The Breiddalur[1] central volcano, eastern Iceland

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CONTENTS

SUMMARY

The Tertiary central volcano of Breiddalur, the first to be described of several—perhaps many—such volcanoes in Iceland, has a volume of about 100 cubic miles of basic, intermediate, and acid lavas and pyroclastic rocks, with a maximum thickness of 5000 to 6000 ft. The basic lavas are unusually thin owing to the fact that they were erupted on a sloping surface. The central volcanicity contrasts with the flood-basalt fissure-eruptions of the surrounding

[1] Breiðdalur in Icelandic. The letter Ð, ð (pronounced as *th* in *there*) is here transliterated *D*, *d*, and Þ as *Th*.

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country; at times the volcano stood up as a cone above the flood-basalt plains, but flood-basalts were all the time being erupted; they were interdigitated with the products of the volcano (so strikingly that the term 'cedar-tree volcano' seems appropriate), and later completely buried it.

The core of the volcano is marked by a profusion of acid lavas, pyroclastic rocks, and minor intrusions; in it the rocks are drastically altered and show variable and sometimes abnormally high dips indicative of cauldron-subsidence. A swarm of dykes locally constituting as much as 20 per cent of the country passes through the core.

The rocks above the core probably in part occupy a crater or caldera; they include agglomerate containing blocks of granophyre, granite, and gabbro from inferred syngenetic intrusions below the volcano; a palagonite-tuff and breccia with basalt pillows, probably formed in a crater lake; two welded acid tuffs; and a thick rhyolite flow joined to its plug-feeder.

Acid rocks are mostly concentrated in or near the core, except for a spectacular group of parasitic rhyolites in which all stages in uncovering of the plug-feeders by erosion are seen. Simultaneous eruption of basic and acid magma from the same orifice is evidenced by one rock, which represents an emulsion of the two magmas, and also by a composite lava, with basic and acid components, which was erupted from a composite dyke.

1. Introduction

VOLCANICITY OF TWO CONTRASTED TYPES is known to be present in the Tertiary basalt regions of the North Atlantic: flood-basalt eruptions of regional extent from fissures, and localized central eruptions from major volcanoes. Geological mapping in the Reydarfjördur area in the summers of 1955 to 1957 revealed the presence there of both types of volcanism, and when the mapping was subsequently extended it became clear that there are several major Tertiary volcanoes in eastern Iceland. Each contains great volumes of acid rocks—lavas, tuffs, agglomerates, and small intrusions—together with andesites and basalts (Fig. 1). Acid lavas and agglomerates are confined to these volcanoes (Fig. 2).

The Breiddalur central volcano is a Tertiary strato-volcano, 5000 to 6000 ft thick in the middle, with a volume of some 100 cubic miles (400 km^3) of basic, intermediate, and acid lavas and pyroclastic rocks. At times it stood up as a cone, but while it was being built flood-basalts were issuing from fissures and covering the surrounding country; the products of the volcano interdigitate with these flood-basalts (Fig. 10). The volcano rests on flood-basalts, and was finally buried by them.

The envelope of flood-basalts is first considered, and then the volcano itself; the subdivision of the volcano adopted for descriptive purposes is shown diagrammatically in Fig. 3.

The work described is part of a regional investigation of the Tertiary volcanic rocks of eastern Iceland, of which the first contribution was a study of the Reydarfjördur area, some ten miles farther north (Walker 1959). It follows the pioneer work of Thoroddssen and, later, Hawkes and his co-workers. The general distribution of acid and basic rocks in the Breiddalur area was shown by Thoroddssen (1901), but since then no work appears to have been published on the area, apart from a recent study of the dyke-swarm and amygdale-minerals (Walker 1960).

The country is mountainous, with summits rising to a maximum of 1200 m (3940 ft). It is deeply dissected by erosion, the main valleys being Breiddalur, Nordurdalur, and that occupied by Berufjördur. Exposures are in general good, but the valley floors have broad spreads of alluvium, and screes or glacial debris conceal many of the higher exposures. Several small corrie glaciers survive in the area.

2. The envelope of the volcano

A three-fold subdivision of the basalts of the envelope has been adopted for use in

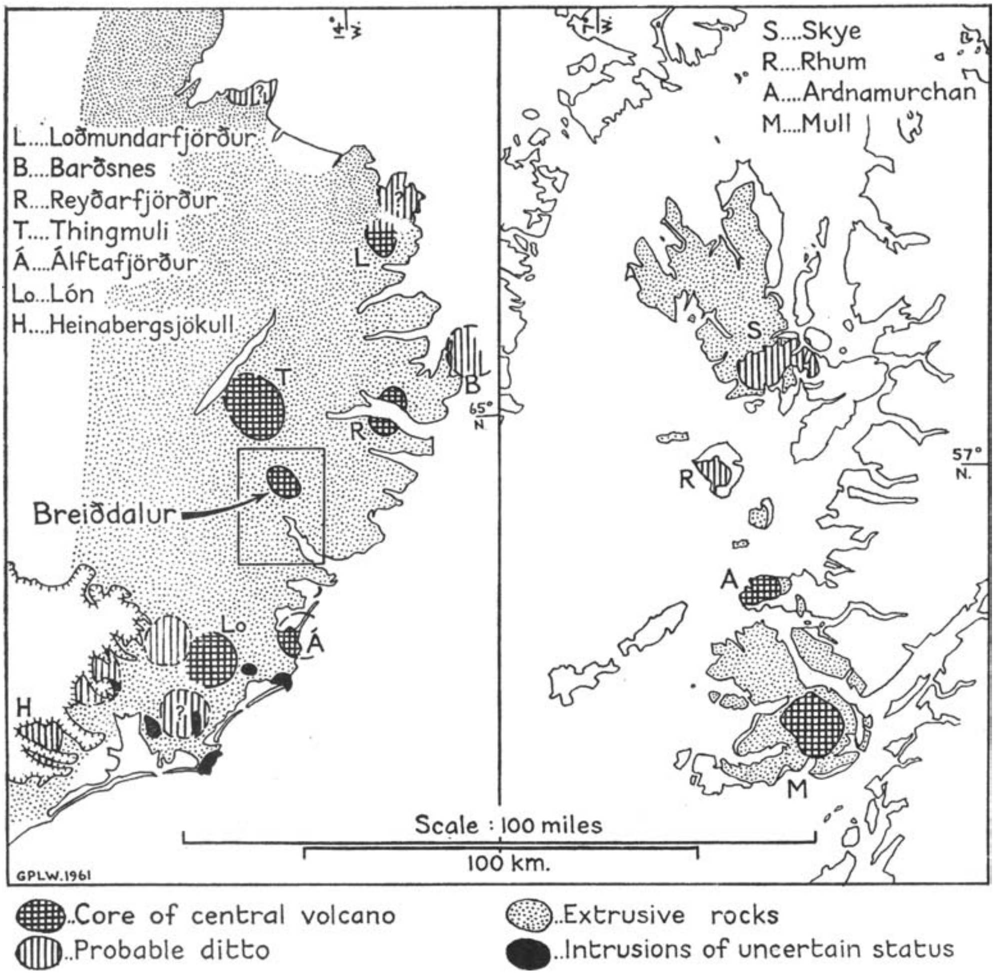


FIG. 1. Index-map of eastern Iceland (left) to show the location of the area described and the positions of other Tertiary volcanic centres. The Hebridean region is shown on the same scale (right) for comparison.

the field for stratigraphical mapping; it can also be correlated with the constitution of the rocks:

Tholeiite: very fine-grained and essentially non-porphyritic basalt containing not more than accessory amounts of olivine; commonly with quartz, chalcedony, and silica-rich zeolites in its amygdales.

Olivine-basalt: essentially non-porphyritic basalt containing more than accessory amounts of olivine; commonly with silica-poor zeolites in its amygdales.

Porphyritic basalt: basalt with more than about 5 per cent of phenocrysts of bytownite; phenocrysts of augite or olivine may also occur in smaller amount.

Although there is a complete transition between tholeiite and olivine-basalt, the amygdale-minerals provide a natural line of demarcation, for they are very sensitive to small variations in composition of the rocks (Walker 1960).

(A) BASALTS BELOW THE VOLCANO

The top of the Graenavatn porphyritic group (Walker 1959, p. 382), a conspicuous and readily mapped group of basalts very rich in feldspar phenocrysts, is a convenient horizon to mark the base of the Breiddalur volcano. There is evidence that the volcano started to form earlier: in places (e.g. near Tóarsel) the group rests on thin tholeiites that resemble the typical products of the volcano; and the Skessa welded acid tuff (Walker 1962), 300 to 400 ft below the Graenavatn group, may be one of the earliest products. Apart from this tuff, however, no acid or intermediate rocks are known below the Graenavatn group, which certainly lies near the base of the volcano. On either side of Breiddalur the group is directly overlain by the distinctive thin lavas of the volcano.

The outcrop of the Graenavatn group has been mapped along 50 miles of strike (Fig. 4). Contours for the top show the general westerly dip and the downward increase in dip that is general in eastern Iceland. The curving of the contours around the east of the central volcanoes of Breiddalur and Thingmuli is interpreted as due to sagging of the floor of each volcano; the amount probably exceeds 1000 ft for the Breiddalur and 2000 ft for the Thingmuli volcano.

Some 9000 ft of basalt lavas are seen below the Graenavatn group east of the volcano; the only acid rocks in this succession are tuffs that are believed to have originated from eruptions of other volcanoes. Most of the lavas are probably true flood-basalts.

(B) BASALTS THAT ARE THE LATERAL EQUIVALENT OF THE VOLCANO

The normal flood-basalt succession that is stratigraphically equivalent to the Breiddalur volcano (Fig. 6) is best seen south-west of Berufjördur and near Skáli The succession is:

(5) Mixed group: mostly tholeiite lavas but including thin groups of olivine-basalt and porphyritic basalt. It is uncertain at what level the lavas cease to be time-equivalents of the Breiddalur volcano and are younger than it.

(4) Fossárvík porphyritic group: over 800 ft thick at Fossárvík, predominantly massive porphyritic basalt lavas. The phenocrysts are mostly small, and

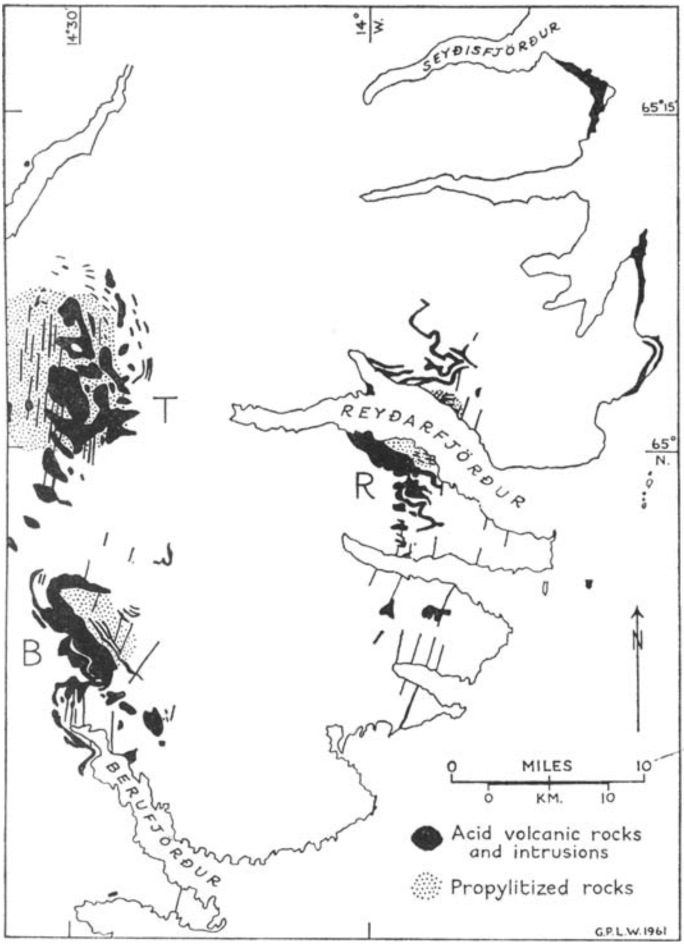


FIG. 2. The distribution of acid rocks in eastern Iceland (bedded acid tuffs in the flood-basalts omitted). The propylitized rocks in the cores of central volcanoes are also represented on this map. *B:* Breiddalur volcano; *T:* Thingmuli volcano; *R:* Reydarfjördur volcano.

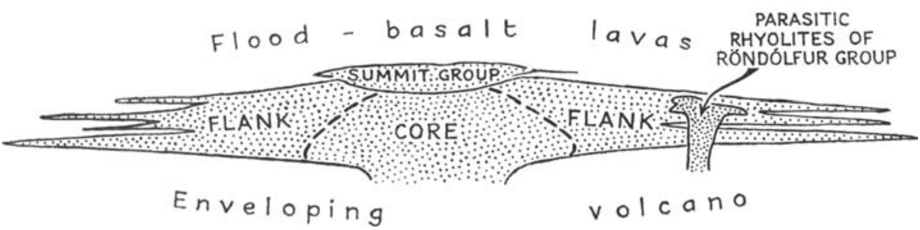


FIG. 3. Diagrammatic section across the Breiddalur volcano showing the subdivisions adopted for descriptive purposes.

seldom make up more than 20 per cent of the rock. The group includes several detrital beds and forms prominent cliffs overlooking Fossárvík and extending around Dys and Godaborg [a photograph, with the Fossárvík group nearly midway up, is reproduced by Tryggvason & White (1955, p. 30)] to the head of Hamarsfjördur. Zeolites are conspicuously abundant.

(3) Mixed group: some 700 ft of mixed olivine-basalt and tholeiite lavas.

(2) Fagridalur olivine-basalt group: up to 500 ft of zeolite-rich lavas. Named from Fagridalur, west of Reydarfjördur, where the group underlies the lowest andesites of the Thingmuli volcano. [Although stippled on pl. 1 in Walker (1959) the group was not named in that paper.]

(1) Group of tholeiite lavas, approximately 500 ft thick, resting on the Graenavatn porphyritic group.

The flood-basalts up to and including the Fagridalur olivine-basalt group are exposed north-east of the Breiddalur volcano, but the higher parts of the succession are replaced by the lavas of the Thingmuli central volcano, which is almost contiguous with the Breiddalur volcano.

(c) BASALTS ABOVE THE VOLCANO

Two of the olivine-basalt groups that occur in the mixed group (5) (above) have been mapped. The upper and thicker of the two, the more persistent, has been named the *Heidarvatn group* from the lake of that name. At Heidarvatn it consists of 300 ft of zeolite-rich olivine-basalts and subordinate porphyritic basalts, and forms a prominent cliff around the head of Breiddalur. South of the Fossá the group thins to about 100 ft of thin *pahoehoe* flow-units, standing on a prominent bench eroded on a thick underlying detrital bed. The group is very thin in the Hvítá, and south of there loses its individuality. It extends only a short distance northwards from Heidarvatn before terminating against the Thingmuli volcano.

3. The relationship between the volcano and its envelope

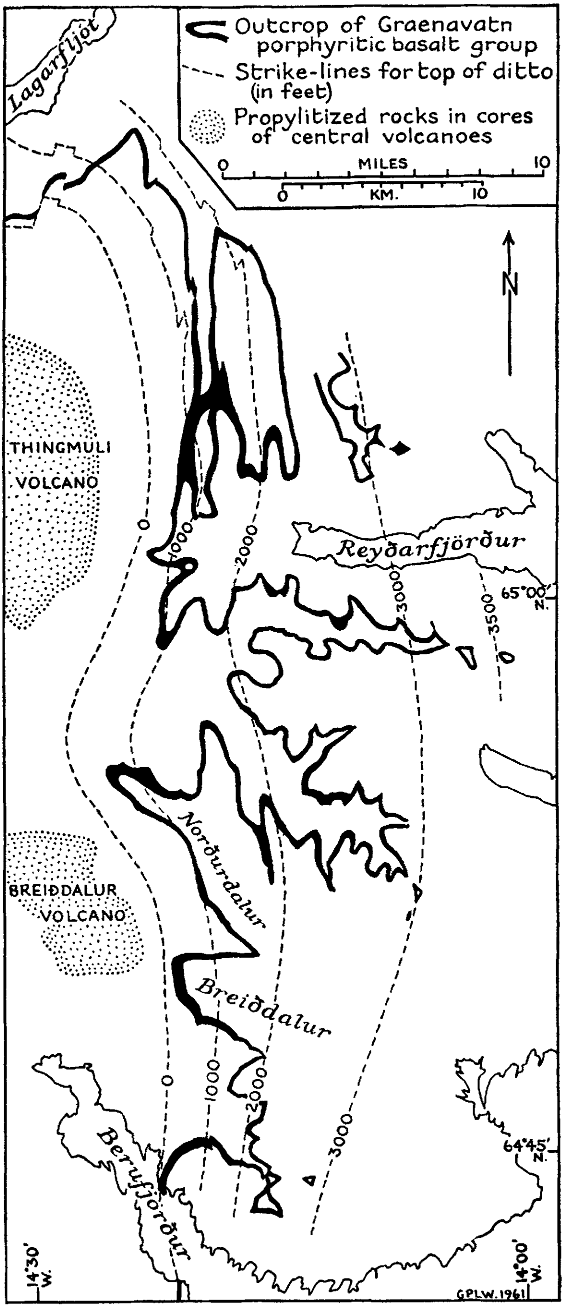
The products of the Breiddalur volcano are distinguished from the flood-basalts of its envelope by the difference in dip and individual thickness of the lavas and by the presence—locally the abundance—of acid and intermediate rocks in the former.

These relations are most clearly seen at the head of Berufjördur, on the southern slopes of Ófaerudalsnafir (Pl. 5). The lavas from the volcano here have a south-westerly dip of 10° to 15°, in contrast to the 6° to 7° of the adjacent flood-basalts.

The tholeiite lava-flows that form a large part of the Breiddalur volcano are unusually thin: the average thickness is less than 15 ft, in contrast to the tholeiite flows in the flood-basalt succession, which average about 45 ft[1] (Table 1). Part of

[1] The average thickness of 33 ft cited by Walker (1959, p. 370) includes many thin lavas from probable central volcanoes of the Bardsnes and Reydarfjördur centres. When these thin flows are omitted, the average thickness is about 45 ft.

FIG. 4. Outcrop map of the Graenavatn porphyritic basalt group, and contour-lines drawn on the top of the group, in relation to the central volcanoes of Breiddalur and Thingmuli.



the 10° to 15° dip at the head of Berufjördur almost certainly represents an original depositional slope, and the thinness of the lavas is attributed to their eruption on the sloping flanks of the volcanic cone.

The thickness of a lava and the slope are closely related. Other things being equal, lavas erupted on to a level surface tend to assume a standard thickness, which is related to the viscosity of the lava. For Icelandic tholeiites this thickness is about 45 ft; for olivine-basalts, 20 ft. The same lava erupted on a sloping surface assumes a reduced thickness which decreases as the angle of slope increases. Striking examples of unusually thin lavas are seen in some of the post-glacial basaltic shield volcanoes of Iceland, such as Skjaldbreidur and Theistareykjabunga (e.g. at Ásbyrgi), where the angle of slope varies from 1° to 7°.

TABLE 1: *Thickness of tholeiitic lavas*

FLANKS OF THE VOLCANO	Number of flows	Total thickness (feet)	Average thickness (feet)
Vadhorn	50	700	14
East side Hnausafjall	25	450	18
South side Geldingabotnar	35	450	13
South-west face Tó	35	about 400	11
North of Thorgrímsstadir	9	110	12
North-west of Thorgrímsstadir	15	240	17
Lower Floguá	9	150	17
Selá	about 18	250	14
Eastern ridge of Skridufjall[1]	23	180	8
Svartagil	23	270	12
Total	242	3200	av. 13
FLOOD-BASALTS			
Flanni, Seydisfjördur	12	650	54
Borgarnes, Seydisfjördur	22	1190	54
Njörvadalsá, Reydarfjördur	28	1390	50
Sómastadatindur, Reydarfjördur	21	1040	50
Hólmatindur, Reydarfjördur	26	1390	53
Vídfjardarmuli, Vídfjördur	19	460	24
Saudtindur, Vadlavík	12	420	35
South Sauddalsfjall, Fáskrúdsfjördur	24	1030	43
Fleinsdalur, Fáskrúdsfjördur	32	1440	45
South Graenafell, Breiddalur	30	1150	38
Merkidalur, Breiddalsvík	20	1130	56
South of Fossárvík, Berufjördur	20	900	45
Total	266	12 190	av. 46

[1] The most striking group of thin tholeiites is that, some 300 ft thick, resting on the Graenavatn porphyritic group on Skridufjall and Dísarstadafell. The group is a succession of *pahoehoe* flows or flow-units averaging 5 to 10 ft thick, and many units are less than 5 ft. The units are mostly without reddened tops, unlike the majority of lavas in eastern Iceland, and the thin detrital beds so frequently intercalated between successive flows are missing; it is thus uncertain to what extent they are distinct lavas or merely *pahoehoe* flow-units, and they have accordingly been omitted from Table 1.

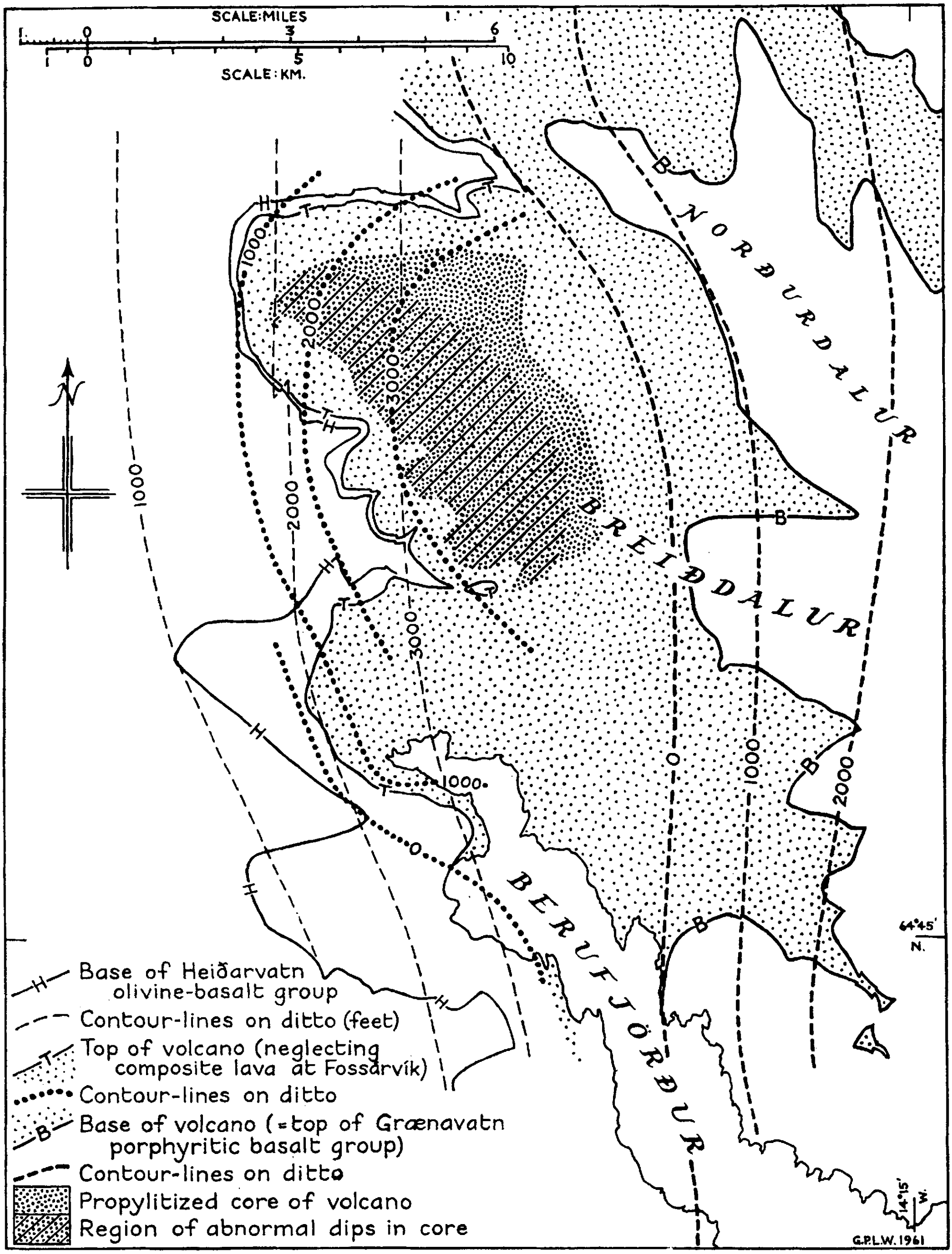


FIG. 5. Structural map of the Breiddalur volcano, with contour-lines drawn on the base and top and on a horizon in the flood-basalts overlapping the volcano.

To anticipate, the pattern that emerges is that of a central volcano, whose products are for the most part distinguishable from the flood-basalts that completely enclose it. In part these flood-basalts are banked up against the sides of a volcanic cone; in part they are the lateral equivalents of the lavas from the volcano, and the two interdigitate.

(A) BERUFJÖRDUR

Interdigitation of the lavas of the volcano with the envelope can be demonstrated in the Kelduskógar–Skáli–Eyvindarnes–Urdarteigur area. The section of basalts in the Hvítá includes, at 400 ft, a single 40-ft flow of basaltic andesite. This flow soon terminates southwards, but northwards it is joined by others of similar composition, and on Eyvindarnes, a mile to the north, over 200 ft of basaltic andesite is seen. A second group of some 200 ft of basaltic andesites west of Eyvindarnes is unrepresented in the Hvítá. The 100 ft of olivine-basalts that separate the two andesite groups fail to persist to the north shore of the fjord near Kelduskógar.

Lower in the succession, the Fagridalur olivine-basalt group is about 500 ft thick west of Skáli and at Urdarteigur. Traced northwards and eastwards it rapidly becomes attenuated; on the north-eastern ridge of Skridufall, for instance, it is reduced to 150 ft, and in the northern part of the Skriduá to less than 100 ft.

Interdigitation of the lavas is equally well seen on Fossárfell. The Fossárvík porphyritic group thins rapidly northwards. This thinning apparently takes place partly by its being banked up against the thin basalts of Leynistangi, and partly, on the steep north-eastern face of Fossárfell, by interdigitating with rhyolites (including a composite flow) and tholeiites from the volcano. Two flows of porphyritic basalt, and perhaps some of the tholeiite flows, are the only representatives here of the Fossárvík group, and even they are missing on the opposite side of the fjord.

These exposures thus give a clear picture of flood-basalt groups thinning into the volcano and of groups of distinctive basaltic andesites and single acid lavas interstratified with them and rapidly thinning outwards from the volcano. Some of the tholeiites in the country south-west of Berufjördur may also be lavas from the central volcano, but they lack individuality and it is impracticable to separate them from undoubted flood-basalt tholeiites.

The southern slope of Ófaerudalsnafir is a dip-slope that is nearly the exhumed surface of the volcano, and over a vertical height of 2000 ft the flood-basalts overlap it. These exposures represent a stage in the history of the volcano when it stood up above the surrounding country as a topographic feature destined later to be buried by overlapping flood-basalts (Pl. 6c).

(B) BREIDDALUR

There is a considerable angular discordance above Thorgrímsstadir between flows of the volcano and the succeeding flood-basalts. The former generally dip north-west or north at about 10° to 15°, whereas the flood-basalts dip west at about 6°. The traces of the stratification on the mountainside are almost parallel, and the discordance is not apparent from a distance. It is, however, readily traced in the

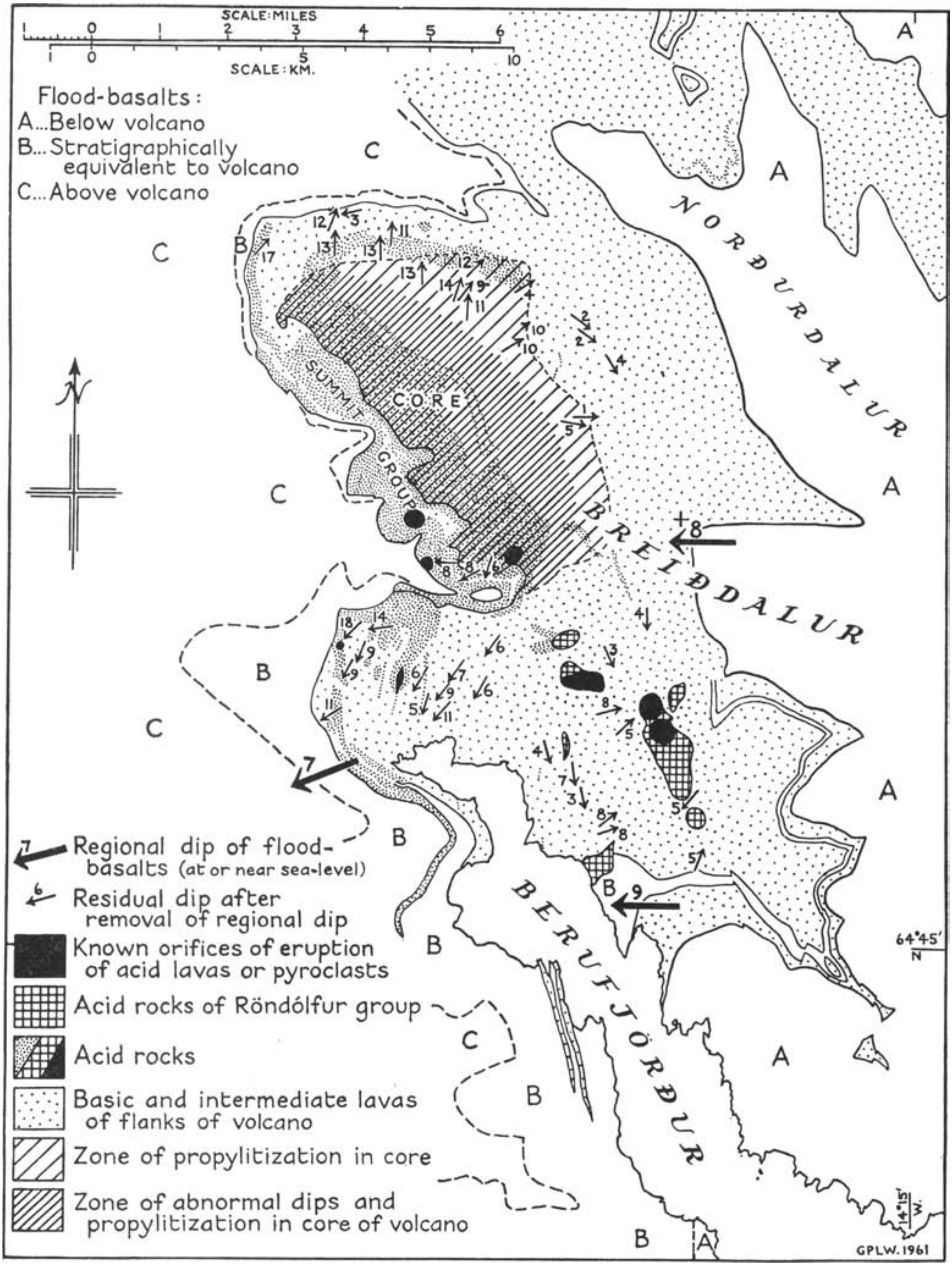


FIG. 6. Simplified geological map of the Breiddalur volcano, showing the probable original depositional dips of the rocks.

field: partly by the difference in dip; partly by differences in composition of the two groups, the andesite lavas and the numerous detrital beds of the volcano being absent from the flood-basalts; and partly by the difference in thickness of the individual lavas, those in the volcano being much thinner (Pl. 8a).

The flood-basalts north of Ófaerudalsnafir rest directly upon the great summit rhyolite flow of Matarhnjúkur, and the position of the top of the volcano is not in doubt. North-westwards from Dýristindur the upper parts of the volcano are largely concealed by scree or moraine, but in places (for instance, below Heidarvatn) the flood-basalts rest upon an acid lava. Along a short stretch on the northern slope of Kistufell a still higher acid flow is seen; this is apparently the lateral equivalent of a thin olivine-basalt group (that below the Heidarvatn group) which terminates against it. This acid flow rests upon tholeiite lavas that either belong to the volcano or are flood-basalts interdigitating with the latest products of the volcano; the latter seems more likely.

4. The flanks of the volcano

(A) THOLEIITE LAVAS

As noted above, the flanks of the volcano are made up predominantly of unusually thin tholeiite lavas. Their smaller thickness is attributed to eruption on the sloping flanks of the volcanic cone. In places there is clear evidence for this depositional slope. The regional dip of the flood-basalts in eastern Iceland is rather uniform in direction and amount (Walker 1960, fig. 1), and is due to tilting after the eruption of the individual lavas. The volcano must have been tilted by a like amount; Fig. 6 shows the residual dips of its lavas after correction for this regional tilt.

These residual dips are considered to approximate to the original slope of the volcano. They average 9° south-west at the head of Berufjördur, and about 9° north-east near Thorgrímsstadir, both outwards from the core of the volcano. The lavas near the base of the volcano on the eastern side show much lower and less consistent outwardly directed residual dips, averaging about 3°. These lavas represent an early stage in the building of the volcano when the slope of the flanks was very gentle.

The tholeiite lavas sometimes have a rubbly top of *aa* type, and at other times of *pahoehoe* type. Vesicles are abundant, particularly near the top of a flow, and a distinctive feature is their frequent large size. Vesicles a foot or more across are common; one at 200 ft in the Krosslaekur is 2 ft 9 in by 1 ft 6 in by 3 ft; another in the stream to the west measures nearly 2 ft.[1]

The vesicles in the lower exposures of the tholeiite lavas usually contain secondary minerals, notably quartz, chalcedony, and the more silica-rich zeolites (mordenite, stilbite, and heulandite, with some epistilbite and scolecite) or sometimes

[1] Such giant amgydales are not rare in eastern Iceland. One on the shore of Berufjördur near Teigarhorn measures 4 ft by 3 ft 6 in. by 10 in.; one on the north shore of Álftafjördur near Melrakkanes is 2 ft 6 in. by 1 ft 6 in.; and one on the south shore of Fáskrúdsfjördur east of Vík measures 3 ft by 2 ft 3 in. All are in thin tholeiite lavas, probably from central volcanoes. Open lava tubes sometimes exceeding these dimensions are also found in these thin lavas.

apophyllite and calcite. Calcite and aragonite are conspicuous in exposures near the core of the volcano (Fig. 7), aragonite usually being paramorphed by calcite.

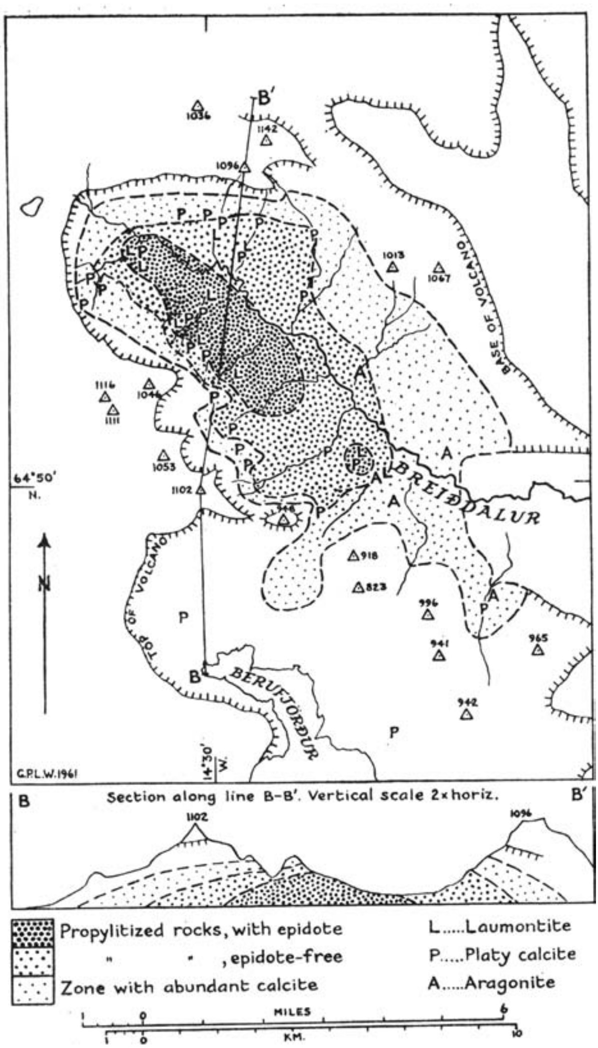


FIG. 7. The zoned hydrothermal aureole in and about the core of the Breiddalur volcano. The two innermost zones constitute the core.

(B) ANDESITE LAVAS

Andesite lavas are widespread constituents of the volcano. It is impossible to give an accurate estimate, but andesites and tholeiites are probably in the ratio 1 : 3 or 1 : 4. The andesite lavas are appreciably thicker than the tholeiites; twelve measured andesite flows above Flaga give an average thickness of 50 ft, and measurements in other parts of the volcano give a similar average.

The rocks are dense and black, with a more or less conchoidal fracture. There is a prominent flow-structure (Pl. 8c), along which the rocks tend to split into thin plates, although less strikingly than in the rhyolite lavas (Pl. 8b). A distinct sheen is seen on fractured surfaces along the flow-structure owing to the parallelism of the minute plagioclase crystals. The tholeiite lavas also show this, but differ in being noticeably coarser in grain and in showing little or no tendency to split along the flow-structure. In the tholeiites the flow-structure is normally parallel to the base of the flow, whereas in the andesites it is often conspicuously folded or contorted.

Andesites are particularly conspicuous in some parts of the volcano. The section above Flaga includes a group of sixteen or more flows totalling 1100 ft in thickness. The same andesite group is again seen on the dip-slopes south of Slöttur and Smátindur and west of Kelduskógar. It is particularly useful in interpreting the structure of the volcano because it demonstrates a marked thinning outwards, away from the core. The 1100 ft of andesites at Flaga is reduced to two flows totalling about 100 ft below Stöng and on Skridufjall, 3½ miles from Flaga, and only one 60-ft flow persists to Kerlingatindur, six miles from Flaga. The andesites on Eyvindarnes total about 400 ft, and thin southwards to about 40 ft in two miles.

These andesites show clearly that at least some of the products of the volcano thin markedly from the core outwards down the flanks. This thinning is achieved by a progressive reduction in the number of flows and not by a reduction in thickness of the individual members.

(c) ACID LAVAS AND PYROCLASTIC ROCKS

Acid lavas are important constituents of the upper parts of the flanks. Associated with them are acid tuffs which are probably products of the same eruptions. The acid lavas are well exposed in two areas: on the dip-slopes south of Ófaerudalsnafir and on the north face of Fossárfell; and near Thorgrímsstadir.

Correlation of the flows on Ófaerudalsnafir and Fossárfell is sometimes difficult, but at least three separate acid flows are known. The lowest has an exposed thickness of about 200 ft in the Illagil, and a little more than 100 ft on Fossárfell. In the Tröllaskrida it rests directly upon some 50 ft of poorly coherent acid tuff; in the Illagil several thin andesite flows intervene.

The lowest rhyolite is seen also in the Selá, and the outcrop follows the Selá downstream to terminate at 200 ft in the Illagil. The Selá exposures are probably of two separate rhyolites, and at one point, at 1000 ft, the plug-feeder of one is seen. The exposed part of the plug is funnel-like and cuts across a number of thin basalts. The rhyolite in the Selá exposures, as elsewhere, has a thick upper layer of green pitchstone breccia, and is sensibly non-porphyritic.

The middle of the three acid flows on the northern face of Fossárfell is a composite flow, with a basal layer of porphyritic basalt averaging 5 to 10 ft thick, and an upper layer averaging 100 to 150 ft of slightly porphyritic rhyolite rich in xenoliths of the porphyritic basalt. The rhyolite has a green pitchstone top. A zone of mixed rocks occurs at the contact between the basalt and rhyolite. The flow is composite in character in all exposures from the Berufjardará to the Fossá. Raudafell, opposite Fossárfell, is in part an outlier of this composite flow; the basic lower part and zone of mixed rocks can be traced round the north and west sides of the hill. Raudafell also marks the site of extrusion of the flow; the rocks dip inwards, and at the southern end of the outlier the western margin (the eastern is obscured by scree) plunges steeply into a composite dyke which is more or less continuously exposed for some 700 ft below the base of the flow. The central and upper parts of Raudafell and the middle of the dyke are of non-xenolithic rhyolite, unrepresented in the Fossárfell exposures.

The uppermost of the three rhyolite flows on Fossárfell attains a maximum thickness of 400 ft and it is directly overlapped by flood-basalts. The flow can be traced north-westwards as far as the Selá, where it rests upon a thick flow of porphyritic basalt (the non-composite termination of the composite lava) that is itself seen to be banked up against the termination of the Selá rhyolite flow. This uppermost rhyolite flow is distinctive in being relatively rich in feldspar phenocrysts.

Several rhyolite flows are seen on the northern flanks of the volcano. The most prominent, exposed above Thorgrímsstadir, has a maximum thickness of about 600 ft. It rests on a green acid tuff up to 100 ft thick, and is overlain by an acid tuff that locally exceeds 200 ft. A second and higher rhyolite is seen at one point, and the remainder of the succession consists of andesites and thin tholeiites, with intercalated acid tuffs and other detrital beds. The main rhyolite flow appears to terminate west of the Hesthalsá, and probably rests upon, or is banked up against, the thick pyroclastic accumulation in that stream. At the other extremity, rhyolite is exposed on Rauditindur but terminates between there and Seldalur; the extent of the flow from west to east is thus about three miles, and the average thickness is about 400 ft. Another rhyolite flow higher in the succession below Heidarvatn has flood-basalts resting on it. A small explosive vent is seen on the slopes north-east of Thorgrímsstadir, with acid tuffs and agglomerate cut by small rhyolite intrusions.

Although acid lavas are prominent in the upper part of the flanks of the volcano, only one has been encountered in the lower part: that of Geldingabotnar, about 100 ft thick, some 450 ft above the Graenavatn porphyritic group. This scarcity may be real, which would imply that acid eruptions were a late feature of the history of the volcano. Alternatively the non-exposure of early acid lavas may be due to an accident of erosion; there are no exposures of the lower parts of the volcano in those parts close to the core, where acid lavas are most likely to occur. The presence of acid tuffs at several horizons low down in the volcano suggests that acid lavas were in fact, erupted at an early stage. The Skessa welded acid tuff, below the Graenavatn porphyritic group, may be one of the earliest products of the Breiddalur volcano. Of the other acid tuffs, one, 30 ft thick and locally rich in feldspar crystals, rests upon the Graenavatn group in the Skriduá; another, 5 ft thick, is seen at 800 ft in the Skriduá. It contains some plant remains.

5. The core of the volcano

The rocks that are considered to constitute the core of the volcano occupy about 15 square miles of upper Breiddalur, and the limits of the core are rather arbitrarily defined by the extent of a zone of intense alteration (propylitization) of the rocks. The following evidence shows that the area thus delineated does include the true core of the volcano:

(1) The basalts and andesites north and south of the core at approximately the same level dip outwards from it. The residual dips, corrected for the regional tilt, reveal a general outward dip on the eastern side of the core also (Fig. 6).

(2) Contour-lines drawn for the base and top of the volcano (Fig. 5) show that it attains its greatest known thickness (5000 to 6000 ft) in the vicinity of the core.

(3) Pyroclastic rocks are developed on an unusually large scale in the core. The thickness of acid tuff and agglomerate in Blágil appears to be of the order of 2000 to 3000 ft, and some of the blocks in the agglomerate measure 10 ft in diameter and cannot be far from their source. Moreover, one agglomerate vent that is clearly the source of some bedded agglomerate between the lavas and one or two rhyolite plugs feeding an acid flow pass through the core, demonstrating that at least some eruptions took place there.

(4) The propylitization could have been accomplished only by the passage through the rocks of great quantities of hot fluids, which implies the existence of a major source of heat. Similar alteration is seen around intrusions of granophyre and gabbro in other parts of Iceland. Intrusions concealed below the core may be responsible for the alteration in Breiddalur and may occupy the magma-chamber of the volcano. Direct evidence for their existence is provided by the blocks of granophyre, granite, and gabbro in agglomerate on Berufjardartindur (see below); the acid intrusive sheets exposed in the core are probably offshoots.

(5) Acid volcanic rocks are present in great volume and probably make up more than half of the total volume of the core.

(6) There is a narrow but very intense dyke-swarm associated with the volcano, which passes through the core (Fig. 8). Acid and composite members of the swarm are confined to the vicinity of the core.

(7) The dips of the rocks in the core are often abnormally high and very variable in direction and amount. No simple pattern of folding can account for them, and they appear to be due to collapse of the centre of the volcano: a form of cauldron-subsidence.

For four reasons the present interpretation of the structure of the core is incomplete. First, the rocks have been drastically altered, and basalts and andesites converted into pale green rocks that are sometimes difficult to distinguish in the field from rhyolite or acid tuff. Secondly, the core is not well exposed; the broad alluvial floor of Breiddalur and the gravel-fans from the tributary streams conceal one-third of its outcrop, and the hillsides are often drift-mantled, exposures being largely confined to the stream-gullies. Thirdly, there is a general lack of distinctive stratigraphical horizons in the core. Fourthly, it is often difficult to decide whether a particular body is a lava-flow or an intrusion.

(A) STRATIGRAPHY AND STRUCTURE

The lowest rocks in the core are thin tholeiites and andesites exposed in the lower courses of most of the tributaries of Breiddalur. These lavas include some of the andesites of the Flaga group. A few porphyritic basalts are also seen, rich in phenocrysts of plagioclase and olivine, the latter pseudomorphed by carbonate.

Above comes a series of thick rhyolites and acid pyroclastic rocks, totalling apparently at least 2000 ft thick in Blágil. The rocks include coarse agglomerate in which blocks of rhyolite and basalt up to 10 ft in diameter are found. Such coarse agglomerate must lie very near the eruptive vent, or in the vent itself. The rocks also include finely laminated tuffs showing slump-structures; such rocks were probably deposited in water, perhaps in a crater lake. The stratigraphical equivalent of this pyroclastic accumulation on the north side of Breiddalur is the more modest thickness of tuffs associated with the Thorgrímsstadir rhyolite lava; acid rocks here reach a combined maximum thickness of 1000 ft.

One feature of much of the core is the steep dip: up to 35° in the basic and intermediate lavas in the Innri-Ljósá and other streams, and 50° to 70° in the pyroclastic rocks in Blágil. Pyroclastic rocks may have an original depositional slope of 30° to 35°, but certainly not 50° or more (the laminated tuffs may originally have been almost horizontal), and it is unlikely that the basalts had an original dip of more than about 15°. In this region of abnormal dips the rocks must therefore have been tilted in different directions and by different amounts after their formation.

There is evidence that the region of abnormal dips has suffered subsidence. The andesite group above Flaga dips south-west at 7° to 10°, but a short distance west of Skardsgil the dip rapidly increases to 15° to 30°, and this increase must be due to downwarping in the area of the Ytri-Ljósá. The acid group above Thorgrímsstadir, if carried up-dip across Breiddalur, should occur 1500 to 2000 ft above exposures of stratigraphically equivalent agglomerate in Blágil, and the rocks in Blágil appear thus to have suffered downwarping by this amount. The dyke-swarm is appreciably less intense than would be expected in Blágil and some other parts of the core and, as discussed in the sequel, is more appropriate to an altitude some 1500 ft higher; it is inferred that a subsidence of this order has taken place since most of the local dyke-swarm was emplaced.

The variable direction of dip in the core must be the result of very irregular subsidence, greater at some points than at others. A form of cauldron-subsidence into the inferred underlying magma-chamber is probably involved, and the numerous intrusive acid sheets in the lower parts of the core are probably apophyses from this magma-chamber. The subsidence took place late in the history of the volcano, but before the eruption of the summit group. It is significant that no sign of ring-dykes or ring-fractures has been discerned; subsidence of a different type is involved at Breiddalur.

(B) MINOR INTRUSIONS

Many basic and intermediate dykes and sheets cut the rocks of the core. Most have suffered propylitization, but some are later. Most are non-porphyritic, but irregular intrusions of basalt with about 40 per cent of feldspar phenocrysts occur in the northernmost stream of Blágil. Andesite plugs include that forming the hill of Ketilhnjúkur, between the Innri- and Ytri-Ljósá; a plug-like dyke south of the

Hesthalsá; and an irregular body of pyrite-rich andesite at 1400 ft in the Ytri-Ljósá. The most remarkable intrusion is a gently inclined log-shaped body of hornblende-andesite, 10 ft in diameter, in tuff at 550 ft on the south bank of the Hesthalsá. The rock is almost unique for Iceland in containing hornblende phenocrysts.

A well-developed suite of acid and composite sheets is seen in the lower course of most of the streams entering Breiddalur from the south-west. These sheets have a general north-westerly strike and south-westerly dip and are possibly centrally inclined. The best-exposed, in the lower Innri-Ljósá, is about 50 ft thick and shows prismatic jointing normal to the margins. Texturally it is a fine-grained granophyre. The presence of pyrite and epidote shows that the rock has been affected by propylitization. These sheets persist outside the core: several are seen above Flaga, and a composite sheet 15 ft thick, with basic margins, is seen in a stream west of the Höskulsstadaá.

(c) THE ALTERATION OF THE CORE

The zone of propylitization includes all rock-types in the core. Basalts and andesites are changed to a pale green rock rich in calcite and chlorite and, in places, epidote. In the most extreme case, barely any feldspar survives alteration, and the pyroxene is entirely altered. Alteration most strongly affects the amygdaloidal upper part and base of a flow, as the porous rocks there allow free movement of the fluids responsible. Rhyolites within the zone of alteration are closely jointed and contain an abundance of disseminated pyrite, and the exposures are extensively ironstained owing to oxidation of the pyrite. Pitchstone is completely absent, but the green rocks found near the margin of some rhyolites are probably highly altered pitchstone.

The outer limit of the zone of propylitization is cupola-shaped. It rises northwards from 200 ft near Flaga to perhaps 1500 ft on Rauditindur; thence it falls to below 500 ft in upper Breiddalur, before rising to attain its greatest altitude of 2000 ft on the eastern ridge of Matarhnjúkur. It is likely that much of the dome, possibly as much as half of it, is concealed below Matarhnjúkur and Ófaerudalsnafir.

The core is mineralogically divisible into two zones (Fig. 7). In the inner zone, epidote is widespread in veins and amygdales and in the body of the rock. Also abundant are quartz, laumontite, and calcite, the last being commonly platy on (0001). In the outer zone, epidote is absent and laumontite is less prominent.

In addition to these two zones in the core, the basalt and andesite lavas in a broad zone around the core are very rich in calcite, including calcite platy on (0001) or with $(21\bar{3}1)$ or $(01\bar{1}2)$ very prominent. There is also an abundance locally of aragonite, occupying large amygdales and veins as radiating aggregates; most of it has since been paramorphed by saccharoidal calcite. Olivine-basalts in these three zones are free from zeolites.

These zones are interpreted as constituting a broad hydrothermal aureole round concealed intrusions of granophyre or gabbro below the core. Similar aureoles have been observed by the writer round some of the granophyre and gabbro intrusions of south-eastern Iceland and Skye. The zone of pneumatolysis of the Mull centre (Bailey & others 1924) is very similar.

6. The summit group

The summit group comprises up to 1500 ft of lavas and pyroclastic rocks, best seen on Berufjardartindur (subsequently referred to as BFT) and Matarhnjúkur, which overlie the core, sometimes unconformably, but are not involved in the propylitization. The group includes the highest-exposed parts of the volcano, and there are grounds for supposing that part of it occupies a crater or caldera. It is in turn overlain by typical flood-basalts, and the two have approximately conformable dip and strike.

Among the more interesting members of the group are an agglomerate rich in fragments of granophyre, granite, and gabbro, rocks which are nowhere exposed at the surface in this part of Iceland; a unique rock that is apparently an emulsion of acid and basic magma; a palagonite tuff and breccia containing basalt pillows; and two welded acid tuffs. A near-by vent constitutes the source of the agglomerate and of the 'emulsion rock'. The group is surmounted by a thick acid lava-flow, the summit rhyolite, which is seen joined to its plug-feeder or feeders.

(A) AGGLOMERATE, TUFF, AND 'EMULSION ROCK'

Below the north-eastern 'nose' of BFT, the lowest member of the summit group, resting on a pink rhyolite lava, is a thick bed of agglomerate. It is ungraded and crudely bedded, and contains an abundance of angular to subangular blocks, sometimes more than 5 ft in diameter, in an incoherent acid tuffaceous matrix. Rhyolite and pitchstone predominate among the blocks, but there is also much granophyre attaining almost the same dimensions, and there are less common blocks of granite and gabbro.

Striking evidence for the simultaneous eruption of acid and basic magma is supplied by a 20-ft bed in the middle of the agglomerate. In the field this bed appears to be a vesicular, grey, altered pitchstone. The rock contains an abundance of phenocrysts of bytownite and oligoclase and a few of forsteritic olivine. Angular blocks, seldom exceeding a foot in diameter, of the same rock-types that are encountered in the agglomerate are common; many are armoured bombs, with a thin coating of porphyritic basalt.

The bed is more likely to be a lava than a welded tuff. Microscopically the rock is seen to be an intimate mixture of a colourless acid glass, with a refractive index of about 1·50, and a fine-grained, near-glassy black basalt. The rock is interpreted as an emulsion of acid and basic magmas, both of which were porphyritic.

A mass of vent-agglomerate that cuts through the underlying rocks is probably the source of the bedded agglomerate described above. Within this vent, and apparently cutting it—exposures are not good enough to reveal the exact relationship—is seen a large mass of vertically flow-banded rock bearing phenocrysts of oligoclase, bytownite, and olivine, and fragments of rhyolite, granophyre, and other rocks. Microscopically this mass is closely similar to the emulsion rock that forms the bed in the agglomerate referred to above. It differs in being non-vesicular. It is seen 700 ft lower down than the bed and is clearly its feeder.

Traced westwards from the main exposure, the agglomerate passes into well-bedded acid tuff in the headwaters of the Ytri-Ljósá, where it attains a maximum thickness of about 400 ft. The tuff locally contains plant remains. Several thin basalt lavas interbedded with the acid tuffs thicken eastwards on the eastern ridge of Matarhnjúkur at the expense of the tuff. North-westwards from Matarhnjúkur there are few exposures, but the tuff appears to thin in this direction. There are indications of the existence of a considerable thickness of tuff north of Dýristindur, but much of the ground here is concealed by moraine and scree. The lowest members of the summit group north of Dýristindur are a rhyolite lava and, in some exposures, thin underlying andesite lavas.

(b) Palagonite tuff and breccia

A mass of palagonite tuff and breccia rests upon the agglomerate below the north-eastern 'nose' of BFT. Its estimated maximum thickness is 500 ft. The basal part is a well-bedded palagonite tuff, containing isolated boulders of rhyolite, granophyre, and other rocks similar to those in the agglomerate. The upper part is a palagonite breccia which is responsible for the overhanging cliffs of the 'nose'. In its typical development the breccia contains abundant amoeboid pillows of basalt, from several inches to several feet in diameter, with glassy chilled margins and sometimes with concentrically arranged amygdales. The pillows are enclosed in a breccia of basalt and basalt glass, the latter extensively palagonitized. Zeolites (phacolite, analcime, faroelite, levyne, stilbite, heulandite, and mesolite) are abundant in amygdales and in angular spaces in the breccia, and apophyllite, gyrolite, and calcite are also present.

The palagonite breccia is in part a pillow-lava and is thought to have a sub-aqueous origin. It is strikingly similar to some of the palagonite breccias in the Móberg Formation of Iceland, which are regarded by most workers as having been erupted in bodies of water (within ice-sheets). The BFT palagonite breccia probably originated in a crater lake.

The palagonite tuff and breccia thin rapidly southwards and westwards, although they are 100 to 200 ft thick in one of the headwaters of the Ytri-Ljósá. The rock is here a well-bedded tuff, lacking exotic blocks and basalt pillows. North and east of BFT a group of thick basalt lavas with aggregate thickness of as much as 300 to 400 ft rests upon, and is probably in part the lateral equivalent of, the palagonite tuff and breccia. The lowest flow is locally columnar. Some of the flows are of olivine-basalt and are quite unlike the typical products of the volcano. It seems more likely that these lavas, and the palagonite tuff and breccia as well, are flood-basalts that at this stage almost completely buried the Breiddalur volcano; this interpretation is adopted in Fig. 10.

(c) The Matarhnjúkur welded tuff

This tuff (Walker 1962) attains its maximum thickness of over 300 ft on Matarhnjúkur, and is believed to have originated from an eruptive orifice at the site of the present rhyolite plug there. It thins rapidly southwards to nothing. Traced northwards, it is 250 ft thick on Dýristindur, and extends at least as far as Baejartindur, where it is 60 ft thick. A second welded tuff, 5 to 10 ft thick, rhyolitic in appearance and conspicuously cavernous and spherulitic, is seen in the headwaters of the Ytri-Ljósá some 20 ft below the Matarhnjúkur tuff.

(D) THE SUMMIT RHYOLITE FLOW

The uppermost and scenically most conspicuous member of the summit group is the summit rhyolite. The outcrop of the flow is marked by crags that wrap round three sides of BFT (Pl. 6a) and extend westwards to Matarhnjúkur, thereafter being much less prominent. The western termination of the flow is ill-exposed on the scree- and moraine-mantled slopes of Ófaerudalsnafir; the eastern termination is seen at the eastern end of BFT, where 100 ft or more of acid tuff is banked up against it.

The present exposures of the summit flow, and those concealed below later basalts, cover 2¼ square miles, and the original extent can hardly have been less than 5 square miles (13 km^2). The maximum exposed thickness is 600 ft, and the average is perhaps 400 ft, which would give an original volume of the order of 0·4 cubic mile (1·6 km^3).

The flow is of almost completely non-porphyritic pink rhyolite; locally the top is a green pitchstone. The rhyolite is noteworthy for folding of the platy flow-structure. Other internal structures are also seen, and in places near the top remarkable tensional features are encountered, in which a solidified crust has been dismembered and fresh acid magma squeezed between the fragments.

A rhyolite plug on the northern face of Matarhnjúkur probably marks the source of the summit flow; exposures of plug and flow extend over a vertical height of nearly 1000 ft. In the lowest exposure, in the Innri-Ljósá, a near-vertical contact with small intrusive offshoots is seen between the rhyolite and the country-rocks. What appears to be a second rhyolite plug joined to the summit rhyolite appears south of the headwaters of the Ytri-Ljósá, where the base of the summit rhyolite falls some 200 ft and the contact and flow-structure parallel to it dip moderately to steeply inwards.

(E) STATUS OF THE SUMMIT GROUP

The summit group rests uncomformably on the rocks of the core and also, south of BFT, on the acid and basic lavas of the southern flank of the volcano. The group thickens rapidly from about 400 ft south of BFT to about 1500 ft, the maximum thickness being attained in the vicinity of the Ytri-Ljósá. South of BFT the summit rhyolite flow is the only member of the group, but in the Ytri-Ljósá and elsewhere a considerable thickness of tuffs and other rocks intervenes between it and the core.

It is not known whether the unconformity is due to erosion or whether it marks a discordance due to a major explosive eruption, but the latter seems more likely. The rocks give a distinct impression of having been deposited in a topographic basin. This, combined with the summit position of the group and the presence of vent-agglomerate and at least one substantial rhyolite plug, suggests that the summit group occupies a crater or caldera. The palagonite tuff and breccia with basalt pillows were emplaced in a crater lake.

7. The dyke-swarm

Basic dykes with a predominant north-north-easterly trend and an average thickness of about 10 ft are numerous in eastern Iceland, and there are convincing grounds for identifying the dykes as the feeders of the basalt lavas. The general distribution of dykes in the Berufjördur area has been considered elsewhere (Walker 1960). There is a narrow swarm of great intensity (dykes constitute over 10 per cent of the country along much of this belt) that passes through, but does not embrace, the core of the Breiddalur volcano (Fig. 8). The swarm attains its greatest known density in the lower course of the Stafheidará, Nordurdalur, where in a distance of one mile, measured across the trend of the swarm, 95 dykes are seen with an aggregate thickness of just over 1000 ft, indicating a dilation of almost 20 per cent. The average altitude of this exposure is 900 ft; the density of the swarm at sea-level here probably amounts to 25 per cent.

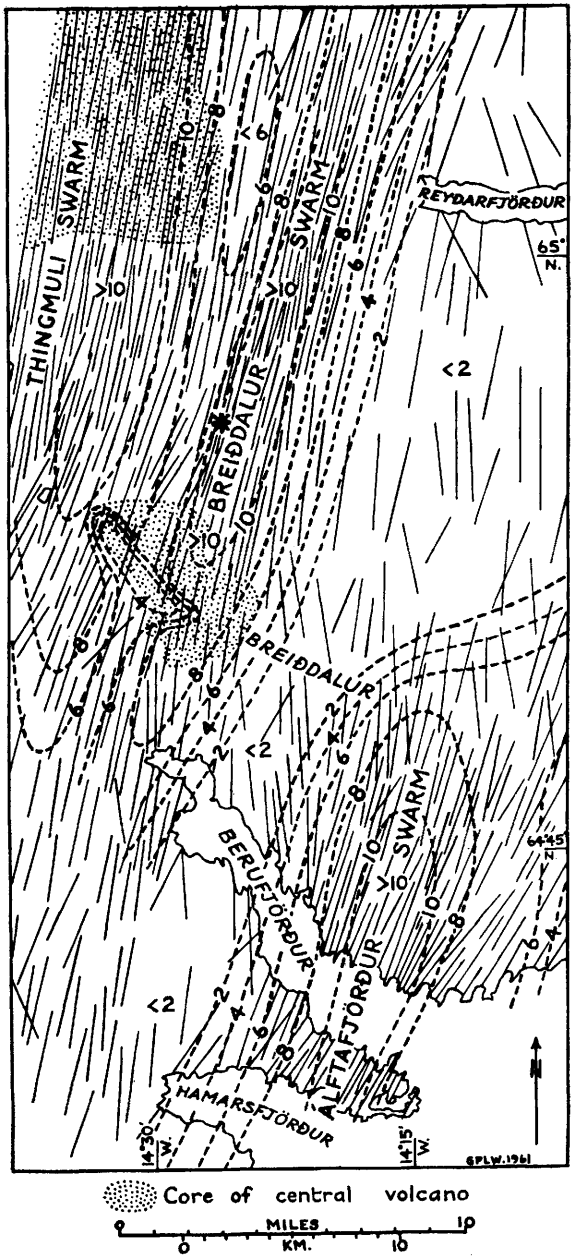
One apparent anomaly is the relatively low density of the swarm in parts of the core. Measurements have been made in twelve strips in a belt of country 2 to 3 miles wide trending parallel with the dyke-swarm through Blágil. The dilation amounts to 15 per cent at an average elevation of 800 ft in Nordurdalur, and about 6 per cent at 400 ft in the Berufjardará valley. Interpolation gives a dilation of 10 per cent at 800 ft in and near Blágil, in contrast to the 5 per cent actually measured. The explanation appears to be that the rocks in the core have sagged down since the majority of the dykes were emplaced. Measurements at 3000 ft on the ridges north and south of Breiddalur give an average dilation of 4 per cent. The measured dilation in Blágil is thus appropriate to an altitude of 2400 ft, which is 1600 ft higher than the measured exposures; downsagging by some 1600 ft is thus inferred to have taken place.

The diminution of the swarm to less than 8 per cent south-west of the Breiddalur centre is a consequence of the northerly strike and westerly dip of the flood-basalts; younger lavas are soon reached on following the axis of the swarm towards the south-west.

Each of the major Tertiary volcanic centres of eastern Iceland has an associated dyke-swarm, and parts of two other such swarms, related to the Thingmuli and Alftafjördur centres respectively, are shown on Fig. 8. These swarms closely resemble those associated with the Mull and other Tertiary volcanic centres in the British area (Richey 1938), and many other examples have been recorded. A large proportion of the basic lavas making up such volcanoes probably issued from flank fissures.

All three basalt types are represented in the dyke-swarm. Especially noteworthy is a group of dykes near the head of Berufjördur that is conspicuously rich in large phenocrysts of bytownite (up to 1·5 cm), with some associated olivine. Acid and composite dykes are well represented to a distance of 5 miles from the core of the volcano. They are appreciably thicker than the basic dykes; their average thick-

FIG. 8. Isopleths of the dyke-swarm, expressed as percentage dilation at sea-level. A few dykes are represented schematically to show the predominant trend. The three belts of high density each pass through a central volcano; the core of the Álftafjördur volcano lies several miles south of the area of this map. *: Stafheidará exposure, where the dyke-swarm attains its maximum density of 20 per cent at 900 ft altitude.



ness is about 40 ft. As noted above, one composite dyke, on Raudafell, is the source of a composite lava-flow. Andesite dykes also occur.

Basic and intermediate sheets are locally abundant in the lower parts of the volcano. Thirteen, with an average thickness of 2 ft, were observed in one 700-ft section on Geldingabotnar, and eighteen measured inclined sheets of vesicular andesite on the south face of Tó have an average thickness of 7 ft. Small intrusive sheets, irregular in form and often with well-developed prismatic jointing, are abundant in Svartagil. Three substantial sills of olivine-dolerite are also known in the area: one, with well-developed columnar jointing, forms a prominent feature east of Dýristindur; the basal part of a second, with conspicuous sheets and veins of dolerite pegmatite, occurs on the summit ridge west of BFT; and the top of a third, rich in phenocrysts of olivine and feldspar, occurs at the base of the north-eastern cliffs of Fossárfell.

8. The Röndólfur group of parasitic rhyolites

The outstanding scenic feature of the eastern half of the volcano is the prominent row of peaks, Röndólfur, Slöttur, Stöng, Smátindur, and Flögutindur. Each mountain has a pedestal of basalt and andesite lavas cut by agglomerate-bearing vents, and each is capped by precipitous and sometimes pinnacled monolithic masses of

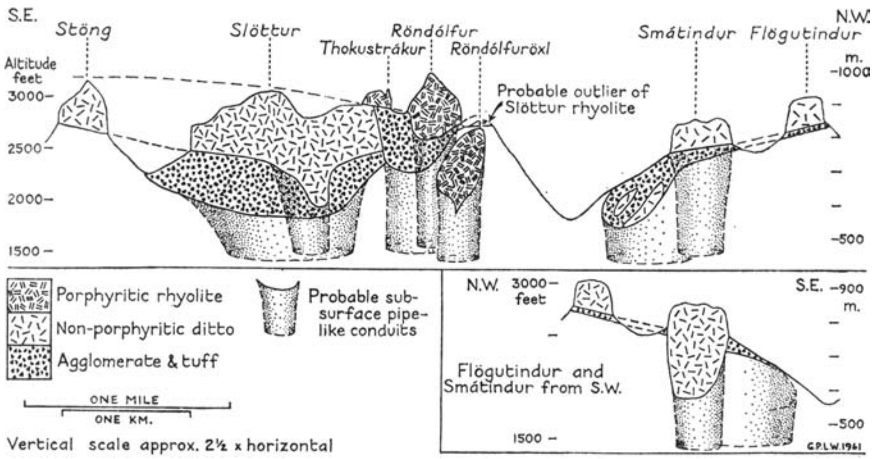


FIG. 9. Profile along the north-eastern side of the Stöng–Flögutindur ridge, showing the extent of exposures of pyroclastic rocks and rhyolites of the Röndólfur group. The probable sub-surface relationships are also shown in block-diagram fashion.

rhyolite. Rock faces are seen with rhyolite exposed over a vertical height of up to 900 ft. The mountains consist of unusually massive rhyolite lavas, probably originally dome-like in form, joined to their plug-like rhyolite feeders, which cut through the agglomerate vents. All stages are seen in the uncovering by erosion of these feeders (Fig. 9). Those below Slöttur and Röndólfur have their topmost, funnel-like portions exposed. That below Smátindur has been eroded to a depth of 700 ft below the base of the extrusion. On Röndólfuröxl and near Kelduskógar, still deeper sections are seen across plugs from which all traces of the inferred lavas have been eroded.

These rhyolites represent a group of parasitic eruptions on the flanks of the Breiddalur volcano which occurred at a late stage in the history of the volcano. Their main interest arises from the opportunity they furnish for studying the source and structure of rhyolite lavas.

(A) SLÖTTUR AND STÖNG

The rhyolite lava capping Slöttur and Stöng now covers an area of 0·3 square mile, but its original extent must have been much greater. Exposures extend for 1·4 miles from the plug-feeder, and if the flow had an original circular outcrop of 1·4 miles radius, its original extent would have been 6 square miles. An average thickness of 500 ft gives an original volume of the order of 0·5 cubic mile (about 2 km^3). The flow is composed of almost entirely non-porphyritic rhyolite.

One of the most accessible exposures of the base is at the southern end of Slöttur, where the flow forms a near-vertical cliff several hundred feet high and rests, with a basal pitchstone about 4 ft thick, on bedded agglomerate and tuff. On Slöttur the exposed thickness of the rhyolite is over 600 ft; the top is not exposed, but the spherulitic rhyolite on the summit is probably near the top of the flow. Below Thokustrákur the flow is 500 ft thick (Pl. 7c) and the top is marked by a layer of white pumiceous dust containing pieces of grey pumice and pebble-like fragments of obsidian an inch or so in diameter.

On Stöng the rhyolite rests conformably on thin basalt lavas, one of which is rich in olivine phenocrysts and approaches in composition a picrite-basalt. What may be a continuation of the same basalt flow is seen below the Slöttur rhyolite west of Thokustrákur, and pieces of a similar rock are seen in the Röndólfur agglomerate. Relations on Stöng are complicated by a thick inclined intrusion of porphyritic dolerite which wraps collar-wise around the rhyolite.

Just below the summit of Slöttur, on the north-east side, the northern end of a cylindrical plug-like intrusion of rhyolite is seen cutting vertically through the agglomerate 400 ft below the base of the Slöttur flow. The plug has a chilled margin of pitchstone several feet thick; it and the rhyolite have a well-developed vertical platy flow-structure. Owing to the apron of scree, the plug cannot be seen to be joined to the flow, but the base of the flow descends steeply in the agglomerate and there is little doubt that the plug marks the source of the rhyolite flow. Near here the agglomerate is most clearly seen to occupy a vent; it is a very coarse, chaotic deposit that presents a steeply inclined transgressive contact against the country-rocks over a vertical height of 500 ft. Elsewhere it is uncertain whether the agglomerate occupies a vent or is deposited around one, although the former is more likely. The agglomerate is the product of explosive eruptions that paved the way for the uprise of the rhyolite.

The agglomerate contains an abundance of more or less angular blocks of rhyolite, pitchstone, and basalt commonly 3 ft in diameter; a few pieces of fossil wood have also been found. The mass has a crude bedding with south-westerly dip; occasional distinct beds unusually rich in acid material are visible, and one contains little-altered blocks of grey pumice up to 3 ft. across. East of the vent, the basic and intermediate lavas in the Skriduá, up to 1000 ft below the lowest exposures of the main agglomerate, are cut by irregular acid intrusions with pitchstone margins associated with small patches of agglomerate; their irregular shape suggests that they have been forcibly injected into the basalts, probably during the explosive eruptions responsible for the main agglomerate-filled vents.

(B) RÖNDÓLFUR

Röndólfur, the highest peak of the group, is a narrow knife-edged ridge of porphyritic rhyolite cutting and capping vent-agglomerate. At the northern and southern end and on Thokustrákur (which is an outlier of the same rhyolite) the rhyolite has the characteristics of an extrusion resting upon agglomerate or, at the southern end of Thokustrákur, on the Slöttur rhyolite. Elsewhere the rhyolite forms a plug-like intrusion with a transgressive contact against the agglomerate that is vertical or steeply inclined inwards. On the eastern side of Röndólfur the pitchstone margin of the rhyolite is excellently exposed and is seen to descend some 300 ft into the agglomerate; on the western side it descends about 400 ft.

The thickness of the extrusion is not known, but on Röndólfur nearly 500 ft is exposed, and rhyolite is exposed over a total vertical height of about 900 ft. The present exposures must constitute only a fraction of the original bulk of the rhyolite.

The agglomerate through which the Röndólfur plug has been emplaced occupies an explosive vent which is exposed over a vertical height of about 600 ft and has transgressive contacts against the country-rocks. Many of the blocks in it are more than a foot in diameter. Most are of rhyolite, pitchstone, and basalt, but a few small pieces of granophyre have also been seen. The matrix is rich in rhyolitic pumice. The agglomerate cuts across the Slöttur rhyolite-flow (Pl. 7c), and the small exposure of rhyolite north of Röndólfur is probably an outlier of the same flow isolated on the northern side of the vent. One large mass of rhyolite in the vent, measuring perhaps 100 ft, appears to be a slipped mass of this flow.

(C) SMÁTINDUR AND FLÖGUTINDUR

Smátindur is a knife-edged and castellated ridge of non-porphyritic rhyolite which, at the two ends and along the eastern side, rests conformably on bedded tuff and agglomerate (Pl. 7a). There is no reason to doubt that the rhyolite mass at these exposures is a lava-flow resting upon the pyroclastic rocks, and the same applies to the rhyolite, 200 to 300 ft thick, that caps Flögutindur; it rests conformably on about 50 feet of bedded acid tuff and is interpreted as an outlier of the Smátindur rhyolite.

On the western side of Smátindur relationships are very different. The rhyolite mass descends steeply on the north-western side through some 700 ft of basalt and andesite lavas (Pl. 7b) and it is clearly a plug-like intrusion, with the steeply-inclined platy flow-structure of the rhyolite parallel to the margin of the plug. The contact with the country-rock is concealed by scree.

Vent-agglomerate is exposed over a vertical height of some 600 ft on the slopes east of the Smátindur rhyolite, associated with several irregular bodies of intrusive rhyolite, some of them arcuate in plan. This agglomerate-filled vent probably continues below Smátindur, and the rhyolite rose through it.

(D) RÖNDÓLFURÖXL

A rhyolite intrusion makes up the north-eastern shoulder of Röndólfur, referred to here as Röndólfuröxl. The mass has a pitchstone chilled margin several feet thick, and a flow-structure which is steeply-inclined and approximately parallel to the margin. In places it shows columnar jointing. A contact that is steeply inclined inwards is seen on the western side of the intrusion, where it cuts across 600 ft of basic and andesite lavas; these lavas are extensively brecciated near the contact.

The rock composing the intrusion is relatively rich in feldspar phenocrysts, and is virtually indistinguishable from the rhyolite of Röndólfur. The Röndólfuröxl plug might thus be identified as the feeder of the Röndólfur rhyolite, were it not for the clear evidence of the plug-feeder on Röndólfur itself.

(E) KELDUSKÓGAR

An intrusion of rhyolite nearly half a mile across is exposed near Kelduskógar. Agglomerate or rhyolite breccia containing basalt fragments separates the rhyolite from the country-rock in the shore exposures. On the eastern side of the mass, rhyolite is in steep contact with altered olivine-basalt, pieces of which are incorporated in the marginal pitchstone breccia.

The Kelduskógar rhyolite, a plug-like intrusion, is believed to be a member of the Röndólfur group. It is exposed at a level stratigraphically 1000 to 2000 ft below the base of the Slöttur rhyolite lava, and the presence of sparse hornblende phenocrysts in the Kelduskógar rock, never encountered elsewhere in Icelandic acid lavas, may be explained by this greater depth. Several dyke-like or irregular intrusions of rhyolite between Kelduskógar and Smátindur probably belong to the same acid volcanic episode.

9. Discussion

One of the main objects of this paper is to point out the existence of Tertiary central volcanoes in Iceland, and to present a structural interpretation of one volcano that, although based on reconnaissance-style mapping, may perhaps serve as a pattern for the recognition and study of others. These volcanoes, of which there may be scores in the Tertiary areas of Iceland, greatly complicate stratigraphical mapping, for each constitutes a major interruption in the stratigraphy. The recognition of the structure and characteristics of these volcanoes is essential in the interpretation of Icelandic geology, for they make up perhaps half the total bulk of Tertiary volcanic rocks.

Another object is to compare and contrast the two types of volcanism that have contributed to the building of eastern Iceland, and to consider the relationship between them. The work has an obvious bearing on the interpretation of the Tertiary volcanic rocks of the British Isles, where the distinction between the two types of volcanism has never been fully resolved.

The picture that emerges from a study of the Breiddalur area is of a contest between the two types of eruption: at times the eruptions of the central volcano succeeded in creating a topographic cone or shield that stood up above the surrounding plains, over which lavas from the volcano spread widely; at other times the flood-basalts overlapped and all but buried the volcano. Indeed, it is likely that at a late stage they completely buried the volcano to form the basalts and palagonite tuff in the summit group on Berufjardartindur before a final recrudescence of activity produced the acid lavas and tuffs of the summit group.

Although the volcano is 5000 to 6000 ft thick, it is unlikely that it ever stood up more than 1000 or 2000 ft above the surrounding basalt plains, mainly because of eruptions of flood-basalts on these plains, but also partly because of sagging by 1000 ft or more of the floor of the volcano. A composite profile across the volcano (Fig. 10) summarizes the interpretation of the structure. The interdigitation with the flood-basalts is shown; so striking is the evidence for it that the term 'cedar-tree volcano' seems appropriate, following the 'cedar-tree laccolith' of Holmes (1887).

This paper is not concerned with petrogenetic problems, but some general considerations are relevant. The contrasts between the two types of volcanism are believed to be bound up with the immediate source of the magma; the flood-basalts were erupted from fissures that tapped a deep-seated source of great hori-

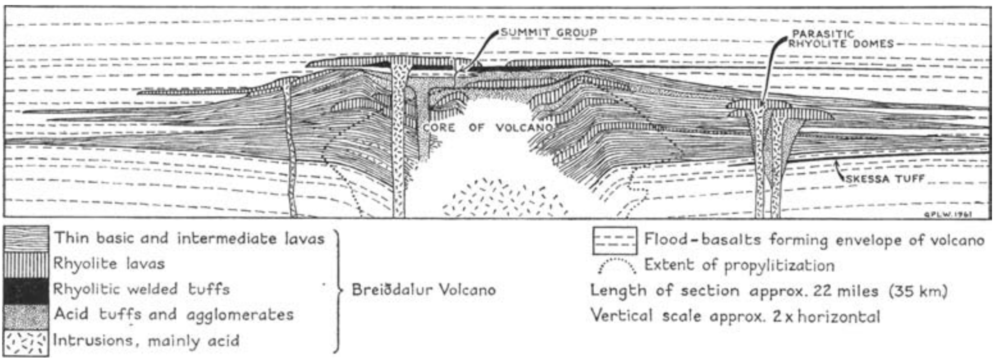


FIG. 10. Schematic composite section across the Breiddalur volcano and its envelope, summarizing the interpretation of the structure and relationships between the rocks.

zontal extent, whereas a central volcano such as that of Breiddalur was fed from a high-level magma-chamber projecting well up into the crust. Einarsson (1950) has reached a similar conclusion in his comparison of post-glacial eruptions from Hekla with those from fissures elsewhere in Iceland.

Icelandic geologists have noted that the flood-basalts erupted in Iceland during the last few thousand years are remarkably uniform in composition throughout a belt stretching from the north of the country to the south-western peninsula; the fissures responsible for these lavas must therefore have tapped a magma reservoir at least 200 miles long and several tens of miles wide: a general subcrustal layer. The Tertiary flood-basalts probably issued from a layer of comparable dimensions.

The great variation in composition of the rocks of the Breiddalur volcano, the explosive character of some eruptions, the extensive alteration, the concentration of dykes into a narrow swarm of great intensity, and the presence of blocks of granophyre, granite, and gabbro in some of the agglomerates all point to the existence of a high-level magma-chamber.

Acid volcanic rocks comprise about 10 per cent of the total volcanic pile in eastern Iceland, but they are confined to central volcanoes such as that of Breiddalur, and make up about 20 per cent of the bulk of these volcanoes, with andesites comprising perhaps another 10 per cent. Such large amounts of acid and intermediate magma seem unlikely to have originated by crystal fractionation of basaltic magma, and a sialic crust seems a more likely source. Recent seismic work in the west of Iceland (Tryggvason & Båth 1961) has, however, failed to reveal a layer that could be identified as sial, and direct evidence for the existence of a sialic crust below eastern Iceland is lacking; but it may be that the great abundance of acid material in the Icelandic central volcanoes is evidence of its existence.

Several central volcanoes broadly similar to that of Breiddalur are now known in eastern Iceland, and the positions of some are tentatively indicated on Figs. 1 and 2. Each one that has been examined has the same general characteristics as Breiddalur, although each differs in detail. Each has a central area of propylitization, within which abnormal dips are often encountered. Each has a great volume of acid volcanic rocks which are concentrated in and around the propylitized zone. Each is made up predominantly of thin tholeiite and andesite lavas. Each has an associated narrow but very intense swarm of basic dykes, and in each the dyke-swarm in the vicinity of the centre contains acid and composite dykes as well as basic. At least two such centres locally have an abundance of granophyre, granite, and gabbro blocks in agglomerate.

One of the volcanoes in eastern Iceland is the great central volcano of Thingmuli (Carmichael, personal communication), which began to form slightly after the Breiddalur volcano and continued to erupt until after the Breiddalur volcano had been buried. Another is the smaller volcano of Reydarfjördur, lower in the stratigraphical succession. A third is probably located north of Lödmundarfjördur (Dearnley 1954). The acid rocks of Gerpir and Bardsnes, near the eastern extremity of Iceland, may mark the top of a fourth volcano. A fifth lies south of Álftafjördur, and the Álftafjördur dyke-swarm (Fig. 8) is related to it. Others are believed to exist in south-eastern Iceland (Fig. 1).

At several points on journeys by road the writer has seen clear indications of the existence of central volcanoes in the Tertiary volcanic districts of western and northern Iceland; such volcanoes may be an important component of the Tertiary volcanic pile. In the east of Iceland they constitute about half its bulk and are distributed at a density of about one in 400 square miles. At this rate, the Tertiary areas of Iceland might contain fifty of these volcanoes.

Several strato-volcanoes are known in the newer volcanic belts of Iceland, and are probably the present-day equivalents of the Breiddalur volcano. To quote Thorarinsson, Einarsson & Kjartansson (1959, p. 146): 'Many mixed central-eruptions result in . . . the stratovolcano or volcano of the Fuji type. Volcanoes of this type are not common in Iceland but to them belong the biggest volcanic edifices in the country. A typical one is Snæfellsjökull (1448 m) . . . [which] is extinct but is known to have had a rhyolitic outburst about 2000 years ago. Eyjafjallajökull (1666 m) erupted in 1821. The biggest one ... is Öræfajökull (2119 m), the highest mountain in Iceland and in volume second only to Etna in Europe. Its summit crater has a diameter of 5 km and is a caldera ... The Dyngjufjöll massif ... is a ruin of an interglacial stratovolcano which has been even bigger than Öræfajökull. The caldera in Dyngjufjöll (Askja) has an area of 45 km^2, and within that caldera a new one was formed ... in 1875.'

Hekla may be another such volcano in a different stage of development, and yet another is probably located near Mývatn. There is no major volcanic edifice near Mývatn, but within a restricted area there are several acid lavas (e.g. Hlídarfjall and Hrafntinnuhryggur), an andesite lava (Lúdent), a diatreme (Víti), several explosive vents, many fumaroles (possibly the surface manifestation of a zone of propylitization), and a concentration of fissures (the surface manifestation of a swarm of dykes). Perhaps the inferred Mývatn centre is at a stage comparable with one of those at which the Breiddalur volcano was all but buried beneath flood-basalts.

The modern central volcanoes of Iceland differ from the Tertiary examples in having a greater bulk of palagonite tuff and breccia in their make-up, a consequence of the fact that many of the eruptions took place below glaciers. The volcanic products therefore show a much greater tendency to pile up near the eruptive orifice, instead of flowing away as lavas. The Tertiary central volcanoes, although comparable in bulk, were probably on this account much less imposing landscape features. The presence of central volcanoes with otherwise apparently similar general characteristics in both the Tertiary and neo-volcanic areas is another example of the striking similarity between Tertiary and Quaternary volcanicity in Iceland.

ACKNOWLEDGEMENTS. The writer is indebted to the Royal Society, the University of London, and the University of Iceland for grants which enabled the five summers of field-work to be carried out; to Messrs R. Edwards and I. L. Gibson, who, in company with the author, mapped the ground at the head of Berufjördur in the summer of 1959; to Professor L. Hawkes, Professor H. H. Read, and Dr J. Watson for critically reading the typescript; to Mrs Walker for typing the manuscript; and to farmers and other friends in Iceland for their kindness and hospitality.

10. Appendix

The andesite lavas. The rocks termed 'andesites' in this paper have been separated from the tholeiites by distinct differences in their field characteristics: differences which make stratigraphical mapping possible. The two groups of rocks thus separated are found to differ systematically in their colour index, content of glass, composition of the plagioclase, density, and chemical composition. Few rocks do not conform.

The andesites are texturally and mineralogically similar to the tholeiites; indeed, a continuous gradation clearly exists between them. The andesites are almost devoid of phenocrysts, and in this respect and on account of their basaltic texture and mineralogy they are quite unlike the typical andesites of orogenic areas, and are perhaps properly termed 'basaltic andesites' or 'tholeiitic andesites'. Chemically they are distinguished from the orogenic andesites by their higher iron and lower alumina content (Table 2). They bridge the gap between the basalts and the rhyolites. The plagioclase is labradorite in the tholeiites, and andesine in the andesites, although on account of the fine grain it is difficult to determine the composition optically. Pyroxene forms small equant granules—only rarely are distinct prisms seen—which are smaller than the plagioclase by a factor of about ¼. The grain-size histograms of Fig. 12 show that, although the field of the tholeiites over-

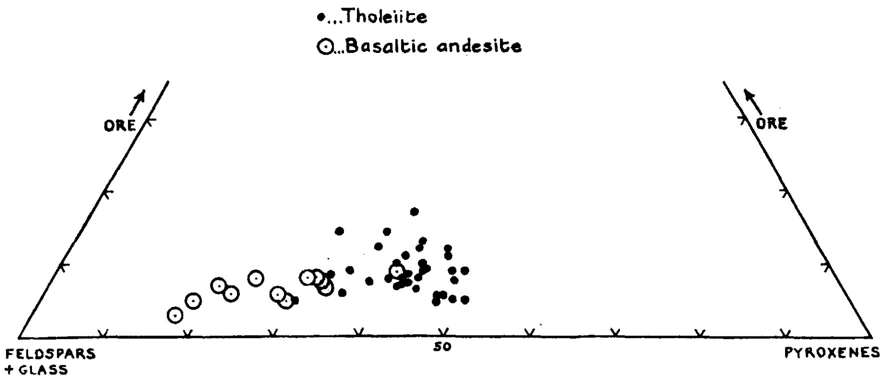


FIG. 11. Modal composition of tholeiite and basaltic andesite lavas (volume per cent). All but some of the tholeiites are from the Breiddalur volcano.

TABLE 2: *Chemical analyses*

	A	1	2	3	4	B
SiO_2	48·8	54·0	56·3	62·7	63·7	54·20
TiO_2	3·0	2·07	2·10	1·27	0·79	1·31
Al_2O_3	13·6	12·6	13·5	13·5	13·5	17·17
Fe_2O_3	5·5	4·1	4·5	2·9	5·0	3·48
FeO	8·8	9·49	6·98	4·48	3·33	5·49
MnO	0·2	0·28	0·27	0·13	0·21	0·15
MgO	5·2	2·8	2·8	2·4	0·8	4·36
CaO	10·6	6·4	6·4	5·5	3·7	7·92
Na_2O	2·8	3·83	3·78	4·16	4·35	3·67
K_2O	0·5	1·43	1·79	1·99	2·43	1·11
P_2O_5	0·4	1·11	0·81	0·18	0·10	0·28
H_2O^+ }	0·6	0·77	0·87	0·61	0·91	0·86
H_2O^- }		0·48	0·26	0·73	0·71	—
	100·0	99·3 (6)	100·3 (6)	100·5 (5)	99·5 (3)	100·00

Andesites of the Breiddalur volcano:
1. Tholeiitic andesite lava, just east of col, west of Tó (specimen p. 468).
2. Tholeiitic andesite lava at 2500 ft, west slope of Tó (specimen p. 467).
3. Andesite lava, summit of Raudafell (east of Dýristindur) (specimen p. 372).
4. Andesite lava, lower of two, just north of col east of Stöng (specimen p. 443).
Analyst: Rosemary Thomas

A: Average of six unpublished analyses of tholeiite lavas, Reydarfjördur area, eastern Iceland.
B: Average andesite (Nockolds 1954, p. 1019).

laps that of the andesites, the latter are on the whole distinctly finer in grain. In the tholeiites, augite is the predominant pyroxene, although some pigeonite appears usually to be present, together with a very small amount of olivine or its alteration-products. In the andesites the fine grain usually makes identification of the pyroxene impracticable, although it is believed to be almost invariably monoclinic; olivine is absent. Both rocks have an abundance of equant opaque grains, slightly larger on average than those of pyroxene.

Dusky brown interstitial glass is a minor constituent of the tholeiites; it averages about 5 per cent of the mode, and seldom exceeds 10 per cent. In the andesites, glass plus interstitial alkali feldspar commonly amounts to 20 to 30 per cent of the mode. As the amount of glass increases, the colour index decreases, from more than 40 (usually around 50) for the tholeiites to less than 40 (commonly around 30) for the andesites (Fig. 11). The specific gravity of the fresh rock is 2·80 or more for the tholeiites, and 2·55 to 2·80 for the andesites.

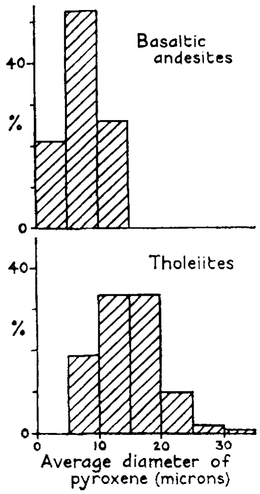


FIG. 12. Grain-size histograms for the pyroxene of tholeiite and basaltic andesite lavas. All but some of the tholeiites are from the Breiddalur volcano.

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PLATES 5–8

PLATE 5

Geological map of the Breiddalur volcano, eastern Iceland. Scale ⅞ inch to 1 mile.

PLATE 6

(*a*) The north-western side of Berufjardartindur, showing the summit rhyolite flow, here 400 ft thick, and showing upward steepening of the platy flow-structure. Four thick underlying basalt lavas, totalling 350 ft, of the summit group are seen on the left.

(*b*) The northern face of Fossárfell, showing a flexure involving lavas of the volcano (including the composite flow, *C*). The position of the top of the volcano is indicated by the dashed line. Relief about 2000 ft.

(*c*) The south-western slopes of Ófaerudalsnafir, from Fossárfell, showing flood-basalts banked up against the slope of the volcano (dashed line).

PLATE 7

(*a*) Smátindur from the east, showing rhyolite (dark on the photograph) resting on tuffs and agglomerates occupying vent (*V*). On the southern side, the Smátindur rhyolite occupies a plug and exposures extend as low as *X*. The rhyolite of Flögutindur (*F*) is probably an outlier of the Smátindur flow; the summit flow of Berufjardartindur behind.

(*b*) Smátindur from the south-west showing steep contact of rhyolite plug against thin basalt lavas (*B*). The rhyolite of Flögutindur (*F*) is probably an outlier of the Smátindur flow.

(*c*) Röndólfur (*R*) from the south-east. The Slöttur rhyolite-flow (*S*), here 500 ft thick and showing upward steepening of the platy flow-structure, rests upon vent-agglomerate (V_1) which is in steep contact (–*C*–) with thin basalt lavas (*B*) over a vertical height of 150 ft. The Röndólfur agglomerate-filled vent (V_2) truncates the Slöttur flow and is cut by the rhyolite plug of Röndólfur; this plug passes into an extrusion, of which Thokustrákur (*T*) is an outlier.

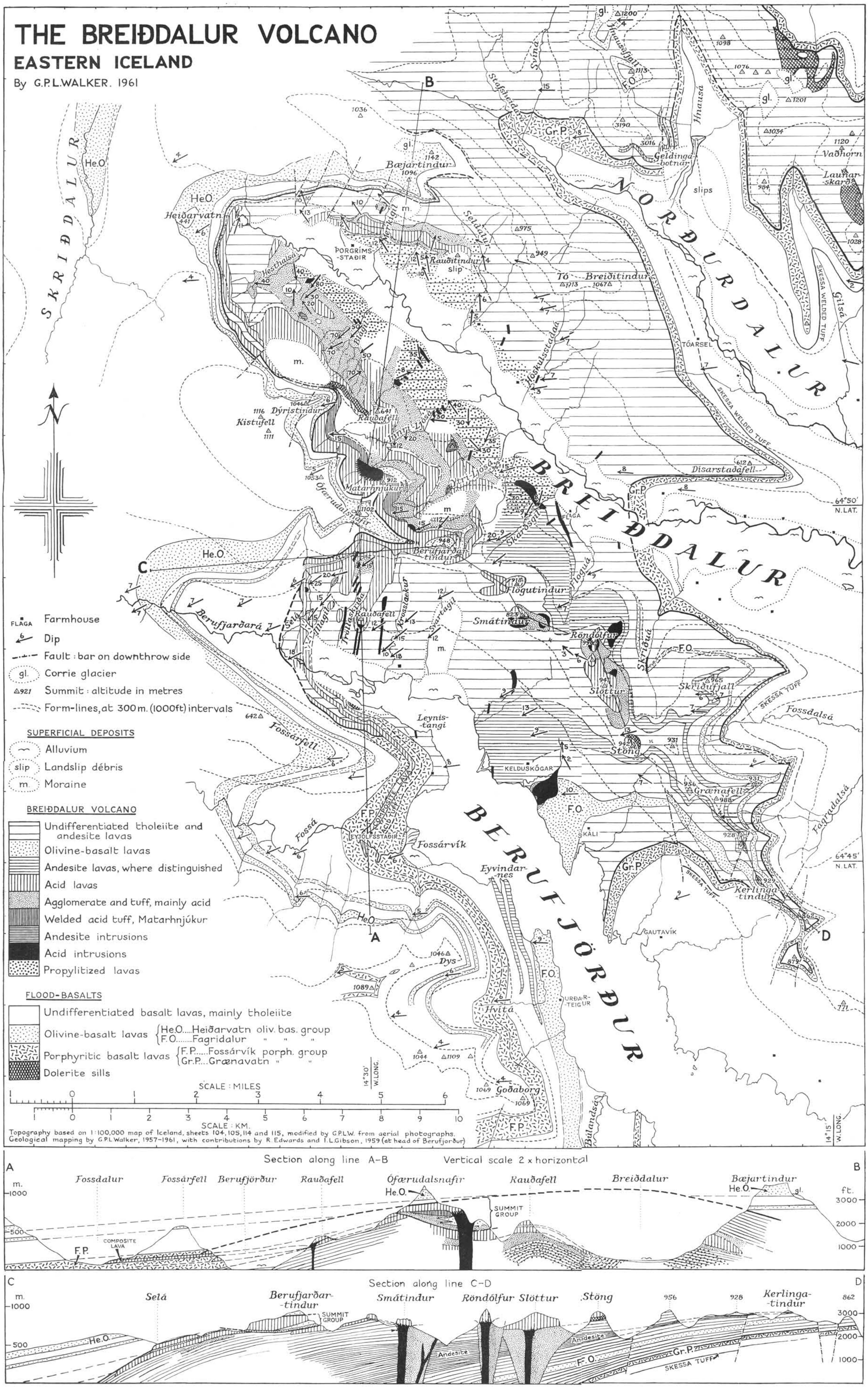
PLATE 8

(*a*) Contact (–*C*–) of the Breiddalur volcano (below) and overlapping flood-basalts on slopes north of Thorgrímsstadir. Nine thin flows of the volcano are seen interbedded with tuffs, and have a combined thickness of 110 ft. Six flows of flood-basalt above have a combined thickness of 150 ft.

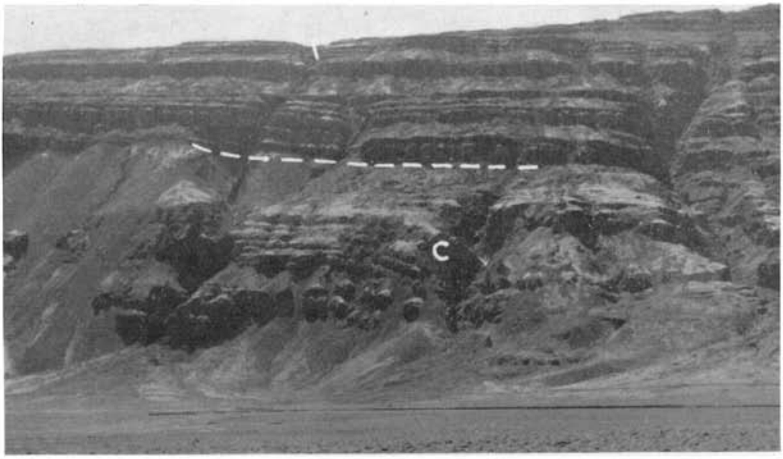
(*b*) Platy flow-structure in rhyolite lava, Slöttur.

(*c*) Platy flow-structure near base of andesite lava on shore near Eyvindarnes, Berufjördur, showing part of a flexure.

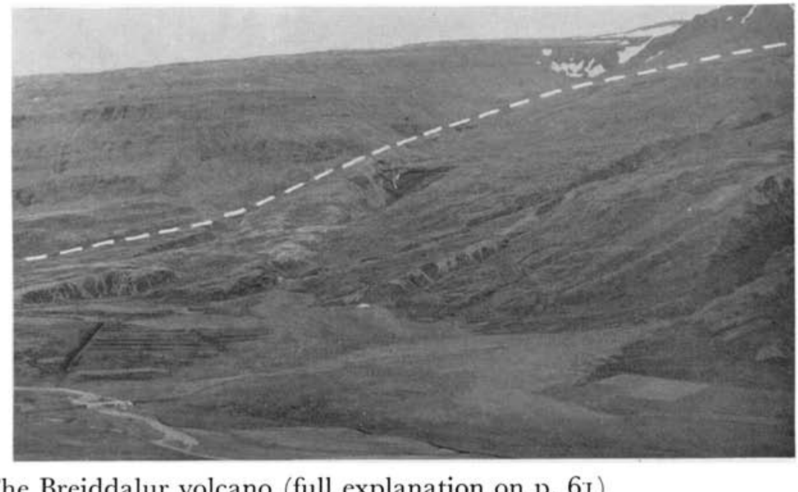
(*d*) The northern face of Tó and Breiditindur, showing thin basalt and andesite lavas of the flank of the volcano.


THE BREIÐDALUR VOLCANO
EASTERN ICELAND
By G.P.L.WALKER. 1961
Farmhouse
Dip
Fault : bar on downthrow side
Corrie glacier
Summit : altitude in metres
Form-lines, at 300 m. (1000ft) intervals
SUPERFICIAL DEPOSITS
Alluvium
Landslip débris
Moraine
BREIÐDALUR VOLCANO
Undifferentiated tholeiite and andesite lavas
Olivine-basalt lavas
Andesite lavas, where distinguished
Acid lavas
Agglomerate and tuff, mainly acid
Welded acid tuff, Matarhnjúkur
Andesite intrusions
Acid intrusions
Propylitized lavas
FLOOD-BASALTS
Undifferentiated basalt lavas, mainly tholeiite
Olivine-basalt lavas {He.O.....Heiðarvatn oliv. bas. group F.O.......Fagridalur " " "
Porphyritic basalt lavas {F.P.....Fossárvík porph. group Gr.P....Grænavatn " "
Dolerite sills
SCALE : MILES
SCALE : KM.
Topography based on 1:100,000 map of Iceland, sheets 104, 105, 114 and 115, modified by G.P.L.W. from aerial photographs.
Geological mapping by G.P.L.Walker, 1957–1961, with contributions by R. Edwards and I. L. Gibson, 1959 (at head of Berufjörður)
SKRIÐDALUR
NORÐURDALUR
BREIÐDALUR
BERUFJÖRÐUR
64°50' N. LAT.
64°45' N. LAT.
14°30' W. LONG.
14°15' W. LONG.
SKESSA WELDED TUFF
SKESSA TUFF
Section along line A–B
Vertical scale 2 x horizontal
Fossdalur
Fossárfell
Berufjörður
Rauðafell
Ófærudalsnafir
Rauðafell
Breiðdalur
Bæjartindur
SUMMIT GROUP
COMPOSITE LAVA
Section along line C–D
Selá
Berufjarðar-tindur
Smátindur
Röndólfur
Slöttur
Stöng
Kerlinga-tindur
Andesite

(*a*) North-western side of Berufjardartindur, showng the summit rhyolite flow. Underlying basalts of the summit group on the left.

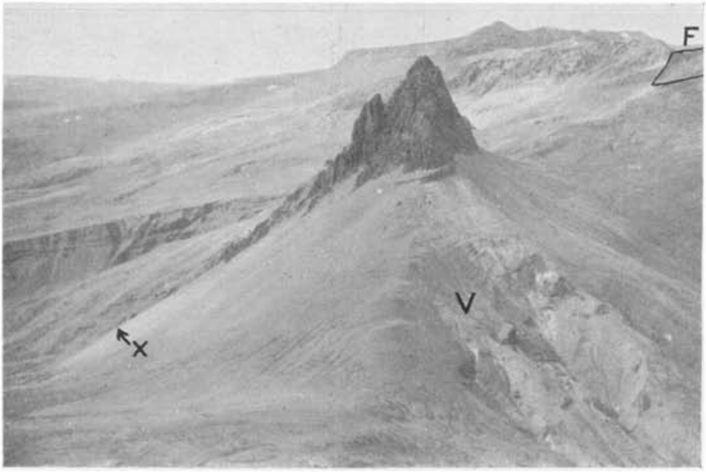


(*b*) Northern face of Fossárfell, showing flexure involving lavas of the volcano.



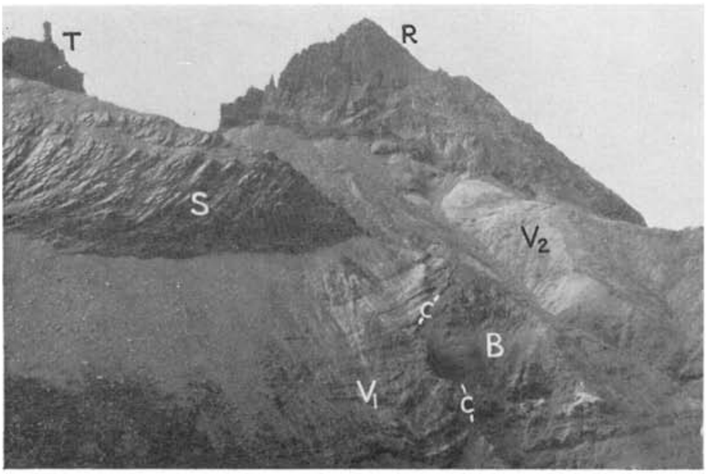
(*c*) South-western slopes of Ófaerudalsnafir: flood-basalts banked against the slope of the volcano.

The Breiddalur volcano (full explanation on p. 61)



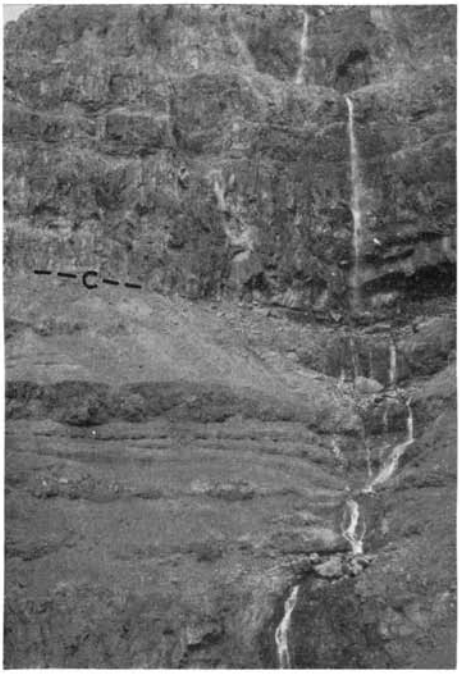
(*a*) Smátindur from the east: rhyolite (dark) resting on tuffs and agglomerates (*V*).

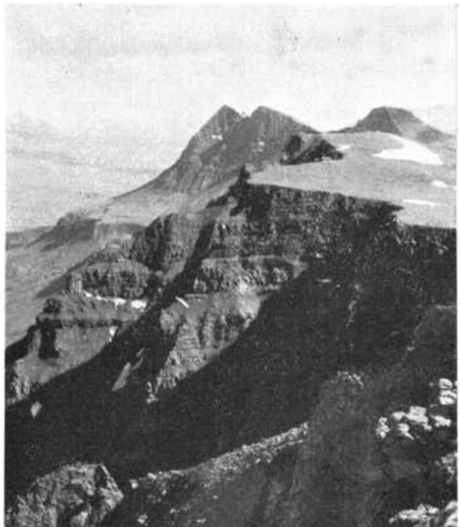
(*b*) Smátindur from the south-west: rhyolite plug in contact with basalt lavas (*B*).



(*c*) Röndólfur (*R*) from the south-east. Slöttur rhyolite flow (*S*) resting on vent-agglomerate (V_1) in contact with basalt lavas (*B*).

The Breiddalur volcano (full explanation on p. 61)





(*a*) (*above*) Contact (*–C–*) of the volcano and overlapping flood-basalts on slopes north of Thorgrímsstadir.

(*b*) (*top right*) Platy flow-structure in rhyolite lava, Slöttur.

(*c*) (*centre right*) Platy flow-structure near base of andesite lava near Eyvindarnes, Berufjördur.

(*d*) (*bottom right*) Northern face of Tó and Breiditindur: thin basalt and andesite lavas.

The Breiddalur volcano (full explanation on p. 61)

DISCUSSION

Professor L. HAWKES welcomed the paper as marking a big advance in our understanding of the Tertiary igneous rocks of Iceland. To have been able to distinguish, in the pile of basic lavas, the flows of the central volcano from the fissure flood-basalts was a notable achievement. The general picture of volcanic activity the author had demonstrated was paralleled by that in central Iceland in historic times. Now that the field-relationships of the rocks had been elucidated it was to be hoped that a petrographical study would be made in the laboratory.

The author attributed the thinness of the central lavas to flow on a slope. Did these lavas thicken on reaching the plain?

Professor F. H. STEWART asked whether the author would say more about the nature of the gabbro and granophyre fragments in the agglomerates and about the rock referred to as representing an 'emulsion' of acid and basic magmas. Were any of the Icelandic volcanoes in this region eroded deeply enough to show ring-dykes or cone-sheets?

Dr M. J. LE BAS expressed concern at Dr Walker's use of the word *andesite*. The rocks so described did not appear to resemble to any great extent typical andesites such as were found in the orogens. Would not some other term, perhaps *trachybasalt*, be more appropriate for these Thulean rocks?

Mr I. L. GIBSON said that the author had convincingly demonstrated the interdigitation of the surrounding flood-basalts with the lavas of the flank of the volcano. Throughout the paper it was stressed that the eruption of two lava-types—flood-basalts and central lavas—proceeded together. Would the author go so far as to say that these two types of volcanicity were independent, or did events in the central volcano control the composition of the contemporaneous flood-basalt lavas?

The AUTHOR, replying to Professor Hawkes, said that the tholeiite lavas of the volcano could at present be identified only by their thinness and by the departure of their dip from the regional dip. This departure, which at times (e.g. east of Skridufjall and on Dísarstadafell) amounted to only 1°, was equated with a depositional slope. While it was possible that some of the tholeiites of normal thickness that conformed with the regional dip were, in fact, products of the volcano, there was at present no means of recognizing them as such.

The gabbro and granophyre referred to by Professor Stewart were indistinguishable mineralogically and texturally from rocks composing major intrusions in the basalts of south-eastern Iceland. The fragments in the Breiddalur volcano were likely to be from similar, buried, intrusions which were syngenetic with the basic and acid lavas. The 'emulsion' rock consisted of two chilled magmas, one acid and one basic, forming a fairly intimate mechanical mixture in which the two still preserved their individuality. The texture was *suggestive of* a mixture of two immiscible liquids. Cone-sheets occurred in the Thingmuli volcano (Carmichael 1962), but ring-dykes had not yet been demonstrated in Iceland.

The author agreed with Dr le Bas that the use of the term *andesite* was not entirely satisfactory, but doubted if any more suitable rock-name was available. The Icelandic rocks were too siliceous to be termed trachy-basalts. Chemically they were similar to orogenic andesites except in their iron oxide and alumina contents.

In reply to Mr Gibson, the author gave it as his opinion that the two types of volcanicity were independent to the extent that events in the volcano had no influence on the composition of the flood-basalts. The reverse was not necessarily true, since some of the lavas identified as products of the volcano were probably flood-basalts originating from fissures on the flanks of the volcano. The porphyritic basalt component of the composite lava-flow of Berufjördur, for example, was clearly a member of the flood-basalt succession, although it emerged from a fissure (on Raudafell) high on the flanks.