3.36	2.43	fe	4.2	5.3	
K_2O	0.79	1.05	0,88	fa	4.8	6.9	
H_2O+	0.08	0.12	0.44	mt	4.3	3.0	5.1
H_2O-	0.12	0.13	0.15	il	8.0	7.9	9.6
P_2O_5	0.12	0.20	0.23	ap	0.3	0.3	0.7
	100 .28	100.44	99.97				

AE... Average of Eldgja Analyses

21 .. Katla lava, Myrdalsjokull (New analysis)

A ... Katla Ash, 1918. (Lacroix 1923)

TABLE VII

Grimsvotn Lavas and Ashes

	1.	2.	3.	4.	5.
SiO_2	49.61	49.80	49.73	50.46	49.90
TiO_2	2.94	2.83	2.51	2.68	2.74
Al_2O_3	11.49	13.87	14.80	13.86	13.51
Fe_2O_3	4.66	1.84	3.10	1.56	2.79
FeO	11.33	12.38	11.53	12.28	11.88
MnO	0.26	0.16	0.15	0.23	0.19
MgO	5.55	4.92	4.92	5.14	5.13
CaO	9.66	9.75	9.55	9.96	9.73
Na_2O	2.45	3.17	2.86	2.86	2.83
K_2O	0.33	0.55	0.52	0.50	0.47
H_2O+	1.00	0.44	0.40	0.11	0.48
H_2O-	0.18	0.07	0.08	0.29	0.15
P_2O_5	0.32	0.22	0.23	tr	0.19
Rest	0.13	0.02	-	0.17	0.08
	99.91	100.02	100.38	100.10	100.10

1. 1903 Ash, Grimsvotn (Mauritzen and Noe Nygaard, 1950)
2. 1922 Ash, " (Barth, 1937)
3. 1934 Ash, " (Barth, 1937)
4. 1934 Lava " (Noe Nygaard, 1951)
5. Average of Grimsvotn rocks.

TABLE VIII

Chemical Analyses, Grimsvotn type.

	1.	2.	3.
SiO_2	48.81	49.60	49.90
TiO_2	1.92	2.46	2.74
Al_2O_3	15.58	13.49	13.51
Fe_2O_3	12.95	3.43	2.79
FeO	0.62	11.38	11.88
MnO	0.24	0.17	0.19
MgO	5.79	5.07	5.13
CaO	10.92	9.90	9.73
Na_2O	2.39	3.01	2.83
K_2O	0.28	0.52	0.47
H_2O +	0.38	0.49	0.48
H_2O -	0.14	0.38	0.15
P_2O_5	0.17	0.18	0.19
Rest			0.08
Total	100.19	100.08	100.10

1. Recent lava from Eldgigur, S.W. Vatnajokull (Noe Nygaard 1952).

2. Recent lava from Kverkfjoll, N.E. Vatnajokull (Tyrrel 1949).

3. Average of Grimsvotn rocks.

TABLE IX.

SKJALDBREITH LAVAS.

	1	2	3	4	5	6	7	8
SiO_2	48.15	47.96	46.84	46.95	48.04	46.28	47.67	47.41
TiO_2	2.00	1.40	2.01	1.32	3.00	2.00	2.17	1.99
Al_2O_3	16.24	14.05	13.65	14.56	12.26	14.64	15.81	14.46
Fe_2O_3	2.12	3.02	3.68	1.41	2.07	2.39	1.70	2.34
FeO	8.74	8.52	9.39	10.57	10.78	10.79	10.41	9.89
MnO	0.20	0.20	0.20	0.25	0.31	0.33	0.16	0.23
MgO	5.84	7.75	8.73	10.47	9.18	9.46	8.08	8.70
CaO	13.36	13.38	12.46	12.19	12.04	11.89	12.23	12.55
Na_2O	2.20	1.90	1.60	1.75	1.82	1.19	1.98	1.78
K_2O	0.33	0.29	0.35	0.25	0.38	0.37	0.27	0.32
H_2O-	0.08	0.42	0.40	0.04	0.08	0.12	0.10	0.18
H_2O+	0.38	1.04	0.38	0.00	0.22	0.18	0.21	0.35
Rest	0.10	0.15	0.30	0.24	0.15	0.36	0.10	0.20
Total	100.04	100.08	99.99	100.00	100.33	100.00	100.89	100.19

1. Skjaldbreith. Loose block in the central crater.
2. Skjaldbreith. Lava flow about 1 km. west of central crater.
3. Skjaldbreith. 9km. WSW. of the central crater.
4. Almannagja.
5. Basalt lava east of Hrafnabjorg.
6. Basalt lava south of Reytharbarmur.
7. Almannagja.
8. Average of Skjaldbreith lavas.

Analyses Nos. 1,2,3,4,5 and 6 quoted from Trygvasson (1943)
Analyses No. 7 quoted from Washington(1922) .

T A B L E X.

Chemical Analyses. Skjaldbreith type.

	1	2	3	4	5	6
SiO_2	49.30	48.80	49.64	49.41	47.41	49.56
TiO_2	1.10	0.97	1.29	1.24	1.99	4.16
Al_2O_3	14.98	16.79	14.76	17.21	14.46	10.36
Fe_2O_3	0.90	0.40	1.60	0.98	2.34	7.04
FeO	9.27	8.83	9.59	8.89	9.89	8.19
MnO	0.19	0.17	0.16	0.13	0.23	
MgO	6.96	6.83	7.55	6.88	8.70	6.04
CaO	12.63	12.54	12.08	12.67	12.55	11.66
Na_2O	2.15	2.09	2.09	2.06	1.78	1.86
K_2O	0.91	1.01	0.29	0.02	0.32	0.65
H_2O +	0.79	0.86	0.24	0.06	0.18	0.29
H_2O -	0.00	0.00	0.06	0.06	0.35	0.25
Rest	0.28	0.32	0.36	0.17	0.20	0.06
Total	99.46	99.61	99.73	100.30	100.19	100.10

1. Lava, Threngslaborgir, C. 500 B.C. (Thorarinsson 1951)
2. Lava, Ketildyngja, C. 2,000 B.C. (Thorarinsson 1951)
3. Early syntectonic Askja lava (Van Bemmelen and Rutten 1955).
4. Pre-tectonic Askja lava (Van Bemmelen and Rutten 1955).
5. Average of 7 Skjaldbreith lavas.
6. Lava, Laki, 1783. (Lacroix, 1923).

TABLE XI

Chemical Analyses, Hekla type.

	1.	2.	3.	4.	5.
SiO_2	61.88	55.41	53.39	54.35	54.47
TiO_2	1.03	1.60	2.28	1.94	1.46
Al_2O_3	16.11	15.84	13.37	14.56	16.12
Fe_2O_3	2.11	2.43	2.07	2.25	0.53
FeO	6.47	9.10	10.62	9.86	8.97
MnO	0.26	0.23	0.20	0.21	0.18
MgO	1.76	2.82	3.30	3.06	4.71
CaO	4.93	6.93	6.90	6.91	8.76
Na_2O	4.21	3.80	3.84	3.82	3.05
K_2O	1.16	0.80	1.19	0.99	1.03
H_2O +	0.34	0.33	1.37	0.83	0.54
H_2O -	0.06	0.03	0.08	0,05	0.30
P_2O_5	0.44	0.40	1.24	0.82	tr
Rest					
Total	100.76	99.76	99.85	99.65	100.12

1. Dacitic Ash, Hekla 1947. (Thorarinsson 1950)
2. Andesitic lava, Hekla 1947. (Thorarinsson 1950)
3. Andesitic lava, Naefrholt, Hekla. (Washington 1922)
4. Average of Hekla lavas.
5. Andesitic? lava, Hagongur. (Noe Nygaard 1950).

TABLE XII

Comparison of Magma types

	1.	2.	3.	4.	5.
SiO_2	47.41	49.90	47.20	54.35	61.88
TiO_2	1.99	2.74	4.21	1.94	1.03
Al_2O_3	14.46	13.51	14.15	14.56	16.11
Fe_2O_3	2.34	2.79	2.87	2.25	2.11
FeO	9.89	11.88	12.31	9.86	6.47
MnO	0.23	0.19	0.16	0.21	0.26
MgO	8.70	5.13	5.20	3.06	1.76
CaO	12.55	9.73	9.95	6.91	4.93
Na_2O	1.78	2.83	3.14	3.82	4.21
K_2O	0.32	0.47	0.79	0.99	1.16
H_2O +	0.18	0.48	0.08	0.83	0.34
H_2O -	0.35	0.15	0.12	0.05	0.06
P_2O_5	-	0.19	0.12	0.82	0.44
Rest	0.20	0.08	-	-	-
Total	100.19	100.10	100.28	99.65	100.76

1. Skjaldbreith average.
2. Grimsvotn average.
3. Eldgja average.
4. Hekla average.
5. Hekla dacitic ash.

TABLE XIII

	1.	2.	3.	4.
SiO_2	47.92	47.41	46.7	47.20
TiO_2	1.35	1.99	2.2	4.21
Al_2O_3	18.86	14.46	15.3	14.15
Fe_2O_3	1.18	2.34	2.9	2.87
FeO	8.66	9.89	12.9	12.31
MnO	0.10	0.23	0.2	0.16
MgO	7.82	8.70	5.9	5.20
CaO	10.46	12.55	9.9	9.95
Na_2O	2.44	1.78	2.8	3.14
K_2O	0.18	0.32	0.3	0.79
H_2O +		0.18		0.08
H_2O -		0.35		0.12
Rest		0.20		0.12
		100.19		100.28

1. First liquid Skaergaard Intrusion.
2. Skjaldbreith type average.
3. Second liquid Skaergaard Intrusion.
4. Eldgja type average.

TABLE XIV

	Skaergaard Intrusion Layered Series	Eldgja type basalts.
$\frac{(FeO+Fe_2O_3) \times 100}{MgO+FeO+Fe_2O_3}$	70 - 75	70 - 75
SiO_2	47 - 46.5	47 - 47
Al_2O_3	16 - 15	14.5 - 13.5
$FeO+Fe_2O_3$	17 - 19	14.5 - 15.5
MgO	7 - 5	6 - 4
CaO	9.5 - 8.5	10 - 10
Na_2O	2.7 - 3	3 - 3

TABLE XV

	1.	2.	3.	4.
SiO_2	47.20	75.06	49.7	49.9
TiO_2	4.21	0.12	3.8	2.74
Al_2O_3	14.15	13.84	14.1	13.51
Fe_2O_3	2.87	0.31	2.7	2.79
FeO	12.31	1.91	11.8	11.88
MnO	0.16	-	0.2	0.19
MgO	5.20	0.28	4.7	5.13
CaO	9.95	1.62	10.0	9.73
Na_2O	3.14	3.16	3.2	2.83
K_2O	0.79	3.22	1.0	0.47

1. Eldgja type average.
2. Vatnajokull rhyolite, Palsfjoll (Noe Nygaard 1952)
3. 10 parts of 1 plus 1 part of 2 reduced equal total of 1.
4. Grimsvotn average.

TABLE XVI.

	1	2	3	4
SiO_2	54.47	54.2	54.35	58.81
TiO_2	1.46	3.2	1.94	1.26
Al_2O_3	16.12	14.1	14.56	12.02
Fe_2O_3	0.53	2.2	2.25	5.77
FeO	8.97	8.7	9.86	9.38
MnO	0.18	0.1	0.21	0.21
MgO	4.71	4.0	3.06	0.72
CaO	8.76	8.1	6.91	5.03
Na_2O	3.05	3.1	3.82	3.91
K_2O	1.03	1.4	0.99	2.39
H_2O +	0.54	-	0.83	0.21
H_2O -	0.30	-	0.05	0.19
P_2O_5	tr	-	0.82	0.71
	100.12		99.65	100.61

1. Modern lava Hagongur. (Noe Nygaard 1950).
2. Mixture; 3 parts Eldgja average plus one part Palsfjoll rhyolite.
3. Hekla avergge.
4. Hedenbergite granophyre, Skaergaard Intrusion (Wager and Deer 1939).

TABLE XVII.

Hekla rocks - comparisons.

	1	2	3	4	5
SiO_2	49.90	47.42	54.35	61.88	64.03
TiO_2	2.74	3.98	1.94	1.03	0.79
Al_2O_3	13.51	11.75	14.56	16.11	11.27
Fe_2O_3	2.79	3.39	2.25	2.11	2.98
FeO	11.88	12.79	9.86	6.47	2.81
MnO	0.19	0.10	0.21	0.26	0.05
MgO	5.13	5.35	3.06	1.76	1.18
CaO	9.73	10.83	6.91	4.93	5.57
Na_2O	2.83	2.36	3.82	4.21	1.82
K_2O	0.47	0.55	0.99	1.16	1.56
H_2O +	0.48	0.95	0.83	0.34	6.23
H_2O -	0.15	0.30	0.05	0.06	0.73
P_2O_5	0.19	0.24	0.82	0.44	0.98
	100.10	100.31	99.65	100.76	100.00

1. Grimsvotn average.
2. Olivine-tholeiite, Kap Daussy, Greenland. Vincent(1950).
3. Hekla andesite average.
4. Hekla, dacitic ash.
5. Residual glass, Kap Daussy tholeiite.

TABLE XVIII

	1.	2.	3.	4.
SiO_2	47.42	64.03	46.7	45.7
TiO_2	3.98	0.79	2.2	2.4
Al_2O_3	11.75	11.27	15.3	12.7
Fe_2O_3	3.39	2.98	2.9	3.6
FeO	12.79	2.81	12.9	18.2
MnO	0.10	0.05	0.2	0.2
MgO	5.35	1.18	5.9	3.5
CaO	10.83	5.57	9.9	8.3
Na_2O	2.36	1.82	2.81	3.2
K_2O	0.55	1.56	0.3	0.4

1. Kap Daussy basalt.
2. Kap Daussy residual glass (20% of 1, by volume).
3. Skaergaard second liquid.
4. Skaergaard third liquid (27% of 3, by volume).

TABLE XIX.

Comparisons - Hawaii - Iceland.

	1	2	3	4	5	6
SiO_2	49.70	47.41	47.98	47.20	49.01	49.90
TiO_2	1.92	1.99	3.53	4.21	3.93	2.74
Al_2O_3	14.65	14.46	15.32	14.15	16.29	13.51
Fe_2O_3	1.88	2.34	2.49	2.87	7.61	2.79
FeO	8.03	9.89	8.86	12.31	4.89	11.88
MnO	0.15	0.23	0.12	0.16	0.27	0.19
MgO	7.80	8.70	6116	5.20	3.62	5.13
CaO	12.10	12.55	10.28	9.95	9.79	9.73
Na_2O	2.09	1.78	3.56	3.14	3.82	2.83
K_2O	0.52	0.32	1.08	0.79	0.80	0.47
H_2O +	0.22	0.18	0.62	0.08	-	0.48
H_2O -	0.09	0.35	0.25	0.12	-	0.15
P_2O_5	0.566	-	0.22	0.12	0.49	0.19
Rest	-	0.20	0.08	-	0.20	0.08
	99.71	100.19	100.55	100.28	100.84	100.10

1. Olivine basalt, Pololu series, Kohala. (Macdonald 1949).
2. Skjaldbreith type average.
3. Olivine basalt, Pololu series, Kohala. (Macdonald 1949)
4. Eldgja type average.
5. Olivine basalt, Pololu series, Kohala. (Macdonald 1949).
6. Grimsvotn type average.

TABLE XX

Comparisons - Hawaii - Iceland.

	1.	2.	3.	4.
SiO_2	52.27	54.35	58.06	61.88
TiO_2	2.13	1.94	1.88	1.03
Al_2O_3	17.05	14.56	18.21	16.11
Fe_2O_3	3.51	2.25	4.87	2.11
FeO	7.20	9.86	2.01	6.47
MnO	0.16	0.21	0.36	0.26
MgO	3.13	3.06	1.59	1.76
CaO	5.82	6.91	3.29	4.93
Na_2O	5.40	3.82	6.12	4.21
K_2O	2.22	0.99	2.75	1.16
H_2O +	0.44	0.83	-	0.34
H_2O -	0.08	0.05	-	0.06
P_2O_5	0.62	0.82	0.65	0.44
Rest	0.18	-	0.05	-
	100.21	99.65	99.99	100.76

1. Oligoclase andesite, Hawi series, Kohala (Macdonald 1949)
2. Hekla andesite average.
3. Oligoclase andesite, Hawi series, Kohala (Macdonald 1949)
4. Hekla dacitic ash.

TABLE XXI

	1	2	3	4	5	6
SiO_2	46.61	47.41	49.76	49.90	47.35	47.20
TiO_2	1.81	1.99	0.94	2.74	1.75	4.21
Al_2O_3	15.32	14.46	14.42	13.51	13.90	14.15
Fe_2O_3	3.49	2.34	3.95	2.79	5.87	2.87
FeO	7.71	9.89	7.77	11.88	8.96	12.31
MnO	0.13	0.23	0.20	0.19	0.23	0.16
MgO	8.66	8.70	5.30	5.13	5.97	5.20
CaO	10.08	12.55	10.22	9.73	10.65	9.95
Na_2O	2.43	1.78	2.49	2.83	2.73	3.14
K_2O	0.67	0.32	1.83	0.47	0.54	0.79
H_2O +	2.07	0.18	1.03	0.48	1.16	0.08
H_2O -	1.10	0.35	2.04	0.15	1.04	0.12
P_2O_5	tr	-	0.21	0.19	0.24	0.12
Rest	-	0.20	0.10	0.08	0.55	-
	100.08	100.19	100.30	100.10	100.94	100.28

1. Lava, Plateau Magma Type, Drynock, Skye. (Bailey etc. 1924).

2. Skjaldbreith type average.

3. Lava, Non Porphyritic Central type, Rudha na h-Uamba, Mull (Bailey etc. 1924)

4. Grimsvotn type average.

5. Dyke, Tholeiite, Salen type, Kintallen, Mull. (Bailey etc. 1924)

6. Eldgja type average.

TABLE XXXIII

	1	2	3	4
SiO_2	55.82	54.35	61.69	61.88
TiO_2	1.62	1.94	1.00	1.03
Al_2O_3	11.47	14.56	14.43	16.11
Fe_2O_3	3.68	2.25	1.23	2.11
FeO	7.66	9.86	5.86	6.47
MnO	0.40	0.21	0.30	0.26
MgO	4.08	3.06	2.81	1.76
CaO	7.88	6.91	4.97	4.93
Na_2O	2.58	3.82	3.20	4.21
K_2O	2.00	0.99	1.72	1.16
H_2O +	1.88	0.83	2.32	0.34
H_2O -	0.66	0.05	0.25	0.06
P_2O_5	0.23	0.82	0.24	0.44
Rest	0.24	-	0.06	-
	100.18	99.65	100.08	100.76

1. Basic Craignurite, Cone-sheet, Sub Acid Magma Type, Mull. (Bailey etc. 1924).
2. Hekla andesite average.
3. Glassy Leidlite, sill, Sub Acid Magma Type, Mull. (Bailey etc. 1924).
4. Hekla dacitic ash.

PART II.

THE GEOLOGY OF SKAFTARTUNGA.

SUMMARY OF PREVIOUS WORK ON ICELANDIC GEOLOGY.

An extensive literature on the geology of Iceland has been built up since work began in the early part of the present century. The following summary is not intended to be comprehensive. Those works have been selected which deal with the broader questions of Icelandic geology or with the origin and age of rocks similar to those encountered in Skaftartunga.

Von Walterhausen (1847) noted the similarity between the palagonite tuffs of Iceland and Sicily and, because the latter were marine deposits, suggested that the Icelandic tuffs were the result of submarine volcanic activity.

Thoroddsen (1906) published his descriptive monograph of Icelandic Geology, the result of extensive field work between the years 1882 and 1898.

He divided the Icelandic rocks into four main groups.

The Basalt Plateau. - of which the east and west coasts of Iceland are principally formed. Thoroddsen regarded these basalts as Miocene in age.

The Palagonite Formation. - whose tuff and breccias form a broad belt in the central part of the island and fill a graben sunk between the Basalt Plateaux of the East and West coasts. Thoroddsen recognised two divisions within these rocks; which he called the older and the younger tuffs. He regarded the bulk of the Palagonite Formation as Pliocene in age, with, possibly, the upper part belonging to the Pleistocene.

The Dolerite Formation. - those grey basalts were regarded as lying in part within and in part above the Palagonite Formation. Thoroddsen describes them as "preglacial and glacial" in age.

The Post-Glacial Basalt Lavas. - which overlie the rocks of the other three groups.

He corrects earlier opinions that the Palagonite Formation was older than the Basalt Plateau and concludes that it is younger and occupies a wide graben sunk in the plateau. He appears to have thought in the first place, that the Basalt Plateau was of Miocene age, and that the Palagonite Formation was of Pliocene Age, but Pjeturss' discoveries of tillite within the Palagonite Formation led him to extend the age of the upper part of the formation upwards into the Pleistocene.

Thoroddsen disputes Von Walterhausen's views on the origin of the tuffs, pointing out that marine fossils occur only in the glacial and Post-glacial terraces near the present coastline; that marine sediments are not found elsewhere in the formation and that many tuffs show evidence of aeolian deposition. Thoroddsen believed the Palagonite Formation rocks to have accumulated on land. He described the unusual structure shown by the basalts and tuffs within the formation but offered no special explanation of their origin.

Pjeturss (1900) announced the discovery of tillites within the Palagonite Formation, and, in a subsequent publication (1939), reported the occurrence of tillites and arctic mollusca within the upper part of the Basalt Plateau. He concluded that the upper part of the Basalt Plateau and the whole of the Palagonite Formation were Pleistocene in age.

Peacock (1925, 1926 (a), 1926 (b), 1926 (c)) in a series of papers discussing the geology of Iceland appears to have been the first clearly to state one of the fundamental problems presented by the Palagonite Formation: the great preponderance of pyroclastics over extrusives among the products of basaltic volcanism. Peacock proposed that the solution lay in the eruption of basaltic magma beneath the Pleistocene ice-sheet. His conclusions depended upon his belief that globular basalts and side-romelane breccias were the result of the chilling of basaltic magma by water, which, in the case of the Palagonite Formation, could only be marine or glacial in origin; that there was no evidence of marine submergence sufficiently great to account for the thickness of the Palagonite Formation and that Pjeturss' discoveries had established a Pleistocene age for the formation.

Hawkes (1938)reviewed the question of the age of the Basalt Plateau and the Palagonite Formation. After examination of Pjeturss' moraines Hawkes concluded that they were fluviatile in origin, and that Pjeturss' view that the upper part of the Basalt Plateau is Pleistocene in age is in error.

He suggested that evidence of volcanic activity in Iceland on Oligocene and Miocene times is lacking and that the Icelandic Tertiary basalts are most reasonably regarded as similar in age to those of Greenland the Faeroes and the Hebrides; that is to say Eocene or possibly Oligocene in age.

Reviewing the evidence for the age of the Central Graben and the rocks overlying the Tertiary basalts, Hawkes suggested that the graben faulting took place in pre-Pliocene times; that within the graben in the Pliocene the sediments at Tjorness were deposited and that, also in the Pliocene, volcanic activity began in the course of which the Palagonite Formation rocks were formed.

Noe Nygaard (1940) investigated the structure of Palagonite Formation tuffs at Kirkjubaejarklauster in Vestur-Skaftarfell-ssysla. He concluded that certain sideromelane breccias which contained globular masses of basalt and were associated with tillites were the products of sub-glacial volcanic eruptions during the Pleistocene. He proposed the name "basalt globe breccia" for them.

Hawkes (1941) described the age and structure of the rocks in central northern Iceland and concluded that the median zone occupied by the Palagonite Formation rocks was a graben-type structure of pre-Pliocene age.

Einarsson (1946) describes in detail the structure of many Palagonite Formation rocks. He disputes the glacial origin of "tillites" within the formation and concludes that the striations are surface features only and have been caused by the movement of ice over pre-existent conglomerates. He suggests that sideromelane may be a component of "sand flows" produced by the eruption of "low temperature" magma.

Anderson and Tyrrel (1949) describe rocks from the Basalt Plateau, the Palagonite Formation and Post-glacial lavas from south east and central Iceland. Anderson found no tillites among the Palagonite Formation rocks examined and concludes that while part of the formation may be sub-glacial in origin much of it has been formed by extrusion of basalt magma into water which is non-glacial in origin.

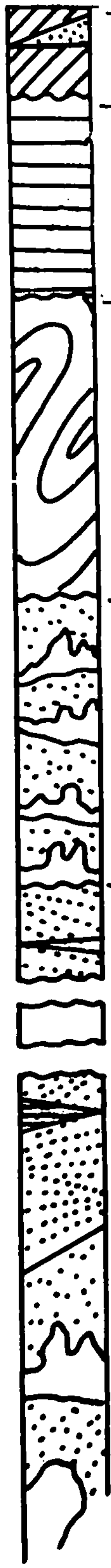
Noe Nygaard (1952) describes rhyolites from Vatnajokull which he regards as interglacial in origin and late Quaternary in age.

Hospers (1954) describes the basaltic rocks of central northern Iceland and their magnetic properties. He concludes that the Tertiary basalts in the area are overlain unconformably by a series of basalts of Quaternary age. (These correspond to Pjeturss' "Grey Phase" and to Thoroddsen's "Dolerite Formation"). He concludes that faulting along the western faults of the central graben took place in part in pre-Pliocene times and in part in post-Pliocene times.

Van Bemmelen and Rutten (1955) describe the geology of central northern Iceland in considerable detail. They support Hosper's conclusions concerning the age of the "Grey Phase" basalts and conclude that these are overlain by Palagonite Formation tuffs which have been formed by sub-glacial volcanic eruptions during the last glacial period. This conclusion is provisionally extended to include all the Palagonite Formation rocks within the central graben north of Vatnajokull and the following succession suggested for northern Iceland.

1. Modern eruptives (Recent).
2. Palagonite Formation. (Pleistocene; last glacial period).
3. Grey Phase or Dolerite Formation. (Pliocene or post-Pliocene).
4. Plateau Basalts. (Tertiary).

GEOLOGICAL COLUMN
SKAFTARTUNGA



MODERN EXTRUSIVES & BASALT GLOBE BRECCIA		
TRACHYBASALT EXTRUSIVES & PYROCLASTICS	INTER-GLACIAL ?	SANDFELL TRACHYBASALTS
RHYOLITE EXTRUSIVES	INTER-GLACIAL ?	MYRDALSJÖKULL RHYOLITES
BASALTIC INTRUSIVE FLOWS & GLOBE BRECCIA	GLACIAL	
AEOLIAN TUFF WITH (DOLERITE FORMATION) FLUVIATILE TUFF & PASALT EXTRUSIVES	INTER-GLACIAL	PALAGONITE FORMATION
BASALTIC INTRUSIVE FLOWS GLOBE BRECCIA & TILLITE	GLACIAL	

DIAG. 15

THE SKAFTARTUNGA ROCKS.

The geological column in Skaftartunga is made up of five groups of rocks. They are listed below. (See Diagram 15).

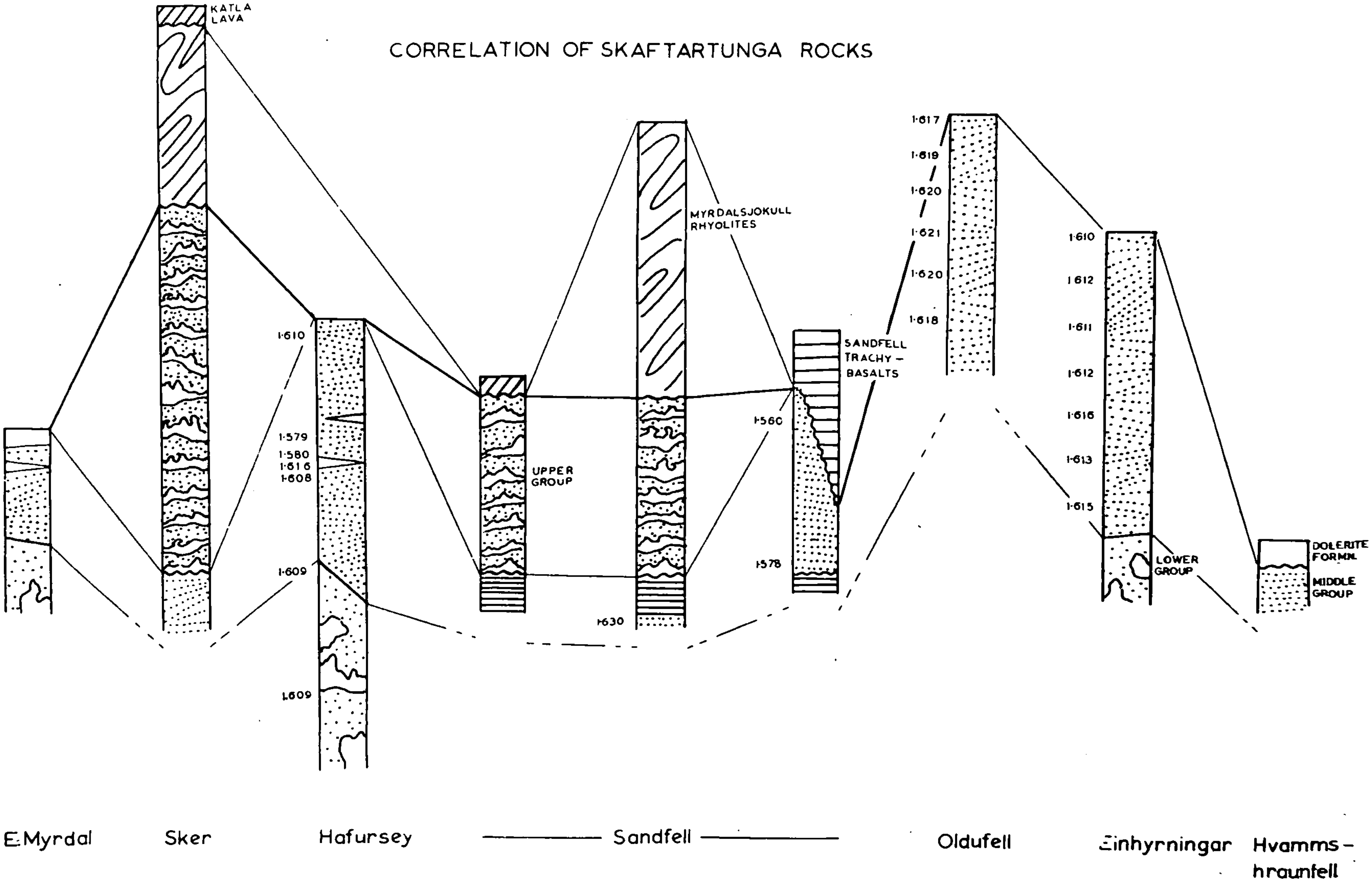
1. The Palagonite Formation. This formation forms the great bulk of the rocks of Skaftartunga and is the oldest of the formations found here. The older Tertiary Basalts which underlie these rocks elsewhere in Iceland are not found in Skaftartunga.

2. The 'Dolerite Formation' basalts. These occur in two small localities; at Hvammshraun fell in Eastern Skaftartunga and at Myrnahofthi on Myrdalssandur.

3. The Myrdalsjokull Rhyolite lavas and tuffs. The lavas occur only on Myrdalsjokull where they overlie Palagonite Formation rocks. Rhyolitic tuffs occur in a restricted locality on the mountain Sker where they too overlie the Palagonite Formation rocks.

4. The Sandfell Trachybasalt lavas. These form a relatively thin sequence of lava flows capping the mountain Sandfell on the south eastern margin of Myrdalsjokull. They do not occur elsewhere in Skaftartunga.

5. The Modern Basaltic Volcanics. These are the most recent of the Skaftartunga rocks. Primary formations are the crater deposits, the lavas and the undisturbed ashes. Secondary formations include ashes transported by wind and water and ash deposits of glacial origin.



DIAG.16

DIAG.16

THE PALAGONITE FORMATION.

The Palagonite Formation was named by Thoroddsen after the material, at that time thought to be a mineral species, which occurs commonly in the tuffs of the formation. The name is a convenient one, for the tuffs, which form a considerable part of the formation, owe their light brown colour to the presence of this material and this feature provides a criterion for distinguishing them from modern materials which otherwise exactly resemble the Palagonite Formation rocks.

The age of the Palagonite Formation is not known with precision. At Tjornes in northern Iceland Pliocene sediments occur which equal in age or are older than the lower Palagonite Formation rocks. The formation itself is unfossiliferous but, following the early discoveries of Pjeturss, tillites have frequently been described from within the formation, and it is now generally agreed that the bulk of the formation accumulated in the Pleistocene.

It is difficult to define an upper limit to the age of the Palagonite Formation. Climatic conditions similar to those in which much of the formation has accumulated prevail in Iceland today, the volcanic activity which is the source of the material of the formation still persists and modern rocks with structures similar to these of the Palagonite

Formation rocks occur. In the course of the present work it was found convenient to distinguish between fragmental rocks which were loose unconsolidated and lacked palagonite and those which contained palagonite and were consolidated or semi-consolidated. The latter are older than the Myrdalsjokull Rhyolites. For the purpose of the present work the extrusion of these acid rocks will be adopted to mark the upper limit of the formation.

The rocks of the Palagonite Formation exhibit a variety of unusual structures as well as more common ones. They are described below.

1. Massive Tuffs and Breccias. These are accumulations of frágmental basaltic rocks with no internal structure. In Skaftartunga the component materials are predominantly vesicular fragments of basalt glass, which rarely exceed one or two centimetres in diameter. Angular basalt fragments occur in variable amount and up to twenty centimetres in diameter.

2. Basalt Globe-Breccias. These rocks contain detached glóbular masses of basalt, usually distributed fairly uniformly in a matrix of vesicular and non-vesicular basalt glass perhaps with a small proportion of aphanitic basalt. The fragments of the matrix rarely exceed 5 centimetres in diameter. The basalt globes vary considerably in size. The smaller ones are a few centimetres in diameter and normally

are nearly spherical, but the larger ones may be several metres in diameter and often assume rounded flattened shapes. These show random orientation within the tuff. The globes have a characteristic structure. The outer part consists of a skin of sideromelane varying in thickness from one or two millimetres to a centimetre. Commonly embedded in this outer skin are fragments of the surrounding breccia. The inner part of the globes is formed of dense basalt which occasionally shows a few vesicles but it is rarely highly vesicular. The outer skin of the globes is traversed by a network of fine cracks or joints which passes in the inner parts into a set of pronounced joints radiating from the centre of the globe. The jointing makes the globes very fragile and it is practically impossible to extract one unbroken even from poorly consolidated breccias.

3. Intrusive Basalt Flows. These are horizontal sheets of basalt which differ in structure in several important respects from normal basaltic flows. These flows almost invariably rest on earlier basaltic ashes and breccias. The lower surface of the flow is normally fairly regular, though somewhat undulating, and it suggests that the lava has flowed over a nearly level and consolidated or semi-consolidated surface. The bottom surface of the flow is chilled and may be composed of sideromelane or tachylite. This surface fits

closely over the underlying ash or breccia, but fragments of the underlying rocks are rarely embedded in it. There is no concentration of vesicles at the lower surface of the flow but occasionally vertical pipe vesicles penetrate the lower surface and extend upwards into the flow for a few tens of centimetres. An irregular and closely spaced jointing system at the lower surface gives place upwards over a few centimetres to columnar jointing parallel to the lower surface of the flow. This zone of regular jointing forms a small proportion of the total thickness of the flow. It gives place upwards into irregular blocky jointing. The upper surface of the flow is a smooth rounded surface but is always of the most extreme irregularity. Apophyses of the most irregular kind extend upwards from the surface of the flow and invade the breccias by which the flows are invariably overlain. The upper surface of the flow consists of a skin of sideromelane up to one centimetre in thickness. A reddening of this surface is never observed and there is no concentration of vesicles at the surface. Fragments of the overlying breccia are commonly embedded in the upper surface.

The flows examined have been poor in vesicles; these were distributed at random throughout the flow and were nearly spherical in shape.

The overlying breccias are formed of angular fragments of non-vesicular sideromelane and tachylite. Basalt globes are commonly present in the breccias. In places the non-vesicular sideromelane fragments in the breccia above the flow can be seen to give place upwards to highly vesicular sideromelane fragments.

The sequence - basalt flow - basalt globe breccia - basaltic ash appears to form a 'unit' which is repeated at least six times on the mountain Sker.

Petrographic examination shows that the flows, the globes and the breccias are formed of identical basaltic materials.

The structures described above suggest that in each unit the following sequence of events took place.

1. A layer of vesicular basaltic ash was deposited.
2. The ash layer was displaced from below by a breccia of non vesicular basalt glass.
3. The breccia layer was displaced from below by a basalt flow.

These are unusual features for basaltic rocks. The repetition of 'units' of the type described in two localities in Skaftartunga made it clear that these structures are not casual in origin. The breccia of non-vesicular sideromelane implies drastic chilling of basalt magma by water which might be marine, lacustrine or glacial in origin. In an effort to determine whether the water was glacial in origin the 'units'

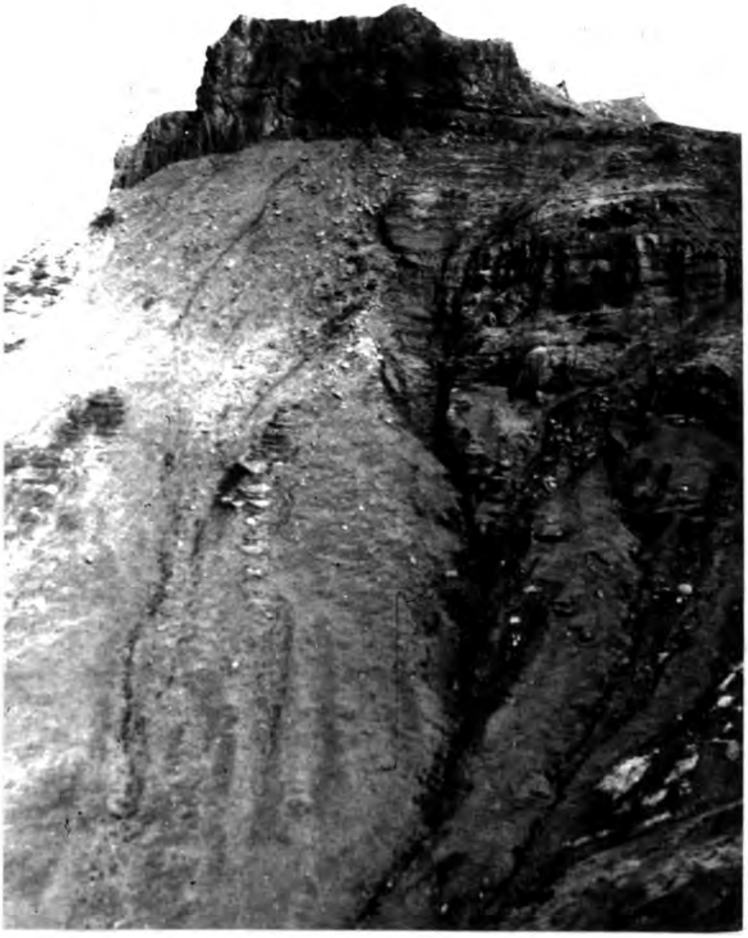


PLATE 37.

Aeolian Palagonite Formation tuffs. A sequence, two hundred metres in thickness on Hafursey.

were searched for glacially striated boulders, but none was found. Subsequently however a modern basalt globe breccia was discovered in circumstances which left no doubt as to its origin within the Myrdalsjokull ice cap. As a result of this and other evidence it has been concluded that the structures are subglacial in origin.

4. Intrusive Basalt Masses. These possess the characteristics of the intrusive flows but are not sheet-like. The forms assumed may be of the most extreme irregularity and always suggest the invasion of incompetent material from below by basalt magma. The material invaded is always a massive tuff or a basalt globe breccia, and most commonly the latter.

5. Pillow Lavas. These have been observed in only two localities and in neither case was it possible to make a detailed examination. They appear to have the characteristics of normal pillow lavas.

6. Aeolean Tuffs. These are poorly sorted accumulations of vesicular and non vesicular sideromelane, tachylite and basalt. Component fragments are usually less than 3 centimetres in size but occasional larger fragments of basalt occur. The deposits show coarse horizontal and cross lamination. This may not be visible close at hand but is clearly seen in the weathered tuffs of cliffs and mountain sides. Cross-laminated units may reach 30 metres in thickness. (See Plate 37).

7. Lacrustrine and Fluviatile Tuffs. These are well sorted accumulations of sideromelane and tachylite. In the deposits thought to be lacustrine in origin the average grain size is about one millimetre, though grains up to one centimetre in size occur. Accumulations of uniform fine grained tuff up to two metres in thickness occur. These may show an unusual type of jointing:- the entire mass of tuff is broken up into roughly equidimensional polygonal blocks between ten centimetres and 50 centimetres in size. These have a uniform outer surface. When broken open, however, they show a small scale columnar jointing radiating outwards from the centre of each block. The large scale blocky jointing is thought to be the result of the drying of the sediments relatively soon after their deposition. The smaller scale columnar jointing within each block is thought to be caused by the contraction of gel palagonite as a result of further drying.

Other lacustrine tuffs show very fine laminar bedding and yet others graded bedding.

The fluviatile tuffs show small scale cross bedding in fine grained well sorted materials.

Both fluviatile and lacustrine sediments occur in association intercalated within the aeolian tuffs.

8. Tillites. These show rounded striated boulders of

PLATE 38.

A striated boulder from Palagonite Formation tillite.
Northern wall of Crater Q Eldgja.

basalt in an unsorted matrix of sideromelane, tachylite and basalt fragments. Almost all the la rger basalt boulders in these deposits show striation in some degree, but boulders with deep parallel striations clearly showing the glacial origin of these conglomerates were very rare. One such boulder has been photographed and is seen in Plate 38 . In order to determine whether the lack of clearly striated boulders in these deposits was unusual, a careful search of the recent moraine of Myrdalsjokull was made. It was found that here too deeply striated boulders were very rare though the materials and structures found correspond exactly with those found in the Palagonite Formation rocks. (See Plate 38).

9. Extrusive Basalt Flows and Basalt Dykes. In addition to the sheet-like 'intrusive' basalts described above, other more normal basalt flows occur within the Palagonite Formation. These have the characteristics of 'extrusive' flows; reddened upper and lower surfaces; concentration of vesicles in the upper part of the flow; and upper and lower surfaces of nearly equal regularity. Glassy surfaces are quite absent and basalt-globe breccias do not occur in association with these flows. Other vertical sheet-like masses of basalt occur in the Palagonite Formation. These dykes are distinguished from the 'intrusive' basalt masses' by their greater regularity and dyke-likee shape. Both extrusive flows and dykes occur only

in association with aeolean tuffs.

Geological work in the Icelandic Palagonite formation is complicated by the lack of fossiliferous beds and of any continuous marker horizon which might be used for stratigraphic purposes. Such stratigraphic work as can be attempted has to be based on lithological character and this changes with such rapidity, both horizontally and vertically, that determination of structure and succession within even a small area is always difficult and uncertain. Specimen profiles were collected from several of the highest mountains in Skaftartunga in the hope that petrographic examination would enable the formation to be zoned, but this hope was not fulfilled.

These conditions make it difficult to determine the presence of, and the effect of, faulting within the Palagonite Formation unless the faulting is modern and has led to the formation of fault scarps. No evidence of modern faulting has been observed in Skaftartunga except near Eldgja, and no conclusive evidence of older faulting has been obtained, though it seems probable that such faults occur.

Thoroddsen (1906) recognized two divisions within his Palagonite Formation which he called the Older and Younger Tuffs. Hafursey, a mountain in the south east of Skaftartunga, is cited as a type locality for the two divisions.

His description of the Hafursey succession is as follows: "The lowest part of the mountain up to a height of 340m. consists of light brown tuff filled with scoria, bombs and large and small fragments of lava. It is divided into extremely irregular strata which assume the most varied shapes and orientations, and is intersected by a branching web of basalt veins with outgrowths and apophyses. Above and lying discordantly on the lower tuffs, occurs a thick sequence of tuff composed of conformable, horizontal or undulating, breccia and tuff layers". Thoroddsen's "tuff filled with scoria, bombs and large and small fragments of lava" are described here as massive tuffs or basalt globe breccias, and his "branching web of basalt with outgrowths and apophyses" are here termed intrusive basalt flows and intrusive basalt masses.

A similar succession has been seen elsewhere in Skaftartunga and although no mapping within the formation has been attempted it has been assumed that the successions are equivalent; in particular, that the thick developments of aeolian tuff which occur extensively in the area are of similar age. This assumption permits the division of the Palagonite Formation into three groups; a Lower and a Middle Group corresponding to Thoroddsen's Older and Younger Tuffs and a third, overlying, Upper Group. (See Diagrams 15 and 16).

The Lower and Upper Groups consist predominantly of intrusive basalt masses and flows, basalt globe breccias, massive tuffs, fluviatile tuffs and tillite. The Middle Group consists of coarsely bedded aeolean tuffs with intercalated lacustrine and fluviatile tuffs and extrusive basalt flows. It is not usually easy to distinguish between rocks of the three groups, because of the great similarity between their component materials. In practice the three groups have usually been distinguished by the presence or absence of basalt globe breccias and tillites, which occur only in the Upper and Lower Groups.

Two ascents of Hafursey were made, but in neither case was it possible to determine a precise boundary between the Lower and Middle Groups, though, over a few tens of metres, a transition from rocks typical of the Lower Group to those typical of the Middle Group was observed. Similar conditions were observed in Skaftartunga generally, where a thick series of coarsely stratified tuffs of the Middle Group overlie the tuffs, breccias and intrusive basalts of the Lower Group.

The creation of an Upper Group was made necessary by the discovery at Sker and Sandfell of a sequence of intrusive basalt flows and basalt globe breccias overlying the tuffs of the Middle Group.

The Lower Group.

At the south eastern point of Hafursey the lower part of the succession consists of basalt globe breccias and massive tuffs. These give place at about two hundred metre contour to tuffs of the Middle Group. The rocks of the Lower Group persist northwards at the base of the mountain but rapid changes in colour, in degree of hardening and in the content and size of basalt globes occur. Where exposure is intermittent it is impossible to determine whether these variations occur within a single unit of the formation or whether several different units are transposed. Similar difficulties are encountered in the Palagonite Formation generally. On the northern part of the mountain where continuous exposures persisted over a distance of nearly a kilometre considerable variations in hardness, in colour, which varied from light brown to a brownish black, and in content of basalt globes was observed within an apparently continuous basalt globe breccia. The lower parts of the mountain are formed occasionally of steep cliffs and in these irregular intrusive basalt masses can be seen. In one such exposure on the western side of Hafursey a nearly horizontal intrusive basalt flow was exposed at a height about 50 metres above the sandur. The flow persisted for about two kilometres and the fairly regular lower surface and highly irregular upper surface could clearly be seen. The flow attained a maximum thickness towards the centre of about 50 metres. It was overlain by a basalt globe breccia. At the north western end of Hafursey the junction between the Lower and Middle Groups was found to be at about the three hundred metre contour. Tillites were not found on Hafursey.

The mountains west of Hafursey and south of Myrdalsjokull proved very difficult to traverse and only a partial ascent of one ridge was accomplished.[1] The lower part of the mountains consists of massive tuffs, basalt globe breccia and intrusive basalt. On the ridge ascended these gave place at about the three hundred metre contour to tuffs of the Middle Group.

No rocks of the Lower Group are exposed at Sandfell.

At Olafshaus a sequence of fluviatile tuff and breccia, basalt globe breccias and intrusive basalt flows about 250 metres in thickness is exposed. Overlying them at the 600 metre contour are aeolean tuffs about 100 metres in thickness.

These may be the lowest members of the Middle Group.

On the low plateau 3 kilometres east of Olafshaus, tuffs of the Middle Group are exposed in the west above the three hundred metre contour. Below this and to the east tillites and massive breccias of the Lower Group occur.

In Holmsadalur, south of Einhyringar, basalt globe breccias, intrusive basalt masses, massive breccias and tillites, of the lower group are exposed. They are overlain on the broad southward trending ridge east of Holmsadalur by rocks of the Middle Group. The junction varies in height from 400 metres in the north to 200 metres in the south.

In the Middle Holmsa gorge one kilometre east of Einhyringar tillite overlies a confused mass of intrusive basalt with which are associated basalt globe breccias.

South of Atlaey the rocks of the lower group are not exposed, except at Hrifuness where a small outcrop of pillow lava occurs.

In northern Skaftartunga the rocks of the Lower Group are similar to those in the south. Intrusive basalt masses, basalt globe breccias, pillow lavas, massive breccias and tuffs and tillites occur. The junction between the Lower and Middle Groups on Gjatindur is near the 700 metre contour. Four kilometres to the south west it is near the six hundred metre contour and appears to fall to about 500 metres at Svartaknuksfjoll a further ten kilometres to the south west. In this region there are thick developments of tillite which is seen in the walls of Craters Q , R, S and V of Eldgja. In crater V they reach 100 metres in thickness and are overlain by tuffs of the Middle Group.

In the valley of the Sythri Ofaera, two kilometres south of the northern mountain Axlir, pillow lavas were seen among rocks of the Lower Group. The occurrence of pillow lavas here and at Hrifuness are the only ones observed in Skaftartunga.

The Middle Group.

Of the materials which form the Middle Group of the Palagonite Formation, those which greatly predominate are coarsely bedded aeolean tuffs and breccias. Several of the highest mountains in Skaftartunga were ascended and found to consist solely of these materials. On Einhyringur, which is 684 metres high, three hundred metres of aeolean tuffs of the Middle Group are exposed and a similar thickness occurs on Oldufell, which is 810 metres high. In northern Skaftartunga the junction between the Lower and Middle Groups rises north-eastwards from Einhyringur, where it occurs near the 300 metre contour, to Svartahnuksfjoll, where it occurs near the 500 metre contour and finally to Gjatindur where it occurs near the 700 metre contour.

On the broad southward-tending ridge east of Holmsadalur the Lower Group is overlain by rocks of the Middle Group at a height of about 300 metres. Here, too, the latter consist mainly of aeolean tuffs but intercalated between these are fluviatile conglomerates and breccias.

East of Holmsadalur exposure is less good. The rocks exposed are predominantly coarsely bedded tuffs and except at one locality, four kilometres east of Holmsadalur near the 200 metre contour, basalt globe breccias were not seen. It is probable therefore that, from Holmsadalur, the junction between the Lower and Middle Groups falls eastwards, and in Eastern

Skaftartunga is below the 200 metre contour. At Rettarfell a horizontal basalt sheet occurs which is thought to be a much eroded remnant of an extrusive flow within the tuffs of the Middle Group. Other minor exposures of basalt occur in Eastern Skaftartunga but were not sufficiently good for their form to be determined.

At Hvammshraunfell Dolerite Formation basalt overlies tuffs of the Middle Group just below the 300 metre contour. These basalts are much coarser in texture and lighter in colour than the Palagonite Formation basalts.

West of Holmsadalur the southern mountain Axlir consists of coarsely bedded Aeolean tuffs with intercalated sheets of lava. These lack glassy surfaces and there are no associated basalt globe breccias. They are thought to be normal extrusive flows within the Middle Group of tuffs.

At Hafursey and in the mountains of Eastern Myrdal, about 20 kilometres to the south west of Holmsadalur, the lower junction of the Middle Group lies near the three hundred metre contour. Here, at varying heights, intercalations of fluviatile and lacustrine sediments occur within the aeolean tuffs which form the bulk of the Middle Group. Basalt dykes were seen cutting these tuffs but were not examined closely.

At Sandfell, ten kilometres north of Hafursey, the development of the Middle Group is unusual. Here no member of the Lower Group is exposed. The oldest rock exposed is a tuff, apparently without internal structure, of which about two metres is exposed. Overlying this tuff is a sequence of horizontal extrusive flows, thirty metres in thickness, and containing twelve members. These basalts show regular and reddened upper and lower surfaces and no surface glass. No basalt globe breccias occur in association. Resting on the eroded upper member of these flows is a series of well bedded tuffs one hundred metres in thickness which dip eastwards at 30 degrees. These are overlain unconformably by the Sandfell Trachybasalts.

Two kilometres to the south of Sandfell the extrusive basalts described above are overlain unconformably by intrusive basalt flows and basalt globe breccias of the Upper Group.

The Upper Group.

These rocks were first seen on the mountain Sker two kilometres south of the Huldufjoll on the southern margin of Myrdalsjokull. They consist of a nearly horizontal series of intrusive basalt flow 'units'. The succession within a unit being, from below, intrusive basalt flow, basalt globe breccia, ash and breccia; intercalations of fluviatile tuff occur between units. On the southern part of Sker the lowest intrusive flow of the series was found overlying the striated surface of an older tuff showing coarse bedding, at a height of about 300 metres. Because of the precipitous nature of this part of the mountain a thickness of only a few tens of metres of this tuff could be examined. It was tentatively identified as a member of the Middle Group.

The intrusive flow units on Sker number about twelve and have an apparent thickness of about four hundred metres. On the lower part of Sker a rhyolitic tuff rests unconformably on an eroded lower member of the series. The series continues northwards into the Huldufjoll where it is overlain unconformably by the Myrdalsjokull rhyolite flows.

Other representatives of the Upper group in Skaftartunga occur only at Sandfell. Here a series of intrusive flow units overlie the eroded and glacially striated surface of the extrusive flows of the Middle Group. The intrusive flow units appear to be about six in number having a total thickness of two hundred metres. They are themselves overlain unconformably by the Myrdalsjokull rhyolites, in the west and modern Katla lavas in the east.

Petrography.

The constituent materials of the Palagonite Formation are all basaltic. They occur in three forms; as sideromelane, a transparent basaltic glass; as tachylite, an opaque basaltic glass, and as aphanitic basalt. All these materials normally show microphenocrysts or pyroxene, of plagioclase and of iron ores and, more rarely, of olivine.

In the hand specimen sideromelane is black in colour and has a vitreous lustre. In thin section it varies in colour from light to dark brown. The refractive index of this material has been measured in twenty five Palagonite Formation rocks; variations within individual rocks up to 0.01 have been observed where this variation occurs the maximum value has been quoted. The maximum values obtained vary from 1.578 to 1.636. The sideromelane is always isotropic.

In Palagonite Formation rocks sideromelane is always altered to some degree to palagonite. The material in the Skaftartunga rocks is similar in character to that described by Peacock (1926), Peacock and Fuller (1928) and, more recently, by Macdonald (1949).

Peacock recognised two palagonite materials, a structureless isotropic material which he named gel palagonite, and a fibrous birefringent material occurring in aggregates with random or sub parallel orientation, which he called fibro palagonite.

Peacock regarded the Icelandic palagonite as the result of the alteration sideromelane tuffs by alkaline hot spring solutions. Macdonald, discussing the Hawaiian tuffs, concluded that palagonite resulted from ordinary weathering of sideromelane tuffs. There is general agreement however that gel palagonite results from the hydration of sideromelane, accompanied by a partial removal of lime and magnesia and nearly complete oxidation or iron. Peacock suggested that fibro palagonite results from the crystallization of a chloritic mineral within the gel.

In the Skaftartunga rocks gel palagonite usually occurs as a replacement product of sideromelane and in this form is seen bordering vesicles and the broken surfaces of sideromelane grains. There is some evidence that gel palagonite may have mobility; in specimen 49 a vein of gel palagonite traverses a crack in perfectly fresh sideromelane. The gel palagonite is usually isotropic but may show grey first order interference colours. The colour varies from light to dark green and from yellow to dark brownish red. It was noticed during the mounting of thin sections that when palagonite material is heated in the absence of air a change in colour from yellow to green may occur in the gel and fibro palagonite.

The refractive index of gel palagonite is variable and is always lower than that of the altered sideromelane. The lowest value determined was 1.512 in specimen No.217.

The fibrous material which forms fibro palagonite appears to develop within the gel material either as minute randomly orientated plates giving aggregate first order polerization colours or as parallel fibrous aggregates usually oriented normal to the surface of the altered fragment. The fibrous material varies in colour from yellow to dark brownish red, and gives first order interference colours where these are not masked by a strong body colour. Extinction is straight. The refractive index of the fibro palagonite in specimen No.14 is close to 1.53.

In the rocks in which the alteration of sideromelane to palagonite is most extensive zeolites and calcite occur in vesicles and in cavities, Among these analcite and natrolite have been identified.

The opaque tachylite glass appears to be more stable than the transparent variety and never alters to palagonite.

Microphenocrysts of labradorite, augite, chrysolite and iron ores occur in both sideromelane and palagonite. The labradorite frequently assumes skeletal and spongy forms suggestive of supercooling of the crystallizing liquid.

In the collection of samples of Palagonite Formation rocks and in their subsequent examination attention was directed principally at the rocks of the Middle Group. These form the great bulk of the rocks exposed in Skaftartunga and their relative uniformity made representative sampling more easy. In addition it seemed likely that if correlation within the formation based on petrographic character could be made, there would be a better chance of success among the aeolean tuffs of the Middle Group than among the complex assemblages of the Lower Group.

The Lower Group - Two rocks of the Lower Group have been examined petrographically both are tuffs from Hafursey.

Specimen No.11 is from the north western point of Hafursey, 160 metres above sea level. The rock lacks internal structure but contains a few detached pillow like masses of vesicular basalt. It might be termed either massive tuff or a basalt globe breccia. In hand specimen, No. 11 is yellow brown in colour, compact and contains irregular vesicular fragments of sideromelane and angular fragments of aphanitic basalt up to four centimetres in size.

In thin section No.11 is seen to consist of an aggregate of fragments of vesicular tachylite and aphanitic basalt. Almost 80 percent of the original sideromelane is now altered to palagonite, of which both gel and fibro varieties occur. Within both palagonite and sideromelane unaltered microphenocrysts of pyroxene, plagioclase and iron ore occur both separately and in glomeroporphyritic aggregates. Rare isolated olivines also occur. The microphenocrysts are normally euhedral.

Specimen No. 13 was collected from a massive tuff overlying No.11 at a height of 270 metres. In hand specimen it is dark brown in colour and the component fragments do not exceed one centimetre in size. In thin section it is similar to No. 14 but has no olivine and is only slightly altered to palagonite, which is almost entirely of the gel variety.

The following determinations were made:-

No. 11 Sideromelane: N 1.609.

No. 13 Sideromelane: N 1.609.

No. 13 Pyroxene; 2V, 52, 56; Ny 1.694; comp. $Wo_{44}En_{38}Fs_{18}$

No. 13 Plagioclase (zoned) Nx ±1 1.561, Nz ±1 1.570; comp. An_{63-67}.

The Middle Group.- Specimen profiles were collected through the rocks of the Middle Group from the mountains Hafursey, Sandfell, Einhyringar and Oldufell.

The Hafursey rocks are all rather similar in petrography. All consist mainly of vesicular sideromelane fragments with some tachylite. The Aeolean tuffs 14,15 and 53 are poorly sorted with fragments normally less than 3 cm. in size and occasionally angular blocks of basalt up to 10 centimetres or more in size. The lacustrine tuffs contain well sorted materials less than 5 mm. in size.

The refractive index of the sideromelane has been measured in each rock. Some variation is observed, but all values fall well within the range of index for basalt glasses given by George (1924). In all rocks more than 80 percent of the original sideromelane is now altered to palagonite of both varieties. The refractive index of the fibrous variety in No. 14 was found to be near 1.53 and this low value suggests that if the material is a chlorite it is probably antigorite.

Unaltered microphenocrysts of augite, labradorite, iron ore and more rarely of olivine occur and are about 0.02 millimetres in size. They form less than five percent by volume of the original glass. Zeolites and calcite occur in cavities in the rocks. In No. 14 analcite has been identified.

The following determinations were made:-

No. 53. 580 metres Hafursey, (tuff).

Sideromelane, N. 1.610.

Pyroxene, 2V, 53, 52; Ny 1.695; comp.$Wo_{43}En_{38}Fs_{19}$

Plagioclase, Nx 1.555, Nz 1.564; comp. An_{51-55}.

No. 17. 450 metres Hafursey (tuff).

Sideromelane, N 1.579.

No. 16. 440 metres Hafursey (tuff).

Sideromelane, N 1.580.

No. 15. 420 metres Hafursey (tuff).

Sideromelane, N 1.616.

No. 14. 400 metres Hafursey (tuff).

Sideromelane, N 1.608.

Fibro-palagonite N near 1.53.

Zeolite, isotropic, N 1.490, analcite.

The Sandfell aeolean tuffs are similar in petrography to those of Hafursey but here less than 50 percent of the original sideromelane has been altered to palagonite and the fibro variety is not so commonly or so extensively developed. Olivine is absent from the upper tuffs Nos. 75 and 31 and is rare in the lowest tuff No. 72. Near the base of the succession sub aerial basalt flows occur and these contain phenocrysts of bytownite, and rarely of olivine, up to one millimetre in size in an intergranular ground mass of labradorite, augite, olivene and iron ore. The olivine may show slight alteration to a dark red product marginally. Radiating fibres of material very similar to fibro palagonite is found in vesicles in this rock adjacent to unaltered ground mass minerals. The following determinations were made:-

No. 31. 400 metres Sandfell. (tuff).

Sideromelane, N 1.560.

Zeolite, positive elongation, straight extinction and low berefringence - probably natrolite.

No. 75. 300 metres Sandfell. (tuff).

Sideromelane, N. 1.578.

Pyroxene 2V 50,52, Ny 1.695; comp. $Wo_{42}En_{38}Fs_{20}$.

Plagioclase (zoned) Nx' 1.556, Nz' 1.576; comp. An_{53-68}.

No. 27. 300 metres Sandfell (sub-aerial lavas, upper flow)

Pyroxene (groundmass) 2V 46, 52, Ny 1.693; comp. $Wo_{40}En_{41}Fs_{19}$

Plagioclase (phenocryst) Nz' 1.573; comp. An_{74}.

Plagioclase(groundmass) Nx' 1.557, Nz' 1.568; comp. An_{55-64}

No. 72. 250 metres Sandfell. (tuff).

Sideromelane, N 1.630.

Pyroxene, 2V, 51. NY 1.696. comp. $Wo_{40}En_{39}Fs_{21}$

Plagioclase, Nx' 1.557, Nz' 1.572; comp. An_{55-70}.

The Einhyringer rocks are all poorly sorted aeolean tuff and their constituent materials are similar to those of Hafursey, but the Einhyringur rocks are less well compacted and rather porous in character. Palagonite is not strongly developed and only about 30 percent of the original sideromelane has been altered. Phenocrysts of augite, Labradorite, Chrysolite and iron ores occur as larger crystals and in greater quantity than in the Hafursey tuffs. Phenocrysts commonly reach 0.2 mm. in size and together form about 10 percent by volume of the original sideromelane, Zeolites are rare in the pore spaces.

The following determinations have been made.

No. 219. 650 metres Einhyringur (tuff).

Sideromelane N 1.610.

Pyroxene 2V 51, 54, Ny 1.696; comp $Wo_{42}En_{38}Fs_{20}$.

Olivine Nz 1.708; comp Fa_{20}.

Plagioclase Nx' 1.554 Nz' 1.561 comp. An_{50-55}.

No. 218. 600 metres Einhyringar (tuff).

Sideromelane N 1.612.

No. 217. 550 metres Einhyringar (tuff).

Sideromelane N 1.612.

No. 216. 500 metres Einhyrningar (tuff).

Sideromelane N 1.612.

No. 215. 450 metres Einhyrningar (tuff).

Sideromelane N 1.616.

No. 214. 400 metres Einhyrningar.

Sideromelane N 1.613.

No. 213 350 metres Einhyrningar (tuff).

Sideromelane N 1.615.

Pyroxene 2V 56, 54, 55, Ny 1.698 comp. $Wo_{45}En_{34}Fs_{21}$

Olivine Ny 1.704 comp. Fa_{23}

The Oldufell tuffs are all Aeolean and very similar to those of Hafursey. More than 80 percent of the original sideromelane is now altered to palagonite of both varieties. Microphysts of Plagioclase, augite and iron ore occur but form less than two percent of the original sideromelane, and rarely exceed .02 mm. in size. Zeolites and calcite are common in pore spaces.

The following determinations have been made.

No. 229. 800 metres Oldufell (tuff)

Sideromelane N 1.617.

No. 230 760 metres Oldufell (tuff)

Sideromelane N. 1.619

No. 231. 720 metres Oldufell (tuff).

Sideromelane N. 1.620.

No. 232. 680 metres Oldufell (tuff).

Sideromelane N. 1.621.

No. 233. 640 metres Oldufell (tuff).

Sideromelane N. 1.620.

No. 235. 560 metres Oldufell (tuff).

Sideromelane N. 1.618.

The Upper Group. - One typical rock from each of the Sker and Sandfell localities has been selected for petrographic examination.

The Sker rock No.55 is the uppermost intrusive flow of the series. The rock contains euhedral phenocrysts of plagioclase and pyroxene, about 2mm. in length. The groundmass consists of a mesh of plagioclase laths, about one millimetre in length, with intergranular subhedral pyroxenes, olivines and iron ores, grading in size from one millimetre downwards. A small amount of interstitial felspathic material may occur, which includes needles of apatite.

The chilled margin of specimen 49, a basalt globe from the Sker sequence, was examined. The outer edge of the rock showed a mesh of plagioclase needles about one millimetre in length, together with subhedral grains of pyroxene, olivine and iron ore in a clear yellow sideromelane of refractive index 1.636. As the rock is traversed away from the outer margin opaque areas begin to develop patchily around these crystals and eventually grow, coalesce and render the entire glass opaque. Though the sideromelane is unaltered a vein of gel palagonite traverses this material and is stained red as it approaches and meets a small olivine which shows slight signs of alteration. The coloration suggests a migration of ferric ions from the crystal to the gel.

The Sandfell rocks are very similar in petrography to that described from Sker. Unlike those of the Lower Group the basalt globe breccias of the Upper Group are always poorly consolidated and within them palagonite is poorly developed.

The following determinations were made.

No. 49. 300 metres Sker (basalt globe).

Sideromelane N. 1.636.

No. 55. 500 metres Sker (intrusive flow).

Pyroxene 2V 43,42,43; Ny 1.701; comp. $Wo_{35}En_{37}Fs_{28}$

Plagioclase (phenocryst) Nx' 1.560; Nz' 1.569 comp. An_{60-66}

Plagioclase (groundmass) Nx' 1.553; Nz' 1.566 comp. An_{49-60}

No. 259. 255 metres Sandfell (basalt globe).

Sideromelane N 1.633

No. 257. 250 metres Sandfell (intrusive flow).

Pyroxene 2V 51,52; Ny 1.685; comp. $Wo_{42}En_{46}Fs_{12}$.

Plagioclase Nx' 1.557; Nz' 1.566; comp. An_{55-60}

Petrography and Correlation in the Palagonite Formation.

The petrographic characters which have been investigated tend neither to support nor to disqualify the correlation proposed. With one exception (that in specimen 55 of the Upper Group) the pyroxenes determined are uniformly diopsidic augites and all the plagioclases are labradorites. Some variation in the refractive index of the sideromelane occurs and this is shown in Diagram 16, but it is not sufficiently well marked to be useful for purposes of correlation. For petrological purposes the Palagonite Formation rocks of Skaftartunga appear to be a homogeneous group.

THE DOLERITE FORMATION.

In Eastern Skaftartunga the upper western slopes of the mountain Hvammshraunfell are covered by peaty soil, in which breaks expose a loose pavement of platy, grey and coarse grained basalt. This rock is petrographically very similar to the basalts which overlie Palagonite Formation rocks ten kilometres to the north-east at Geirlandshraun on the eastern side of the Skafta valley, and which are shown on Thoroddsen's map of 1906 as Dolerite Formation basalts. On this basis it is suggested that the Hvammshraun rock may be an outlier of the main mass of the Dolorite Formation rocks at Geirlandshraun, separated from them by the Skafta valley.

At Myrnahofthi 2 km. east of the farm Myrar at Thykkvabaejarklauser on Myrdalssandur an isolated outcrop of grey coarse grained basalt occurs in the banks of the Kuthafljot. The exposed basalt is about 3 metres in height and extends laterally for about 20 metres. The upper surface is much eroded. A few nearly sperical vesicles occur throughout the basalt which is broken by a few vertical joints. No other outcrop is seen until the Eldgja lavas are reached four kilometres westward. This basalt, too, strongly resembles the Geirlandshraun Dolerite Formation rocks in petrography and it is suggested tentatively that it may be a distant outlier of the formation. A single short visit was made to the Geirlandshraun basalts where specimens were collected.

Petrography.

The Hvammshraunfell, Myrnahofthi and Geirlandshraun rocks differ conspicuously from all other basalts encountered in Skaftartunga by their light grey colour and coarse grain and by the ophitic texture they exhibit in thin section. Two of them, the Hvammshraunfell and Myrnahofthi rocks, differ further in possessing two pyroxenes.

In all these rocks the groundmass felspar is sub-hedral somewhat zoned and may show inclusions of iron ore and pyroxene. Pyroxene occurs only in the groundmass. The two pyroxenes present in two of the rocks can not mutually be distinguished in thin section. In all three rocks the pyroxene is colourless and occurs ophitically. Iron ore occurs as subhedral plates and cubes and interstitially. Interstitial tachylite is present in the Hvammshraunfell rock. There is some variation in the amount of olivine present in the Myrnahofthi and Geirlandshraun rocks, it occurs only in the groundmass where it is rather rare. In the Hvammshraunfell rock olivine is common in the groundmass and occurs as phenocrysts up to 2 mm. in size. In all three rocks porphyritic felspars occur.

The following determinations were made.

No. 285. Hvammshraunfell.

Olivine phenocrysts. NY 1.711, comp. Fa_{26}

Pyroxene 2V 47,47,48, Ny 1.695; comp.$Wo_{39}En_{40}Fs_{21}$

Pyroxene 2V 18, 17, 18. Ny not determined.
Pidgeonite.

Plagioclase. (Groundmass). Nx' 1.556, Nz' 1.572;
comp. An_{70-53}.

No. 272. Myrnahofthi.

Olivine groundmass Nz 1.720, comp. Fa_{25}

Pyroxene, 2V 53,52,51. Ny no determination;
Diopisitic augite.

Pyroxene, 2V 20,26,25,23; Ny 1.701; comp.
$Wo_7En_{50}Fa_{43}$

Plagioclase, (phenocryst)Nz' 1.573; comp. An_{74}

Plagioclase, (groundmass)Nx' 1.556; comp. An_{54}

No. 279. Geirlandshraun.

Pyroxene 2V 45,45,47,47; Ny, no determination.
Diopsidic augite.

Plagioclase (phenocryst) Nx' 1.560, Nz 1.571,
comp. An_{60-69}.

Plagioclase (groundmass)Nx' 1.552 Nz 1.565;
comp. An_{47-57}

THE MYRDALSJOKULL RHYOLITES.

The Myrdalsjokull rhyolites, or liparites, occur in two groups of nunataks, projecting through the ice of Myrdalsjokull, north and south of the Kotlujokull glacier. The southern group extend over an area of nearly 6 square kilometres and the northern group over more than 12 square kilometres.

The base of the southern group is seen on the Huldufjoll, Here the rhyolites overlie unconformably the tuffs and breccias of the Upper Group of the Palagonite Formation. In places the reddened and scoreaceous lower surface of the rhyolites rests directly on the Palagonite Formation rocks, and in others a few metres of breccia of angular rhyolite fragments 5 to 10 centimetres in diameter intervenes.

The rhyolite exhibits a kind of close spaced platy jointing which was probably originally horizontal and perhaps was caused by laminar flow in the viscous lava. The flow may consist entirely of dull grey slaty rock or black glass, and often of streaks of the one in the other parallel to the platy jointing. Devitrifying spherulites occur in the glass and are arranged in zones parallel to the jointing. Vesicles occur in zones parellel to the jointing but, unlike the spherulites, are usually streaked, in some cases to such a degree that the rock assumes a shaly appearance. Whilst horizontal jointing does occur, most commonly it has been acutely folded so as to resemble the isoclinal folding of metamorphic rocks. In the southern area each exposure shows one flow unit only and it is supposed that a single flow is present, perhaps between 100 and 200 metres in thickness locally.

The upper surfaces of the rhyolites are everywhere heavily eroded and striated. On the westernmost nunatak of the southern group a recent Katla lava overlies the striated upper surface of the rhyolites.

The rocks of the northern group of nunataks are very similar to those of the southern group. On the southernmost nunatak a continuous exposure of rhyolite 100 metres in height is seen. The flow here is much contorted, and folds in it are seen enveloping cavities filled with reddened rubbly material, perhaps originally part of the upper surface of the flow. In the lower rocks of this exposure phenocrysts of felspar and pyroxene a few millimetres in length were seen; these were absent in the upper rocks. However no clear evidence that more than one flow was present was found here.

At the eastern end of the northern group of nunataks, five kilometres south west of Sandfell, a cliff section exposes a 50 metre section through the rhyolite. Here an irregular horizontal layer of reddened rubbly material between one and five metres in thickness divides the rhyolite into two equal and roughly horizontal layers. Unfortunately this exposure could not be examined closely; it provides the only evidence that a sequence of relatively thin flows may be present.

On the ridge Sker about six kilometres south west of the Huldufjoll a small exposure of rhyolitic tuff about two metres in thickness occurs overlying unconformably member rocks from the Upper Group of the Palagonite Formation. The exposure occurs in a small hollow on the eastern flank of the ridge near the 300 metre contour. The tuff is formed for the most part of dull black firmly consolidated ash, but within it a small breadcrust -type bomb ten centimetres in length was found,which was composed of rhyolitic glass with a few felspar phenocrysts. Also within the body of dull ash horizontal streaks, a few centimetres in thickness and a few metres in length, of apparently solid rhyolitic glass occur. The origin of these streaks is not clear but it seems possible that they represent local welding together of the ash fragments to form intercalations of welded tuff within the main tuff body.

Petrography.

Under the microscope the Myrdalsjokull rhyolites show a glassy or cryptocrystalline base in which phenocrysts of plagioclase occur always, though in varying amount, and phenocrysts or pyroxene occur sometimes.

Petrographic evidence suggests that all the rocks were originally glassy and that the cryptocrystalline base of some rocks is a devitrification product.

In the glassy rocks the colourless glassy base of the rock has a refractive index close to 1.51 and is crowded with microlitic needles of plagioclase, for which extinction angles suggest the composition as medium oligoclase, and a green faintly pleochroic pyroxene. Phenocrysts of oligoclase, zoned and embayed, and pyroxene may occur. Quartz is entirely absent as a primary crystalline material in all the rhyolites.

In some rocks the microlites show fluidal structure and the glassy base is crossed by streaks of devitifying cryptocrystalline material parallel to this structure. Other circular patches of devitrified material straddle the streaks and suggest devitrification has extended radially from points within the streaks. The structures give the rocks a banded and spherulitic appearance in hand specimen.

In other rocks the groundmass consists entirely of cryptocrystalline material. The green pleochroic pyroxene has been identified as a diopside-rich ferrosalite; the pyroxene microlites which occur in all the rhyolites show similar pleochroism, are thought to be of similar composition.

In specimens from the northern group of nunataks irregular pores within the rock contain small cubes of analcite, and groups of radiating fibres of an unidentified chloritic material resembling fibro palagonite. Others from the same locality contain tridymite in the pore spaces.

The following determinations were made.

No. 49. Huldufjöll.

Glass N 1.513.

Plagioclase phenocrysts Nx' 1.535 Nz' 1.549 comp. An_{15-30}.

Pyroxene microlites, pleochroism, Z green, Y or X yellow green extinction z/c47.

No. 20. Nunatak 2 km. north of Huldufjoll.

Glass N. 1.510.

Pyroxene phenocryst 2V 60,61; Ny 1.711; comp. $Wo_{50}En_{20}Fs_{30}$

pleochroism Z green, Y yellow green, X green.

extinction Z/c 45.

No. 457. Small nunatak, summit of Kotlukollar.

Glass N. 1.506.

No. 462. Easternmost nunatak of Kotlukollar. Upper unit.

Glass N. 1.505.

No. 467. Locality as 462, Lower unit.

Glass N 1.506.

No. 6. Breadcrust bomb. Sker.

Glass N 1.510.

No. 69. "Welded" tuff. Sker.

Glass N 1.513.

No. 70. Rhyolite tuff. Sker.

Glass N 1.513.

THE SANDFELL TRACHYBASALTS.

The Sandfell trachybasalts are found only on the mountain Sandfell in western Skaftartunga.

On the western slopes of the mountain the series is about 50 metres in thickness and overlies unconformably tuffs of the Middle Group of the Palagonite Formation at a height 450 metres above sea level. The Palagonite Formation tuffs thin rapidly eastward while the trachybasalts show a corresponding thickening.

At the eastern end the lower slopes of the mountain are everywhere mantled in a thick apron of scree formed principally of blocks from the upper members of the trachybasalt series. It seems probable however that here the whole height (250 metres) of the mountain is occupied by trachybasalt lavas and pyroclastics.

The series is nearly horizontal with individual flows varying in thickness from 10 to 20 metres. A variable quantity, about one or two metres in the upper part of the succession, of reddened, scoreaceous material occurs between the flows. Only the upper seventy metres of the series was examined closely but observation from the foot of the eastern end of the mountain suggests that the relative thickness of the pyroclastics increases in the lowest part of the series, and may exceed that of the lavas.

The surface features of the flows are well preserved and good examples of ropy surfaces are seen in sections through the lavas. In thin flows and at the surface of thick flows the trachybasalts are dull black in colour, but in the inner parts of the thicker flows the colour is blue grey mottled with light grey. Vesicles, which occur at the upper and lower surfaces of the flows are always empty.

On the southern slopes of the mountain near the four hundred metre contour three vertical spines of trachybasaltic material project from the upper part of the scree apron. They are formed of the black variety of trachybasalt arranged as a series of concentric, vertical, cylindrical shells, each of which shows horizontal columnar jointing. The largest of the spines has a base about twenty metres in diameter, from which the sides regularly converge upwards to an apex about 20 metres above the base.

The contacts between the spines and the lavas were obscured by scree. Microscopic examination shows that the spines and the lavas are very similar in petrography. It seems certain therefore that the spines represent the channels through which at least some of the trachybasalts were extruded.

The upper surfaceof the lavas on the summit plateau of Sandfell is obscured by thick layers of modern volcanic ash, presumably originating in the many modern eruptions of Katla, but the plateau is a nearly level surface and remarkably free from evidence of prolonged erosion. The general shape of the mountain - a flat plateau abruptly truncated by steep cliffs at the edges - lacks the rounded and smoothed character which would point to a prolonged period of glacial erosion.

Petrography.

The Sandfell trachybasalts contain phenocrysts of olivine, plagioclase, pyroxene and iron ore in a groundmass of plagioclase, pyroxene, iron ore and glass. The olivine phenocrysts are forsterite rich hortonolites. They are very rare and have been seen only in one specimen (No. 78), and never in thin section. In this rock they occur as a small clump of crystals, each about 1 mm. in diameter. The plagioclase phenocrysts are lime-rich andesines up to 2 mm. in length, slightly zoned and strongly embayed; often showing a spongy structure which encloses groundmass material.

The pyroxene phenocrysts are iron-rich augites, up to 0.5 mm. in size; slightly rounded and tending to yellow green in colour.

The smaller pyroxene and plagioclase phenocrysts occur occasionally in glomeroporphyritic groups.

The porphyritic iron ore is skeletal.

The groundmass consists of a mesh of oligoclase laths and sub-hedral grains of pyroxene and iron ore in a matrix of glassy or cryptocrystalline material. There is some variation in the size of the oligoclase laths. Where these are long the texture is intergranular; where the laths are stumpy the texture tends to become equigranular. The matrix where glassy, is colourless, and where cryptocrystalline, is reddish brown in colour. This variation in the colour of the base is believed to cause the mottling seen in hand specimen.

In the varieties which are black in hand specimen the petrography is similar but here the matrix of the groundmass is formed of opaque black tachylite.

In one of the lavas (No. 79) a xenolith 4 centimetres in diameter was found consisting of a porous or vesicular acidic glass (N 1.501) crowded with stumpy prisms of sodic oligoclase. No potash felspar and no dark mineral is present.

A xenolith, reputedly of basement material, in a lava from the Massive Central of France (Departmental No. 2093) is very similar in appearance. It was found that the French xenolith consisted of a porous acidic glass (N. 1.498 - 1.505) crowded with stumpy prisms of medium oligoclase and containing microlitic needles of pyroxene. No potash felspar could be found in this rock. The similarity between the two xenoliths is suggestive, but the existence of a granite crust beneath Iceland has never been established. It seems certain however that the Sandfell xenolith is derived either from basement material or from the rhyolites of Myrdalsjokull.

The following determinations have been made.

No. 78. Trachybasalt, 410 metres, South face of Sandfell.

Olivine phenocryst Nx 1.725, Ny 1.760, Nz 1.769; comp. Fa_{52}

Pyroxene phenocryst 2V 45,47,50. Ny 1.703; comp. $Wo_{37}En_{34}Fs_{29}$

Plagioclase phenocryst Nx' 1.550 Nz' 1.558; comp. An_{44-48}.

Plagioclase groundmass Nx' 1.535 Nz' 1.551; comp. An_{15-32}

No. 77. Trachybasalt, spine, 400 metre contour, S. face of Sandfell.

Plagioclase phenocryst Nx' 1.549 Nz' 1.559; comp. An_{43-47}

Plagioclase groundmass Nx' 1.536 Nz' 1.550; comp. An_{16-29}.

No. 79. Xenolith in trachybasalt 440 metres S. face of Sandfell.

Glass N 1.501.

Plagioclase phenocryst Nz' 1.541; comp. An_{10}

No. 2093. Xenolith lava, Massif Centrale, France.

Glass N 1.498 - 1.505.

Plagioclase phenocryst Nx' 1.540; comp. An_{22}.

MODERN BASALTIC EXTRUSIVES AND PYROCLASTICS.

The modern volcanic rocks of Skaftartungs have three sources; the volcanoes Eldgja, Laki and Katla.

The volcano Eldgja and its eruptive materials have already been described in detail.

The volcano Laki has been touched upon in earlier chapters in connection with the outcrop of the Eastern flow of the 1783 eruption; and the chemistry of the lava of 1783. The volcano itself and the greater part of its lavas lie outside the area studied and are not discussed.

The volcano Katla lies below the ice of Myrdalsjokull at a height about 1200 metres above sea level and about 5 kilometres west of the southern group of rhyolite nunataks. The precise location of the volcano is not known, but in the course of the present work the general area in which the volcano was known to lie was visited. No volcanic materials were found and the surface features of the ice cap gave no indication of a possible site for the eruptive vent.

This has been the experience of other investigators and it is generally believed that, whatever the nature of the products beneath the ice, the surface products of Katla are basaltic ash and scoria only.

During the present work modern basaltic rocks were discovered on and near Myrdalsjokull in four localities.

In each case circumstantial evidence strongly suggests that they are eruption products of Katla. Two of the occurrences show that surface extrusion of lava has taken place from Katla; the two others are accumulations of pyroclastics and lava which are believed to be representative of the sub-glacial products of Katla eruptions.

A modern basaltic lava was discovered overlying Myrdalsjokull rhyolite on the Eythorsson nunatak, three kilometres north west of the Huldufjoll. The lava is covered by several metres of basaltic ash and is exposed only on the northern side of the nunatak at the extreme eastern end, where it forms the upper lip of a vertical cliff of rhyolite more than a hundred metres in height. The flow is about two metres in thickness and is formed of dense basalt with reddened, rubbly upper and lower surfaces of the type normally found on extrusive basalt flows. The upper surface is quite free of striation.

The outer parts of the flow have been shattered by frost action and are in a highly unstable condition. For this reason it was not possible to examine the flow in detail or to examine the few metres of basaltic ash which underlie it.

A specimen was collected from the frost shattered part of the flow and it was discovered that a few slightly vesicular drops of basalt glass were adhering to the surface. It is presumed that these had been blown into crevices in the lava, in a liquid condition, during the eruption of Katla in 1918.

This lava flow has all the characteristics of a normal extrusive lava flow and there can be no doubt that it has originated in this way. But it is a little difficult at first sight to see how a lava flow came to be emplaced on a small outcrop of rhyolite 1000 metres high on the ice cap. Even though the volcano Katla lies only six kilometres to the west the intervening surface materials are entirely ice and snow.

After the eruption of Hekla in 1947 it was noticed that during the eruption a thin flow of lava had covered a pocket of snow in a gulley. The lava had solidified but the snow beneath, which had been covered by a superficial layer of ash, had remained unmelted. This observation at once offers a possible explanation of the emplacement of modern lava on the Myrdallsjokull nunatak.

It is a matter of observation that the whole surface of the ice cap is blackened by ash during the eruptions of Katla. It seems entirely possible that the volcano could have established a temporary crater through the ice from which lava was extruded; that the extruded lava could have flowed over the surface of the ice cap, while the ice and snow beneath protected by a layer of ash which at this short distance from the volcano may have been of considerable thickness, remained unmelted.

It must have been purely by chance that a small part of the surface covered by the flow was solid rock. This chance has however preserved a small portion of the flow while the remainder has probably been destroyed by the movement of the underlying ice and buried by later accumulation of ice and snow.

The lower surface of this flow is now about 20 metres above the ice surface. There is no reliable means of estimating at what date the surface of the ice was twenty metres higher on this part of the ice cap but it seems probable that it can not have been less than several hundred years ago. This lava, then, was extruded from a modern eruption of Katla but not one of the most recent ones.

Two kilometres south of Sandfell on the northern margin of the Kotlujokull glacier modern basaltic lavas are found overlying intrusive flows and breccias of the Upper Group of the Palagonite Formation. There appear to be four flows present, two metres in average thickness and with deposits of alluvial basaltic ash and moraine with rhyolite boulders of considerable thickness intervening between them. Near the glacier they are in part covered by thick layers of recent moraine. The whole series is now much dissected by the melt water streams and rivers which issue from this part of the ice cap. The lavas are dense in the central parts and have highly vesicular upper and lower layers. The upper surface occasionally shows good pahoehoe structure which is without striation.

The lavas dip eastward, away from Myrdalsjokull, at about 100 metres per kilometre. There is no evidence of faulting in the series and it must be supposed that the dip is original. These lavas, then have flowed eastward from Myrdalsjokull. It is tentatively suggested that they may represent extrusions of lava from Katla similar to that already described, and may have flowed from Katla over the surface of the ice cap to their present positions. The possibility exists, then, that the lavas of Myrdalssandur may originate in part from Katla. It has been seen in an earlier chapter that the lavas of Katla and Eldgja are very similar in chemistry and petrography. In view of this similarity and the general poor exposure on the sandur it seems unlikely that the question of the origin of the lavas can be resolved. Because the exposed Katla lavas at Sandfell are rather thin and therefore unlikely to be the feeders of the thick and extensive flows of the sandur, it has been assumed provisionally that the sandur flows originated from Eldgja.

The floor of the broad valley immediately east of Olafshause is covered by Eldgja lava. At its northern end this valley is blocked by an unnamed glacier tongue of Myrdalsjokull.

South of the glacier tongue for a distance of about 2 kilometres the surface of the Eldgja lava has been striated by a recent advance of the glacier. In retreating to its present position the glacier has left behind, overlying the striated Eldgja lavas, a deposit of moraine and basalt globe breccia, about one square kilometre in area and about 5 metres in thickness.

In structure the deposit consists of a lower layer of moraine less than one metre in thickness which contains glacially striated boulders and which overlies the striated Eldgja basalt. Above the moraine lies a breccia about 4 metres in thickness which is formed of angular fragments of black vesicular and non vesicular sideromelane, tachylite, and aphanitic basalt all less than 3 centimetres in diameter. Within the breccia occur detached globular masses of basalt between ten and twenty centimetres in diameter. The globes possess an outer skin of sideromelane about 5 millimetres in thickness in which breccia fragments are embedded. The globes, some of which are broken, but the majority of which are entire, are penetrated by a close network of joints and will disintegrate if an attempt is made to detach them from the matrix. The breccia matrix is poorly consolidated and is being rapidly eroded by melt-water streams from the glacier. Microscopic examination shows that the breccia fragments are fresh and lack palagonite.

PLATE 39.

Modern volcanics; showing structures developed under sub-glacial conditions. An outer basalt globe breccia(1) is invaded by an inner basalt breccia(2) Both breccias are traversed by an irregular basalt dyke having a brecciated surface(3) The rocks have been deposited recently by the Kotlujokull glacier. The rocks are thought to originate from Katla.

The upper surface of the breccia is overlain by a few centimetres of loose morainic material containing striated boulders of basalt.

A similar modern basalt globe breccia but with a more complicated structure occurs within a few metres of the southernmost tip of the Kotlu-jokull glacier, about three kilometres north west of Hafursey, and one kilometre east of the mountain Sker. The Kotlujokull breccia has an area of about one thousand square metres and has a maximum thickness of about ten metres. The exposures reveal several masses of moraine, breccia and basalt with complex interrelationships which were not fully investigated. The rocks are transected by two deep gullies, the most western of which displays important details of the internal structure of the breccia, while in the eastern gully the top and bottom relationships of the same mass of breccia are exposed.

A photograph of the western gully is seen in Plate 39. It shows an outer mass of basalt globe breccia which has been intruded by a breccia without globes. An irregular dyke-like mass of basalt intrudes both the inner breccia and part of the outer basalt globe breccia. Close examination of the surfaces of the basalt dyke shows it to be formed of shattered but coherent fragments of sideromelane exactly resembling those of the inner breccia. It is clear that this breccia is the result of autobrecciation of the dyke-like mass as it intruded the globe breccia from below.

The basalt globe breccia has a semi-consolidated matrix of angular fragments of non vesicular sideromelane, tachylite and aphanitic basalt usually less than 5 centimetres in size. Within this breccia detached globes of basalt occur which are between twenty and thirty centimetres in size. The globes have the usual coating of sideromelane in which fragments of the breccia are embedded.

The inner breccia is formed of non vesicular fragments of sideromelane and tachylite less than two centimetres in diameter.

The dyke is formed of aphanitic basalt with an outer shattered coating of sideromelane. A few rounded vesicles occur and also irregular internal cavities bounded by aphanitic basalt. The dyke is cut by irregular joints usually more or less normal to the surfaces at the outer parts of the dyke but irregular and blocky in the inner parts.

In this gully neither the upper nor the lower contacts of the breccias are exposed.

In the eastern gully the lowest rock exposed is a loose moraine containing striated boulders of basalt and palagonite tuff. This is overlain by a soft laminated silt which is orange or yellow in colour and apparently contains fragments of vegetable material. A few yards further east similar materials are found overlying the striated surface of Palagonite Formation rocks and it seems likely that these rocks underlie the materials just described. In places the silts are nearly horizontal but in others they are contorted, and irregular fragments have been detached and caught up in the overlying material, which is a loose black glassy ash containing occasional striated boulders. The basalt globe breccias described from the western gully overlie this bouldery ash. Also overlying it is another morainic material containing striated basalt boulders and rhyolite fragments. The contact between the rhyolite bearing moraine and the basalt globe breccia is complex, and intimate. The breccias are cut by linear joints along which some slight differential movement of the two sides has taken place. The breccia and rhyolite bearing moraine are both overlain by a layer of black glassy ash with occasional striated boulders resembling that which underlies them. Caught up in this upper bouldery ash are "floating" angular blocks of the breccia. Microscopic examination shows the sideromelane breccias to be free from palagonite.

The two modern basalt globe breccias have been described in detail because in both cases there is some evidence of the age of the deposits. The one overlies modern lava and the other occurs together with fragments of rhyolite. Both occupy areas which have been covered by ice within the last few hundred years and modern glacial moraine occurs at the upper and lower surfaces of both breccias.

In each case it is possible to state with some confidence that no bodies of lacrustrine or marine water have been present in modern times.

It appears to be unquestionable that the water which caused the drastic chilling of basalt magma to form sideromelane was, in both cases, glacial in origin.

In neither case does the evidence suggest that the breccias were formed in situ. Neither locality shows evidence of modern eruptive volcanic activity in situ and the associated moraines show no sign of alteration by heat from the breccias. The large fractured angular blocks of breccia of the Kotlujokull occurrence and the uniform horizontal sheet-like form of the Olafshause rocks can hardly be the result of volcanic eruption in situ. It is probable therefore that the rocks originated at some eruptive centre in the inner parts of Myrdalsjokull and were transported to their present position at the fringes of the ice cap by the outward migration of the ice.

If this migration has taken place then the time of eruption of the materials and the time of their final deposition may have been widely separated. Microscopic examination shows the absence of palagonite and of zeolites and calcite in the breccias, and suggests a modern age for them. It is suggested therefore that they represent the materials erupted sub-glacially by Katla, that fragments of a loose mass of such deposits at the site of the volcano have become detached by the pressure of moving ice and have been transported, frozen within the ice, to their present situation.

Petrography.

No detailed petrographical work has been undertaken on the Katla rocks. One of them, the nunatak lava, which seemed most clearly to be a product of the volcano, has been analysed. The analysis has been quoted in Table VI, and commented upon in earlier chapters. It is indistinguishable in chemistry from the Eldgja lavas. In petrography also this rock is very similar to some of the more quickly cooled Eldgja rocks. Microphenocrysts of basic labradorite and of pyroxene about 0.01 mm in size occur in an aphanitic groundmass of intergranular texture formed of medium labradorite, olivine, pyroxene and iron ore. The Sandfell basalts are similar in texture and in mineralology.

In the case of the Katla globe breccias, the refractive index of the sideromelane has been determined and is compared below with those of normal sub-aerial glassy ashes which are believed to originate from Katla. These breccia fragments contain small phenocrysts of labradorite, olivine, pyroxene and iron ore in a base of sideromelane or tachylite.

Katla ash (?) Sandfell, overlying trachybasalts.

Sideromelane N 1.612.

Katla ash (?) Overlying Katla lava on Eythorsson nunatak.

Sideromelane N 1.609.

Katla ash, adhering to Katla lava on Eythorsson nunatak.

Sideromelane N 1.625.

No. 190. Globe breccia, overlying Eldgja lava near Olafshause.

Sideromelane N. 1.635.

No. 22. Dyke intruding inner breccia, southern margin of Kotlujokull.

Sideromelane N 1.626.

No. 23. Breccia without globes surrounding No. 22.

Sideromelane N 1.621.

THE ORIGIN AND THE AGE OF THE SKAFTARTUNGA ROCKS.

Much controversy has arisen over questions of the age and the origin of Icelandic rocks. They have centred principally around the mode of formation of the sideromelane in tuffs and breccias and on the nature of rocks variously described as fluviatile conglomerates and tillites. The two problems occur simultaneously in the case of Palagonite Formation rocks.

The Palagonite Formation. It is a widely held belief among geologists that sideromelane is produced only when basaltic magma is drastically chilled by water. It appears however that this belief is not quite true. The following passages from Stearns and Macdonald (1946) are informative. (P.199.) "Thin beds of ash are intercalated with the lavas of all the volcanoes .... All of the ash beds were originally composed principally of the glassy ejecta formed by lava fountains, but in most places both the ahs and lapilli are now entirely altered to yellowish brown or orange palagonite."

(P.200). "The littoral cones formed by steam explosion where lava flows entered the sea, are superficially quite similar in composition to many of the cinder cones. They consist largely of vitric ash, of sand and silt grades, enclosing irregular lapilli and bombs up to 2 feet across.

Many bombs show ribbon and spindle shapes. The matrix differs, however, from that typical of cinder cones built by lava fountains at vents. The latter is highly inflated, many of the lapilli are pumice and the small ash fragments show typical arcuate shard outlines resulting from fragmentation of pumiceous material. In contrast, the small fragments of the littoral cones are dense or only moderately vesicular. The shards are angular and the arcuate forms are absent or comparatively rare. The difference results from the fact that the gases accompanying lava fountains at vents are of internal origin, the lava undergoing active inflation during the explosion, whereas the steam which atomized the liquid lava in the littoral explosions is of external origin."

In an earlier chapter Stearms and Macdonald describe stratigraphic sections through the Hawaiian volcanoes. In these the proportion of ash to lava varies from about 1 part in ten to about 1 part in one hundred.

In Hawaii, then vesicular-sideromelane tuffs and breccias are normal sub-aerial products of volcanism, while non-vesicular-sideromelane tuffs and breccias are the result of drastic chilling, by water, of magma poor in gas.

In Iceland then, the presence of sideromelane itself does not indicate chilling by water. It is the form assumed by the sideromelane which provides the c riterion. The

Hawaiian evidence suggests that where breccias of angular sideromelane fragments without vesicles occur and where sideromelane forms a non-vesicular selvidge to basalt, water has been present to effect the chilling, but where breccias of vesicular sideromelane occur, either water or air may have been the chilling medium.

The Skaftartunga rocks have been described in earlier chapters. They have been divided into three groups. In two of these groups (the Upper and the Lower) breccias of non-vesicular sideromelane are common. In three localities, within the rocks of the Lower Group, tillites containing striated boulders, such as that shown in Plate 38, have been found. It is suggested that in both these groups water has been the chilling agent in the formation of the sideromelane and that this water has been glacial in origin.

In both groups the forms assumed by the basalt and sideromelane masses are very similar to those shown by the rocks which are thought to be sub-glacial products of Katla, and which certainly were deposited and probably were formed, in modern times and under glacial conditions.

The rocks of the Middle Group differ significantly from those of the other two. Here the rocks are principally tuffs formed of vesicular sideromelane, for which either water or air may have been the chilling agent. These tuffs show aeolian bedding and possess intercalations of lacustrine and fluviatile tuffs. In Skaftartunga the aeolian tuffs may reach 300 metres in thickness. Horizontal and regular layers of basalt occur within them, which have the characteristics of normal sub-aerial lava flows.

For these rocks the structures shown strongly suggest deposition sub-aerially, or, in other words, under interglacial conditions.

The problem presented by the preponderance of pyroclastics over extrusives in the Palagonite Formation generally, has not yet been dealt with.

In the case of the rocks of the Upper and Lower Groups the preponderance can be explained by the shattering of the solid products, as magma comes into contact with water. This is an effect described by Stearns and Macdonald (1946. P.19) "for lava erupting under water or water-saturated rocks".

In the case of the rocks of the Middle Group, which are believed to have accumulated sub-aerially, this explanation clearly does not apply unless the constituent materials are derived in large part from the Lower Group and have been transported and redeposited by wind action. This is the explanation offered.

<u>The Dolerite Formation.</u> These rocks are poorly exposed in Skaftartunga and indeed the correlation of the Skaftartunga

"Dolerite Formation" rocks with those of Geirlandshraun is precarious. However, Thoroddsen (1906) discusses the geological relationships of the Dolerite Formation rocks in the region east of Skaftartunga. He says (P. 311) "I have found aeolian tuffs in other places under the dolerite lavas, namely in Skaftarfellssysla, and, as already mentioned, enormous masses of tuff and breccia rest on the dolerites southward from Hlothufell and also at Oraefajokull and at Laganes".

It appears, then, that at least in Skaftarfellssysla the Dolerite Formation lavas overlie aeolian tuffs and are in turn overlain by other tuffs and breccias of the Palagonite Formation.

It is tentatively suggested that these Dolerite lavas may have been erupted when the aeolian tuffs of the Middle Group of the Palagonite Formation were being deposited, and thus represent an interglacial extrusion of lava.

The Myrdalsjokull Rhyolites. The cliffs of the Huldufell expose the Myrdalsjokull rhyolites lying unconformably on rocks of the Upper Group of the Palagonite Formation. They are therefore younger than these rocks: but the question arises Were the rhyolites extruded under glacial conditions? Field evidence bearing on this question is meagre. Breccias are uncommon among the rhyolitic rocks and have been found only in one locality of small extent between the rhyolitic flows and the Palagonite Formation rocks. It seems unlikely however that the rhyolitic tuffs could have been deposited on Sker at a distance more than five kilometres from the main mass of rhyolite, under conditions of general glaciation. Particularly so, as the tuff exhibits in part the characteristics of a welded tuff. It is probable then that the extrusions were sub-aerial. Since the time of their extrusion the Myrdalsjokull rhyolites have been heavily eroded by glacial action and what was probably a single massive flow or series of flows has now been deeply dissected and broken up into the present scattered nunataks.

Rhyolite flows similar in chemistry (see Table XXV1) and in structure are described by Noe Nygaard (1952) from Vatnajokull and by Van Bemmelen and Rutten (1955 p.75) from northern Iceland. The former has concluded that the Vatnajokull rhyolites are late Quaternary in age and interglacial in origin and the latter that the Hrafntinnuhryggur and related rhyolites are probably sub-glacial in origin and, by implication, late Quaternary in age.

The Sandfell Trachybasalts. In the field the Sandfell trachybasalts overlie rocks of the Middle Group of the Palagonite Formation, but other clear evidence of their age is lacking.

In part the features shown by the lavas are contradictory.

The absence of mineral infillings in the vesicles; the well preserved ropy surfaces within the succession, and the close conformity between the slope of the plateau surface and the dip of the lavas, all argue a relatively youthful age for the series.

On the other hand the restriction of the lavas to Sandfell and the abrupt truncation of the flows at the edges of the mountain appear to indicate a period of prolonged erosion since the lavas were extruded.

The xenolith of acidic glass within one of these lavas, which has a refractive index close to that of the Myrdalsjokull rhyolites, may be derived from them and indicate a post-rhyolite age for the trachybasalts; and this seems more probable than that the fragment should be derived from a hypothetical deep-seated granite rock.

The simple tabular form of the mountain suggests that it has not suffered erosion from glacial action for a period as prolonged as that of the Myrdalsjokull rhyolites.

For these reasons it is suggested that the trachybasalts are younger than the rhyolites.

The problem of the restricted distribution of the trachybasalts remains unanswered, but it appears possible that if their extrusion took place during the early or late stages of an interglacial period the extension of flows laterally might have been prevented by the presence of ice.

Modern Basaltic Extrusives and Pyroclastics. Little can usefully be added to the earlier discussion of the Katla and Eldgja rocks. It is perhaps significant that more than 20 sub-glacial eruptions of Katla are known to have occurred since the year 900. It would be surprising if some of the materials formed sub-glacially had not found their way to the margin of the ice cap.

In the present context, it is perhaps also significant that at the margins of the ice cap the Eldgja lavas pass, without interruption or change in structure, beneath the ice; and at the north eastern margin of the ice cap part of an Eldgja crater now almost entirely buried beneath ice can be seen. Two parallel ridges of ice, which apparently reflect the form of the crater beneath, can be traced inwards from the margin of the ice cap for a distance of two kilometres. These features suggest a relatively recent and perhaps considerable advance of the ice cap.

Summary. The mode of formation of the Skaftartunga rocks has been discussed and it has been suggested, on the basis of their composition, structure and distribution that they have accumulated during a series of glacial and inter-glacial periods. During the first two glacial periods and the intervening interglacial basaltic rocks were erupted and deposited; during a subsequent interglacial, rhyolitic and possibly trachybasaltic lavas were erupted; finally during the present semi-glacial period basaltic rocks have been erupted both sub-glacially and sub-aerially. The total cumulative thickness of the eruptives is more than 1400 metres. Evidence of the age of the rocks is lacking except for the presence of tillites in some of them. It is provisionally assumed that all the Skaftartunga rocks are of Quaternary age.

TABLE XXIII

Refractive Index Determinations on Palagonite Formation Sideromelanes

Upper Group

Sker.		Sandfell.
300 m.	1.636	1.633

Middle Group.

Hafursey.		Sandfell.		Oldufell.		Einhriningar.	
580 m.	1.610	300 m.	1.578	800 m.	1.617	650 m.	1.610
450 m.	1.579	250 m.	1.630	760 m.	1.619	600 m.	1.612
440 m.	1.580			720 m.	1.620	550 m.	1.611
420 m.	1.616			680 m.	1.621	500 m.	1.612
400 m.	1.608			640 m.	1.620	450 m.	1.616
				560 m.	1.618	400 m.	1.613
						350 m.	1.615

Lower Group.

Hafursey.	
270 m.	1.609
160 m.	1.609

TABLE XXIV

Olivine and Pyroxene determinations. Tuffs and flows of the Palagonite Formation.

Upper Group.

Sker.

Flow 500 m. Sker. $Wo_{35}En_{37}Fs_{28}$

Sandfell.

Flow 250 m. $Wo_{42}En_{46}Fs_{12}$

Middle Group.

Hafursey.

Tuff 580 m. $Wo_{43}En_{38}Fs_{19}$

Sandfell.

Tuff 300 m. $Wo_{42}En_{38}Fs_{20}$

Flow 300 m. $Wo_{40}En_{41}Fs_{19}$

Tuff 250 m. $Wo_{40}En_{39}Fs_{21}$

Einhyrningar.

Tuff 650 m. $Wo_{42}En_{38}Fs_{20}$

Tuff 650 m. Fa_{20}

Tuff 350 m. $Wo_{45}En_{34}Fs_{21}$

Tuff 350 m. Fa_{23}

Lower Group.

Hafursey.

Tuff 270 m. $Wo_{44}En_{38}Fs_{18}$

TABLE XXV

Dolerite Formation Basalts.

	Geirlandshraun	Hvammshraunfell	Myrnahofthi
Olivine	-----	Fa_{26}	Fa_{25}
Plagioclase (phenocrysts)	An_{60-69}	------	An_{74}
Plagioclase (groundmass)	An_{47-57}	An_{53-70}	An_{54}
Pyroxene	Augite	$Wo_{39}En_{40}Fs_{21}$	Augite
		Pidgeonite	$Wo_{7}En_{50}Fs_{43}$

TABLE XXVI

Chemical Analyses of Icelandic Rhyolites.

	1.	2.	3.	4.	5.	6.	7.
SiO_2	70.22	75.06	74.88	74.92	74.99	73.63	75.01
TiO_2	0.41	0.12	0.14	0.17	0.02	0.24	0.33
Al_2O_3	13.78	13.84	12.96	13.49	11.77	12.75	12.27
Fe_2O_3	1.76	0.31	0.77	0.74	2.16	1.33	0.80
FeO	3.08	1.91	1.05	1.66	2.00	1.80	2.78
MnO	0.13	-	tr	tr	0.07	0.06	0.06
MgO	0.16	0.28	0.14	0.25	nil	nil	0.08
CaO	1.39	1.62	1.03	1.16	1.38	1.12	1.87
Na_2O	5.42	3.16	4.62	4.03	5.17	4.96	3.36
K_2O	3.43	3.22	3.54	3.14	2.59	3.15	2.80
P_2O_5	0.11	tr	nil	nil	tr	0.26	0.02
H_2O +	0.04	0.17	0.55	0.22	nil	0.49	0.25
H_2O -	0.02	0.06	0.34	0.11	nil	0.22	0.13
	99.95	99.82	100.13	99.96	100.15	100.01	99.98

1. Huldufjoll, Myrdalsjokull Rhyolite, (new analysis)
2. Palsfjoll, Vatnajokull Rhyolite, (Noe Nygaard 1952)
3. " " " (" " ")
4. East Geirvortur " " (" " ")
5. West Geirvortur " " (" " ")
6. Mith-Bergvatnsa " " (" " ")
7. Hraftntinnuhryggur. North Iceland (Wright 1915).

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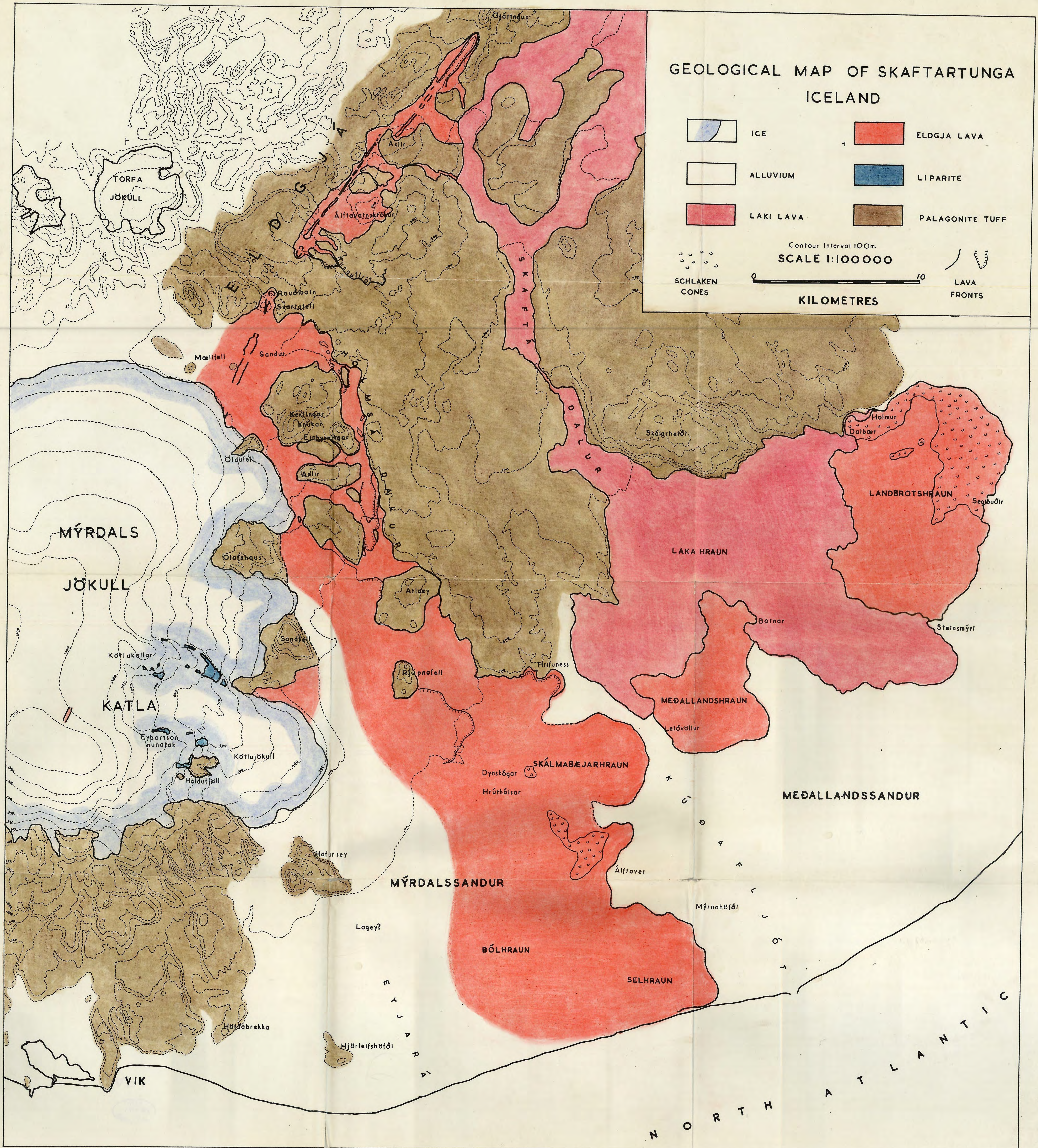
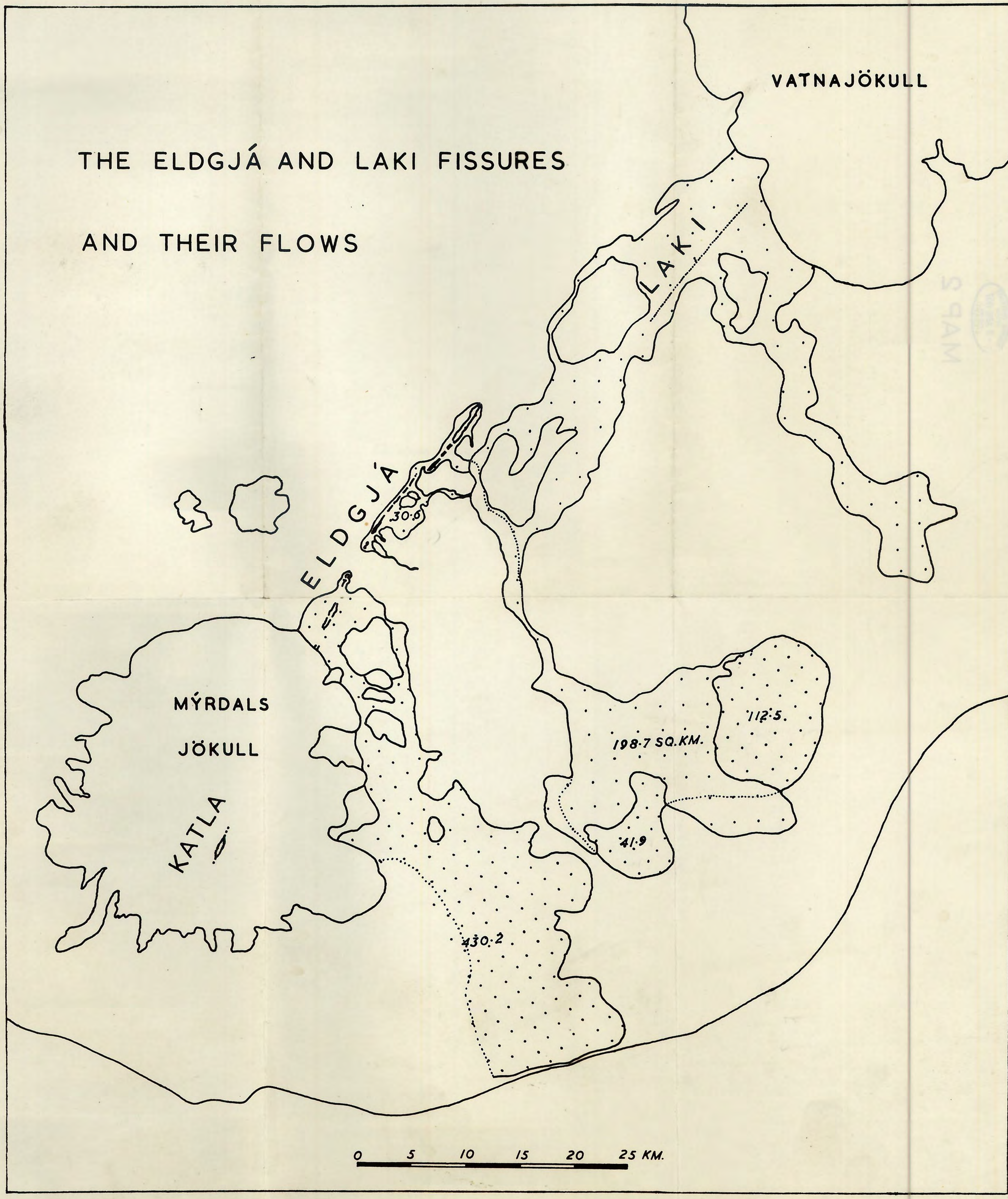

GEOLOGICAL MAP OF SKAFTARTUNGA
ICELAND
ICE
ELDGJA LAVA
ALLUVIUM
LIPARITE
LAKI LAVA
PALAGONITE TUFF
Contour Interval 100m.
SCALE 1:100000
SCHLAKEN CONES
LAVA FRONTS
KILOMETRES
TORFA JÖKULL
ELDGJÁ
SKAFTÁ
SKAFTÁ DALUR
HÓLMSÁ
DALUR
MÝRDALS JÖKULL
KATLA
Kötlukallar
Kötlujökull
Höfuðbrekka
Hafursey
Hjörleifshöfði
MÝRDALSSANDUR
EYJARÁ
VIK
NORTH ATLANTIC
LAKA HRAUN
LANDBROTSHRAUN
MEÐALLANDSHRAUN
MEÐALLANDSSANDUR
SKÁLMABÆJARHRAUN
BÓLHRAUN
SELHRAUN
KÚÐAFLJÓT
Álftaver
Mýrnahöfði
Leiðvöllur
Botnar
Steinsmýri
Holmur
Dalbær
Skálarheiði
Atley
Hrífuness
Mælifell
Sandur
Kerlingar hnúkar
Einhyrningar
Álftavatnskrókur
Svartafell
Rauðibotn
Öldufell
Ólafshaus
Sandfell
Rjúpnafell
Dynskógar
Hrútholsar
Lagey?
Eyborsson nunatak
Höldujökull
Gjátindur
Axlir


GEOLOGICAL MAP OF SKAFTARTUNGA
ICELAND
PALAGONITE FORMATION
AEOLIAN TUFF
EXTRUSIVE LAVA FLOWS
LACUSTRINE & FLUVIATILE TUFF
INTRUSIVE LAVA FLOWS
BASALT GLOBE BRECCIA
TILLITE
ELDGJA LAVAS
KATLA LAVAS
KATLA SUBGLACIALS
RHYOLITE
TRACHY BASALT
CORRELATION DIAG. 16
Contour Interval 100m.
SCALE 1:100000
0
10
KILOMETRES
SCHLAKEN CONES
LAVA FRONTS
Gjátindur
TORFA JÖKULL
ELDGJÁ
Axlir
Álftavatnskrókur
Rauðibotn
Svartafell
Mælifell
Sandur
SKAFTÁRDALUR
HÓLMSÁ
Kerlingar hnúkar
Einhyrningar
Hvammshraunfell
Öldufell
MÝRDALS JÖKULL
Ólafshaus
Atley
Sandfell
Kötlukollar
KATLA
Kötlujökull
Hrífuness
Skálarheiði
Holmur
Dalbær
LANDBROTSHRAUN
Seglbúðir
LAKA HRAUN
Botnar
Steinsmýri
MEÐALLANDSHRAUN
Leiðvöllur
SKÁLMABÆJARHRAUN
Dynskógar
Hrútháls
MEÐALLANDSSANDUR
KÚÐAFLJÓT
Hafursey
Álftaver
Mýrnahöfði
MÝRDALSSANDUR
Lagey?
BÓLHRAUN
SELHRAUN
EYJARÁ
Höfðabrekka
Hjörleifshöfði
VIK
NORTH ATLANTIC


THE ELDGJÁ AND LAKI FISSURES
AND THEIR FLOWS
VATNAJÖKULL
LAKI
ELDGJÁ
30·6
MÝRDALS
JÖKULL
KATLA
198·7 SQ.KM.
112·5.
41·9
430·2
0 5 10 15 20 25 KM.

OLDER LAVAS

YOUNGER LAVAS

CRATERS

GEOLOGICAL MAP OF THE VOLCANO ELDGJÁ

CONTOUR INTERVAL 50 M.