GEOLOGY OF THE REYDARFJÖRDUR AREA, EASTERN ICELAND

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Quarterly Journal of the Geological Society 1958; v. 114; p. 367-391
doi:10.1144/gsjgs.114.1.0367

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Read 27 November 1957

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SUMMARY

A succession of nearly 15,000 feet of volcanic rocks, mostly plateau-basalt lavas, is described from the Reydarfjördur area. This area is in the middle of the large Tertiary outcrop of eastern Iceland, and the rocks described constitute the lower parts of the exposed succession there. They dip uniformly west-south-west at 4–7 degrees.

Tholeiites, olivine-basalts, and porphyritic basalts rich in phenocrysts of basic plagioclase make up the bulk of the lava pile, and there is little sign of any systematic distribution of these types. Lavas of a particular type tend to form groups of flows, and these can be readily mapped in the field and clearly have a wide horizontal extension.

Two long periods of acid volcanism are distinguished, both having given rise to a considerable bulk of acid and intermediate lavas and pyroclastic rocks. Two more acid volcanic episodes are represented in the mapped ground by acid tuffs, and a fifth is represented by the copious outpourings of acid and intermediate lavas and pyroclasts of the Thingmuli central volcano which was later built on the platform of plateau lavas described in this paper.

The bulk of the lavas are regarded as the product of fissure eruption, and two examples have been found of a lava connected to its dyke feeder. The dyke swarm in the area is estimated to contain over 500 dykes, mostly basic, with a general northerly trend.

I. INTRODUCTION AND HISTORICAL SURVEY

ICELAND, the largest remnant of the Brito-Arctic basaltic province, is built almost entirely of volcanic rocks. These range in age from the Tertiary to the present day, and well over 100 eruptions have been recorded since the island was colonized rather more than 1000 years ago. Viewed broadly, the structure of the island is simple. Volcanic rocks of Quaternary and Recent age occupy a broad belt curving across the country from the north-east to the south and south-west coasts, and these newer volcanic rocks rest upon an immensely thick Tertiary volcanic succession which outcrops in two large areas, one to the east and the

other to the west and north-west of the newer belt. These Tertiary rocks generally have a dip of a few degrees towards the newer volcanic belt, and the structure is thus broadly synclinal. The present work is a study of the lower parts of the exposed succession in the Reydarfjördur[1] area, in the middle of the Tertiary outcrop in eastern Iceland.

Reydarfjördur is a deep indentation of the sea midway along the east coast. When the writer first visited it in 1954 he was impressed by the immense thickness of Tertiary lavas exposed there and dipping steadily westwards for a distance of many miles. Previous estimates had placed the thickness of Tertiary volcanic rocks in Iceland as around 10,000 feet[2], but the present work has established that the thickness is not less than twice this figure, and probably nearer 25,000 feet.

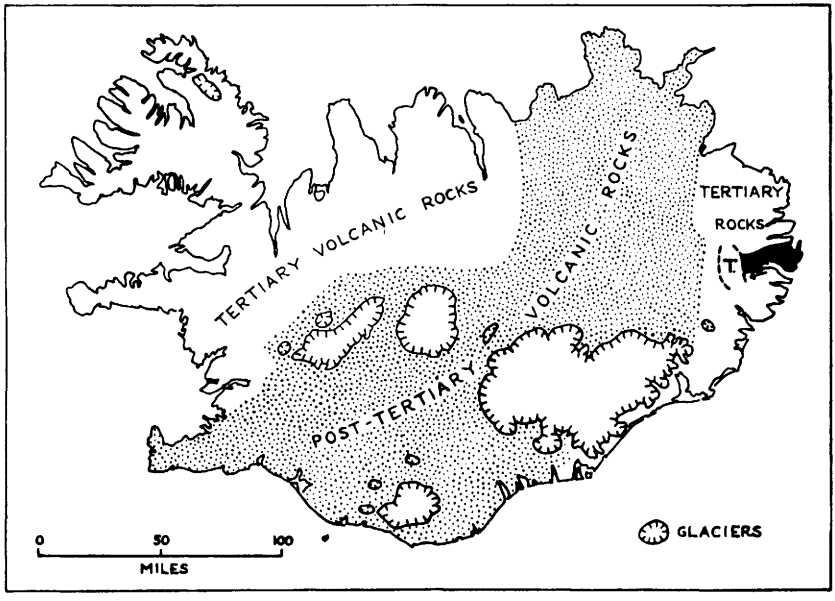

FIG. 1.— Outline geological map of Iceland to show the location of the Reydarfjördur area (solid black) and the Thingmuli central volcano (T) in relation to the Tertiary volcanic region of eastern Iceland.

The lava series is well stratified and preliminary work in 1954 suggested that mappable stratigraphic horizons were not lacking. This was fully borne out by field work in the summers of 1955 and 1956, when a strip of country 30 miles long running along the north of Reydarfjördur was mapped and it was found possible to establish a stratigraphical sequence for the lower 15,000 feet of plateau lavas exposed there. The lava series can be mapped like a bedded sedimentary series.

The area described in this paper covers half of the distance between the eastern extremity of Iceland and the western limit of Tertiary rocks in this part of the island (Fig. 1). Resting upon the plateau lavas

[1] Place-names are taken unmodified from the 1 : 100,000 topographic maps of Iceland, Sheets 114 (Gerpir) and 104 (Fljótsdalshérad).

[2] Finarsson (1954) estimates on the basis of gravity anomalies the total thickness as something near 5000 metres.

described here and exposed west of Reydarfjördur is the great accumulation of lavas and pyroclastic rocks of a major Tertiary central volcano, which the writer has named the Thingmuli volcano.

The area is readily accessible by boat or by road from the west and although rather sparsely populated there are several small towns, of which Neskaupstadur, with a population of 1300, is the largest. The country is mountainous, with summits reaching 4000 feet, and is deeply dissected by glaciated U-valleys, one of which is occupied by Reydarfjördur. Exposures are generally good. The main valley glaciers have carried most of their detritus out to sea, but the numerous corrie glaciers, of which there are still a few on the higher ground, have left much morainic debris, and there are broad aprons of scree below the steeper slopes.

The Tertiary volcanic region of eastern Iceland was mapped in outline towards the close of the last century by Thoroddssen (1906) and he established the main features of the geology of the area. On his geological map (1901) he indicated liparite on either side of the Bardsnes peninsula, on the shore between Eskifjördur and Sellátur, and in a large area west of Fagridalur (Thingmuli volcano), with basalt in the remainder of the area.

Since the time of Thoroddssen, acid tuffs and lavas have been described from a number of points along the east coast of Iceland by Hawkes (1916 A and B, 1924), Dearnley (1954), and Tryggvason & White (1955), and basalt lavas collected from Reydarfjördur were described by Holmes (1918). Intrusions described from the vicinity of Reydarfjördur include the Sandfell laccolith (Hawkes & Hawkes 1933), an acid dyke (Hawkes & Harwood 1932), and a composite dyke (Guppy & Hawkes 1925), and the larger intrusions farther afield in south-eastern Iceland have been studied by Cargill, Hawkes & Ledeboer (1928), Anderson (1949) and Tyrrell (1949).

II. Lava Types

The rocks in the Reydarfjördur area are predominantly basaltic lavas, but andesites and rhyolites[1] are also well represented. Sedimentary and pyroclastic rocks constitute less than 10 per cent of the total thickness. The lavas were erupted subaerially; many thin sedimentary partings between successive flows are wind-blown dust (Hawkes 1916B), a number of dust or tuff beds contain the remains of terrestrial plants, and there are no pillow-lavas or marine sediments.

The following estimate of the relative proportions of the different rock types is based on the field mapping, the microscopic examination of the specimens collected, and chemical analyses.

		Feet	*Percentage*
Basalt lavas	tholeiite	7,000	48
	olivine-basalt	3,400	23
	porphyritic basalt	1,800	12
Andesite lavas		400	3
Acid lavas		1,100	8
Detrital beds (sedimentary and pyroclastic)		900	6
Total thickness		14,600 feet (4,450 metres)	

[1] The term "rhyolite" is applied in this paper to all the acid lavas; many of them are, in fact, dacite.

Of the basalt lavas, the most abundant are tholeiites—fine-grained silica-saturated basalts normally free from olivine.

Olivine-bearing basalts are less common. Although some are rich in olivine, true picrite-basalts are rare. Mapping of the lavas requires the ready field recognition of these rock types, and, as may be seen from the following summary of their main differences, typical tholeiite is a very different rock in the field from typical olivine-basalt.

THOLEIITE	OLIVINE-BASALT
Very fine-grained.	Much coarser in grain.
Weathered crust grey to pale brown. Spheroidal weathering uncommon.	Weathered crust brown to black. Spheroidal weathering common.
Amygdales empty or bearing celadonite, chalcedony, quartz and chlorophaeite, usually without zeolites.	Amygdales bear zeolites.
	Olivine is visible in the hand-specimen in some of the olivine-basalts.
Pipe-amygdales and basalt-pegmatites rare.	Pipe-amygdales and basalt-pegmatites common.
Well-developed flow structure within the body of the rock.	Flow structure confined to a streaking-out of amygdales.

Transitional types are not always reliably distinguished in the field, and require microscopic study.

A third basalt type is characterized by phenocrysts of bytownite-anorthite up to 2 cm. in diameter that may make up to 50 per cent of the rock. The plagioclase is usually accompanied by less abundant phenocrysts of augite and sometimes olivine. The basalts with more than about 10 per cent of porphyritic feldspar are referred to in this paper as porphyritic basalts, and they are very distinctive in the field.

The acid lavas are usually pale grey and have a well-developed flow structure, splitting parallel to it into thin plates. Many of the acid flows have black or green pitchstone developed at top or bottom, often spherulitic. There is almost always a few per cent of small phenocrysts of plagioclase feldspar ranging in composition from albite to andesine, accompanied by sparse phenocrysts of an iron-rich clinopyroxene (ferro-augite), an opaque iron mineral, rare hypersthene, and pseudomorphs probably after fayalite. Fresh fayalite is rare. Phenocrysts of quartz or potash feldspar have not been observed.

The andesite lavas are transitional in character between rhyolite and tholeiite. They are dark rocks with a flinty feel under the hammer, and are less fissile than the acid lavas, usually free from phenocrysts, and finer in grain than the tholeiites. In the field one would unhesitatingly group all but the porphyritic basalts into a single series with transitional characters, from olivine-basalt through tholeiite and andesite to rhyolite.

III. Structural Characters of the Lavas

Thickness of flows.—The average thickness of 550 measured lava flows is just over 30 feet. There is a certain correlation between the thickness of a flow and the rock type, as is shown by the following figures :—

Olivine-basalts	170	flows, average	23	feet.
Porphyritic basalts	87	,, ,,	31	,,
Tholeiites	250	,, ,,	33	,,
Andesites	25	,, ,,	40	,,
Acid lavas	20	,, approx	100	,,

There is a very close correlation between grain-size of the rock and thickness of the flow ; as a general rule, the thicker the flow the finer the grain of the rock. At one end of the scale, the more coarse-grained olivine-rich basalts are usually less than 20 feet thick and must represent a very fluid magma, whereas the acid rocks, felsitic or glassy, form flows that often exceed 100 feet, and must have been very viscous.

The thickest flow of basalt seen is a 130-foot tholeiite flow exposed in the Grjótá[1], west of Hólmatindur. On Hólmatindur six flows of tholeiite have been observed, each with a thickness of 100 feet or more. These figures are exceeded by some acid flows, which have a thickness of more than 200 feet.

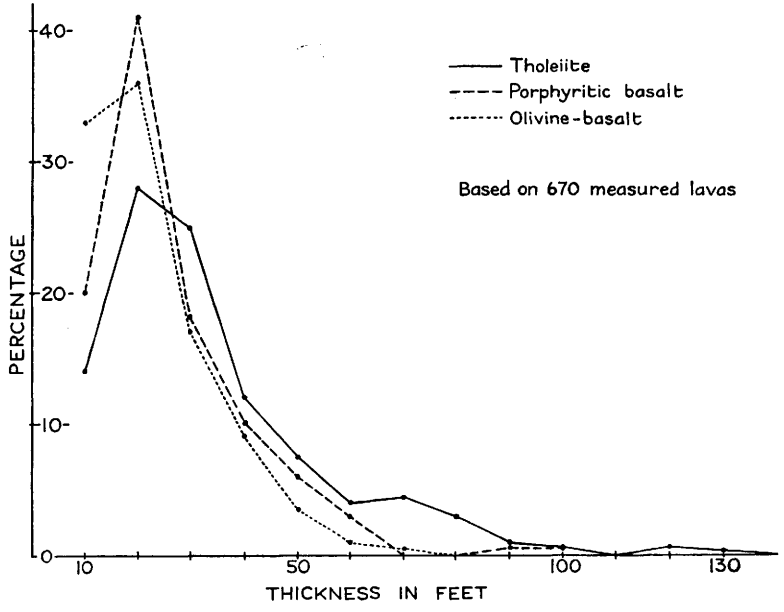

FIG. 2.—The thickness of basalt lavas of the three types.

Horizontal extent of flows.—Little is known of the horizontal extent of individual flows, but many, and probably most, flows extend for at least several miles. Cliff sections characteristically show parallel stratification of the lavas, individual flows being traceable by eye for considerable distances, and relatively seldom is a flow seen to end. Groups of flows may often be traced in the field for distances of 15 miles or more, and in that distance they may show little variation in thickness.

Single flows of sufficiently distinctive characters and clear exposure to be traced far in the field are uncommon, and only one really satisfactory example has been found. This flow is at the base of the Vindháls porphyritic group, a prominent group of porphyritic basalts some 5000 feet up in the lava succession (see Pl. XIX, and Fig. 3). Its distinctive feature is the abundance of small feldspar phenocrysts, which are accompanied by phenocrysts of augite and some of olivine. The flow is missing

[1] The termination *á* signifies *river*.

where the Vindháls porphyritic group is exposed on the northern shore of Reydarfjördur, but it appears near the summit of Snaefugl and on the south side of the Víkurvatn corrie. Thence it is traceable northwards around the base of Vindhálstindur, where its thickness is 50 feet, to the ridge south of Nordfjördur, where it has increased in thickness to nearly 100 feet and is seen joined to its dyke feeder. What is believed to be the same flow has been traced as far as Hrútatindur, north of Nordfjördur, and the known exposures extend for 12 miles along the strike by four across it.

If the wide extent of some flows or groups of flows has been established, examples are not wanting of others that thin out within a short distance. Some of the acid lavas in the Sellátur area, for instance, can be traced for only a mile or two.

Gravity features and composite flows.—A number of flows of porphyritic basalts show heterogeneities that can be explained by crystal fractionation in place or possibly by composite eruption. One 20-foot flow on the south face of Graenafell has upper and lower portions of non-porphyritic tholeiite and a central part, five feet thick, bearing some 20 per cent of feldspar phenocrysts. Several porphyritic basalt flows have been found in which the content of feldspar phenocrysts near the base is much lower than that in the middle and upper parts, probably due to rising of the crystals.

Lava tubes.—A beautifully exposed infilled lava tube was located on the north of the ridge midway between Lakahnaus and Sellátratindur. It is roughly circular in section and 20 to 25 feet in diameter, with well-developed concentric banding and concentric distribution of the sparse amygdales. The enclosing lava is olivine-basalt and the rock of the tube is of similar composition, although somewhat coarser in grain.

Empty lava tubes are very commonly encountered at the base of a lava flow, horizontal and cylindrical in form, with a diameter ranging from several inches to several feet.

Aa and pahoehoe.—The great majority of the tholeiite flows in the Reydarfjördur area have a rather blocky or rubbly top of aa type (Icelandic *apalhraun*), while most of the olivine-basalts, and practically all the more coarse-grained and more olivine-rich types, are pahoehoe (Icelandic *helluhraun*). Hawaiian experience (Wentworth & Macdonald 1953) suggests that pahoehoe is more characteristic of flows in the immediate neighbourhood of the eruptive orifice, aa developing in the same flow at a greater distance from the source. In Iceland the composition of the lava may also be a significant factor.

Flow structure.—The acid lavas and some of the andesites are highly fissile rocks, splitting readily into plates about half an inch thick. The tholeiites have a well-developed flow structure, due to a parallelism of the feldspar crystals in the rock, but there is less tendency for the rocks to split into plates. The flow structure is usually nearly parallel to the bottom and top of a lava, but sometimes the acid lavas show intense folding or overfolding of the flow layers, as on the shore east of Sandvík. Large magmatic rolls are often seen in the andesite flows, as in those near the top of the Sellátur acid group (Pl. XIX) in the Selá.

Another effect of flow is the drawing-out of vesicles or amygdales. In the tholeiites individual vesicles are flattened, while in the olivine-basalts the effect is more usually the formation of layers of small amygdales in which the individual amygdales are not markedly deformed.

Vesicles, amygdales and basalt-pegmatites.—The distribution of these depends on the lava type. The olivine-basalts are rich in amygdales, characteristically infilled with secondary minerals such as the zeolites, calcite, gyrolite and apophyllite. The amygdales are not very large, two inches being the normal maximum size, and showy specimens of the minerals are not readily collected.

Pipe-amygdales are practically confined to the olivine-basalts and are best developed in the more coarse-grained and olivine-rich types. The pipe-amygdales are of two distinct kinds, short and long. The short ones are found at the base of flows of pahoehoe and are up to six inches in length and a quarter to half an inch in diameter. The long ones are one to two inches in diameter and usually pass right through the lava from bottom to top, but continuous pipes are less common than pipe-like bodies of basalt-pegmatite bearing trains of small zeolite-filled amygdales.

In the olivine-basalts amygdales are most abundant in the upper part of the flow, where they are often streaked out into crude layers. In the porphyritic basalts, on the other hand, the amygdales are distributed throughout the flow, although most abundant towards the top, and they are typically small (less than half an inch in diameter) and nearly spherical.

The tholeiites are usually not markedly vesicular or amygdaloidal, but such vesicles as do occur are often large and markedly flattened horizontally; many of these as seen in section attain a length of one foot and a depth of one or two inches. The vesicles are either empty or carry celadonite, chalcedony, quartz, chlorophaeite or sometimes zeolites (especially mordenite, stilbite, heulandite or mesolite). In place of the amygdaloidal top of the olivine-basalts many tholeiite flows have a thick, rubbly and practically non-vesicular top.

Basalt-pegmatite is found in most of the more olivine-rich basalts, being coarser in grain than the lava in which it occurs, and it is rich in titanaugite prisms up to 3 mm. long and zeolites. Besides forming the matrix of amygdale trains in long pipe-amygdales it is found as more or less horizontal sheets, usually an inch but exceptionally as much as six inches thick. The pegmatites present a sharp but unchilled contact with the basalts in which they occur, and most of them must be regarded as auto-intrusions formed when the lava was still hot.

Jointing.—A crude columnar jointing is sometimes seen, but the only good example is shown by the thick flow of tholeiite just above the upper acid tuff and lignite bed on Hólmatindur. It shows the three-tiered arrangement described by Tomkeieff (1940) from the Giant's Causeway. Columnar or prismatic jointing is well developed in many dykes and other minor intrusions, such as that on the north face of Sellátratindur.

IV. Stratigraphy

Introduction.—A sedimentary series is mapped by the recognition and tracing of distinctive horizons, and the lavas of the Reydarfjördur area are so well stratified and are present in such variety that they can be treated in the same way. There is no scarcity of mappable horizons, and mapping is facilitated by the tendency of lavas of a particular type to form groups of flows. Especially valuable are the groups of porphyritic basalts, which are distributed fairly evenly through the lava succession. Each group has a thickness of 100 to 300 feet and contains from two to a

dozen separate lavas. The porphyritic basalts are readily recognized in the field and usually form prominent scarps. Groups of olivine-basalt or tholeiite can sometimes be mapped, although their boundaries are less reliably located. The occasional beds of acid tuff interbedded with the lavas are also useful, although being soft and readily eroded they are seldom exposed.

The stratigraphy of the 15,000 feet of volcanic rocks forming the lower part of the succession in the Reydarfjördur area will now be described, as summarized in Fig. 3. Their upper limit is arbitrarily taken at the base of a group of thick flows of andesite which are regarded as forming the base of the overlying central volcano of Thingmuli. For convenience of description certain lava groups and tuffs have been assigned local names.

Some of the lava groups vary in thickness; Fig. 3 gives the average thickness of each group within the limits of the area mapped.

Rocks below the Bardatangi tuff.—The 1500 feet of volcanic rocks below the Bardatangi tuff in the cliffs east and north-east of Gerpir include a considerable development of acid and intermediate lavas, and acid lavas form the base of the exposed succession east of Sandvík. The base of the volcanic succession is nowhere exposed.

North of Hádegistindur, rhyolite, apparently a single flow, attains a thickness of 200 feet. On the coast just east of Sandvík it forms two separate lava flows, with well-developed platy flow structure that in places is conspicuously folded. The margins of these flows are glassy, and locally rich in spherulites, some of which are hollow and contain mordenite.

Overlying the lower acid group of Sandvík is thin andesite followed by some 400 feet of tholeiite lavas. On the Gerpir cliffs these lavas include several andesites and two intercalated acid tuff beds, one of which bears plant remains. The lavas are followed on the Gerpir cliffs by a second group of acid lavas, comprising five flows with an aggregate thickness of 350 feet, thinning northwards. These are followed in turn by a number of flows of tholeiite and, just below the Bardatangi ash, several thin and decomposed olivine-basalts.

The lowest rocks on Bardsnes are stratigraphically only a few hundred feet higher than those of Gerpir. The lowest rock on Bardsnes is a porphyritic andesite flow on Mónes, 50 feet of which is exposed. Resting on it is a rhyolite flow 50 to 100 feet thick, relatively rich in feldspar phenocrysts, and with a green glassy top.

Overlying the rhyolite between Mónes and Bardsneshorn is a considerable thickness of bedded agglomerate and acid tuff. The dip is steeply towards the west, and must be largely an original depositional dip, the agglomerate forming part of a volcanic cone with its centre east of the present coast-line. The agglomerate contains blocks of rock up to two feet in diameter, and although mostly of rhyolite, pitchstone and andesite there are also fragments of basalt, indicating the existence of basalt lavas below the exposed succession on Mónes.

The agglomerate contains a four-inch seam of coal, and on the eastern shore of the peninsula very near Bardsneshorn there are several carbonized trees in the position of growth, buried by the ash. Two, each about one foot in diameter, can be seen projecting some 12 feet upwards into the ash. Another has a diameter of three feet near the base. This plant bed is at about the same height in the succession as the tuff bearing plant

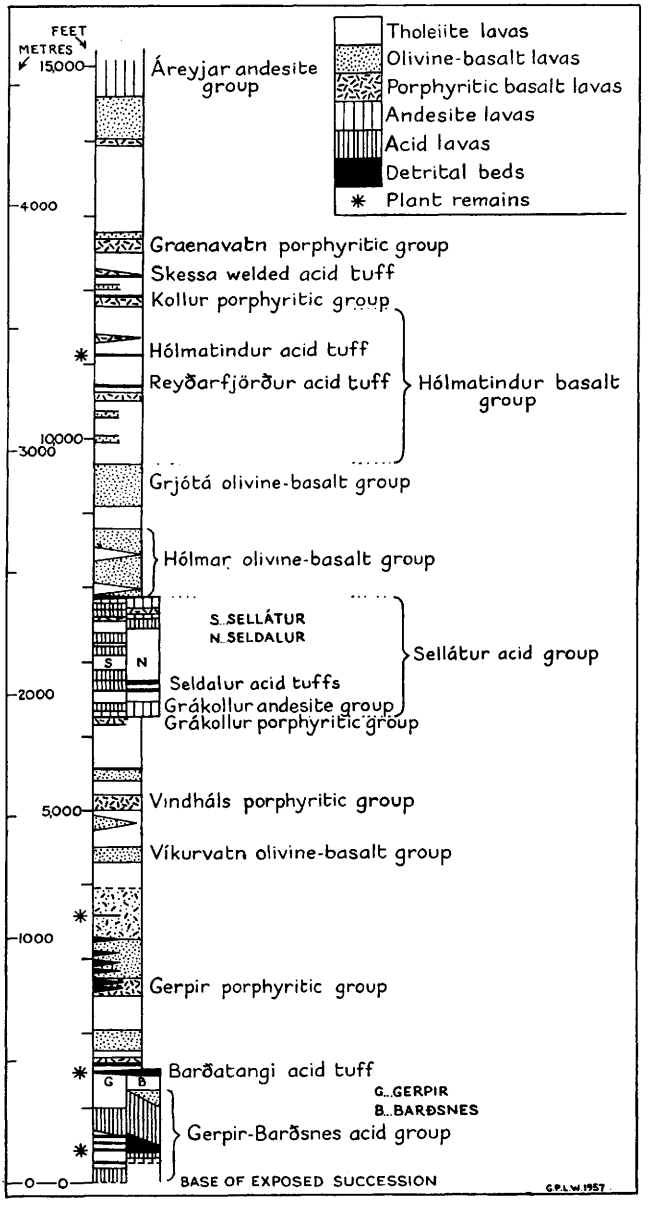

FIG. 3.—Stratigraphic sequence in the Reydarfjördur volcanic pile.

remains at the foot of the Gerpir cliffs, and the two may be of the same age.

Overlying the agglomerate are two or perhaps more acid flows attaining at least 400 feet in aggregate thickness. Each flow has well-developed platy flow structure and a glassy top. On the west coast of Bardsnes a rhyolite flow at least 200 feet thick forms the striking pink cliff of Raudubjörg. There is a considerable development of spherulitic rocks and green pitchstone at the margins of this flow, and some composite spherulites attain three inches in diameter. They have a central cavity infilled with chalcedony.

The acid rocks on Bardsnes have an aggregate thickness which cannot be far short of 1000 feet, for they constitute the whole of one 830-foot cliff and the base of the acid group is not exposed. The thickness, however, is clearly very variable, for the top descends very rapidly in height from the east to the west of the peninsula, and the later basalt lavas can be seen to be banked up against what must have been an acid volcano east of the present coastline. Rhyolite and agglomerate form the lower part of the cliffs along the whole of the eastern coast of the peninsula, the level of the top falling gradually southwards and reaching sea-level at Sandvík.

The lavas banked up against the acid rocks north of Heppa include a group of olivine-basalts, rich in zeolites, that are unrepresented on Gerpir but are in turn overlain by tholeiite, and, as elsewhere, the Bardatangi tuff rests upon the tholeiite.

The Bardatangi tuff.—Nearly 100 feet of bedded tuff is exposed in the crescentic bay of Bardatangi. It is variable in composition, and sometimes rich in crystals of oligoclase-andesine and squashed fragments of acid pumice. The tuff includes a plant bed two or three inches thick containing large pieces of carbonized wood.

Although usually marked by a pronounced terrace on the mountain sides, the tuff is seldom exposed inland. On the north-eastern shoulder of Heppa the thickness is reduced to 20 feet. On the shore at Vadlavík and in the Gerpir cliffs a tuff bed 40 feet thick and rich in small oligoclase crystals is almost certainly a continuation of the Bardatangi tuff. On Hádegistindur it includes pebble-beds.

The thickness of the tuff at Bardatangi suggests that the eruptive orifice was near. The tuff, several hundred feet above the uppermost rhyolites of the Bardsnes peninsula, may represent the final eruption of acid material in the Gerpir–Bardsnes acid volcanic episode.

Rocks above the Bardatangi tuff.—The Bardatangi tuff is overlain by tholeiite. In the Gerpir cliffs this is succeeded by a 30-foot bed of basaltic dust which forms a second prominent terrace on the face of the cliffs. Resting on this detrital bed are one or two flows of richly porphyritic olivine-basalt. One, of small lateral extent, has over 50 per cent of feldspar phenocrysts and some of augite and olivine. Porphyritic flows of similar character at Bardatangi and separated from the tuff by 250 feet of tholeiite lavas may be of the same group, and so also may be a prominent group exposed above the raised beach platform east of Neskaupstadur.

Succeeding the porphyritic basalts, but sometimes separated from them by a few flows of tholeiite, is a group of zeolite-rich olivine-basalts, rather fine in grain and relatively poor in olivine. On the south face of Gerpir and six flows up from the tuff, a small cave at the base of a flow has a

hole in the roof looking like the mould of a tree trunk some two feet in diameter, and in the scree below the cave a block of basalt was found enclosing a fragment of carbonized wood six inches long.

Above the olivine-basalts comes a group of tholeiites 400 to 500 feet thick, comprising about 15 flows. These tholeiites are rich in chalcedony and quartz and near the top, where overlain by the Gerpir porphyritic group, they contain zeolites of fine quality including heulandite, mesolite and epistilbite.

The Gerpir porphyritic group.—This is a spectacular group of richly porphyritic basalts averaging 200 feet in aggregate thickness and comprising about six lava flows. This is one of the most valuable stratigraphic horizons in the Reydarfjördur area, for the rocks are distinctive in their highly porphyritic nature and are very well exposed, forming a prominent and often precipitous escarpment. The group has been traced from Nordfjördur to Krossanes, and reappears again at the tip of the peninsula south of Reydarfjördur, a lateral extent along the strike of 17 miles. In the direction of dip the base of the group extends from sea-level to an altitude of 2000 feet near the top of Gerpir. The only variation in thickness is a diminution to half of the normal thickness north of Nordfjördur and in the cliffs south of Vadlavík ; in the latter locality the group is associated with and overlain by sandstones and conglomerates and the diminution appears to be due to penecontemporaneous erosion.

Typically the rocks of the group contain about 40 per cent of feldspar phenocrysts of average size 5 mm., together with augite and olivine, and an abundance of zeolites, especially mesolite, in small spherical amygdales. A flow of tholeiite comes in above the basal porphyritic flow on Gerpir and the peak to the south. Small dolerite sills are seen on the escarpment west of Gerpisvatn and elsewhere. Near Vadlavík the group includes several rather thick basaltic dust beds.

Rocks above the Gerpir porphyritic group.—The lowest flows above the Gerpir porphyritic group are fine-grained olivine-basalts, and these are followed by mixed olivine-basalts and porphyritic basalts and, in Súlnadalur, several picrite-basalts rich in iddingsite pseudomorphing phenocrysts of olivine. The thick detrital beds associated with these lavas include conglomerate and sandstone and several basic tuffs rich in large and well-formed crystals of bytownite. In Súlnadalur one of the conglomerates contains pebbles which, although mostly of porphyritic basalt and tholeiite, include some of andesite. North of Vadlavík one conglomerate contains abundant pebbles of rhyolite and basalt of various types. The pebbles are wind-polished and some have a crude dreikanter shape. Another detrital bed includes a thin layer of pale-weathering acid tuff.

A prominent group of mixed porphyritic basalts and olivine-basalts rests upon these rocks. The group is some 900 feet thick and comprises 30 to 40 separate flows. About halfway in the series on the south side of Einstakafjall a very fine-grained dust bed contains abundant impressions of pine needles and the leaves of deciduous trees. South of Vadlavík the series includes a bed about 30 feet thick of palagonite tuff, traceable for several miles, and another, about 30 feet thick and showing current-bedding, is seen on the south-eastern slopes of Nípukollur. At the top of the group comes several hundred feet of tholeiite lavas with some interbedded porphyritic basalts and olivine-basalts.

The Víkurvatn olivine-basalt group.—This prominent group of coarse-

grained olivine-basalts, 100 to 200 feet thick, is well exposed and has been traced from Reydarfjördur to Nordfjördur. It is overlain by a group of tholeiites of about the same thickness, well exposed on Vindhálsöxl. Above these tholeiites on the eastern shoulder of Vindhálstindur are several flows of unusually coarse-grained ophitic olivine-basalt. They have small lateral extent and elsewhere appear to be missing from the sequence, their place being taken by tholeiites extending to the base of the succeeding group.

The Vindháls porphyritic group.—This valuable stratigraphic horizon consists on Vindhálstindur of four flows of porphyritic basalt with an aggregate thickness of rather less than 200 feet. On the escarpment of Skuggahlídarbjarg there are five flows and the aggregate thickness has increased to 300 feet. The Vindháls group is everywhere well exposed and with the overlying tholeiites forms a prominent line of cliffs. The group has been traced from Reydarfjördur to north of Nordfjördur and, as described on a previous page, the lowest flow has been followed over most of this distance. It is easily distinguished from the other flows in the group, which are less porphyritic.

Rocks above the Vindháls porphyritic group.—Between the Vindháls porphyritic group and the Grákollur groups comes about 1000 feet of basalt lavas, predominantly tholeiites but including a thin group of olivine-basalts 300 feet up and several beds of acid tuff. One of these is exposed on the col Sléttuskard, and another rather higher in the sequence on the hill to the east. A prominent bed of tuff is seen also north of the col between Grákollur and Vindháls. It is at least 30 feet thick and is rich in small crystals of oligoclase.

The Grákollur porphyritic and andesite groups.—A thin group of porphyritic basalts forms a convenient horizon in the vicinity of Grákollur and Vindháls. On the south-eastern side of Grákollur the group contains from three to five flows of highly porphyritic basalt with a total thickness of rather less than 100 feet. The group is faulted in Hrafnadalur and south-west of there it is hard to follow, but apparently thins out and is represented by a single thin flow on the coast. The group likewise thins out and disappears a short distance north-west of Grákollur.

The Grákollur porphyritic group itself is thus not a good horizon, but on Grákollur and Vindháls it is almost immediately overlain by a group of flows of andesite and andesitic tholeiite which can be traced north-westwards into Seldalur. The porphyritic and andesite groups together form a convenient base to the succeeding Sellátur rhyolite group.

The Sellátur acid group.—The geology of the country between Sellátratindur, Eskifjördur and Grákollur is dominated by a series of thick rhyolite lavas interbedded and interfingered with tholeiites and andesites. The total thickness of lavas, from the Grákollur groups to the top of the uppermost rhyolite and andesite is about 1700 feet, and where the acid rocks are fully developed there are eight flows of rhyolite with an aggregate thickness of over 1000 feet.

The acid flows are generally well exposed and often give rise to prominent vertical or overhanging cliffs 100 feet or more high. The rocks have a very well-developed flow structure, often contorted and folded, and they split readily into thin plates which accumulate as broad scree aprons at the foot of the cliffs. In the hand-specimen the rhyolites are pale grey or occasionally pink or red, and small phenocrysts of feldspar are aligned in the direction of flow. On Lakahnaus, tridymite is abundant as

small platy crystals on joint surfaces, and cristobalite is also commonly seen.

The top and bottom of each flow are usually marked by a considerable thickness of glass or breccia. There is, for instance, much green pitchstone associated with one of the flows north of Sellátratindur. Often the top of a flow is highly vesicular, and spherulitic rocks with lithophysae are sometimes abundant, as at the top of the flow composing the serrated ridge of Glámsauga, where the lithophysae range up to two inches in diameter.

A plug of rhyolite is exposed above Sellátur farm. It is exposed over a vertical height of 600 feet and in plan the outcrop is of hour-glass shape, with a constriction almost dividing it into a pair of plugs. The rock is fissile and pale grey, very similar in appearance to the rhyolite of the uppermost two flows on the ridge to the north, and has small phenocrysts of feldspar. There is a marginal selvedge four or five feet thick of black pitchstone. At its northern end the plug appears to be continuous with the rhyolite flow below the topmost flow, and is possibly its feeder.

The highly fissile rhyolite lavas have clearly proved an obstacle to the passage of basic dykes, and the basic magma has often spread out laterally along the flow structure. Small sills of basalt, usually not more than five feet thick, are quite abundant in the rhyolites, as on the coast at Sellátur.

Flows of rhyolite do not always extend far laterally, and they make rather poor stratigraphic horizons on this account. Individual flows also lack distinctive characters. There is evidence that at times the rhyolites stood up above the surrounding country as small volcanic hills, to be submerged by later basalt lavas (cf. Hawkes 1916B). Thus, south-west of Helgustadafjall one rhyolite flow dips 12° SW., and on Helgustadafjall itself the upper rhyolite flows are horizontal. As the regional dip is 6° SW. this implies original depositional dips of 6° SW. and 6° NE. respectively at the two localities. A group of basalts 300 to 500 feet thick between rhyolites west of Helgustadafjall thins to less than 100 feet between the same two rhyolites less than a mile away on the eastern side of the mountain.

The lavas interbedded with the rhyolites are mostly tholeiites, but near the top of the Sellátur group there is a thin group of richly porphyritic basalts and several flows of andesite.

Over an area of about one square mile in the vicinity of, and including, the famous Helgustadir Iceland Spar Mine the basalts have suffered drastic hydrothermal alteration, being converted into a pale green rock rich in calcite and chlorite. The approximate limits of this alteration are indicated by a dotted line on the map (Pl. XIX). Several intrusive sheets of rhyolite are seen on the shore cutting this altered basalt. These, or a larger body from which they are offshoots, seem to have been responsible for the alteration. The only other acid intrusions seen in the Sellátur area are the Sellátur plug and several acid and composite dykes.

Traced northwards, the rhyolite lavas thin and die out one by one, and north of Seldalur there is only one flow of rhyolite, although several flows of andesite persist. The succession here is composed largely of unusually thin pahoehoe flows of tholeiite. In Seldalur the rhyolites near the base of the Sellátur group are represented by three thick beds of acid tuff, green in colour and rich in flattened pumice fragments an

inch or two in diameter. These tuff beds attain an aggregate thickness of over 100 feet in Seldalur, and they are known to extend a considerable distance northwards, where they constitute valuable stratigraphic horizons.

The Sellátur rhyolite group is clearly recognizable south of Reydarfjördur, where rhyolite lavas are very well represented and are associated with several rhyolite plugs. On the south shore of the fjord opposite Sellátur farm, basalt lavas are cut by acid sheets and have suffered hydrothermal alteration similar to that at Helgustadir. A large mass of basic and acid agglomerate near Eyri farm may represent a buried volcanic cone. Farther southwards, rhyolites apparently at the same level are seen on either side of Fáskrúdsfjördur, and the Sandfell laccolith (Hawkes & Hawkes 1933) and composite dykes associated with it (Guppy & Hawkes 1925) may belong to the same acid igneous episode.

The Hólmar olivine-basalt group.—This is a group 1000 feet thick predominantly of zeolite-rich olivine-basalts. At Hólmanes the lowest few flows are tholeiites, separated by a thick detrital bed from the underlying andesite. Above the tholeiites come coarse-grained olivine-basalts rich in olivine and some picrite-basalts. A flow of basalt with small feldspar phenocrysts follows, and the remainder of the group consists of olivine-basalt with, near the top and forming a conspicuous scarp above the road summit, a single 90-foot flow of tholeiite. Elsewhere the Hólmar group contains a thin group of tholeiite lavas, perhaps at the same horizon.

On the summit of Sellátratindur the group includes a thick red cinder deposit containing bombs, and a thick lava just below it has almost certainly been erupted from a dyke exposed just south of the summit. Similar cinder deposits are found at about the same level on the ridge south-west of Sellátratindur, probably representing buried cinder-cones along the line of an eruptive fissure, and another deposit of similar character is seen on the lower slopes of Hólmatindur just south-west of the head of Eskifjördur, with basalt lavas banked up against it.

Overlying the Hólmar group are about five flows of tholeiite, with an aggregate thickness of 200 feet. This group is readily mapped and constitutes a useful horizon, although there is a marked tendency for the tholeiites to be obscured by screes from the overlying olivine-basalts.

The Grjótá olivine-basalt group.—This, the finest group of olivine-basalts in the area, comprises on the southern slopes of Hólmatindur some 25 to 30 flows of olivine-basalt with an aggregate thickness of 550 feet. Some of the flows are rich in small phenocrysts of olivine, often replaced by iddingsite. Basalt pegmatites are abundant, and zeolites conspicuous. The olivine-basalts are well exposed on steep rubbly slopes, with the massive centre of each flow forming a small cliff.

The Hólmatindur basalt group.—The 2000 feet of basalt lavas between the Grjótá group and the Kollur porphyritic group are predominantly tholeiitic, and include some of the thickest flows seen in the area. There are also several thin groups of olivine-basalt and porphyritic basalt that are useful local stratigraphic horizons, and two thick beds of acid tuff, one of which is associated with an abundance of plant remains.

The tholeiite lavas, of which on Hólmatindur there are about 33 separate flows with an average thickness of 50 feet, have massive prismatic jointing, often with well-developed chisel-markings on the joint surfaces, and several flows above the upper acid tuff bed have crude columnar jointing. One, that immediately above the tuff, shows columnar jointing approach-

ing in perfection that of the Giant's Causeway. This flow is 120 feet thick on the southern face of Hólmatindur, and another flow of tholeiite in the Ljósá is slightly thicker than this. Several flows attain a thickness of 100 feet.

A bed 20 to 30 feet thick of acid tuff (the Reydarfjördur tuff on Pl. XIX) is well exposed in the Ljósá and in the stream above the village of Reydarfjördur. It is a pale-weathering rock with abundant flattened fragments of pumice up to two inches in diameter in a matrix of glass shards. In a stream section a short distance west of the Ljósá the tuff is cut by an 11-foot basic dyke that has fused it to a black pitchstone to a distance of two feet from the contact. A short distance below the tuff a thin but very persistent group of porphyritic basalts forms a convenient stratigraphic horizon ; the tuff itself is seldom exposed.

A second bed of acid tuff (the Hólmatindur tuff on Pl. XIX) is seen higher in the succession and again it is well exposed only in occasional stream sections. In a gully on the south-western shoulder of Sómastadatindur it is more than 30 feet thick and includes several beds of lignite that have an aggregate thickness of seven or eight feet. The lignite is interbedded with tuff that is sometimes rich in pumice fragments, sometimes a pale-weathering dust, and occasionally rich in feldspar crystals. In the Ljósá and on the northern face of Hólmatindur, pale-weathering tuff is again found associated with lignite. On the southern face of Hólmatindur there are abundant fragments up to two feet long of silicified wood evidently from the same tuff bed, and although no complete trunks were seen it is clear that the trees must have had a diameter of two to three feet. The tholeiite flows above the Hólmatindur tuff have several other acid tuff intercalations, some of them bearing plant remains.

The Kollur porphyritic group.—The rocks of this group are noteworthy on account of the size and abundance of their feldspar phenocrysts. These often exceed a centimetre in diameter and may compose up to 50 per cent of the rock. A lower content of phenocrysts is sometimes seen in the lower parts of a flow than in the middle or upper parts, probably due to gravity differentiation.

On Kollur the group embraces seven flows, with an aggregate thickness of 200 feet, but eastwards and south-eastwards the thickness decreases. The group constitutes a very useful horizon, traced from near sea-level west of Reydarfjördur to nearly 3000 feet on Sómastadatindur, and porphyritic basalt probably belonging to this group caps Hólmatindur. Above the Kollur group is a bed of tuff, very seldom exposed, which forms a prominent bench on the hillsides. It attains a thickness of 40 feet on the north-eastern ridge of Kambfell, where it is pale-weathering and largely composed of acid material. Above are about 20 or 30 flows of tholeiite having an aggregate thickness on Kollur of 600 feet, often bearing chalcedony in their amygdales. Halfway up in this tholeiite series is a bed of acid tuff (Skessa tuff on Pl. XIX). On Skessa and Kambfell, south of Reydarfjördur, it is welded and has a thickness of about 20 feet. The rock is pink and rhyolitic in appearance, and the bed has a basal portion of pale grey pitchstone.

On Kollur, the Skessa tuff is eight feet thick and its outcrop marked by a line of springs. Resting on it are two thin flows of porphyritic basalt. These flows are absent on the south face of Graenafell, while in places on the north-eastern side of Kollur their place is taken by several flows of olivine-rich basalt.

The Graenavatn porphyritic group.—This well-marked group of porphyritic basalts is one of the most useful stratigraphic horizons in the area mapped. It has been traced, with little variation in thickness, 11 miles from the head of Skógdalur to the road summit in Fagridalur. Where best exposed, as on the southern face of Graenafell, the group comprises some ten flows with a combined thickness of rather more than 200 feet. The rocks for the most part contain 20 to 30 per cent of feldspar phenocrysts, although there is one flow 20 feet thick in this section with over 50 per cent. A composite flow is also seen here, with non-porphyritic margins and a porphyritic central part.

Rocks above the Graenavatn porphyritic group.—Under this heading come 2000 feet of basalt lavas, overlain by the thick andesites which are regarded as the basal flows of the Thingmuli volcano. Some of the basalts may well belong to this volcano, but it is uncertain at what stage the volcanic mound began to take shape, and as the andesites seem to be the lowest undoubted products of the volcano they are taken here as marking its base. The lavas at the base of this group include a few olivine-basalts, but otherwise the lower half of the group is made of rather thin tholeiite lavas. They are followed by a thin group of porphyritic basalts, and the upper part of the group is largely made up of fine-grained and rather olivine-poor olivine-basalts.

V. The Sequence of Lava Types

In the foregoing descriptions there is little sign of any rhythm in the sequence of lava types erupted. No one type is confined to a single level in the lavas, tholeiites, olivine-basalts and porphyritic basalts alternating without regularity. This availability of each magma at a number of times is of great petrogenetic significance, as is the tendency of lavas of a particular type to form discrete groups of flows. Lavas of uniform character were erupted over a wide area for a long period before the composition of the magma changed and lavas of another type were erupted for a comparable period. The composition of the magma being erupted changed more than 50 times during the accumulation of the 15,000-foot pile.

The lavas include a considerable bulk of acid material, and two long periods of acid volcanism are recognized. The first is represented by the rhyolite lavas and pyroclasts and associated andesite lavas of the coast between Bardsneshorn and Vadlavík, and the Bardatangi tuff is perhaps the closing phase of this long period. The second is represented by the copious outpourings of acid and intermediate lavas in the Sellátur area and to the south. A third episode is represented by the even more copious outpourings of the Thingmuli central volcano which was later established.

In addition, there is clear evidence of other acid volcanic episodes outside Reydarfjördur. One episode is seen in the three thick and several thin acid tuff beds in and just above the Hólmatindur basalt group. The size of the pumice fragments and the thickness of some of the beds point to the relatively close proximity of the eruptive orifices. The Skessa tuff may represent a separate acid episode, or it may be the final acid phase in the same episode.

Lower down in the lava pile the rhyolite- and andesite-bearing pebble-

beds above the Gerpir porphyritic group suggest the existence of outcrops of rhyolite at that time in the area. The Bardsnes–Gerpir rhyolites are separated by 2000 feet of basalt lavas from the pebble-beds, and are unlikely to have contributed. The Sléttuskard tuff is more than 500 feet below the lowest of the Sellátur rhyolites, and although it may possibly represent the commencement of this long period of acid eruption it is more likely to be due to an earlier cycle of acid eruptions in another area.

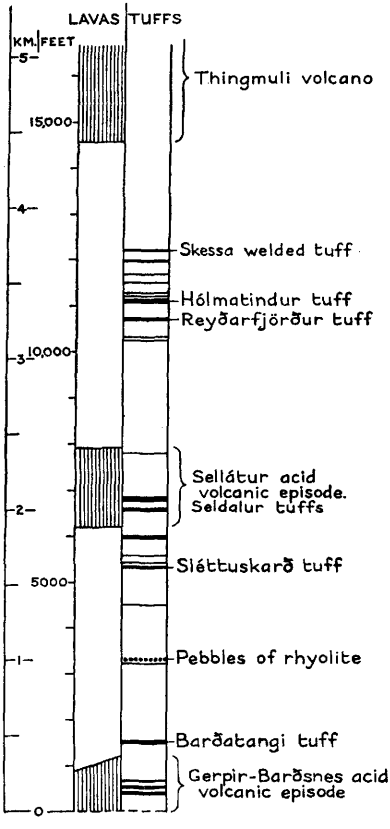

FIG. 4.—The distribution of acid tuffs in the stratigraphic sequence of Reydarfjördur in relation to the three periods of eruption of acid lavas.

Acid magma has thus clearly been available for eruption in bulk during the greater part of the Tertiary volcanic history of eastern Iceland. Perhaps the episodes represented only by tuff in the mapped ground may be correlated with known acid lavas or intrusions elsewhere, as, for instance, the acid eruptive centre of Lodmundarfjördur, 25 miles to the north (Dearnley 1954), and the centre in upper Breiddalur only 15 miles to the south-west.

It remains to point out the constant association of rhyolite and andesite lavas, the latter always subordinate in bulk. There is a tendency for andesite lavas to open or terminate an acid eruptive episode.

VI. Dykes and Other Minor Intrusions

The lavas are associated with an intense swarm of dykes, and it is estimated that in the 27 miles from the eastern extremity of Iceland to the base of the Thingmuli central volcano just west of Fagridalur there are over 500 dykes with an aggregate thickness of more than 5000 feet, representing a crustal stretch of 4 per cent at sea-level. The dykes in the six additional miles westwards to the Grimsá bring the total to about a thousand.

The average thickness of 570 measured dykes is 11 feet, but individual dykes range from a few inches to over 100 feet (Fig. 5). The dykes are characteristically disposed approximately at right angles to the lava stratification. This may be because they are preferentially injected along the jointing of the lavas, but more probably it implies original vertical attitude and subsequent tilting of the dykes with the lavas. Dykes intruded into the rhyolite lavas of the Sellátur area are controlled

by the platy flow structure of the rhyolites, and often send offshoots along the flow structure.

The majority of the dykes have no vertical displacement associated with them, and in the others the displacement seldom exceeds five feet. The dykes at the head of Kvígindisdalur are exceptional, and along one of them there is a vertical displacement of 50 feet to the east, a second of 20 feet to the west, and a third of 10 feet to the east.

Practically all of the dykes are basic, but two acid dykes have been seen in the Sellátur area, one on the eastern side of Helgustadafjall and the other near the northern end of the Glámsauga ridge. Four composite dykes are exposed on the four-mile stretch of shore south-east of Sellátur, each with acid centre and basic margins.

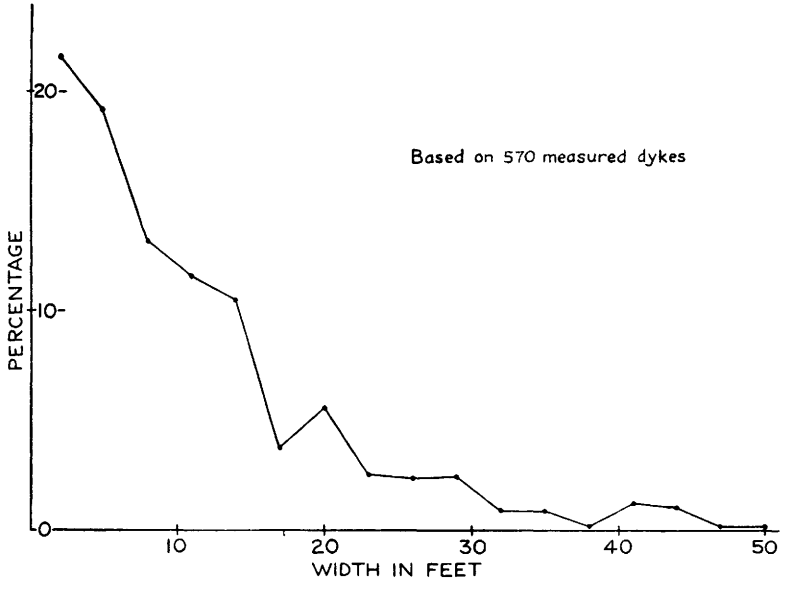

FIG. 5.—The thickness of dykes in the Reydarfjördur area.

No detailed study has been attempted of the composition of the basic dykes, but tholeiites, olivine-basalts and porphyritic basalts appear to be developed in proportions comparable to those in the lavas. Some dykes have glassy chilled edges. Small xenoliths of gabbro are not uncommon in the porphyritic dykes. A few dykes of olivine-dolerite have patches of veins of pegmatite parallel to their margins. Amygdales are not particularly common. Occasional dykes pass upwards into a palagonite breccia.

Distribution of dykes.—Although there is a general northerly trend, the dykes often tend to form two sub-swarms with trends inclined at about 50 degrees, as illustrated by the map, Fig. 6. The dyke-swarm is far from uniform in intensity. There is a well-marked local concentration in the vicinity of the rhyolite centre of the Sellátur area, and a second and even greater concentration east of and in the Thingmuli central volcano. In both, the basic dykes which are the rule elsewhere are

joined by a sprinkling of acid and composite members. There is an indication of a third concentration near the town of Neskaupstadur.

The distribution of dykes is best treated statistically, and the dykes have been studied in short strips of well-exposed country, and the following quantities determined :—

n. The number of dykes, from which can be derived a value for N, the number of dykes per mile across the trend of the swarm.

t. The aggregate thickness of the dykes, which can be converted into T, the aggregate thickness per mile.

S. From T, the percentage stretch represented by the dykes.

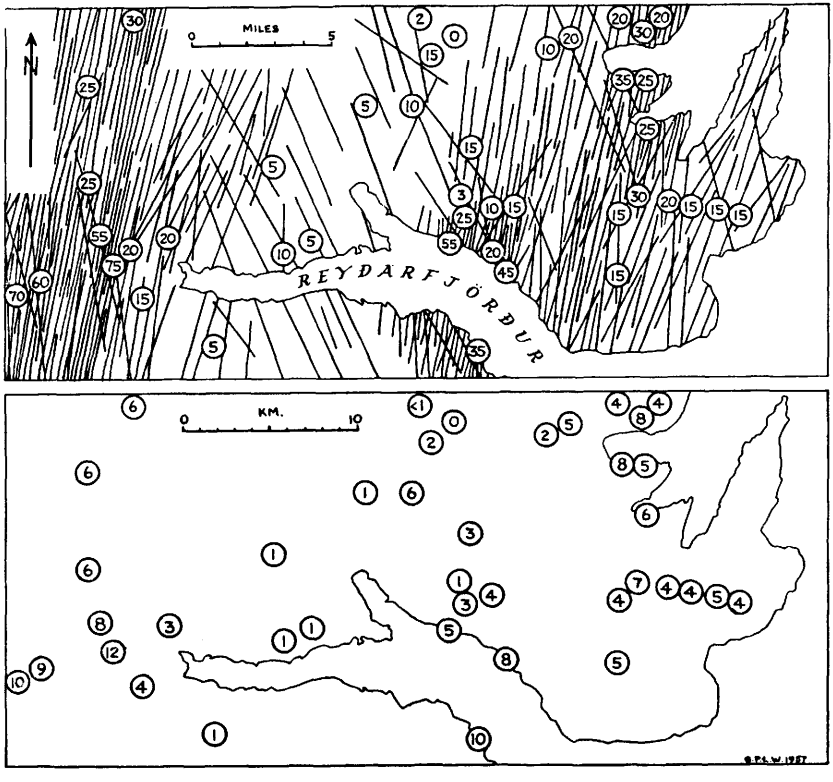

FIG. 6.—Sketch-maps of dyke distribution in the Reydarfjördur area.

Above : trend and distribution of dykes, approximately one dyke in five being represented. Figures give the number of dykes per mile.

Below : the intensity of the dyke-swarm expressed as percentage stretch.

This has been done for forty strips of country with a total length across the trend of the swarm of 26 miles ; in all, 590 dykes have been counted, with an aggregate thickness of 6400 feet. The swarm attains its greatest intensity in the Thingmuli volcano, where N approaches 100 and S exceeds 10 per cent in some strips. The data have been incorporated on the map, Fig. 6.

On the diagram, Fig. 7, the density of the swarm is plotted against

stratigraphic height in the lava sequence, and it is clear that the number of dykes, N, does not vary regularly, the intensity being related more to position in the swarm with respect to local concentrations about volcanic foci.

The intensity of the dyke-swarm does, on the other hand, vary regularly with altitude, everywhere decreasing upwards. This is well shown in the Sellátur area. On the shore the swarm is very intense, and in places N reaches 50 and S exceeds 6 per cent. Relatively few of these dykes pass up into the overlying olivine-basalts of the Hólmar group, in which

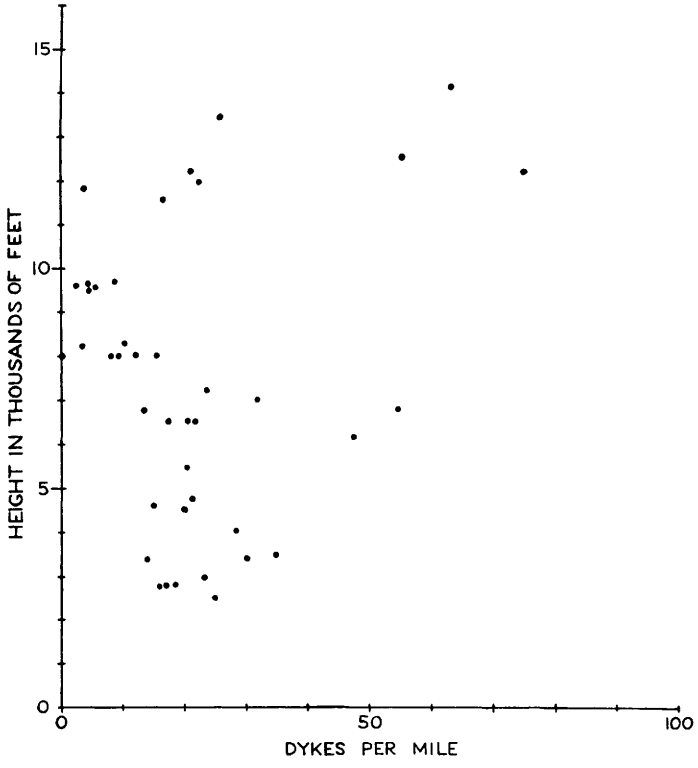

FIG. 7.—The intensity of the dyke-swarm, expressed in terms of the number of dykes per mile, showing its variation with height in the lavas.

N has fallen to an average of less than 10, and S to less than 3 per cent. Perhaps this diminution is due to the acid lavas acting as a dyke-trap, rising basalt magma being diverted along the flow-banding and thus being prevented from entering the overlying olivine-basalts. More probably, the observed distribution is due to most of the dykes in this area pre-dating the olivine-basalt lavas.

Sills and plugs.—Sills a few feet thick are common in some of the acid flows but are otherwise scarce in the ground mapped. Several are found at the top of the Sellátur acid group or the base of the succeeding Hólmar olivine-basalt group. The olivine-dolerite sill of Hólmaháls is the largest of these. It is 100 to 200 feet thick and in a distance of rather more

than one mile transgresses upwards from the topmost rhyolite of the Sellátur group to about 500 feet up in the Hólmar group. Olivine-dolerite sills of similar composition and, like the Hólmaháls sill, containing veins of coarse-grained dolerite-pegmatite are found cutting rhyolite south of Oddskard and olivine-basalt lavas capping one of the peaks east of Sellátratindur.

An olivine-dolerite dyke exposed in a cliff section just west of the Sellátur rhyolite plug expands mushroom-wise into a sill of small lateral extent, 50 to 100 feet thick. Just to the west a second intrusion of olivine-dolerite has the form of a cylinder, nearly circular in cross-section and about 100 feet in diameter, with axis plunging into the hill at 10 to 20 degrees. The dolerite, intruded into and chilled against an acid lava, shows concentric banding and is cut by thin veins of dolerite-pegmatite.

A small mass of olivine-free dolerite with prismatic jointing stands up as a rocky prominence on the eastern side of Ófeigsdalur. Most of the contacts are masked by scree, but a vertical chilled contact is visible at one point on the north side of the body and the adjacent lavas are reddened by alteration. The body is almost certainly a vertical plug. What may be a second plug is exposed a short distance east of Sellátur farm.

On Haugaöxl the basalt lavas over an area of nearly half a mile square have been steeply uptilted, and it can be demonstrated that the uplift amounts to at least 600 feet. The uplift bears a striking resemblance to the top of the Sandfell laccolith (Hawkes & Hawkes 1933), the size of the uplift and the dip of the lavas being closely comparable, but no intrusive igneous mass is exposed at Haugaöxl and its possible presence below can only be inferred.

VII. Dykes and Fissure-eruption

The bulk of the basalt lavas are believed to be the product of fissure-eruptions. The following is the evidence in support of this origin :—

1. Dykes are numerous ; the number exposed in 27 miles across the trend of the swarm is estimated at over 500, and many more must be concealed below the lavas. In the same area, the number of basalt lavas is about 500. The composition of the dykes appears to be closely comparable with that of the lavas.

2. Alternative channels through which the basalt magma may have attained the surface are notably scarce ; in the 200 square miles of country examined only one undoubted plug, that of Ófeigsdalur, has been found.

3. Two instances have been found of a lava in visible continuity with its dyke-feeder. One is seen on the south face of Graenafell, a porphyritic dyke about 30 feet wide being joined to one of the flows of the Graenavatn porphyritic group. The second, also of porphyritic basalt, is near the crest of the ridge south of Nordfjördur, where a dyke averaging 20 feet wide is joined to the lowest flow of the Vindháls porphyritic group. A third example of fissure-eruption is exposed at the summit of Sellátra-tindur, although continuity between dyke and lava is lost.

4. Mapping of the lava series has revealed a remarkable uniformity in the lava stratigraphy within the limits of the area mapped. Rhyolites apart, there seem to be no centres of preferential accumulation of lava, and the eruptions must have been of true flood-basalt type, such as are held to be characteristic of fissure-eruptions (Tyrrell 1937).

5. In present-day Iceland, fissure-eruption is the typical form of volcanic eruption, although a number of small shield volcanoes are known. In the extensive post-glacial lava fields relatively insignificant lines of spatter or cinder cones and craterlets are all that marks the line of the eruptive fissure. One of these post-glacial lavas has its dyke-feeder exposed where cut through by the gorge of the Jökulsá just below the waterfall Dettifoss in northern Iceland.

Against the hypothesis of fissure-eruption can be set the peculiar distribution of dykes shown in Fig. 7. In the conception of ideal flood-basalt eruptions, the eruptive fissures are distributed randomly over a broad area with little sign of local concentrations, and the result of successive eruptions is the formation of a lava plain of low relief. Assuming that one dyke gives birth to one lava, and that the average lateral spread of a lava is ten miles, then the number of dykes per mile at the base of the 15,000-feet lava pile should be 50 and the number should fall off linearly with height in the pile. The actual plot of dykes is far from linear, and the dykes tend instead to congregate into local swarms. The diminution in intensity of the dyke-swarm with increasing altitude is, however, valid evidence in support of fissure-eruption.

VIII. Subsequent History of the Area

The dip of the lavas is remarkably uniform in direction and amount, the angle of dip seldom departing from 3 to 7 degrees and the direction from west-south-west. There seems no reason to doubt that this is due to subsequent tilting rather than being an original depositional dip. Intercalated sedimentary beds are invariably bedded approximately parallel to the stratification in the lavas, and the two lavas which are joined to their dyke-feeder have flowed up the present dip as well as down[1]. Bedded chalcedony floors to amygdales are always horizontal or nearly so, but this does not invalidate the general conclusion and may imply merely that deposition of chalcedony post-dated the tilting of the lavas in which it occurs.

Faults are notably scarce and, where they do occur, the downthrow is small. The faults are normal, with a hade of 60 to 70 degrees towards the downthrow side, and sometimes bear vertical or near-vertical slickensides. Several feet of fault-breccia is usually present. The following list includes all the known faults with a throw of 100 feet or more, the amount being quoted to the nearest 50 feet. About half the faults throw to the west and half to the east. The trend is north to north-east.

Graenafell	Downthrow to	W.	of 200 feet.
Fault on east side of Lakahnaus		E.	100–150
Fault one mile west of Breiditindur		W.	150
Hrafnadalur, west fault		W.	350 approx.
,, east fault		E.	150
Fault west of Vindháls		E.	250
Fault east of Vindháls		E.	100
Vindhálstindur		E.	150
Fault east of Sléttuskard		W.	200
Fault between Hesthaus and Snaefugl		E.	150
Sandvíkurskard		W.	100

[1] Einarsson (personal communication) has found bent pipe-amygdales in dipping lava in northern Iceland, indicating a lava flow up the present dip. Although searched for, examples of this have not yet been found in the Reydarfjördur area.

Dyke intrusion has seldom been accompanied by vertical movement of the wall-rocks, and the faults, most of which are well exposed, do not usually contain dykes, even though they are potential channels for dyke intrusion. The faulting is believed to be later than the dyke intrusion, and due to entirely different stress conditions. It probably took place at the same time as the regional tilting and was due to operation of the same forces.

The tilting has affected not only the lavas of the ground mapped, but also the rocks of the Thingmuli central volcano. Little is known of the subsequent geological history of eastern Iceland. At some stage after the tilting, a long period of erosion reduced the land-surface to a peneplain, and this was later uplifted 3000 to 4000 feet. Since the uplift, approximately two-thirds of the land above sea-level has been eroded away, and the peneplain is preserved only as small plateau-remnants on the summits or as a uniform summit-level. Glacial erosion is very marked.

At some time since the Ice Age the sea stood at a level relatively about 100 feet higher than at present. All the fjords have gravel terraces at their head, and estuarine clays are found west of Eskifjördur. Most of the side streams entering the fjords have a gravel delta standing about 100 feet above sea-level, for example that above the town of Reydarfjördur. Some of the headlands have a wave-cut bench at 50 to 100 feet, for example, east of Neskaupstadur, at Mónes on Bardsnes, and south of Vadlavík. At Sandvík the old gravel bar stands 100 feet above the present bar.

IX. Discussion

A succession of volcanic rocks, with a thickness claimed to be 14,600 feet, has been described, and the evidence for this thickness will now be considered, and first whether the regional dip of 3 to 7 degrees is an original depositional dip and whether the lavas are possibly disposed like the foreset beds of a delta, in which case the measured thickness would be spurious. The available evidence indicates that the present dip is mainly due to tilting subsequent to the eruption of the lavas. Secondly, there is the possibility that the lavas belong to a series of overlapping shield volcanoes and the thickness in any one place, although considerable, therefore much less than 15,000 feet. The evidence is against this possibility, for not only are the measured dips constant in direction and amount in the 30 miles from Gerpir to Fagridalur, but there is relatively little variation in thickness of each lava group in the ground mapped.

The observed variation in thickness almost always involves an increase in the direction of dip, in several lava groups quite marked. Examples are the lavas between the Grjótá olivine-basalt group and the Reydarfjördur acid tuff, which thicken from 400 feet on Innra-Hólafjall to 1000 feet on Sómastadatindur; the lavas between the Kollur and Graenavatn porphyritic groups which thicken from 300 feet on Sómastadatindur to about 700 feet at the head of Reydarfjördur; and the lavas between the Bardatangi tuff and the base of the Gerpir porphyritic group, which increase from 950 feet on Gerpir to 1100 feet at Vadlavík.

Although most groups of lavas are not exposed over more than three or four miles in the direction of dip, buried shield volcanoes would almost certainly be detected, for a slope of only 5 degrees on the flanks of a

shield volcano would show in section as a change of 450 feet per mile in the thickness of its lavas, and by considerable variations in the direction and amount of dip.

Where a central volcano does occur (Thingmuli in the ground west of Fagridalur), its existence is very clear. Dips in its lavas are very variable and sometimes high; the lavas include a great bulk of rhyolite and andesite; pyroclastic rocks are developed on a considerable scale; there is a large central area of drastic hydrothermal alteration; and dykes are associated with the lavas in great abundance, accompanied by a host of cone-sheets and other minor intrusions.

It may be concluded, then, that flood-basalt eruptions, mostly from fissures, took place over a very long period of time and resulted in the accumulation of some 15,000 feet of lavas. There is evidence of a small central volcano in the Sellátur area, where acid and intermediate lavas were poured out in bulk and a marked concentration of dykes occurred. The central volcano of Thingmuli was built up on the platform of lavas described in this paper.

One noteworthy feature of the lava pile is the absence of rhythm in the sequence of lava types. Tholeiites, olivine-basalts and porphyritic basalts follow each other with little sign of regularity, and there is no evidence of any systematic change with time in the composition of the magma. Moreover, acid magma seems to have been available in eastern Iceland during the greater part of its volcanic history (Hawkes 1924), and five main episodes are now known.

The lavas are of subaerial origin, and thin sand or dust layers between the flows appear to indicate a windy climate and perhaps near-arid conditions, such as those which prevail in the interior of Iceland today, where rain-water soaks almost immediately into the porous lavas. The almost complete absence of any evidence of penecontemporaneous erosion and the extreme rarity of conglomerates in the lava pile point to the same conclusion.

Acknowledgments.—The writer is indebted to the University of London Central Research Funds Committee for grants for the field work, and to the National Research Council, Reykjavík, for permission to undertake this study in Iceland; to Dir. Thorbjörn Sigurgeirsson and Professor Trausti Einarsson, Professor H. H. Read, Dr. J. Sutton and colleagues in London, and Professor L. Hawkes, for their help and encouragement; and to the inhabitants of the Reydarfjördur district for their kindness and hospitality.

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EXPLANATION OF PLATES XVIII & XIX

PLATE XVIII

Above : Nípukollur cliff (north-east of Neskaupstadur) from Bardsneshorn. The cliff is some 2600 feet high and contains approximately 80 basalt lava flows.

Below : Vindháls from near Lakahnaus. The fault between Vindháls and Grákollur is shown by the broken white line.

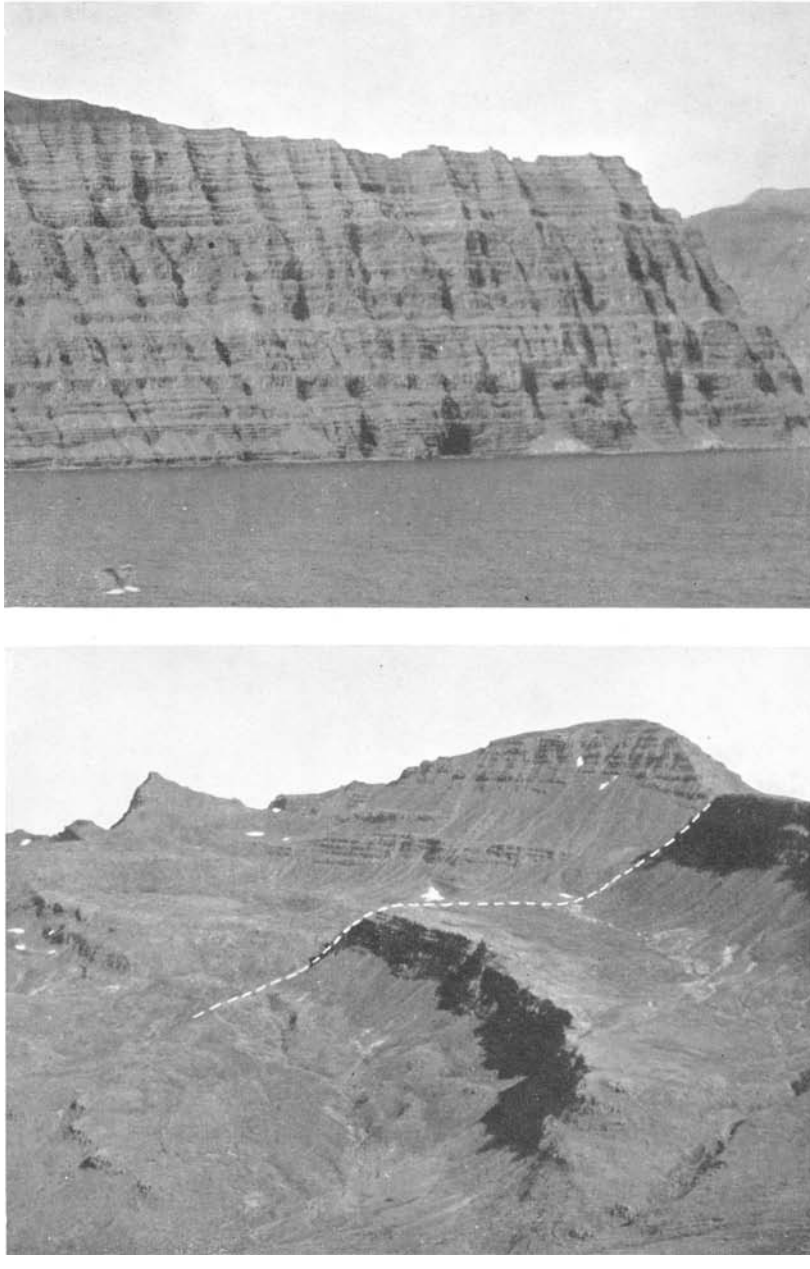
PLATE XIX

Geological map of the Reydarfjördur area of eastern Iceland. Scale, 1 : 100,000, or 1 inch to 1½ miles approx.

DISCUSSION

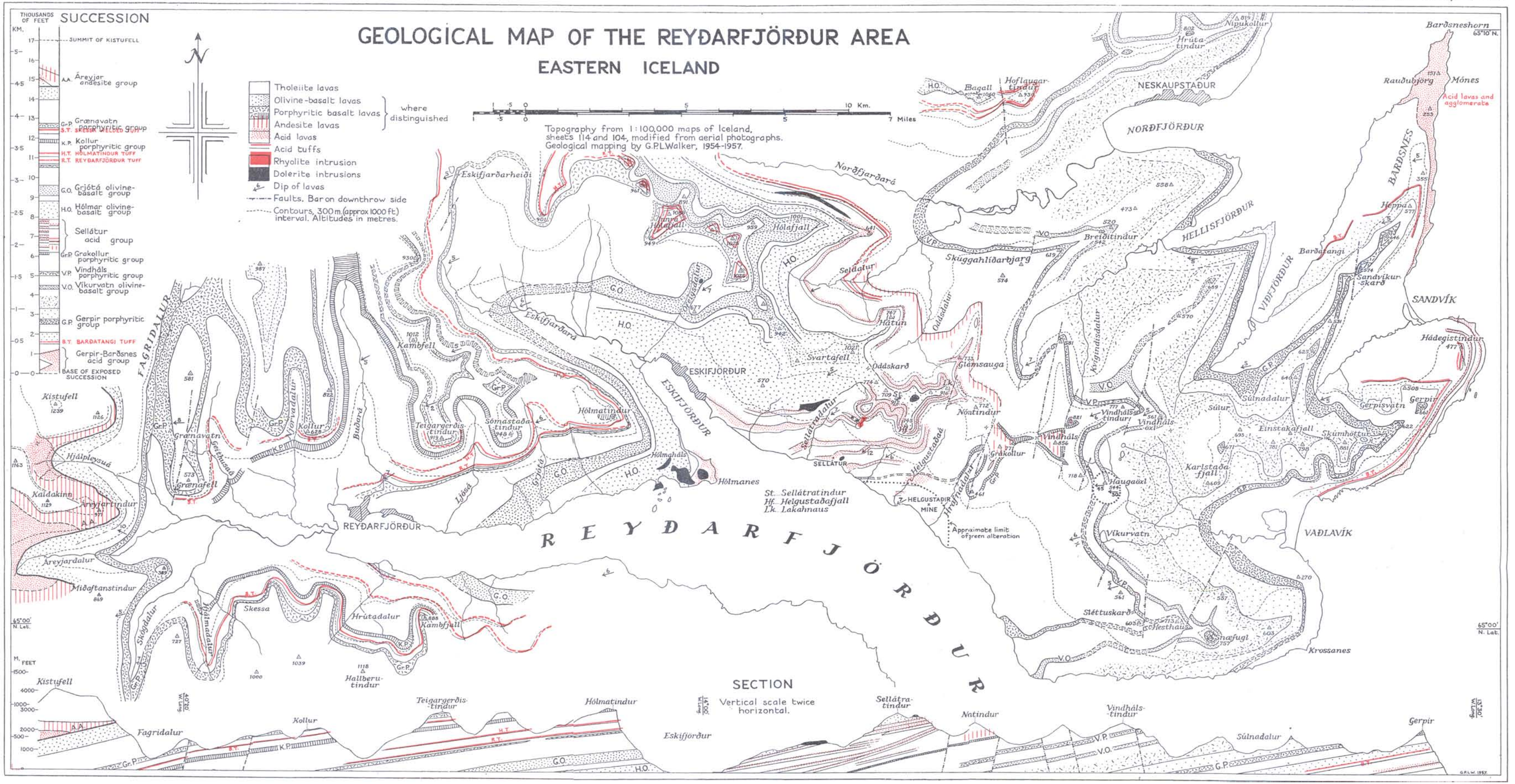
The PRESIDENT (Professor HAWKES) said that the igneous rocks exposed in the east of Iceland comprised a more variable volcanic sequence than that of any other remnant of the Brito-Icelandic province, and he welcomed the beginning of the mapping of this hitherto neglected area. The results would be of much value in the understanding of one of the great periods of igneous activity in earth history. He had long ago drawn attention to the widespread occurrence of acid volcanic rocks throughout the area and had suggested that extrusion of acid material might have continued *pari passu* with that of basic lavas during the long history of volcanism recorded in the pre-Quaternary rocks. With the completion of Dr. Walker's mapping, this question should be settled.

There was as yet no reliable evidence regarding the precise age of the volcanism. One conclusion to be drawn from Dr. Walker's present work was that at the eastern coast of Iceland there was at one time at least 15,000 feet of rock above that now exposed there at sea-level. The removal of this great thickness required a prolonged period of erosion and this must be taken into account in considering the later history of volcanism. He noted that the general strike of the dykes and faults was



Tertiary Basalt Scenery, Eastern Iceland

GEOLOGICAL MAP OF THE REYÐARFJÖRÐUR AREA
EASTERN ICELAND



at a considerable angle to that of the lavas, and he asked the author to comment on this.

Dr. D. A. ROBSON asked whether Dr. Walker had found any evidence of vertical movement associated with the fissures into which the dykes were intruded.

Dr. F. DIXEY thought that a comparison of the volcanic succession of eastern Iceland with the great basic outflows of the upper Karroo or Stormberg (early Jurassic) succession of southern Africa might be of interest. In the lower Zambezi region the lavas were about 4500 feet in thickness and comprised mainly basalt, but rhyolites also were well developed, near the top of the sequence, to a thickness of about 400 feet. Again, in this region, although the basalts were essentially of the fissure type, some contemporaneous volcanoes had been recognized. The source of the acid lavas was probably represented by intrusions of syenite which broke through the basalts; carbonatite pipes of the same period of activity also cut the lavas. Finally, innumerable dykes and sills of dolerite occurred in the sediments underlying the lavas, and an impressive dyke-swarm cut the basement rocks (Pre-Cambrian) against which the Karroo sequence was faulted; for example, along the Cholo fault-line scarp limiting this Karroo area to the north-east, several hundred parallel dykes occurred within a distance of about 50 miles, and they gave rise to numerous narrow ridges running down the face of the scarp. They ran parallel with the neighbouring part of the East African coast.

Professor S. E. HOLLINGWORTH said that his own acquaintance with the Reydarfjördur area was a passing visit in connexion with a study of certain rhyolitic rocks in the Lodmundarfjördur area. He was therefore interested in the comparisons with the intrusive rhyolites mapped by the author. In the Lodmundarfjördur area there appeared to be strong deformation of the adjacent lavas as by forcible injection of a diapiric type, perhaps somewhat resembling the Sandfell granophyre mass described to the Society by the President in 1932. Were any comparable features present in the author's area?

The E.–W. extension of the crust implied by the great dyke-swarm appeared to be analogous with the N.–S. tension faulting and open fissuring in the Recent lavas of the Mývatn area to the north. It would appear that the crustal stresses were similar both in Tertiary and in Recent times.

He also asked what significance the author would attach to the presence of layers of palagonite referred to in the paper. Were these suggestive of a subaqueous origin, in contrast to the subaerial origin of the red dust layers between flows elsewhere in the succession?

The AUTHOR thanked the President for his remarks. The present work certainly tended to confirm that extrusion of basic and acid material had proceeded side by side in eastern Iceland, and both basic and acid magmas must have been available in bulk for extrusion throughout much of the volcanic history of the area. He hoped that some use could be made of the numerous plant beds found between the lavas in eastern Iceland to date the volcanism.

The departure of the general strike of dykes from that of the lavas in much of eastern Iceland might be partly accounted for by the lavas being tilted at some time subsequent to the intrusion of the dyke-swarm, but perhaps more important was the marked tendency of the dykes to be concentrated into sub-swarms trending towards central volcanic

complexes. Preliminary work indicated the existence of several dyke-foci in eastern Iceland, such as those of Thingmuli and upper Breiddalur, and the minor one of Sellátur. Mapping of the dykes over a much wider area would, however, be required before the distribution of dykes could be fully understood.

The author agreed with Dr. Dixey that the relations in southern Africa seemed to be broadly parallel to those in eastern Iceland.

In reply to Dr. Robson, the great majority of the dykes had no vertical displacement associated with them, and what displacement there was seldom exceeded five feet.

The author said that the only feature in Reydarfjördur area comparable with those in Lodmundarfjördur mentioned by Professor Hollingworth was the small area of uplifted basalts on Haugaöxl, and here the intrusion which was inferred to be responsible for the uplift was not exposed. In the Thingmuli central volcano west of Reydarfjördur the basalt lavas were very strongly deformed, similarly to those in the Lodmundarfjördur area.

The significance of the palagonite layers was not yet known. They were well-stratified beds traceable for several miles and showed current-bedding in places; they were probably deposited under subaqueous conditions.