GEOLOGY OF THE FÁSKRÚDSFJÖRDUR AREA, EASTERN ICELAND

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Summary.

This is a stratigraphic description of the geology of an area of 400 km² in eastern Iceland, bisected by the fjord, Fáskrúdsfjördur. The Tertiary volcanic pile which makes up the area has a thickness of about 3500 m and is mostly of basalt lavas, inclined to the west at a small angle. The middle portion of the succession is a region of considerable complexity, in which acid and intermediate lavas and pyroclastic rocks are very prominent. This region includes a magnificent example of a laccolith, that of Sandfell, and four lavas of unique type which are composite and consist of rhyolitic and basaltic components which were erupted simultaneously. The paper includes maps showing the distribution of dykes and of amygdale minerals.

I. Introduction.

This paper is the result of a geological examination of some 400 km² of vountry in the Austfirdir, the eastern fjordlands of Iceland, lying between Reydarfjördur and Stödvarfjördur. Fáskrúdsfjördur bisects the area, and steepsided and often precipitous ridges rising to over 1000 m form the backbone of the two peninsulas of Vattarnes and Hafnarnes on either side. Trending westwards as they do across the strike, these ridges supply a magnificent section across a great thickness of rocks.

The Tertiary volcanic rocks which make up this area are mostly basalt lavas, forming a well-stratified succession with general westerly dip. Near the middle of this succession is concentrated a considerable bulk of acid rocks forming the "Reydarfjördur Acid Volcanic Succession". Locally in the vicinity of the acid rocks the dip does not conform to the regional pattern, and sometimes this is due to updoming such as that produced by the Sandfell laccolith. The rocks are cut by a dense swarm of dykes, many of which are probably the feeders of the lavas, and especially noteworthy are composite dykes, several of which are seen to be the feeders of unique composite lava flows in which basalt and rhyolite components were erupted simultaneously.

The mapping, which has been done at intervals from 1956 to 1962, is an extension of that north of Reydarfjördur (Walker, 1959), and many stratigraphic units are common to both areas. We acknowledge the preliminary study made of part of the area, mainly around Thernunes and Berunes, by P. Ibbotson and M. D. McQueen in 1956, and of the ground south of Fáskrúdsfjördur by R. F. Wilson and R. G. Wright in 1958.

The area has often been visited by geologists. Thoroddsen (1901) indicated the distribution of basalts and liparites (rhyolites) on his map, and noted the steep inclination of the basalts around Sandfell. Hawkes and Hawkes (1933) mapped the Sandfell and demonstrated its laccolithic form. Hawkes and Harwood (1932) made a chemical study of one of the nearby acid dykes. The prominent acid tuff exposed on the shore of Fáskrúdsfjördur has been described by Tryggvason and White (1955) and by Hawkes (1916). A welded acid tuff has been described recently by Walker (1962), and composite lava flows by Gibson and Walker (1963). Mineralogical and chemical studies making use of specimens

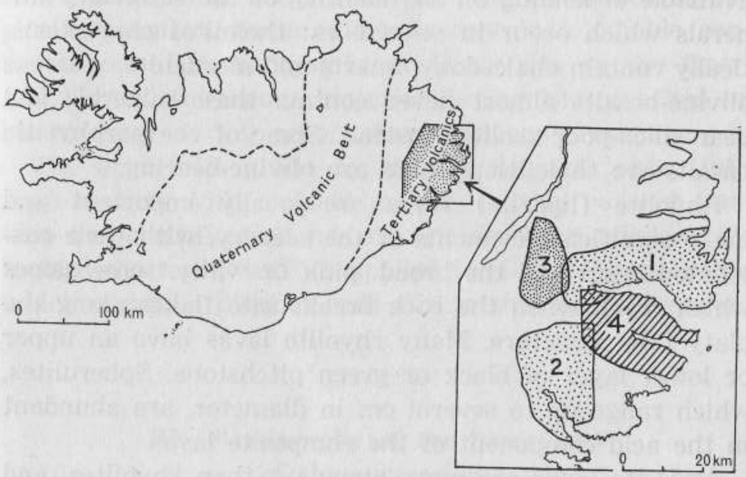


Fig. 1. Index map showing the location of the Fáskrúdsfjördur area (4) in relation to other recently-mapped areas:
1. Reydarfjördur area (Walker, 1959)
2. Breiddalur Volcano (Walker, 1963)
3. Thingmúli Volcano (Carmichael, 1964)

from the Fáskrúdsfjördur area have been made by Carmichael (1960 a and b; 1961, 1962, 1963) and Walker & Carmichael (1962 a and b). All of the works cited deal with isolated facets of the geology; the present paper is the first account of the geology of the Fáskrúdsfjördur area as a whole.

II. Rock types.

As in the ground north of Reydarfjördur, stratigraphic mapping is possible because the basalt lavas belong to three contrasted types which can be distinguished in the field: olivine-basalts which contain substantial amounts of olivine; tholeiites which are almost if not quite free from olivine; and porphyritic basalts which have abundant phenocrysts of plagioclase feldspar. Tholeiites grade into olivine-basalts, but a natural line of demarcation is available depending on the identity of the secondary minerals which occur in amygdales: tholeiites characteristically contain chalcedony, quartz and mordenite, whereas olivine-basalts almost never contain these minerals and bear silica-poor zeolites instead. Some of the porphyritic basalts are tholeiitic; others are olivine-bearing.

Rhyolite (liparite) lavas are locally important and make significant elements of the scenery, with their castellated crags and the broad, pink or white, scree slopes which result when the rock breaks into flakes along the platy flow structure. Many rhyolite lavas have an upper or lower layer of black or green pitchstone. Spherulites, which range up to several cm in diameter, are abundant in the acid component of the composite lavas.

Andesite lavas are more abundant than rhyolites, and some of them form thick flows with conspicuous cliffs along their outcrop. Two types are distinguished in this paper: basaltic andesites which resemble, and grade into, tholeiites (but they are finer in grain and have a better-developed flow structure than tholeiites); and rhyolitic andesites, which grade into rhyolites but differ from them in being darker on a fractured surface and in lacking pitchstone. To a considerable extent tholeiite, the two types of andesite, and rhyolite can be distinguished in the field, the distinction often depending partly on other minor characters such as the common yellowish alteration of the slaggy top of a rhyolitic andesite flow. On the map the basaltic andesites are not separated from tholeiites.

Many acid tuffs are interbedded with the lavas. Usually they are rich in pale-coloured pumice fragments, of ovoid shape due largely to compression by the rocks above. Often they contain fragments of basalt and rhyolite. Many contain feldspar crystals of the same size (around 5 mm long) and distinctive crystal habit (elongated along the "a" crystallographic axis, and of square cross-section, with {010} and {001} equally developed) as phenocrysts in rhyolite lavas, and these crystals have been separated from the rhyolitic magma in which they occurred by explosive eruption. Some tuff beds contain a notable concentration of such crystals, evidently due to the finer, and lighter, tuffaceous material having been washed or blown away during penecontemporaneous erosion.

The acid tuffs grade by increasing particle-size into agglomerates with an acid matrix. In this paper a particle-size classification has not rigidly been adhered to; instead the term "tuff" is applied to all pyroclastic rocks which occur as distinct beds within the lava succession.

III. Stratigraphy of the lower part of the succession.

(a) ***Skrúdur.*** — The island of Skrúdur, 3 km east of Vattarnes and just off the area covered by the map is composed of acid volcanic rocks, mostly rhyolite, with some pitchstone. It is not certain if these acid rocks occupy a volcanic vent, or whether they form part of the stratified succession; if the latter, they lie stratigraphically lower than the lowest basalts on Vattarnes, and are perhaps correlated with the rhyolites of Bardsnes and Gerpir, farther north.

(b) ***Vattarnes Peninsula.*** — The 1000 m of rocks described in this section lie mainly east of the road which crosses the peninsula and are made of the following approximate proportions:

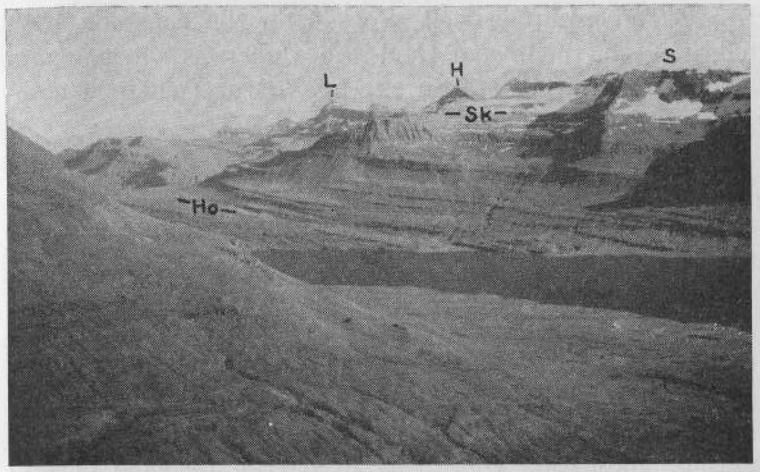
tholeiite lavas	60%
olivine-basalt lavas	20%
porphyritic basalt lavas	15%
tuffs and sedimentary beds	5%

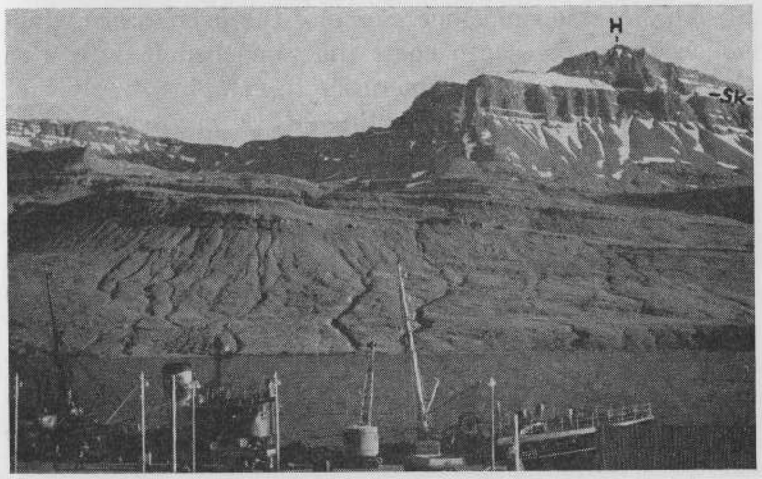
The succession includes three of the readily-mapped marker horizons of the succession north of Reydarfjördur (Walker, 1959): the Gerpir and Vindháls Porphyritic Groups, and the Víkurvatn Olivine-basalt Group.

The lowest rocks exposed are two or three massive tholeiite flows at the eastern extremity of the peninsula. Overlying them is a prominent group of richly porphyritic lavas, the Gerpir Porphyritic Group, consisting of several massive flows totalling 50 to 60 m thick. These flows are very resistant to erosion, and project northwards into Reydarfjördur as a narrow headland; these basalts are also believed to constitute the island of Andey, lying across the mouth of Fáskrúdsfjördur.

Some 400 m of mixed olivine-basalts, porphyritic basalts with varying percentages of feldspar phenocrysts, and tholeiites follow. On account of its mixed nature, no stratigraphic subdivision has been attempted. The mixed group forms steep and often unscaleable cliffs backing the strandflat around the end of the peninsula. Zeolites, notably mesolite, are conspicuously abundant. The group includes a number of sedimentary and other detrital beds, including one notable boulder bed with rounded to subangular boulders up to 1 m in diameter. This bed is exposed at an altitude of 200 m above Vattarnes, where it has a thickness of about 3 m (diminishing rapidly downdip to under 1 m, and passing into a coarse pebbly sandstone), and the boulders are mainly of tholeiite and porphyritic basalt, commonly amygdaloidal. This bed is believed to mark the course of a stream or river flowing over the Tertiary lava plain, and it may be a continuation of one of the detrital beds seen near Vadlavík (Walker 1959, p. 377). The top of the mixed group is marked by some 4 or 5 tholeiite flows, each about 10 m thick, which cap the cliffs around the eastern end of the peninsula.

The next stratigraphic unit to be mapped is the Víkurvatn Olivine-basalt Group. The rocks are distinctive in being very coarse-grained, and also in bearing large ophitic augite crystals prominent on exposed surfaces as pale-coloured patches, or on weathered surfaces as projecting pustules up to 1 cm in size. The group includes massive flows, especially conspicuous on the south coast, and also thin pahoehoe flow-units, and all flows are rich in zeo-





Tertiary basalt scenery

Fig. 2. North side of Vattarnes peninsula, looking across the upper part of Reydarfjördur from above Búdareyri. L = Lambafell (1097 m); H = Hoffell (1101 m); S = Sauddalsfell (> 1100 m); Ho = top of Hólmar Olivine-basalt Group; Sk = Skessa Tuff.

Fig. 3. North side of Hafnarnes peninsula, from Búdir. H = Háöxl (1101 m); Sk = Skessa Tuff.

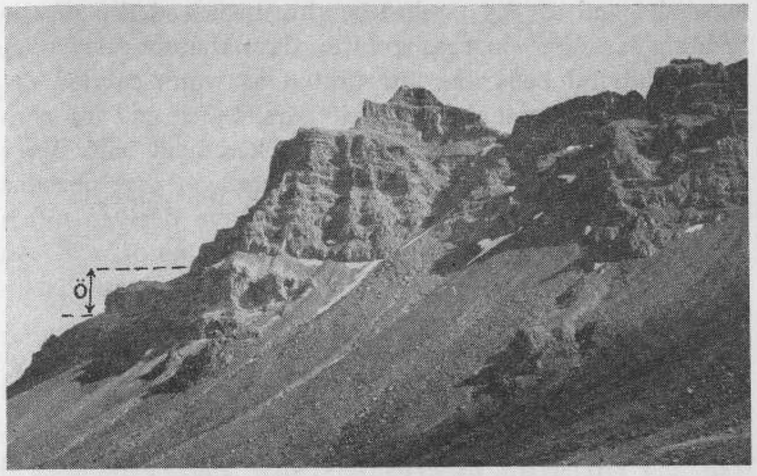
lites.* The group is well exposed on the coast on both sides of the peninsula, and the thickness varies from 50 m at sea level to 25 m on Halaklettur (where it comprises three flows).

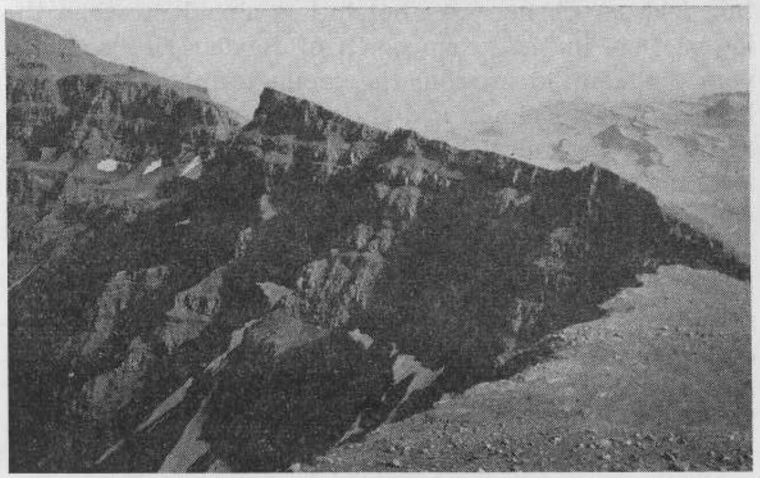
Detrital beds occur immediately below and above the Víkurvatn Group, and are well exposed on the coast and at 370 to 400 m at the top of the gully south-west of the summit of Halaklettur. The lower bed is about 10 m thick on the north coast, where it consists of well-bedded sandstones passing laterally into conglomerates. The pebbles, of rhyolite and basalt, are water-rounded and range to 15 cm in size. The former contain phenocrysts of sodic plagioclase, and similar crystals are found loose in the matrix, indicating that it is in part a resorted crystal tuff. On Halaklettur the bed is 6 to 8 m thick and is a pebbly coarse sandstone. Some of the pebbles are wind-polished. On the south coast the same bed is 5 to 6 m thick and is less conglomeratic. It contains crystals of plagioclase as also does another bed 1 m thick a short distance below.

The upper bed is 6 m thick on the north coast and contains an abundance of acid tuffaceous material; pieces of rhyolitic rock up to 15 cm are seen, and well-formed crystals of sodic plagioclase are common and constitute more than 50% of some thin layers. On the south coast the bed, rather fine-grained and well-bedded, is similarly rich in plagioclase. A second bed, 1 m thick and also rich in acid tuffaceous material, is seen a short distance farther west.

These detrital beds, being soft and readily-eroded, are seldom exposed inland although responsible for prominent hillside benches. In common with all the detrital beds

* The group is very rich in zeolites at most other localities. It is probable that some zeolite-rich olivine-basalts near the top of the mixed group north of Reydarfjördur were misidentified by Walker (1959, p. 378) as belonging to the Víkurvatn Group; the ophitic olivine-basalts on Vindhálsöxl described in that paper as a separate group do in fact comprise the Víkurvatn group, and the group is unusual on Vindhálsöxl in being free from zeolites.





Tertiary basalt scenery, Vattarnes Peninsula.

Fig. 4. North face of Örnólfsfjall. The face is about 300 m high, capped by olivine-basalt lavas of the Hólmar Group. Ö = Örnólfsfjall composite lava flow, here mostly of rhyolite.

Fig. 5. Cliffs on the north side of the ridge between Örnólfsfjall and Ljósafjall.

near the end of the peninsula, the measured dip of the bedding is a few degrees greater than that of the lavas. These detrital beds are interpreted as water-carried deposits, and are notable for their persistance and for containing a large proportion of reworked acid tuff. They represent extensive sedimentary veneers, in part perhaps due to Tertiary sheet floods, which have derived much of their material from nearby accumulations of acid ash (the products of near-contemporaneous acid volcanic eruptions) in the vicinity.

Above the uppermost detrital bed is a thin group of tholeiite lavas some 100 m thick, locally on Hrútafjall containing a thin porphyritic basalt at the base.

Next comes the Vindháls Porphyritic Group, of 3 to 5 massive flows totalling about 70 m thick. The rocks contain feldspar phenocrysts, but in less abundance than the lowest flow in the group north of Reydarfjördur. Being very resistant to erosion, the group forms a prominent headland near Kolmúli and cliffs farther inland. The road across the central ridge of the peninsula along much of its length follows the mountainside shelf at the top of the group.

Above comes a rather monotonous succession of thick lavas, mostly tholeiites, totalling some 300 m in thickness. This series includes near its middle a thin group of porphyritic basalts, averaging 10 m in total thickness and consisting of two flows rich in feldspar phenocrysts. It also includes at least two thick tuff beds, exposed in the bay midway between Höfdahús and Brimnesgerdi, on the south coast, and again in the Heljará. The lower is about 10 m thick, brown in colour, and andesitic or basaltic in composition, and it is seen at the mouth of the Heljará. The higher is a green acid tuff or agglomerate, also about 10 m thick, containing fragments up to 15 cm of rhyolite and pumice. Although not bedded, the planar flattening of the pumice combines with a fracture system of the type described by Tryggvason and White (1955) to simulate bedding. This second tuff is

taken to mark the base of the Reydarfjördur Acid Volcanic Succession, described in the next section.

IV. The Reydarfjördur Acid Volcanic Succession.

(a) ***Introduction.*** — The Reydarfjördur Acid Volcanic Succession is a lenticular series of rocks which ranges from 400 to 800 m thick and contains practically all the acid and intermediate volcanic products of the Fáskrúdsfjördur area. The base is defined by an acid tuff, T_1, which is due to the first of the long series of explosive acid eruptions of the Succession. The top is defined by the base of a conspicuous group of olivine-basalt lavas, the Hólmar Group, which appears to mark the end of acid volcanicity in the area. The Succession extends north of Reydarfjördur to include the Sellátur Group (Walker, 1959, p. 378) and also about 100 m of rocks below the Sellátur Group which include, or are stratigraphically equivalent to, the earliest acid eruptive products of the Succession.

The following are the approximate percentage areas covered by each rock-type in the Succession:

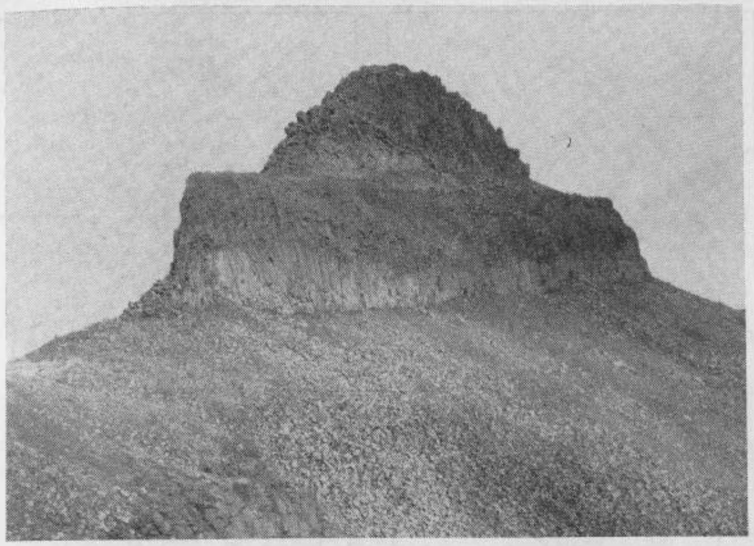
rhyolite lavas and intrusions	14%
agglomerates and tuffs, mostly rhyolitic .	13%
rhyolitic andesite lavas	7%
tholeiite and basaltic andesite lavas	65%
porphyritic basalt lavas	1%

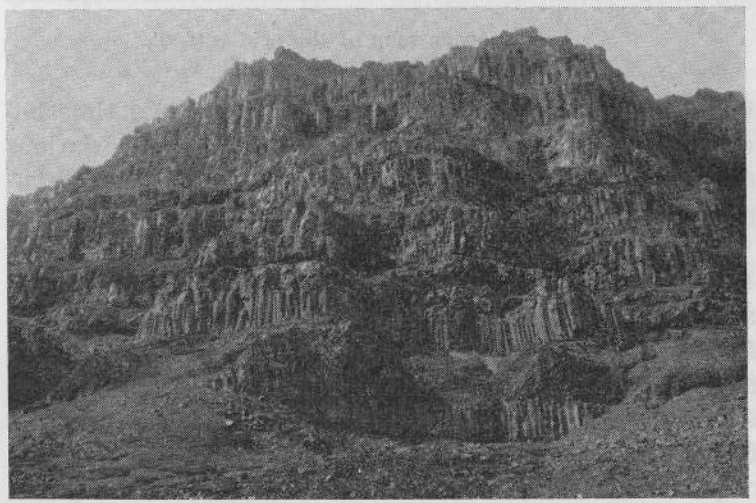
Traced away from the region of greatest thickness (Reydarfjördur), flood basalts are seen to interdigitate with rocks of the acid succession in much the same fashion as at the Breiddalur Volcano (Walker, 1963), showing that eruptions of flood basalts were contemporaneous with the production of acid and intermediate lavas. These flood basalts, which are not included in the table of percentages above, are best developed near the town of Búdir and the country to the south, where they make up the Örnólfur Olivine-basalt and Kumlafell Tholeiite Groups which occupy an area about 30% that of the whole Reydarfjördur Acid Succession.

Six phases can be distinguished in the history of eruption of acid and intermediate magma in the Succession. The pattern of activity during each of the first three phases was very similar, with partly explosive acid eruptions taking place in a "central" area on the northern side of the Vattarnes peninsula, and the eruption of mostly basic and intermediate lavas in the "flank" areas farther south and east. The Fourth Phase was exceptional in that much of the acid magma was emplaced in the form of a laccolith rather than as surface extrusions. The Fifth Phase is represented only north of Reydarfjördur and is not considered here. The Sixth Phase closed with the extrusion of the last of the four distinctive composite lavas.

(b) ***The First Phase.*** — An explosive eruption opened the First Phase and produced an agglomerate, Ag_1, in the "central" area near Eyri and Berunes, and the bedded acid tuff, T_1, distributed in the "flank" areas to south and east. The agglomerate is well exposed in the streams near Eyri (on the south side of Reydarfjördur). It has a matrix of green or brown colour which is pumiceous, and it contains fragments, averaging 3 cm but ranging to 1 m in diameter, of a variety of rocks including tholeiite, porphyritic basalt and rhyolite. The whole deposit shows an almost complete lack of stratification or sorting and this, combined with the large size of some of the fragments, the considerable thickness of the deposit (150 m or more) and the fact that the base is nowhere seen suggests the possibility that the agglomerate formed in, or at any rate very close to, the explosive vent.

The bedded tuff, T_1, is one of the most persistent in the Fáskrúdsfjördur area and has been traced from Reydarfjördur to Stödvarfjördur. Inland it is usually obscured by drift and the best exposure is on the shore about 100 m west of the mouth of the Heljará, where the whole thickness of just over 10 m is seen. T_1 thins southwards





Columnar basalt lavas.

Fig. 6. The two flows, totalling about 75 m thick, above the Hólmatindur Acid Tuff and Lignite, capping Midaftanshnjúkur. Gudrúnarskard on the left.

Fig. 7. The east face of Hoffell. The lower two flows, which overlie the Hólmatindur Acid Tuff and Lignite, are conspicuously columnar.

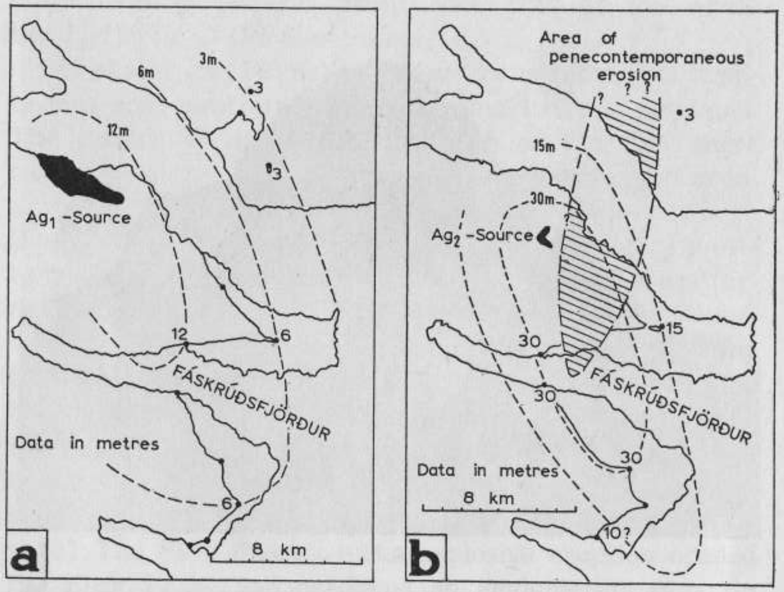


Fig. 8. a. Isopach map of the acid tuff, T_1.
b. Isopach map of the acid tuff, T_2.

to about 4.5 m at Stödvarfjördur, at the same time becoming finer in grain and well-bedded. These variations are compatible with a source within the area now occupied by Ag_1, and a south-easterly dispersal (fig. 8a).

Overlying Ag_1 on the south side of Reydarfjördur (fig. 9) is a series of about 9 rhyolite lavas, R_1, which average about 25 m in individual thickness but range from a few metres to over 60 m. These flows, which are never all present in the same vertical section, are very restricted in lateral extent, and only one flow has an outcrop exceeding 2 km in length. Three of these flows are of particular interest. One, the most westerly of the group and directly overlying Ag_1, is unusual in that it possesses a good columnar jointing normal to the platy flow structure. The second, one of the thickest — it is 60 m thick — is noteworthy in being extremely rich in phenocrysts of sodic plagioclase. This flow, pink in colour and very massive, is exposed in the stream due north of Berutind-

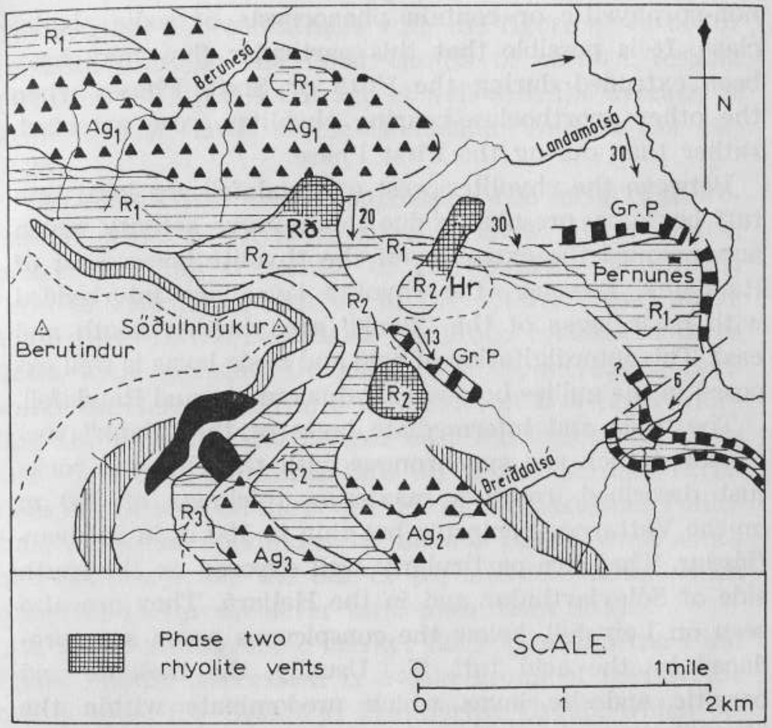


Fig. 9. Detailed map of the Berunesá—Raudafell area, showing stratigraphical relationships and the aberrant dips associated with the Thernunes uplift. Rd = Raudafell; Hr = Hrafnakambar;; $Ag_{1, 2, 3}$ = applomerates of 1st, 2nd, 3rd Phases; $R_{1, 2, 3}$ = rhyolites of 1st, 2nd, 3rd Phases; Gr.P. = Grákollur Porphyritic basalt Group.

ur, where it overlies Ag_1. The third flow, the upper of two on Flatafell (a small hill 1 km west of Raudafell), is of interest due to the fact that it is visibly linked to its plug-feeder which outcrops on the north-east side of the hill.

The rhyolite plug which is the feeder of the Flatafell flow is roughly circular in plan, and the margin is marked by a layer of black pitchstone which can be clearly seen cutting through the subjacent flow. The rhyolite of Flatafell is unusual also in containing phenocrysts of anorthoclase: the other First Phase rhyolites are either non-porphyritic or contain phenocrysts of sodic plagioclase. It is possible that this particular flow may have been extruded during the Fifth or Sixth Phases when the other anorthoclase-bearing rhyolites were extruded, rather than during the First Phase.

Between the rhyolites west of Raudafell are local thin tuff horizons, presubably due to explosive activity which accompanied the extrusion of the rhyolite lavas. East of Raudafell, however, the rhyolite lavas are interbedded with basic lavas of the "flank" area further south and east. This interdigitation of acid and basic lavas is well exposed in the gullies between Hrafnakambar and Raudafell.

The basic and intermediate lavas of the "flank" succession, which are synchronous with the rhyolitic rocks just described, reach a maximum thickness of 300 m on the Vattarnes Peninsula but thin to 100 m in Stödvarfjördur. They are particularly well exposed on the south side of Sóleyjartindur and in the Heljará. They are also seen on Leirufell, below the conspicuous green scar produced by the acid tuff, T_2. Usually, the tholeiite and basaltic andesite lavas which predominate within the "flank" succession lack red beds between the individual flows, which is taken to mean that they were erupted at very short intervals. Often this makes it difficult to be certain whether one is dealing with separate lava flows or merely with flow-units. The flows are unusually thin, as is shown by the following thickness data:

Location	number of flows	total thickness (m)	average thickness (m)
South side of Sóleyjartindur	18	125	7.0
Heljará	16	61	3.8
Villingaá	18	61	3.4
North-west ridge of Múli	11	46	4.2
North-east ridge of Múli	9	61	6.8
Low on north face of Hafranesfell	8	37	4.6
Total	80	391	5.0

The average above contrasts with the figure of 14 m for tholeiite lavas in the flood basalts of eastern Iceland (Walker, 1963, p. 36) but agrees well with the average of 4 m for basic lavas of the Breiddalur Volcano (*loc cit*, p. 36).

The First Phase "flank" succession also includes a prominent group of rhyolitic andesite lavas (RA_1) which, besides forming the cliffs of Hafranesfell (above the farm of Hafranes), outcrop in the Villingaá and above Víkurgerdi. In the Breiddalsá the group consists of three flows, with aggregate thickness of 40 m, increasing eastwards on Hafranesfell to a maximum of five flows totalling 160 m, while still farther east the number of flows and their total thickness falls off again. Similar variations can be seen on the south side of the Vattarnes Peninsula, where the maximum thickness is 100 m, while south of Fáskrúdsfjördur the one or perhaps two flows which comprise the group never total more than 30 m.

A useful stratigraphic marker horizon within the First Phase "flank" succession is a thin group of porphyritic basalt lavas, the Grákollur Porphyritic Group, which occurs about 170 m above T_1. One of the more accessible and better-exposed localities is at the top of a small hill west of Sóleyjartindur where there are three flows, the two lower ones richly porphyritic, together totalling some 20 m. The Group is widespread on both sides of Reydarfjördur, but is apparently missing south of Fáskrúdsfjördur. It reaches its maximum thickness of 30 m and is most richly porphyritic on Grákollur (north of Reydarfjördur) and on Sóleyjartindur, where it contains as many as four separate flows. Elsewhere the porphyritic flows sandwich tholeiite and (in the Selá) rhyolite flows.

(c) ***The Second Phase.*** — An explosive acid eruption, which produced a mass of agglomerate and the thickest acid tuff of the Fáskrúdsfjördur area, initiated the Second Phase. The agglomerate, Ag_2, is poorly exposed and is seen only in the Breiddalsá (fig. 9), where the exposed thickness is 30 m. It rests on part of the "flank" succession of the previous phase rather than on Ag_1 or R_1. The agglomerate is very similar to Ag_1 and again the large size of the fragments — some exceed 30 cm — and the absence of sorting suggest the close proximity of the vent.

In the "flank" area to the east and south, this explosive eruption is represented by the bedded tuff, T_2. Conspicuous exposures occur near Eyri on the south shore of Fáskrúdsfjördur, and about 1 km east of Kjappeyri on the north shore (Hawkes, 1916; Tryggvason & White, 1955). At both localities it is separated into two beds with a combined thickness of 30 m by a thin basalt lava. Up-dip from Kjappeyri exposures are poor and the large number of faults makes correlation of the tuff horizons difficult, but what may be the same tuff occurs at 670 m on Sóleyjartindur. Here the tuff, which forms an almost horizontal bench, is about 12 m thick and is notably different in appearance from the tuff exposed on the shore, being richer in basic material. On the Hafnarnes Peninsula T_2 forms the plane along which the Sandfell Laccolith has been intruded, and the tuff is split by intrusive acid sheets associated with the laccolith north of Saudabólstindur. Farther east T_2, still about 30 m thick, forms the conspicuous green scar on Leirufell and the summit of Thríklakkar.

The isopach map for T_2 (fig. 8b) shows two interesting features. Firstly, the tuff is absent within an oval-shaped area covering part of the Vattarnes Peninsula and extending to the north side of Reydarfjördur. As most of this area is close to the explosive vent, which is probably located near the Ag_2 outcrop in the Breiddalsá, this suggests that the tuff was locally entirely eroded away before the eruption of the overlying basalts. Secondly, like T_1, dispersal of the tuff was mainly to the south-east, perhaps indicating that north-westerly winds prevailed at the time of deposition of both tuff layers.

The acid lavas, R_2, of the Second Phase have a distribution similar to that of the First Phase. A group of

three flows with an aggregate thickness of 50 m is exposed in the Breiddalsá resting on Ag_2 (fig. 9). These flows have a limited lateral extent, and only one persists as far as the Bægsli ridge.

While rhyolitic eruptions were proceeding in the Breiddalsá area without any noticeable disturbance of the underlying strata, the intrusion of three rhyolite plugs farther north was accompanied by the large-scale updoming of the pre-existing rocks to form the Thernunes Uplift, described later. Two of these plugs (those which form the conspicuous hills of Raudafell and Hrafnakambar) are seen to be continuous with extrusive rhyolite lavas.

The "flank" succession of the Second Phase consists predominantly of thin tholeiite and basaltic andesite lavas. These lavas reach a maximum thickness of 140 m on the Vattarnes Peninsula but thin rapidly southwards and on Leirufell only three thin tholeiite flows are seen. One of the few places where the whole "flank" succession can be seen is on the Sandfell–Vindfell ridge (fig. 13) where T_2 at the base forms the intrusive level of the Sandfell Laccolith and T_3 at the top occurs in the updomed rocks stratigraphically 80 m higher.

Rhyolitic andesite lavas are subordinate components of the Second Phase "flank" succession and none is found on the Hafnarnes Peninsula. North of Fáskrúdsfjördur, however, a single flow outcrops in the upper reaches of the Gilsá and two flows reaching a maximum combined thickness of 50 m are exposed on Kerlingarfjall.

(d) ***The Thernunes Uplift.*** — Over a large area north of the farm of Thernunes the dip departs from the regional trend and the rocks form an important structural dome. One of the basalt groups involved in the updoming is the Grákollur Porphyritic Group. The outcrop falls steadily, in conformity with the regional dip, from Sóleyjartindur westwards as far as the Selá, where it reaches sea level. If this dip continued, the Group should be more than 100 m below sea level about 2 km farther west, whereas in fact the Group reaches an altitude of 360 m above sea level on Hrafnakambar and has thus been updomed by about 500 m.

The updomed lavas on the shore near Berunes show intense alteration, with the development of such minerals as chlorite, calcite, epidote and, locally, a lime garnet. This alteration, which is most intense on the coast east of the mouth of the Berunesá, is similar to that recorded by Cargill et al (1928) from around gabbro and granophyre intrusions in south-eastern Iceland.

In the same general area there are two sets of minor intrusions, one acid, and the other intermediate in composition. The former, well exposed between the mouth of the Berunesá and Thernunes, consist of rhyolite sheets which average about 4 m in thickness and are inclined at about 50° to the north-west. They could comprise a small segment of a cone-sheet swarm. The latter comprises a dense swarm of intermediate (andesitic) sheets, averaging less than one metre in thickness; the sheets invariably have tachylitic margins and are generally inclined to the stratification of the lavas at angles of up to 40°, the direction being variable.

The area affected by both sets of minor intrusions is clearly related to the zone of intense alteration (fig. 10a) and to the dome-shaped uplift. It is thought that the updoming was produced by a concealed intrusion; that the zone of alteration is part of its metamorphic aureole; and that the acid and intermediate sheets, and the three rhyolite plugs, are related to this concealed body. This intrusion could be the source of the fragments of granophyre occasionally found in one of the later tuff beds, T_3.

(e) ***The Third Phase.*** — The Third Phase also opened with an explosive eruption. The resulting agglomerate, Ag_3, outcrops in the higher reaches of the Breiddalsá where it is approximately 100 m thick and rests on R_2 (fig. 9). A bedded tuff equivalent, T_3, has been found on the Vattarnes Peninsula where it occurs just below the summits of Grákollur and Múli. Elsewhere, north of Fá-

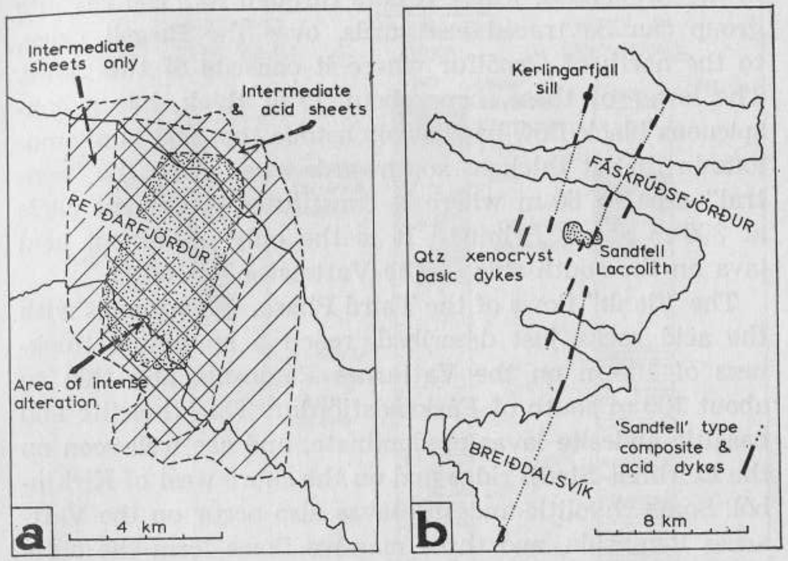


Fig. 10. a. Map showing the coincidence of the area of intense alteration (associated with the Thernunes uplift and extending across Reydarfjördur to the Helgustadir area) with the swarm of intrusive sheets. — b. The distribution of 'Sandfell type' composite dykes in eastern Iceland and the location of the Sandfell Laccolith.

skrúdsfjördur, its presence can only be inferred from a shelf-like physiographic feature, typical of those produced by thick tuff horizons within a basalt succession. South of Fáskrúdsfjördur the tuff has been found at three further localities: on Leirufell; on the Sandfell–Vindfell ridge; and on the north shore of Stödvarfjördur about 1 km west of Kirkjuból. At the last two localities the tuff is intimately associated with a richly porphyritic basalt lava containing unusually large phenocrysts — some exceed 1.5 cm — of bytownite feldspar.

Overlying the agglomerates in the Breiddalsá are five flows of rhyolite, R_3. Three form conspicuous scarps on the north side of Breiddalur, and one particularly massive flow about 60 m thick outcrops on the south side below Ljósafjall. The feeder for this last flow is exposed in the Breiddalsá, where it cuts through R_2. The rhyolite group can be traced eastwards, over the Bægsli ridge, to the north of Örnólfur where it consists of two flows. The lower of these, here about 15 m thick, has a conspicuous black flow-banded pitchstone top, and is anomalous in that it thickens southwards away from the "central" area to 60 m where it constitutes prominent cliffs at 300 m above Brimnes. It is the only prominent acid lava on the south side of the Vattarnes Peninsula.

The "flank" flows of the Third Phase, synchronous with the acid rocks just described, reach a maximum thickness of 150 m on the Vattarnes Peninsula and thin to about 100 m south of Fáskrúdsfjördur. Thin tholeiite and basaltic andesite lavas predominate, and are well seen on the Leirufell–Stedji ridge and on the shore west of Kirkjuból. Some rhyolitic andesite lavas also occur on the Vattarnes Peninsula, and three massive flows form the cliffs which cap Kerlingarfjall. A single rhyolitic andesite lava occurs down-dip in Gilsárdalur in a succession otherwise entirely of thin tholeiites, and even this massive flow fails before the shore of Fáskrúdsfjördur is reached. East of Kerlingarfjall, tholeiites form the summits of both Múli and Grákollur, capping T_3.

(f) ***The Örnólfur Olivine-basalt and Kumlafell Tholeiite Groups.*** — After the close of Phase Three there was a pause in the eruption of acid rocks and typical flood basalt lavas were erupted over most of the area that had earlier been the scene of rhyolitic eruptions. These flood basalts comprise a lower group of olivine-basalts, which are particularly well exposed on the Örnólfur ridge; and an upper group of massive tholeiites, which are best seen in the cliffs forming the upper part of Kumlafell. On the Hafnarnes Peninsula and near Búdir the eruption of flood basalts persisted from the close of Phase Three until the eruption of the Hólmar Group. Elsewhere, late acid and intermediate lavas of Phases Four to Six form lenses interrupting the flood basalt sequence. The strati-

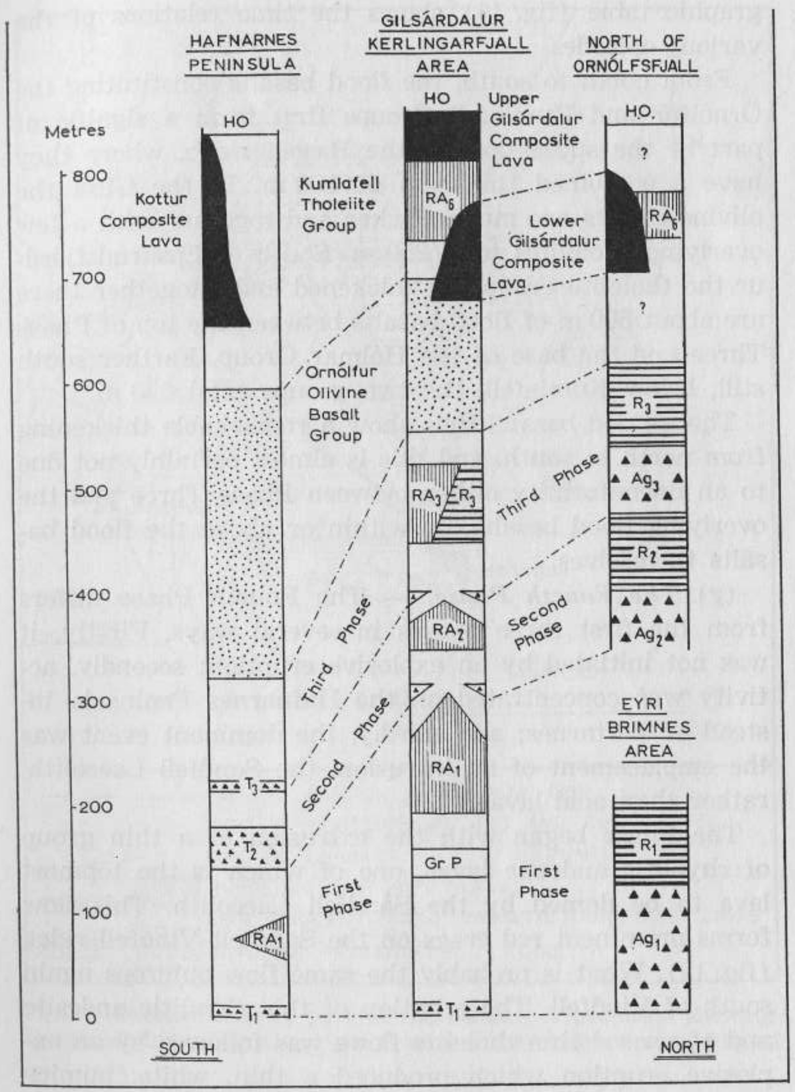


Fig. 11. Diagrammatic stratigraphic vertical sections through the Reydarfjördur Acid Volcanic Sucession. For clarity, the local fourth phase, including the Sandfell Laolith, has been omitted. Also no attempt has been made to subdivide the upper part of the acid succession, as the fifth and sixth phases are only fully developed on Helgustadafell, north of Reydarfjördur.

graphic table (fig. 11) shows the time relations of the various episodes.

From north to south, the flood basalts constituting the Örnólfur and Kumlafell Groups first form a significant part of the succession on the Bægsli ridge, where they have a combined thickness of 100 m. In the Gilsá the olivine-basalts are much thicker and together with a few overlying tholeiites total 250 m. South of Fáskrúdsfjördur the tholeiite group has thickened and altogether there are about 500 m of flood basalts between the top of Phase Three and the base of the Hólmar Group. Farther south still, below Kumlafell, the two groups total 650 m.

These flood basalts thus show a remarkable thickening from north to south, and this is almost certainly not due to an unconformity either between Phase Three and the overlying flood basalts, or within or above the flood basalts themselves.

(g) ***The Fourth Phase.*** — The Fourth Phase differs from the first three phases in several ways. Firstly, it was not initiated by an explosive eruption; secondly, activity was concentrated on the Hafnarnes Peninsula instead of Vattarnes; and thirdly, the dominant event was the emplacement of an intrusion, the Sandfell Laccolith, rather than acid lavas.

The Phase began with the extrusion of a thin group of rhyolitic andesite lavas, one of which is the topmost lava to be domed by the Sandfell Laccolith. This flow forms prominent red crags on the Sandfell–Vindfell ridge (fig. 12). What is probably the same flow outcrops again south of Vindfell. The eruption of this rhyolitic andesite and of several thin tholeiite flows was followed by an explosive eruption which produced a thin, white, pumice tuff, and it is believed that this tuff marks the escape to the surface of some of the rhyolite magma of the Sandfell intrusion. Somewhat later, one or two rhyolitic andesite lavas were erupted farther east, where they now form prominent cliffs about 100 m below the summit of Vindfell (786 m). Thus two periods of extrusion of rhyo-

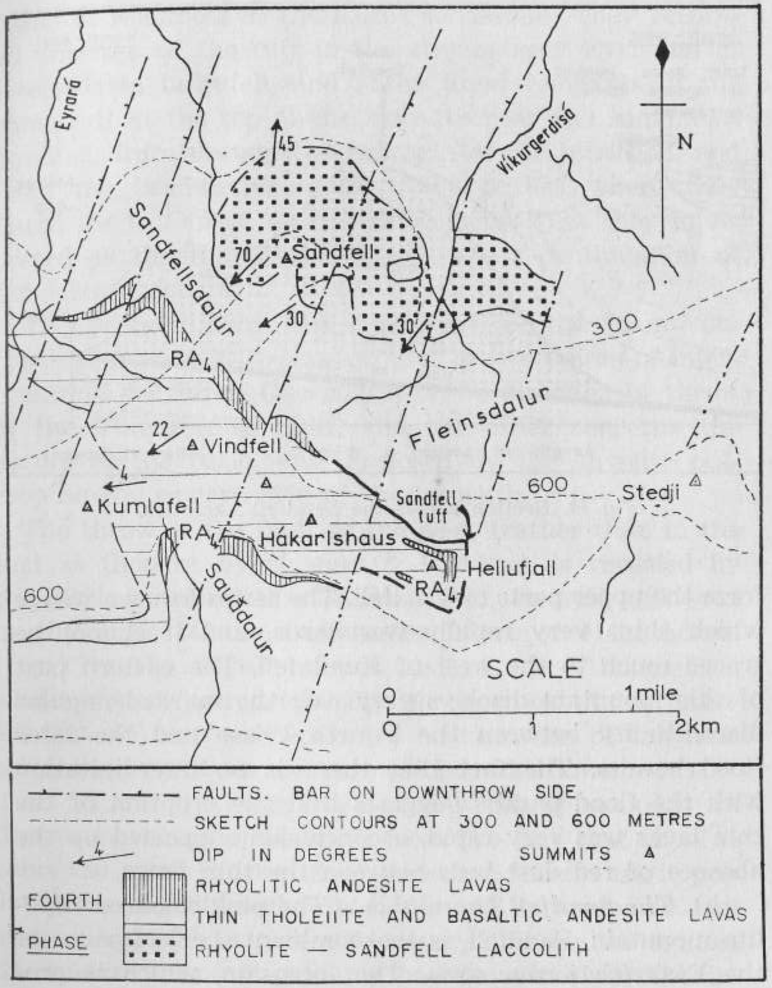


Fig. 12. Detailed map of part of the Hafnarnes peninsula showing the Sandfell Laccolith and the related rocks of the Fourth Phase.

litic andesites are separated in time by the intrusion of the Sandfell Laccolith.

The extrusion of a thick series of thin tholeiite and basaltic andesite lavas brought the Fourth Phase to a close. These flows probably formed a cone or elongate ridge at least 200 m high centred on the Sandfell, and

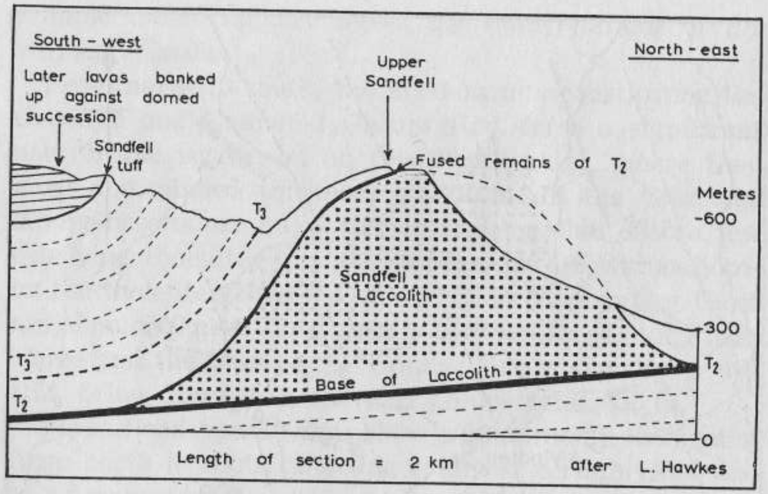


Fig. 13. Section across the Sandfell Laccolith.

form the upper parts of Vindfell. The series forms a wedge which thins very rapidly westwards, and it cannot be traced much to the west of Kumlafell. The eastern part of this mountain displays very well the marked angular discontinuity between the Fourth Phase and the later flood basalts. The fact that there is no interdigitation with the flood basalts suggests that the eruption of the thin lavas was very rapid, a conclusion supported by the absence of red dust beds between the thin flows.

(h) ***The Sandfell Laccolith.*** — The pink-coloured rhyolite mountain, Sandfell, is the dominant scenic feature of the Fáskrúdsfjördur area. The intrusion, which is probably unparalleled in the North Atlantic Tertiary volcanic province, has been observed by many geologists and studied in detail by Hawkes and Hawkes (1933). They showed that it is a laccolith of porphyritic rhyolite, with a maximum thickness of about 600 m, which has updomed the basalt lavas of its roof (figs. 13, 14, 15 and 16). They estimated the thickness of this roof as 540 m, and suggested that the rhyolite was intruded along a thick acid tuff layer (T_2 of the present authors), a prominent

plane of weakness in the basalt succession. They recorded outcrops of the tuff in the stream near Eyri and at intervals to Leirufell, and noted fused remnants of the same tuff at the top of the laccolith near the summit of Sandfell, from the northern margin of the intrusion, and from the headwaters of the Víkurgerdisá where they found the tuff fused to a black glass by what they interpreted as the thin downfaulted eastern continuation of the laccolith.

The present study has confirmed all the main conclusions of Hawkes & Hawkes, but in two points of interpretation we differ. One concerns the direction of throw of the Víkurgerdisá fault, and the other concerns the nature of the basic mass enclosed by the rhyolite outcrop on the eastern side of the laccolith.

The throw of the fault to the west (rather than to the east as thought by Hawkes & Hawkes) is revealed by the displacement of the Sandfell Tuff, an acid tuff seen in the cliffs of the northeastern face of Hákarlshaus (fig. 12). The rhyolite mass east of the Víkurgerdisá, whilst similar petrographically to the rock of the Sandfell, cannot be the downfaulted continuation of the Laccolith but must be a separate sill intruded lower down.

As regards the large basic mass which appears low on the eastern flank of Sandfell, from the fact that rhyolite veins the mass Hawkes & Hawkes concluded that it predated the rhyolite and formed part of the updomed roof of the laccolith. In places, however, it is chilled against the acid rock and it probably post-dates the rhyolite intrusion. The acid veins are thought to be rheomorphic in character and due to the mobilisation of the rhyolite by the basic magma and its subsequent injection into the dolerite.

(i) ***The Fifth & Sixth Phase.*** — Two additional Phases are distinguished in the country north of Reydarfjördur. Of these, the Fifth is not represented south of the fjord and will not be further considered here. The Sixth Phase is most strongly developed around Sellátratindur, north

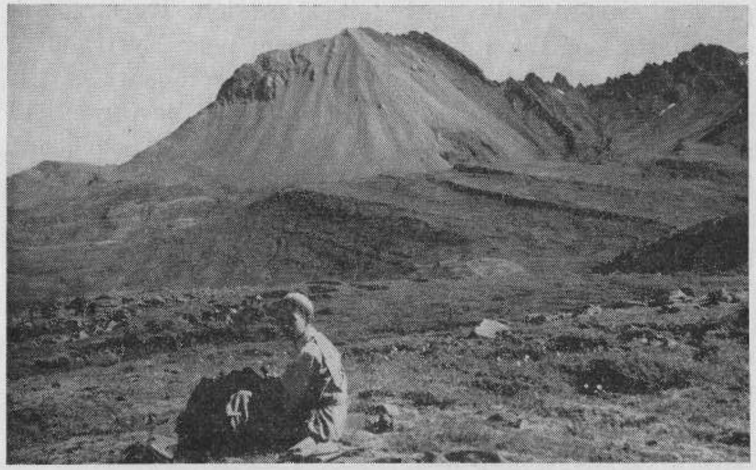


Fig. 14. The Sandfell Laccolith from the west, showing the updomed lavas and, in the foreground, lavas with the normal regional dip.

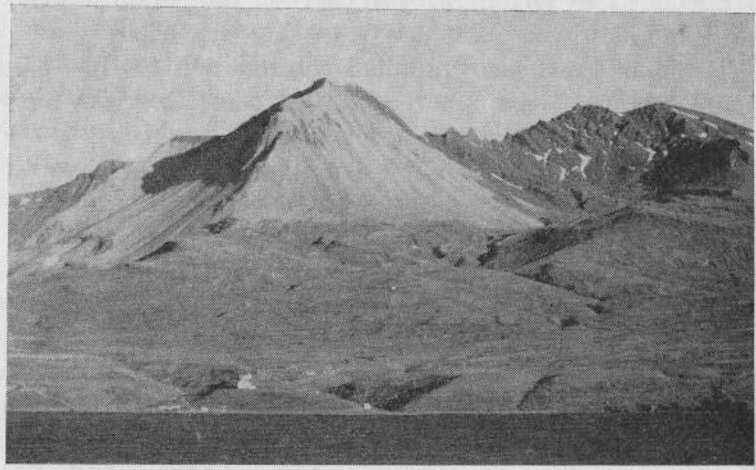


Fig. 15. The Sandfell Laccolith from the opposite side of Fáskrúdsfjördur.

of the fjord, but some lavas are also found south of the fjord and will now be discussed.

Five flows in the Fáskrúdsfjördur area are definitely part of the Sixth Phase. Three are composite flows, described in the following section, while the other two are exceptionally massive rhyolitic andesite lavas which were erupted approximately simultaneously. One of these two forms conspicuous cliffs in Gilsárdalur, where it attains a maximum thickness of 100 m, and it has a lateral extent of 5 km. The other flow, which is almost as thick, outcrops on Södulhnjúkur (fig. 9).

(j) ***Composite lava flows.*** — The four composite lava flows which occur near the top of the Reydarfjördur Acid Volcanic Succession are in many ways unique. Each has two components, one of basalt and the other of rhyolite, and the two were erupted essentially simultaneously from dykes. A detailed description has already been given elsewhere (Gibson & Walker, 1963), and the following is only a brief resumé of their relationships. The earliest, the Lower Gilsárdalur Composite Lava, belongs to the Fourth Phase but is for convenience discussed here, while the remaining three, (the Upper Gilsárdalur, Örnólfsfjall and Köttur Composite Flows) were erupted more or less simultaneously during the Sixth Phase. In order to make the following account more comprehensible, the flows are not described in stratigraphic order.

Cutting through a massive rhyolitic andesite flow on both the north and south sides of Gilsárdalur is a composite dyke about 50 m thick, with basaltic margins and a rhyolitic centre. On the north side the dyke is in direct continuity with an acid extrusion 60 m thick which rests on the rhyolitic andesite flow (fig. 17). Closer examination of the rhyolitic extrusion reveals that it is itself composite, there being a thin veneer of basalt, less than 1 m thick, underneath the rhyolite. On the eastern side this veneer can be seen to be continuous with the basic margin of the composite dyke. The contact between the rhyolite and the basic margin shows no mutual chilling or

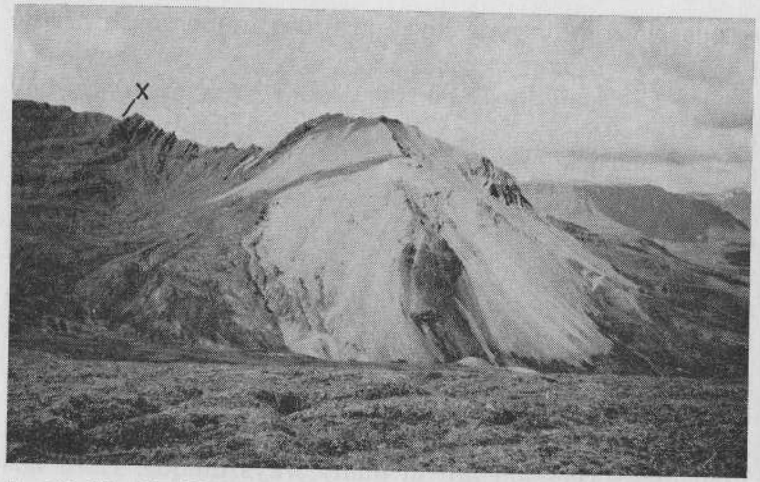


Fig. 16. The Sandfell Laccolith from the east, showing the updomed lavas of the roof and, in the middle, the mass of dolerite believed to be intrusive into the Sandfell rhyolite. The updomed roof extends as far as X, and the basalt lavas on the ridge to the left are believed to be banked up against the dome.

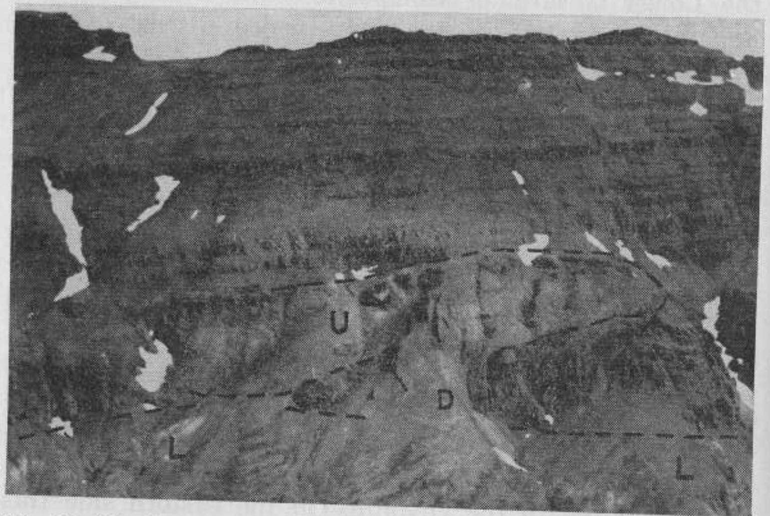


Fig. 17. The Upper Gilsárdalur Composite Flow (U, outlined by dashed line) and its composite dyke feeder (D), on the north side of Gilsárdalur. The top of the Lower Gilsárdalur Composite Flow (L) is also indicated by a dashed line.

intervening slag and there is every indication that the basalt and rhyolite were extruded simultaneously from the same fissure. Along the top of the composite body the rhyolitic portion is chilled to a pitchstone which in turn is overlain by a tuff bed. The latter is not disturbed or veined by the rhyolite while, near the eastern termination of the flow, undisturbed basalt lavas are seen banked up against the rhyolite and tuff, establishing beyond doubt the extrusive nature of this composite body.

A further outcrop of the same composite lava is found on Kjappeyrarmúli where it rests on the same rhyolitic andesite flow. Here the proportions of rhyolite and basalt are very different: basalt now predominates, and the rhyolite forms a small basin-shaped mass within the basic component of the flow. The basalt-rhyolite contact shows no mutual chilling and on the south side of the ridge, where both components show a flow structure, this structure is parallel with the mutual contact. The composite dyke is exposed a few metres east of the outcrop of the composite flow and, although direct continuity cannot be established there is little doubt that the Kjappeyrarmúli portion of the lava was also fed by the dyke.

The Örnólfsfjall Composite flow is exposed in the cliff at 630 m on the north side of Örnólfsfjall. Directly northeast of the summit, where the flow reaches its maximum thickness of 50 m, it is mainly of rhyolite with a 5 m basal layer of basalt. East and west of here the rhyolitic portion of the flow thins, and the basic portion thickens, until the whole 40 m thickness of the flow is of basalt. On a large scale, the contact between the two components is smooth and gently curving, but in detail it is irregular, with veins of rhyolite penetrating the basalt and marginally chilling it. The rhyolite is chilled to a pitchstone only at the top of the flow.

The rhyolite of the Upper Gilsárdalur and Örnólfsfjall composite flows and their associated dykes is conspicuously xenolithic; the xenoliths are of basalt similar to, but finergrained than, the basic component of flows and

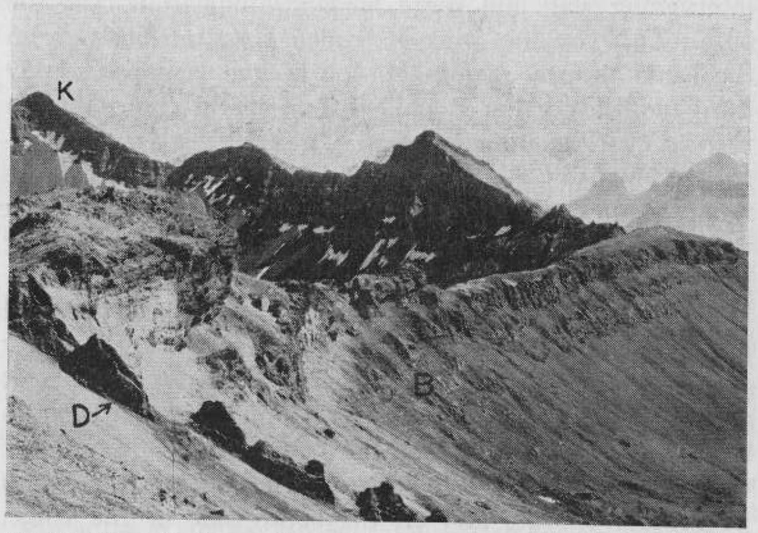


Fig. 18. View to the south-east from near the summit of Gráfell, showing rhyolite of the Köttur Composite Flow (forming crags, left foreground), cut by a basic dyke (D) and resting on basalt lavas (B). K = Kumlafell.

dykes; their margins are often highly irregular in form, and sometimes chilled. It is thought that they were of plastic magma at the time when they were incorporated into the rhyolite as xenoliths, before the composite lavas were extruded.

A single composite flow is found south of Fáskrúdsfjördur: that of Köttur. On the north-eastern shoulder of Eyrartindur it is seen joined to its composite dyke-feeder. Here the flow is 12 m thick and the acid and basic components are of almost equal thickness. South of Eyrartindur the rhyolite rapidly increases in thickness until, where it constitutes the summits of Köttur and Gráfell, it exceeds 200 m (fig. 18). The rhyolite is thus here dome-like in form. The basalt component cannot be seen, being concealed below the extensive rhyolitic screes from this dome. Later basalt lavas which cap Eyrartindur are clearly banked up against this rhyolite dome, confirming its extrusive nature. The rhyolite component is

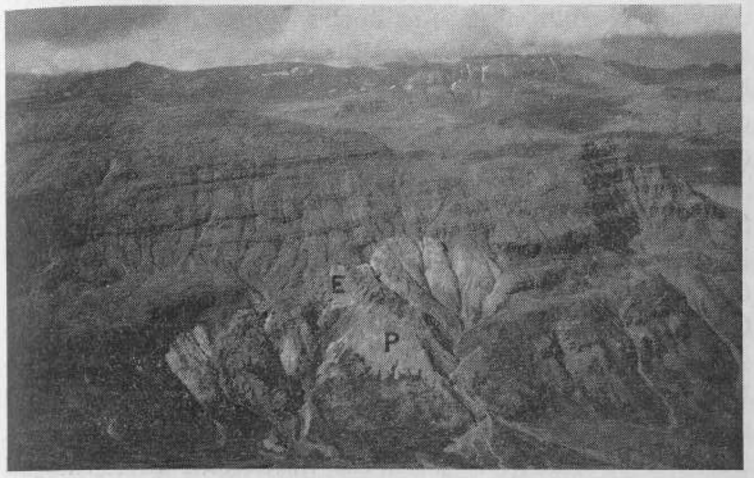


Fig. 19. The south-east side of Södulhnjúkur–Berutindur, showing a rhyolite extrusion (E) of the Fourth Phase, with the rhyolite plug (P) which has updomed it and the basalt lavas between. Later flood basalts are seen banked up against the rhyolite extrusion.

Fig. 20. Ljósafjall from the east, showing the prominent shoulder in the middle due to the rhyolite extrusion of the Fourth Phase.

unusual in containing anorthoclase phenocrysts. It is almost devoid of basalt xenoliths except adjacent to the basalt, while the presence of at least two pitchstone layers within the rhyolite suggests that it may be composed of several flow-units.

The earliest composite flow, the Lower Gilsárdalur flow, has a structure similar to the Köttur flow, but it is much less well exposed. It occurs on either side of Gilsárdalur, transected by the dyke-feeder of the Upper Gilsárdalur composite flow. Two more exposures of the same flow are seen farther north on either side of the Breiddalsá, where the flow is no longer composite and rhyolite alone is found. One of these northerly exposures forms a prominent step on the north side of Ljósafjall (fig. 20); the other, on the south side of Södulhnjúkur (fig. 19), has been updomed by a plug-like intrusion of rhyolite which is believed to be its feeder. This plug is on the same line as the dyke which feeds the flow in Gilsárdalur.

The rhyolite of the Lower Gilsárdalur composite flow is almost unique for eastern Iceland in containing phenocrysts of quartz. The basaltic lower component, and basaltic xenoliths in the rhyolite, contain sparse xenocrysts of quartz.

V. Stratigraphy of the Upper Part of the Succession.

(a) ***Introduction.*** — The rocks described in this section come above the Reydarfjördur Acid Volcanic Succession and make up the western half of the Fáskrúdsfjördur area. The 1600 m succession is made up of the following approximate percentages of the main rock-types:

tholeiite lavas	65 to 70%
olivine-basalt lavas	15%
porphyritic basalt lavas	10%
acid tuffs and thick sedimentary beds	5 to 10%

Although tholeiite lavas predominate, stratigraphic mapping is facilitated by the occurrence of several well-defined groups of olivine-basalt and porphyritic basalt lavas, and of several thick acid tuffs. One group of porphyritic basalts in particular (the Grænavatn Group) proves to be unusually persistent and enables the rocks of Fáskrúdsfjördur to be correlated with those as far away as the Lagarfljót, to the north, and Álftafjördur, to the south, a total distance of 70 km (Walker, 1964, fig. 1).

(b) ***The Hólmar and Grjótá Olivine-basalt Groups.*** — A prominent group of olivine-rich basalts, the Hólmar Group, almost everywhere forms a prominent escarpment above which occurs a mountainside bench (for example, the benches of Breidihjalli and the upstanding shoulders of Södulhnjúkur, Örnólfsfjall, Kjappeyrarmúli and Álftafell). The group rests in places directly, or almost directly, on acid lavas and it markes the end of acid volcanicity in the Reydarfjördur centre. The olivine-basalts of the group are conspicuously rich in zeolites, as in the very acessible exposures on Sléttuströnd.

The Hólmar Group thins slowly southwards from 150 m or more at Reydarfjördur to 100 m or less south of Stödvarfjördur. A second, and higher, group of olivine-basalts (the Grjótá Group) also thins southwards from about 80 m at Reydarfjördur to zero south of Fáskrúdsfjördur (a few thin flows of porphyritic basalt below Digritindur are at about the same horizon, but no olivine-basalts are seen in this area). The tholeiite lavas which separate the Hólmar and Grjótá Groups thin up-dip from 150 m to nearly zero on Örnólfsfjall.

Several ill-exposed acid tuffs, not shown on the map, accompany the olivine-basalts. One overlies the Grjótá Group on the summit of Ljósafjall. Another, on Örnólfsfjall, probably separates the Hólmar and Grjótá Groups, and erosion on it is probably responsible for the conspicuous bench on top of the former group on Breidihjalli and elsewhere.

Approximately 150 m of tholeiite lavas rest on the

Grjótá Group and intervene between it and the next mappable stratigraphic horizon, the Reydarfjördur Porphyritic Group. One of these tholeiite lavas exposed at 460 m east of Digritindur contains small gabbro xenoliths. An acid tuff bed, containing small feldspar crystals, also occurs; it is exposed on Sléttuströnd at 120 m in the stream from the corrie east of Kambafell, where it is 1.3 m thick and is overlain by a single 7 m flow of porphyritic basalt; the same tuff, 1.5 m thick, is seen at 360 m south-east of Hoffell, and at 450 m east of Digritindur. A 6 m bed of sandstone is seen at 370 m in the stream west of the Hádegisá, silty at the base and pebbly at the top where it includes sparse and ill-rounded boulders of basalt up to 60 cm. Sodic plagioclase crystals of pyroclastic origin appear in parts of this sandstone. A prominent bed of palagonite tuff occurs on either side of the Stödvará (Pal. T. on the map).

(c) ***The Reydarfjördur Porphyritic Basalt Group and Acid Tuff.*** — The group of richly porphyritic basalt lavas seen in the Búdará just above the village of Búdareyri, north of the western end of Reydarfjördur, is usually represented south of the fjord by a single porphyritic basalt flow up to 15 m thick. This flow is well exposed in a scarp just above the delta of the Hrútá (the stream north of Hallberutindur); at 270 m in the stream west of Eyrarfjall; at 215 m in the Ljótunnará (the stream south of Sauddalsfell); at intervals around the north pedestal of Digritindur; just below Lakaskard (the col north of Álftafell); and at 320 m in the Stödvará where it rests upon a 3 m conglomerate containing boulders up to 40 cm. The basalt disappears up-dip, east of Hoffell and Digritindur. Although thin and in places missing, it constitutes a useful stratigraphic horizon, especially when treated in conjunction with the prominent acid tuff which rests directly or almost directly on it: the Reydarfjördur Tuff.

This acid tuff is one of the thickest in eastern Iceland although, being an ill-consolidated rock, it is seldom exposed and its outcrop easily overlooked. It is pale-coloured and rich in flattened fragments of acid pumice up to 5 cm in maximum size. Normally the tuff is homogeneous and unbedded, and it is probably an ignimbrite, the product of an ash-flow, due to a single explosive eruption from an unidentified source. It has a maximum thickness of 10 m. It is 9 m thick on the southwest ridge of Midaftanshnjúkur. At 320 m in the Stödvará it is 6 m thick. Northwest of Álftafell it is about 6 m thick and is separated from the porphyritic basalt below by a single 20 m tholeiite. At 750 m on the north face of the easternmost summit of Háöxl it is 8 m thick.

The next mappable stratigraphic horizon is the Hólmatindur Tuff. An average of 150 m of predominantly tholeiitic lavas intervenes, sometimes including a thin porphyritic basalt (on Kambfell and Eyrarfjall) near the middle. In places olivine-basalts appear near the top, just below the Hólmatindur Tuff, as on Midaftanshnjúkur. Several minor beds of acid tuff are also encountered in the succession. One is seen 30 m above the Reydarfjördur Tuff in the Stödvará and on Háöxl. Another underlies the olivine-basalt at 840 m on Midaftanhnjúkur. A basalt flow on the ridge south-east of this peak is distinctive in containing an abundance of xenoliths of gabbro up to 15 cm in diameter.

(d) ***The Hólmatindur Acid Tuff and Lignite.*** — The only lignite bed in the Fáskrúdsfjördur area is intimately connected with this acid tuff: evidently the tuff rotted rapidly in Tertiary times to a moist soil on which vegetation flourished. The lignite is exposed at 415 m in the stream east of Kambfell; at 520 m in the corrie north of Sauddalsfell; at 460 m on the eastern side of Hoffell; and at 390 m in the stream south of Sauddalsfell. Silicified wood probably from the same horizon is seen at 600 m on the eastern slopes of Eyrarfjall. The lignite bed is up to 1.5 m thick at the first-mentioned exposure, but it is clearly not a commercially valuable deposit. South of the Tunguá the lignite fails, and all that is seen

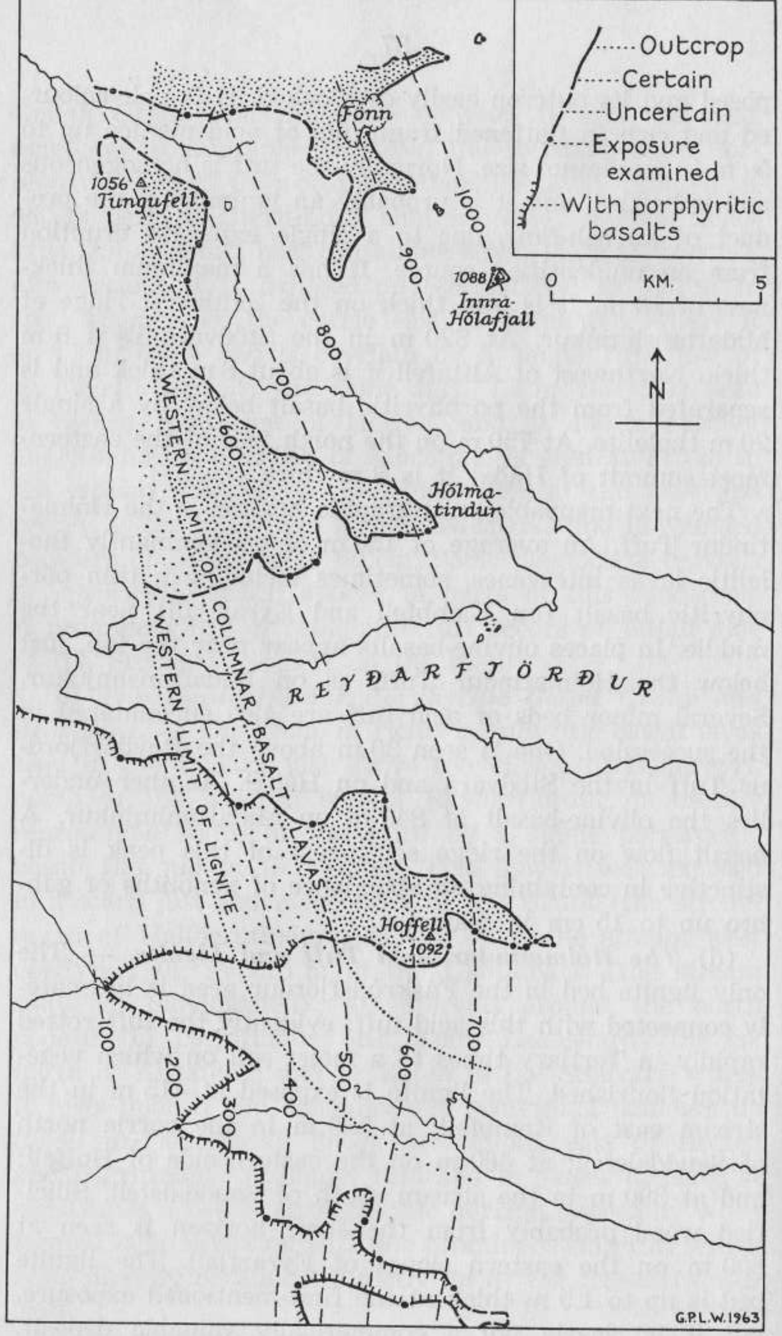


Fig. 21. The distribution of lignite and columnar basalt above the Hólmatindur Acid Tuff. Strike lines for the Tuff, with altitudes given in metres, are also shown (dashed lines).

is a 1 to 3 m bed of pale-coloured tuff. The probable distribution of the lignite bed is shown on the map, fig. 21.

Several prominent flows of columnar basalt appear above the tuff and lignite on Hoffell, Lambafell and Midaftanshnjúkur (figs. 6 and 7). The distribution of columnar basalt is very similar to that of lignite, as shown by fig. 21. The explanation may be that columnar jointing develops in a basalt lava that is ponded in a topographic depression, and lignite is also most likely to be concentrated in such a depression. Over most of the area where columnar basalt is missing above the tuff, a 30 m group of thin flow-units of porphyritic basalt is seen; the distribution of this porphyritic basalt is also shown on fig. 21. The Hólmatindur tuff itself is an air-fall acid tuff that has been to some extent resorted, by water or wind, since its deposition. It is the lowest of a group of several thin acid tuffs distributed over 60 m of vertical height. In the southern half of the Fáskrúdsfjördur area the uppermost tuff of the group becomes the most prominent; it is 6 m thick on Digritindur, and the 872 m summit east of Háöxl is flat due to the stripping-off of this tuff.

Above, as far as the base of the next mappable basalt group, comes a monotonous series of thick tholeiite flows totalling 270 m north of Hallberutindur and about half that thickness on Lambafell. Such an up-dip thinning of a group of lavas is common in eastern Iceland. Near the top of this series, at 650 m south of Sauddalsfell is a 9 m bed of palagonite tuff.

(e) ***The Kollur Porphyritic Basalt Group.*** — South of Reydarfjördur this group is often represented only by a single massive flow, but it is easily identified, being very rich in conspicuously large (up to 2 cm) phenocrysts of bytownite, together with some (smaller) olivine and augite. Although the main flow is never more than about 30 m thick, it is unusually massive and forms a prominent scarp feature, as on Lambafell (where it has a crude columnar jointing). It often shows a notable upward increase in the proportion of feldspar phenocrysts, due to a rising of the crystals in the lava, either because of they were less dense or because they were buoyed up by gas bubbles. Apart from a few isolated exposures, the Group fails south of Fáskrúdsfjördur.

(f) ***The Skessa Welded Tuff.*** — An account of this remarkable welded tuff, the first of its kind to be found in Iceland, appears elsewhere (Walker, 1962) and no detailed description is called for here. The tuff is pink and rhyolitic and averages 8 m thick. On account of the pink colour it can easily be distinguished from the shore of Reydarfjördur high (at 700 m) on Kambafell and (at 550 m) on peak 809 m to the west. Some of the best exposures are on either side of Daladalur, and the tuff attains its greatest thickness (14 m) at 480 m in the Tunguá.

The Skessa Tuff is interpreted as having originated near Röndólfur, in Berufjardarströnd (some 20 km south of Fáskrúdsfjördur) by an explosive acid eruption, and spread rapidly northwards as an incandescent tuff-flow; the tuff particles were sufficiently hot and plastic when they came to rest to weld together into a hard and vesicular rhyolitic rock, with a chilled glassy base. It represents a type of eruption which has not been experienced in Iceland in historic time.

The Skessa Tuff is the product of a single eruption. In places it rests upon a considerable thickness of soft pumiceous acid tuff, the product of an earlier eruption probably from a different source, as at 730 m on the southern side of Sauddalsfell, where it is 15 m thick. The presence of plant remains here between it and the Skessa Tuff establishes that an appreciable time interval elapsed between the two eruptions. Elsewhere the two tuffs are separated by up to 60 m of tholeiite lavas.

(g) ***The Grænavatn Porphyritic Basalt Group.*** — An average of 75 m of tholeiite lavas separates the Skessa Tuff and the next mappable stratigraphic unit, the Grænavatn Porphyritic Group. Not only is the Group one of the most persistent basalt horizons in eastern Iceland, but it is also one of the best exposed, almost everywhere forming a prominent escarpment or precipitous cliffs. It would be pointless to select specific exposure for description, since the Group is almost equally well exposed along the whole of its outcrop, from 120 m west of the head of Reydarfjördur to nearly 1100 m just below the summit cap of Lambafell, and on Háöxl.

The Group typically consists of 5 to 10 separate basalt flows, some of them highly porphyritic, with an aggregate thickness averaging 60 m. Zeolites are everywhere common, and the Group affords some of the best exposures for the new zeolite, garronite (Walker, 1962 a; the most accessible exposure is a 610 m on the north face of Skessa); and the rare zeolite, gismondine (Walker, 1962 b; the best localities are at 910 m on Eyrarfjall, and on Sauddalsfell and Hoffell).

The lavas above the Grænavatn Group are mostly tholeiites, but they include some olivine-basalts; two thin groups of olivine-basalt are seen on the western ridge of Hallberutindur, and they may be correlated with olivine-basalts seen at 920 m on Vadhorn and 950 m on the peak west of Jökultindur. No attempt has been made to map the distribution of these thin olivine-basalts. Several minor acid tuff beds are also seen. One, 1 m thick, appears at 980 m on Thúfutindur, and another occurs 15 m below the summit of Sauddalsfell. Some of the tholeiite lavas are believed to be outlying flows on the flanks of the Breiddalur Volcano: for example, the uppermost 450 m of Vadhorn is made of very thin tholeiite flows (of the type characteristic of central volcanoes) averaging under 5 m thick.

VI. Plant Remains.

Plant remains are found in two different situations in eastern Iceland. Some are found in interbasaltic sedimentary or tuff beds, occasionally as distinct lignite layers. Others — generally the moulds of trees, or part of trees — are found enclosed in basalt lavas. Both types are found in the Fáskrúdsfjördur area, and the nine occurrences we know are as follows:

1. A fallen block of basalt on the coast 300 m west of the abandoned farm of Skálavík contains a zeolite-lined mould of a tree 1.4 m long by 13 cm in diameter.
2. On the shore about 150 m south-east of Kolfreyjustadur, the lower part of a basalt flow contains a number of fossil samplings, probably in the position of growth. Six measured examples have diameters of 23, 15, 13, 10, 10 and 10 cm respectively.
3. A basalt lava at an altitude of 570 m on the south-east ridge of the 721 m peak of Stedji, 20 m above a group of thin flow-units of porphyritic basalt, contains a tree mould 1 m above its base with a box-work of thin basalt veins injected along contraction cracks in the charred timber. The tree is evidently in the position of growth; the mould extends intermittently upwards for more than 1 m, and is continued farther upwards as a crudely cylindrical mass of jasper. Nearby, three horizontal cydinders of jasper, 25, 20 and 15 cm in diameter, probably represent the infilled moulds of part of broken-off tree stems. The wood itself has now completely disappeared.
4. Occasional pieces of carbonised wood are found in acid tuff at 350 m on the north slopes of Södulhnjúkur.
5. Occasional pieces of fossil wood are seen in acid tuff at about 150 m in the stream east of the Gilsá.
6. A mould of a tree, 30 cm long by 8 cm in diameter, was seen near the base of a basalt flow at 340 m in a stream south of Kjappeyrarmúli.

7. The Hólmatindur Acid Tuff has, at or near its top, a bed of lignite (localities are listed on a previous page) up to 1.5 m thick. Silicified wood is abundant, probably from the same bed, at one point.
8. The thick acid tuff below the Skessa Tuff contains plant remains at its top at several localities: for instance, at 750 m in Vatnsdalur; at 780 m on the south side of Sauddalsfell; and (with tree fragments) at 570 m on the south-east of peak 918 m, Kambfjall. At 580 m in the Tinnudalsá the Skessa Tuff is traversed by open branching tubes up to 10 cm in diameter and 1.5 to 3 m above the base of the tuff; these tubes are almost certainly the moulds of saplings in the position of growth, overwhelmed by the tuff flow.
9. A mould in basalt of a small piece of charred timber was seen in one of the flows of the Grænavatn Porphyritic Group at 820 m on the south-east shoulder of Gódaborgarfjall, 1.5 km west of Sauddalsfell.

Occurrences such as those listed above confirm the subaerial origin of the basalts, and show that vegetation often flourished on the Tertiary basalt lava plains.

VII. The Dyke Swarm.

A swarm of approximately 200 basic dykes, with average trend nearly due north, crosses the Fáskrúdsfjördur area. Individual dykes range in thickness from less than one to more than 15 m, and the average thickness is about 3 m. The swarm is most concentrated on the coast near Thernunes where, in a distance of 1 km across the trend of the swarm, the number of dykes reaches 20, and dykes make up about 9% of the total rock exposed: the country has here suffered a 9% dilation. Variations

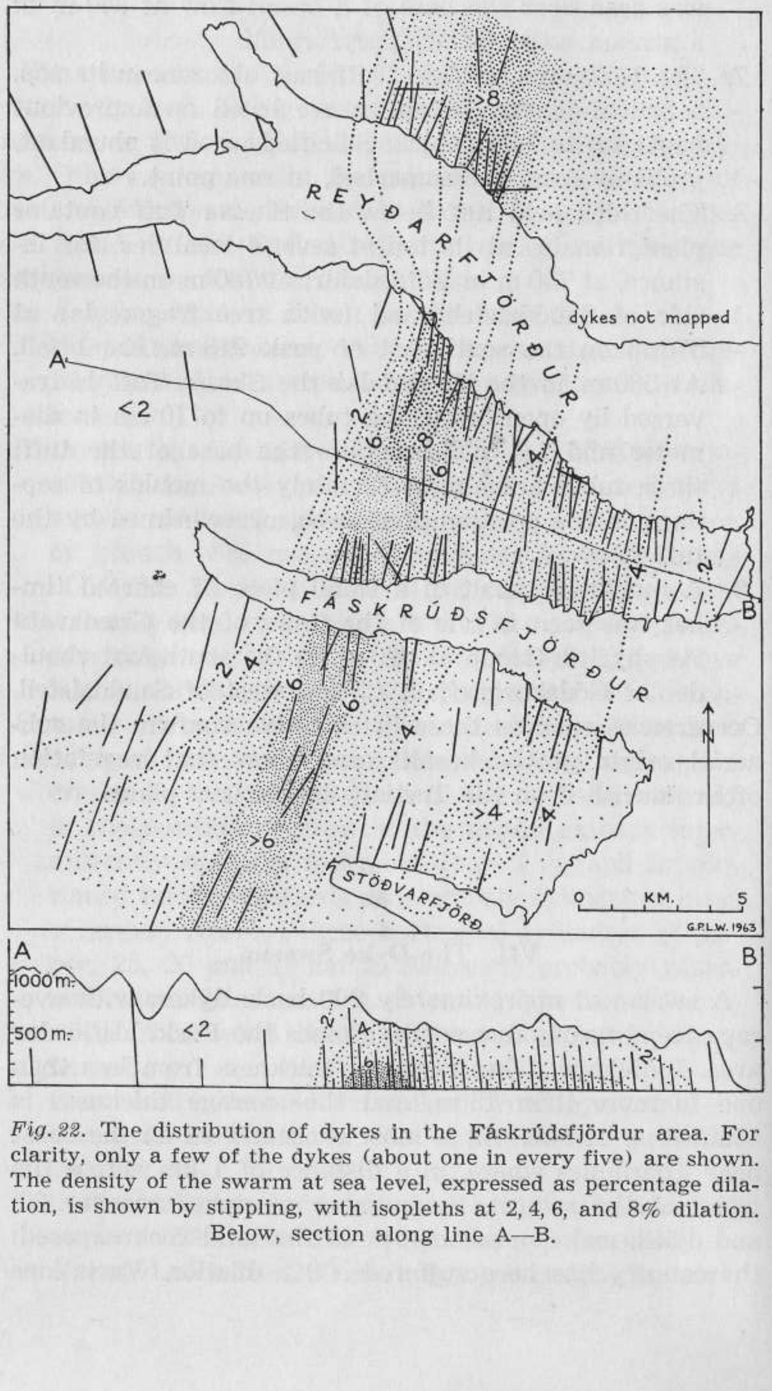


Fig. 22. The distribution of dykes in the Fáskrúdsfjördur area. For clarity, only a few of the dykes (about one in every five) are shown. The density of the swarm at sea level, expressed as percentage dilation, is shown by stippling, with isopleths at 2, 4, 6, and 8% dilation. Below, section along line A—B.

in the density of the swarm are best revealed by plotting a map showing the variation in the percentage dilation, fig. 22. As the density of the swarm invariably falls off rapidly with topographic elevation (section, fig. 22), the significant relationships are revealed only when the dilation is plotted at a single fixed elevation, and on the fig. 22 the dilation is plotted for sea level (the level for which it is most easy to collect data). This map shows that the zone of maximum density of the swarm trends east of north and passes through Thernunes, with a subsidiary maximum through Sóleyjartindur. The pattern conforms with that usual for eastern Iceland, of a swarm of great density passing through the region where acid rocks are most concentrated, in this case the acid rocks of the Reydarfjördur Acid Volcanic Succession.

It is believed that the basic dykes, or at any rate some of them, represent the feeders of the basic lavas, although in the Fáskrúdsfjördur area no example has yet been found of a dyke visibly joined to a lava flow.

Acid dykes are less common than basic dykes, and most of the examples of the former in the Fáskrúdsfjördur area are composite, possessing basic margins. The thickness of the composite dykes averages about 20 m and is systematically greater than that of the basic dykes; invariably the acid central component of a composite dyke is much thicker than the basic margins, which is probably a reflection of the much higher viscosity of acid magma compared with basic magma. The general characteristics of composite dykes in the Hebridean region, and the interpretation of these dykes (the basic margins were still hot when the acid centre came into place; and the basic magma which formed the margins is a hybrid which must have incorporated some of the acid magma before it reached its present position) are summarised by Bailey and McCallien (1956); the Fáskrúdsfjördur dykes differ in no important respects from the Hebridean examples.

Two distinct groups of composite dykes occur in the

Fáskrúdsfjördur area. One, of about six members, forms a small swarm centred on the Sandfell Laccolith (fig 10b), and is characterised by the possession of phenocrysts of quartz and sanidine (sodic plagioclase and fragments of a granophyric quartz, alkali feldspar intergrowth may also be present). The other, with four members, occurs farther west and lacks sanidine; three at least of these dykes attained the surface and extruded composite lava flows.

The composite dykes of the Sandfell group average 15 m in thickness and are composite where seen in shore sections, but when the same dykes are traced to the summits of the ridges 600 to 700 m higher, they are invariably thinner and commonly lack basic margins. One dyke, seen just below the summit of Kerlingarfjall, is entirely acid, with thin pitchstone margins. As it is traced upwards it is found to be joined to a tabular rhyolite body with a crude columnar jointing which forms the summit of the mountain, and is probably a sill. Another dyke is exposed at intervals for a distance of 14 km or more, and the exposures of it between Stödvarfjördur and Breiddalsvík were described by Guppy & Hawkes (1925). Two basic dykes which contain quartz xenocrysts and cut the Köttur composite lava flow are tentatively grouped with the Sandfell group, and one of these may have fed a basalt lava with quartz xenocrysts which underlies the Hólmar Group on Kumlafell.

In view of the fact that basic magma was erupted in such great volume during the Tertiary in eastern Iceland, it is surprising that there are so few basic sills and plugs. A few of these are, however, seen in the Fáskrúdsfjördur area and it is appropriate to mention them here. They are easily distinguished from the lavas as they are coarser in grain and often show a pronounced columnar jointing. The main intrusions are listed below:

1. A plug of dolerite with a near-circular cross-section forms the spectacular needle-like prominence west of the summit of Sóleyjartindur.

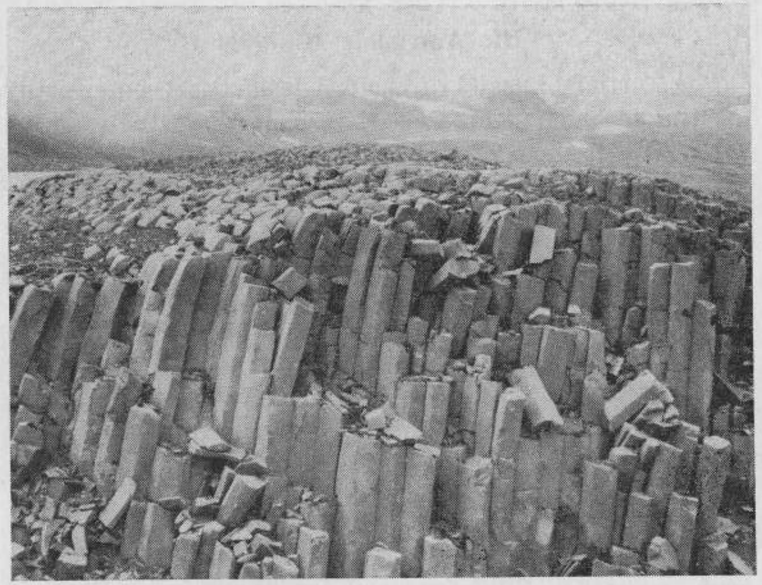


Fig. 23. Columnar dolerite sill, west of Lambadalstindur.

2. An irregular dolerite intrusion cuts the tuffs found just west of the Lower Gilsárdalur Composite lava on the north side of Gilsárdalur.
3. A large, irregular dolerite intrusion occurs on the north-west side of Kerlingarfjall.
4. The group of headlands north of Eyri farm, Reydarfjördur, are composed of a coarse dolerite and are probably separated parts of a single sill.
5. Thick dolerite sheets, inclined to the north, cut through basalt lavas on Lambadalstindur and Kambfjall. They have a particularly well-developed columnar jointing (fig. 23). Another, similar, sheet is seen in Launárskard.

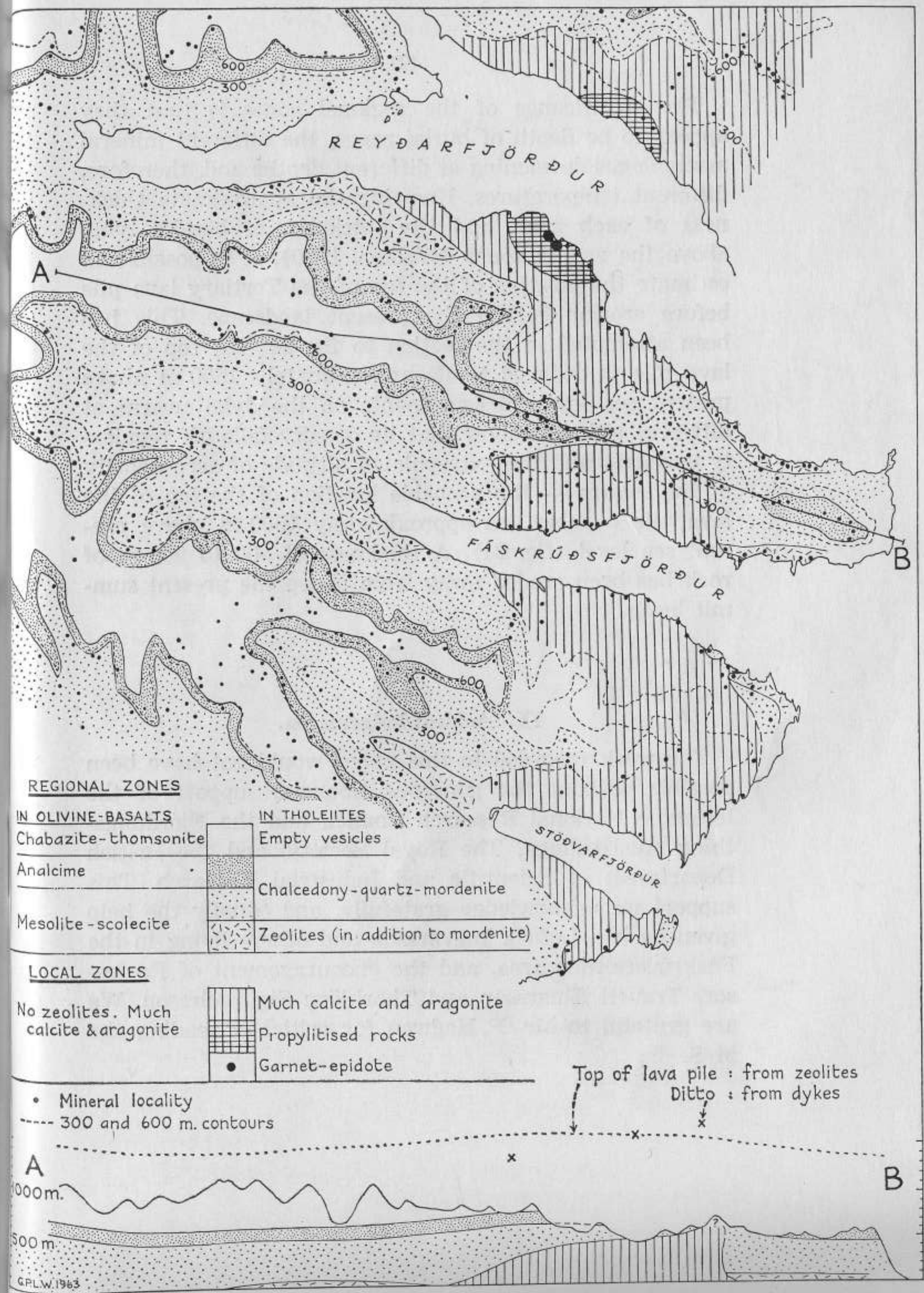
VIII. Amygdale Minerals.

The Tertiary basalts of eastern Iceland are noteworthy for the secondary minerals they contain in their amygdales. The pattern of distribution of these minerals has been discussed elsewhere (Walker, 1960), and the following account is a brief summary, in explanation of the distribution map, fig. 24.

Over a large area, where the dyke swarm is most dense and where acid volcanic rocks are concentrated, the lavas contain mostly calcite, aragonite, quartz and chalcedony in their amygdales, forming what is referred to on fig. 24 as a local zone. In the middle of this calcite-aragonite zone, on both sides of Reydarfjördur, is a small area of intense alteration (propylitisation) of the rocks, with the development of minerals such as chlorite, epidote and garnet. These local zones are believed to represent a fossil Tertiary geothermal 'high' of the same general type as is seen in places such as Krísuvík and Hveragerdi at the present day.

In the remainder of the Fáskrúdsfjördur area, the amygdale minerals form assemblages which can be shown when mapped to occupy well-defined and nearly horizontal zones (of regional extent), each zone being characterised by a distinctive mineral assemblage. In the olivine-basalt lavas, members of the zeolite group predominate in amygdales, and three zones can be mapped: an upper zone containing chabazite, thomsonite, and lesser amounts of phillipsite, levyne, gismondine and garronite; a middle zone in which these minerals are joined by analcime, stilbite and heulandite; and a lower zone in which mesolite and scolecite as solid aggregates also occur. In a parallel series of zones in tholeiite lavas, zeolites are found only in exposures very near sea level, while quartz, chalcedony, opal and mordenite (mordenite is a highly siliceous zeolite) occur up to about the same level as analcime does in the olivine-basalts. Above, tholeiite lavas have empty vesicles.

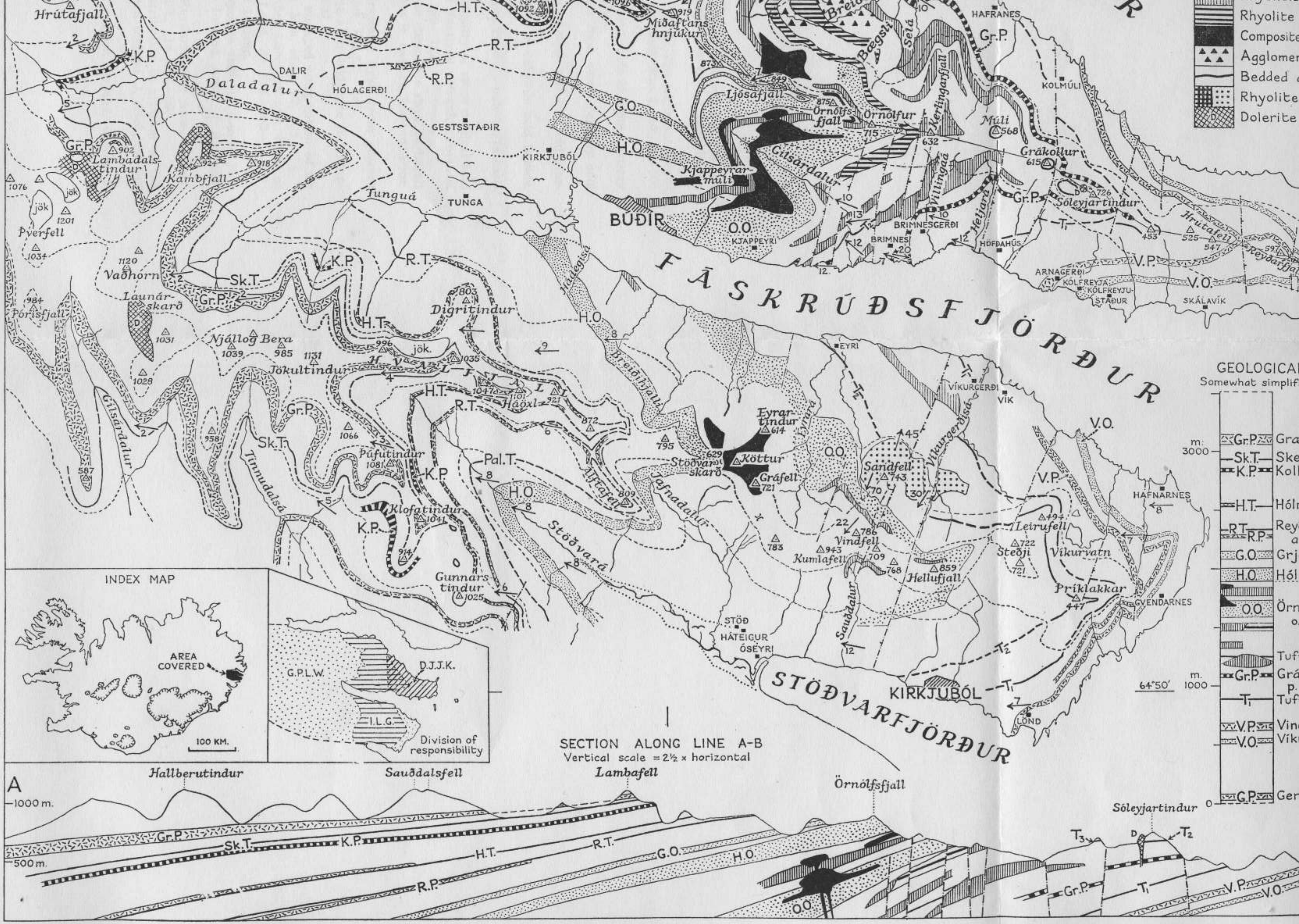
Fig. 24. The distribution of amygdale minerals in the lavas of the Fáskrúdsfjördur area. Below, section along line A—B.



The significance of the regional zones is that they appear to be depth of burial zones, the different mineral assemblages developing at different depths and, therefore, different temperatures. Knowing the approximate thickness of each zone, and the thickness of basalts lying above the zeolite zones (Walker, 1960), it is possible to estimate the position of the top of the Tertiary lava pile before erosion carved the present landscape. This has been attempted in the section to fig. 24; the top of the lava pile is deduced to lie approximately 1500 m above present sea level. Measurements on the dyke swarm at different altitudes show that its density falls off regularly upwards, and the extrapolated altitude of zero density of the swarm — the probable location of the top of the lava pile — also lies approximately 1500 m above present sea level (fig. 24). A thickness of 300 to 900 m of rock has been eroded away from above the present summit levels.

IX. Acknowledgements.

The work recorded in this paper would not have been possible without the generous financial support of the Icelandic National Research Council and the Fjórdungsthing Austfirdinga, The Royal Society, and the British Department of Scientific and Industrial Research. This support we acknowledge gratefully, and equally the help given by Mr. Lúðvík Ingvarsson and others living in the Fáskrúdsfjördur area, and the encouragement of Professors Trausti Einarsson and Thorbjörn Sigurgeirsson. We are grateful to Mr. P. Hadwen for critically reading the M/S.


FÁSKRÚÐSFJÖRÐUR
STÖÐVARFJÖRÐUR
BÚÐIR
KIRKJUBÓL
Hrútafjall
Daladalur
Lambadalstindur
Kambfjall
Tunguá
Þverfell
Vaðhorn
Launárskarð
Þórisfjall
Njáll og Bera
Jökultindur
Digritindur
HVALFJALL
Háöxl
Gilsárdalur
Tinnudalsá
Þúfutindur
Klofatindur
Gunnarstindur
Stöðvará
Álftafell
Jafnadalur
Breiðihjalli
Hádegisá
Eyrartindur
Köttur
Gráfell
Stöðvarskarð
Eyrará
Sandfell
Víkurgerðisá
Vindfell
Kumlafell
Sauðdalur
Hellufjall
Leirufell
Steðji
Víkurvatn
Priklakkar
Miðaftanshnjúkur
Ljósafjall
Örnólfsfjall
Örnólfur
Kjappeyrarmúli
Gilsárdalur
Bægsli
Selá
Kerlingarfjall
Villingaá
Heljará
Múli
Grákollur
Sóleyjartindur
Hrútafell
Reyðarfjall
DALIR
HÓLAGERÐI
GESTSSTAÐIR
KIRKJUBÓL
TUNGA
KJAPPEYRI
BRIMNES
BRIMNESGERÐI
HOFDAHÚS
ARNAGERÐI
KOLFREYJA
KOLFREYJUSTAÐUR
SKÁLAVÍK
HAFRANES
KOLMÚLI
EYRI
VÍKURGERÐI
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GVENDARNES
STÖÐ
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ÓSEYRI
LÖND
INDEX MAP
AREA COVERED
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D.J.J.K.
I.L.G.
Division of responsibility
SECTION ALONG LINE A-B
Vertical scale = 2½ × horizontal
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Sauðdalsfell
Lambafell
Örnólfsfjall
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Rhyolite
Dolerite
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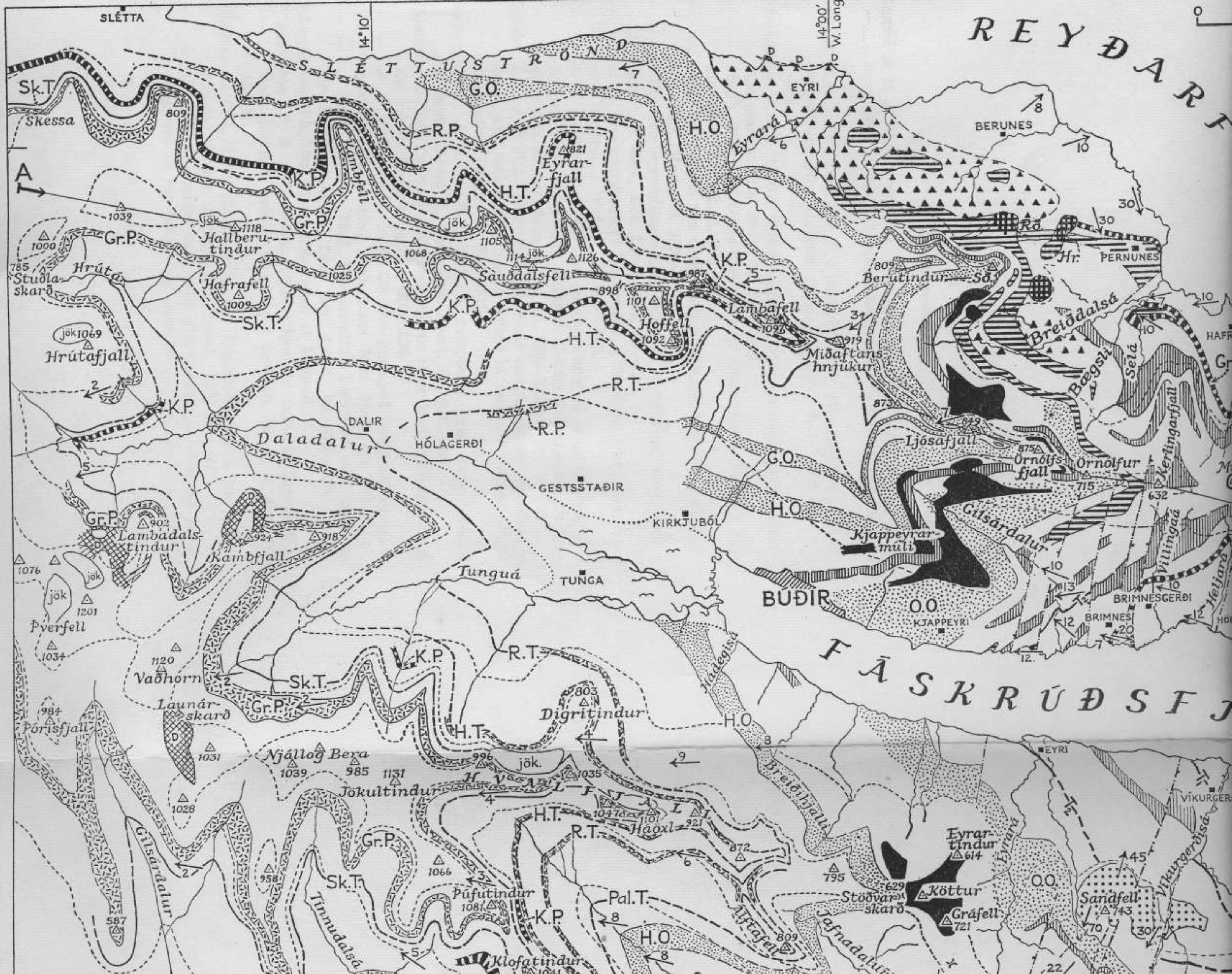

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Skessa
G.O.
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Pal.T.
Eyrará
EYRI
BERUNES
PERNUNES
Eyrarfjall
Kambfell
Hallberutindur
Sauðdalsfell
Hoffell
Lambafell
Berutindur
Miðaftanshnjúkur
Hrútafjall
Hafrafell
Stuðlaskarð
Hrúta
Breiðdalsá
Bægsli
Seiá
Kerlingarfjall
Ljósafjall
Örnólfsfjall
Örnólfur
Gilsárdalur
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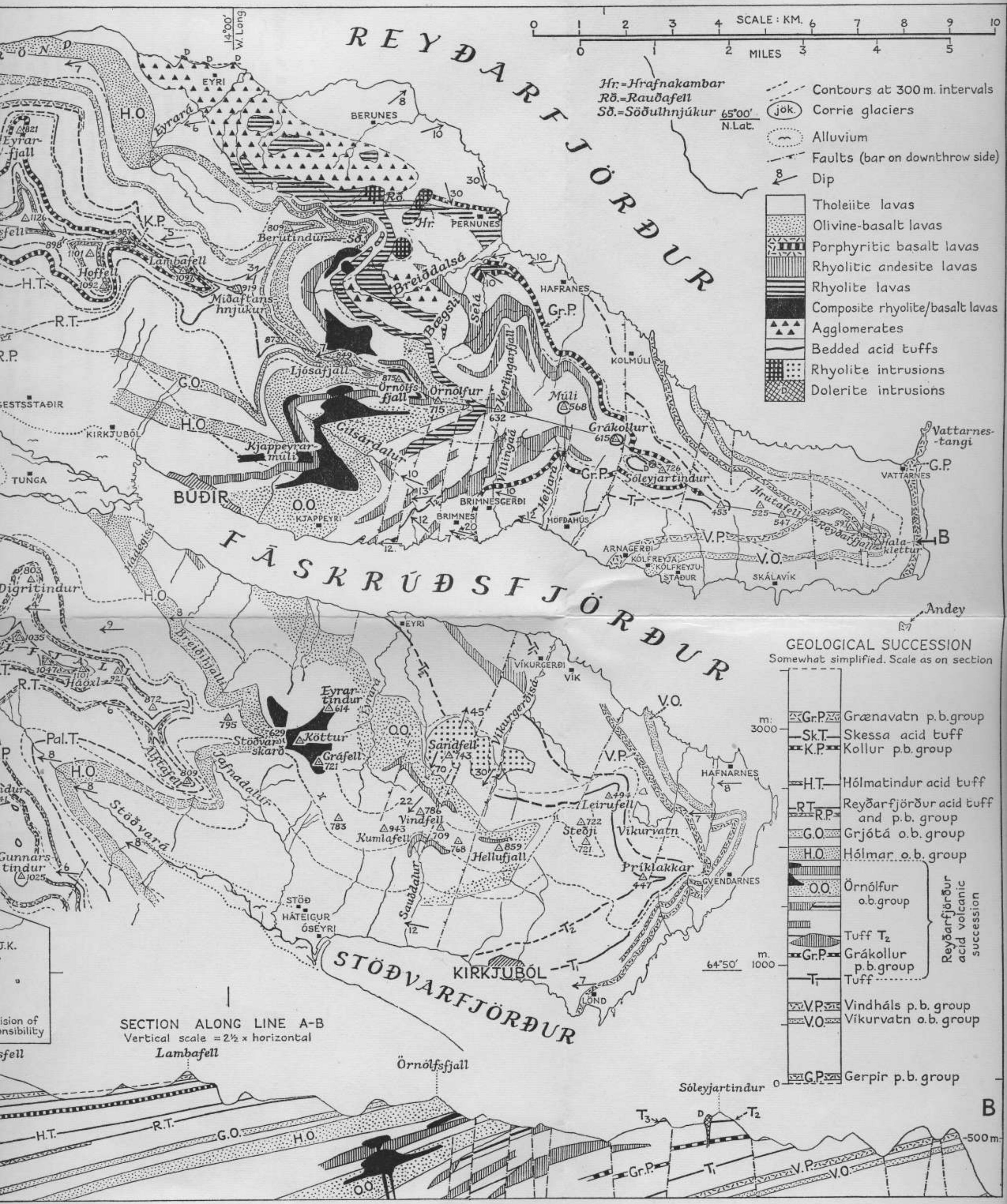
Hallberutindur
Sauðdalsfell
Lambafell
Örnólfsfjall


REYÐARFJÖRÐUR
FÁSKRÚÐSFJÖRÐUR
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MILES
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Hr.=Hrafnakambar
Rö.=Rauðafell
Sö.=Söðulhnjúkur
65°00' N.Lat.
14°00' W.Long.
64°50'
Contours at 300 m. intervals
Corrie glaciers
Alluvium
Faults (bar on downthrow side)
Dip
Tholeiite lavas
Olivine-basalt lavas
Porphyritic basalt lavas
Rhyolitic andesite lavas
Rhyolite lavas
Composite rhyolite/basalt lavas
Agglomerates
Bedded acid tuffs
Rhyolite intrusions
Dolerite intrusions
GEOLOGICAL SUCCESSION
Somewhat simplified. Scale as on section
Gr.P. Grænavatn p.b. group
Sk.T. Skessa acid tuff
K.P. Kollur p.b. group
H.T. Hólmatindur acid tuff
R.T. R.P. Reyðarfjörður acid tuff and p.b. group
G.O. Grjótá o.b. group
H.O. Hólmar o.b. group
O.O. Örnólfur o.b. group
Tuff T2
Gr.P. Grákollur p.b. group
T1 Tuff
V.P. Vindháls p.b. group
V.O. Víkurvatn o.b. group
G.P. Gerpir p.b. group
Reyðarfjörður acid volcanic succession
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m. 1000
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SECTION ALONG LINE A-B
Vertical scale = 2½ x horizontal
Lambafell
Örnólfsfjall
Sóleyjartindur
B
-500 m.
EYRI
BERUNES
PERNUNES
HAFRANES
KOLMÚLI
GESTSSTAÐIR
KIRKJUBÓL
TUNGA
BÚÐIR
KJAPPEYRI
BRIMNESGERÐI
BRIMNES
HÖFÐAHÚS
ARNAGERÐI
KÓLFREYJA
KÓLFREYJUSTAÐUR
SKÁLAVÍK
VATTARNES
Vattarnes-tangi
Andey
VÍKURGERÐI
VÍK
HAFNARNES
GVENDARNES
STÖÐ
HÁTEIGUR
ÓSEYRI
KIRKJUBÓL
LÖND
Eyrarfjall
Hoffell
Lambafell
Miðaftanshnjúkur
Berutindur
Breiðdalsá
Bægsli
Selá
Kerlingarfjall
Ljósafjall
Örnólfsfjall
Örnólfur
Múli
Grákollur
Gilsárdalur
Kjappeyrarmúli
Villingaá
Heljará
Sóleyjartindur
Hrútafell
Reyðarfjall
Halaklettur
Digritindur
Háöxl
Hádegisá
Breiðihjalli
Eyrartindur
Köttur
Gráfell
Stöðvarskarð
Álftafell
Jafnadalur
Stöðvará
Gunnarstindur
Eyrará
Sandfell
Víkurgerðisá
Vindfell
Kumlafell
Hellufjall
Sauðdalur
Leirufell
Steðji
Víkurvatn
Priklakkar