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A Contribution to the Geology of Loðmundarfjörður

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2 PLATES AND 5 FIGURES
IN THE TEXT

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CONTENTS

I. TERTIARY BASALTS

The east coast Tertiary basalts of Iceland have an exposed thickness at Loðmundarfjörður of at least 1000 m. The full succession however is probably much greater as the series dips westwards at 3° to 5°, and high peaks of over 1000 m (for example the Beinageitarfjall Mountain) may be found up to 25 km from the coast at the eastern edge of the fault valley of the Héraðsflói.

In the Loðmundarfjörður area the series may be divided into: —

3. Upper Basalt Series: (90 m exposed but probable thickness much greater)
2. Rhyolite-Tuffs (Ignimbrites): 60—90 m
1. Lower Basalt Series: ca. 770 m

The lavas may have been poured out from central craters, as was possibly the case with the truncated vent exposed in the Hraundalur valley, or from fissures. There are many dykes in the region but all are associated with a late tensional period and evidence of these dykes acting as feeders for the basalts is nowhere exposed. The eruptions were subaerial and occasional intercalations of clay and lignite may be seen in a number of east coast localities. The nearest of these outcrops of 'surtarbrandur' lie on the southern side of Loðmundarfjörður on the Brimnesfjall peninsula.

Hraundalur Vent

Immediately east of Kerling in Hraundalur an agglomerate and tuff vent cuts the basalts and is itself truncated and capped by later basalts (Fig. 2).

The coarse agglomerate outcrops over a considerably wider area in the valley floor to the north than the actual hill, thus indicating a former greater extent of the cone in that direction. Boulders of

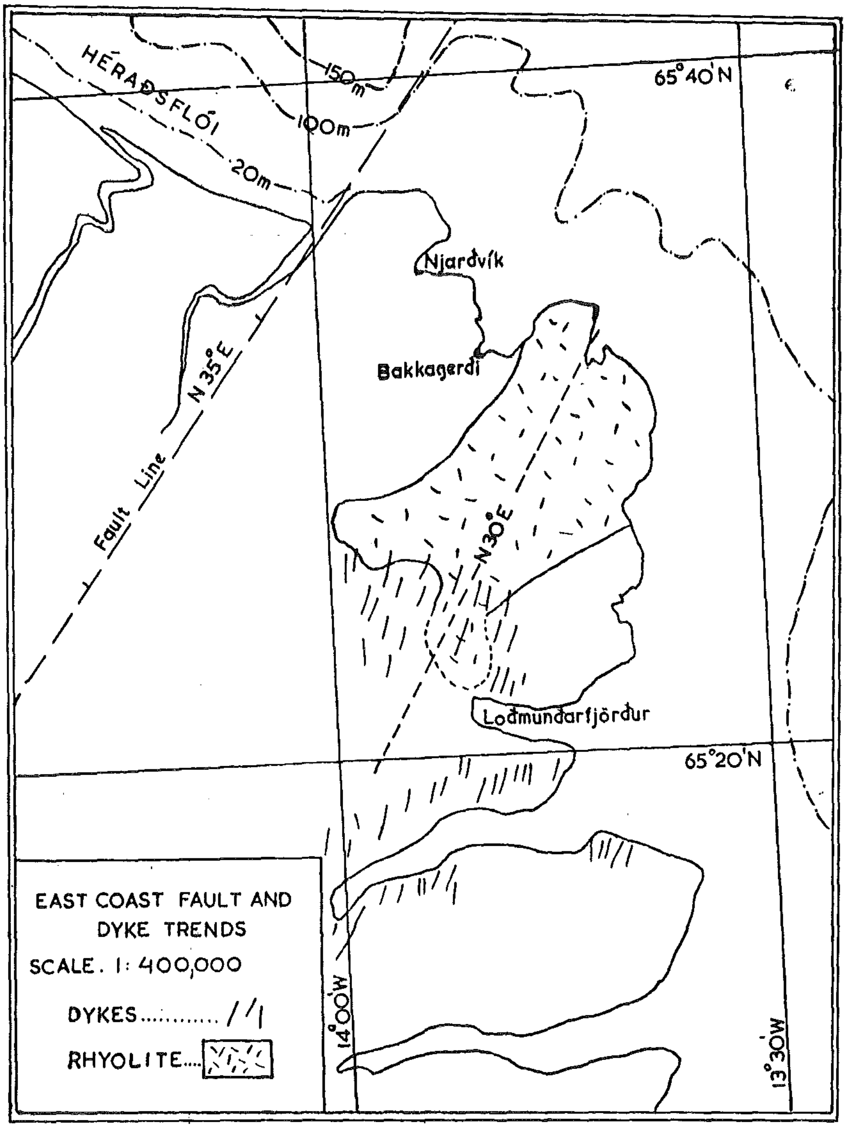

Fig. 1.

basalt up to 0,5 m across are common but the greater part of the cone is composed of fragments 3—8 cm across, showing a crude bedding which dips outwards from the central area, at an angle of 30°—35°.

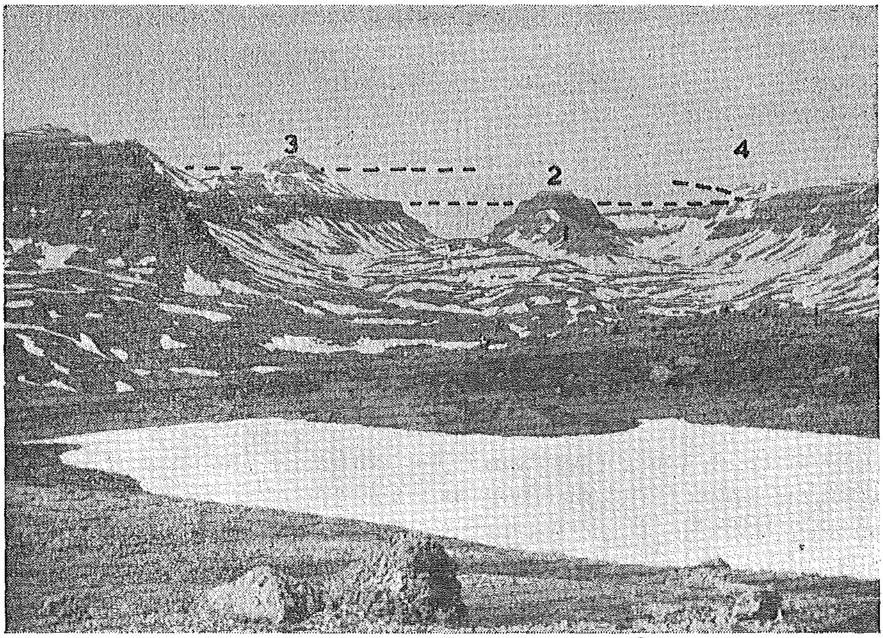

Photo: M. Murray.

Fig. 2. Karlfell — Hraundalur Vent. Looking west up Hraundalur. — 1: Vent; 2: Kerling Hill with sill forming summit plateau; 3: Karlfell; 4: Jónsfjall. The acid welded tuff is marked by broken lines, below and above which are horizontal basalts.

The central area of the cone coincides with a complex series of gabbroic sills and dykes. A vertical pipe occurs about 3—5 m across, and from it radiate irregular sills and dykes cutting the vent agglomerate; for instance one intrusive on the north side branches from the pipe as a dyke and then passes into a sill lower down the hillside. Within the pipe, in a weathered, soft, green basic matrix are large angular blocks (60—100 cm across) of porphyritic dolerite and gabbro. The rock contains plagioclase, labradorite, augite and a small amount of orthopyroxene, with accessory ilmenite. Ophitic structure is well developed and many large phenocrysts of labradorite are present.

If the cone is assumed to have been more or less circular it would have extended a few hundred yards to the north and overlain the gabbroic rocks which now outcrop in the valley floor as a series of striated rock pavements and roches moutonnées. The semicircular arrangement of the dip and strike of the bedded tuffs which make up the cone is open on the northern side towards the gabbroic rocks. Petrologically these isolated gabbroic outcrops are similar and probably constitute a sill with a thickness of 7 to 9 m.

Two specimens from the sill show similar compositions and were collected from the extreme ends of the exposed series of rock pavements. One has abundant small phenocrysts of olivine, showing evidence of corrosion, many large labradorite phenocrysts and a considerable amount of more basic plagioclase of the bytownite-anorthite range, the groundmass is a typical coarse, ophitic dolerite with clinopyroxene and labradorite and accessory skeletal ilmenite. The second is almost identical except that the plagioclase phenocrysts are slightly less calcic in general and bytownite is not so common as in the former specimen. No large amounts of orthopyroxene (hypersthene) occur, but the presence of this mineral together with the calcic plagioclase shows a eucrite trend to these rocks.

A chilled upper margin of the sill may be seen just north of the summit of the vent and the outcrop to the west has a similar chilled margin against the horizontal basalts on the lower surface of the sill, a continuation of which appears in the lower basalts of Kerling, where it splits and fingers out into the basalt flows.

Intrusion of these associated dykes and sills took place before the basalt capping was poured out from neighbouring sources. Later dykes of the N30° E-S30° W regional swarm cut the whole series.

An analcite bearing dyke to the south of the plug has a NW-SE strike and occurs in much shattered and tilted zeolitic basalts, with local dips up to 60°. The rock is an analcite-basanite, containing labradoritebytownite plagioclase, clino-pyroxene (augite) and numerous porphyritic olivines; analcite is a common interstitial mineral and magnetite-ilmenite forms an important accessory.

The basalt capping of the vent shows a slightly flow-banded rock with microphenocrysts of somewhat serpentinised olivine, labradorite and clinopyroxene with accessory ilmenite and magnetite.

No lavas can with certainty be recognised as originating from the vent and it may represent purely a local explosive phase during the outpouring of the basalts. So far as it is known no such vents have been previously described from Iceland although numerous necks occur in the Faeroes (*Geikie,* 1897, p. 295).

II. RHYOLITE-TUFFS (Ignimbrites)

Physiographic Features

At height of ca. 700 m a 60—90 m thick bed of rhyolitic (welded) tuff occurs over a wide area to the south of the main rhyolitic intrusion. The tuffs cover an area from Bungufell, in the east across Karlfell and Miðfell to Herfell in the west, but thin out in all directions, especially to the north. A prominent plateau is formed by erosion of these relatively soft tuffs, but on Herfell, Miðfell and Karlfell an upper series of basalts has protected the tuffs from complete erosion.

The upper surfaces are almost horizontal and the lower surfaces are regular and rest upon the basalts apparently with complete conformity.

There is no evidence to connect these tuffs with any volcanic cones in the neigbourhood, but it seems very probable that the explosive phase which gave rise to these great thicknesses of volcanic ejecta was connected with the intrusion of the rhyolite mass just to the north. An estimated minimum area covered by the tuff is 50 square km and the average thickness is about 60 m, thus giving a minimum volume of 3000 mill. m^3 or 3 cub. km. Throughout most of its thickness the rock is devitrified, granular and earthy in nature and although soft does not fracture with ease. No bedding is visible but a marked vertical jointing is developed on the northern face of Karlfell (NW of point 926 m) where columns 3—6 m high may be seen.

Petrology

The typical tuff specimen is white-grey or brown in colour, with a rough surface and contains a large number of foreign rock fragments within a mass of devitrified glassy pumice shards. The lapilli consist of varieties of spherulitic rhyolite, trachyte, olivine-basalt, and dolerite together with crystal fragments of orthoclase, albite, pyroxene and magnetite, embedded in a compact groundmass of bent and flattened glassy shards of pumice. Specimens show pumice fragments that are frequently collapsed and the glassy shards are compressed to give a compact structure, partly crystalline in places. The glassy fragments are slightly birefringent and show signs of incipient crystallization around the rims. These features, especially the bending and flattening of the glassy shards, are taken to be evidence of a hot plastic nature on deposition, and show a close parallel to the Eastern Californian tuffs as described by *Gilbert* (1938, p. 1842, Plate 3, especially Fig. 6), and to the Taupo-Rotorua (New Zealand) acid tuffs (*Marshall*, 1935, p. 323).

Marshall introduced the term "ignimbrite" to include these types of deposit and defined them as ". . . . igneous rocks of acid or perhaps intermediate composition which have been formed from material that has been ejected from orifices in the form of a multitude of highly incandescent particles which were mainly of a minute size." The origin ascribed to these tuffs was first put forward by *Iddings* (1920, p. 331), where it is stated, "when exploded fragments of molten lava, large or small fall together in a still heated condition . . . . they may be plastic enough to weld together in a more or less compact coherent mass."

Marshall (1935) followed up the idea and suggested formation in a similar manner to the tuffs of Katmai, in Alaska (as described by *Fenner*, 1925, p. 198), and Gilbert also regarded them as the products of "nuées ardentes" showers.

The tuffs of Loðmundarfjörður may thus be classified under the broad term of ignimbrites of Marshall's "Lapidites" of the "Paeroa Type" (*Marshall*, 1935, p. 333) which are described as having brownish colour, being less coherent than other types and earthy in hand specimens. They contain fragments of a great variety of volcanic rocks, the lapilli consisting of rhyolites and andesites etc., all of which are already well crystallized and showing some alteration at times, such as the chloritisation of ferromagnesian minerals. The fine portion consists of shreds of glass. Well marked columnar structure with vertical jointing is said to be a characteristic feature.

Thus, except for the fact that no andesites occur in the Loðmundarfjörður tuffs the above descriptions may be equally well applied to these deposits.

An interesting feature is developed at the margins of all the dolerite dykes which cut the ignimbrites. Here a glassy marginal facies invariably is found, black in colour and having a conchoidal-fracture and the lustre of pitchstone. Small dull non-vitreous lenses occur mottling the surface. Microscopically it is clearly of fragmental origin containing lapilli of trachyte, spherulitic rhyolite and basalt and crystals of augite, plagioclase and alkali-felspars. Examples of this glassy variation may be seen invariably where dolerite dykes of the regional swarm cut across the ignimbrite series, as for instance on the northern face of Karlfell (NE of point 926 m) and also below a thick crinanite sill forming the summit plateau of Kerling north of the Hraundalsvarp.

The possible significance of these marginal glassy rocks will be considered later, (see p. 24).

III. RHYOLITE INTRUSION COMPLEX

In the northern part of the region covered in this work the contact of a large intrusive rhyolitic mass with the Tertiary basalts is exposed.

General Geological Relations

The intrusive mass covers an area of about 130 km^2 and is marked on the "Geologische Karte von Island" of *Thoroddsen* (1906) as "Liparit u. Granophyr." It forms the most northerly of many intrusions indicated in the east coastal areas on this map, although the other intrusions, especially those to the south (in south-east Iceland) are complex acid-basic masses, *Hawkes* (1928 & 1933 etc.) *Anderson* (1949).

The Bakkagerði-Loðmundarfjörður intrusion forms a five mile wide outcrop, about ten miles long and with a general NE trend. On Thoroddsens map four isolated areas of "Liparit u. Granophyr" are shown as small outcrops to the south-west of the main intrusion. These correspond to the ignimbrite deposits of this paper and as such are not intrusive as implied by Geologische Karte von Island.

An interesting feature of the rhyolite is the fact that on its southern margin it exhibits extrusive relations, while to the north the mass is intrusive.

Extrusive Rhyolites and Obsidians

In a number of localities along the southern margin of the rhyolite intrusion, extrusive rhyolites are found showing vesicular structures, slaggy lenses, and ropy flow banding. Underlying these rocks is an irregular green agglomerate up to 10 m thick indicating intense pyroclastic activity preceding the acid eruptives.

At the eastern end of the Orustukambur cliffs a series of scattered exposures shows a thick mass of pitchstone agglomerate containing boulders up to 2 m across of flow-banded pitchstone in a grey-green weathered matrix. The finer grained green tuff contains fragments about 1,3 cm across of olivine-dolerite, perlitic pitchstone, trachyte, flow-banded rhyolite and basalt together with crystals of andesine and labradorite and olivine. The ground mass appears to be an altered yellowish-green glass (possibly palagonite?).

The tuff and agglomerate is underlain by fractured and much disturbed sub-horizontal basalts with local dips up to 30°. It is just below these basalts that the intrusive rhyolites are exposed. See below (page 19).

Dipping outwards from the surface tuff and agglomerates a 4—6 m thick flow of pitchstone occurs on the western side of the exposure, enclosing lenses of a red weathered breccia. This is followed by and passes up into steeply dipping thick flows of banded spherulitic rhyolite. The same type of sequence may be seen on the eastern side, exposed in a number of stream gullies; the dip is again outwards from the centre at about 50°—55°. Lenses of black obsidian are enclosed in the rhyolite. 300 m to the north of the main exposure at the river confluence, a 3—5 m thick flow of pitchstone occurs locally, again containing lenses of red breccia which is overlain by a 10 m thick series of spherulitic rhyolites. A typical specimen of the rhyolite shows radiating masses of minute rod-like crystals in a floworientated groundmass of partly devitrified volcanic glass containing many imperfect spherulites. Phenocrysts of sanidine and plagioclase (albite-andesine) together with euhedral zircons are common. The spherulitic structure is due to the radiating masses of quartz and felspar as circular, which show the characteristic black crosses under crossed-nicols.

Red agglomerate lenses pass laterally into banded flows, which show slaggy layers and flow-brecciation.

The above features suggest that this area is the site of one of the eruptive vents associated with the main intrusion. A characteristic trait of the rhyolites is the pronounced flow-banding especially well developed in the Orustukambur cliffs. The banding dips steeply away from the eruptive centre but within 150 m the flow-lines are horizontal. Further west they again become steeper but this time dipping to the east. The whole cliff section thus shows the flow-lines in the form of a flattened trough with a north-south axis.

On "North Hill"[1]) a similar series of steeply dipping flow-planes are developed below the thick crinanite sill forming the summit plateau of the hill. Here the rhyolites are again spherulitic; the rock is almost identical to that of the extrusion centre of the Skúmhattardalur river (p. 19) and to that of Skúmhattardalsbrík. The groundmass consists of radiating clusters of felspar crystals, with phenocrysts of andesine and quartz.

Below the rhyolite series of "North Hill" is a 9 m thick pitchstone or obsidian breccia resting on a shattered basement of basalts with local dips of 30°—40°. A section up the stream at this point shows the succession of basalt, pitchstone-agglomerate and tuff, and following above this, banded rhyolite. This succession is essentially similar to that of the Skúmhattardalur river (p. 19); below the waterfall at the western end of the Orustukambur cliffs, in the river valley the basalt basement is again exposed.

Hence it is seen that these extrusive characters persist along the whole of the exposed southern portion of the rhyolite mass, being preceded by intense pyroclastic activity.

According to *Williams* (1932, p. 142) ".... with few exceptions, such as Lassen Peak, volcanic domes lie within the craters of ash and lapilli cones, their rise having been preceded by intense pyroclastic activity, sometimes of long duration." Many of the structures attributed to these volcanic domes resemble the features exhibited by the rhyolites of the southern part of this intrusion, at Orustukambur and at "North Hill," in that they consist of a series of strongly banded spherulitic rhyolites dipping outwards from the vents. Before discussing the mode of origin and emplacement of the Bakkagerði-Loðmundarfjörður intrusion the field characteristics must be considered further.

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1) This hill is not named on the Danish Geodetic Institute Map (Blað 113), 1:100,000 but is marked above the 'Or' of Orustukambur. It was called "North Hill" for convenience of reference.

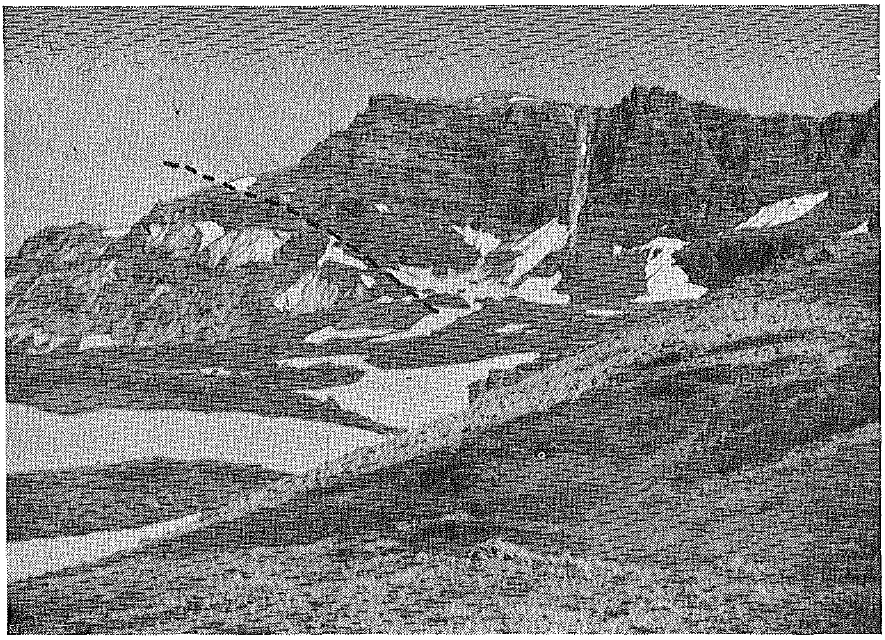

Photo: M. Murray.

Fig. 3. Skúmhattardalsbrík. South Face. — The vertical trachyte dyke is on the right, and the broken line indicates the junction between the intrusive rhyolites (below) and the basalts (above).

Intrusive Rhyolites

The main mass of the rhyolite is intrusive and it may be seen in many localities to the north of the watershed to cut across many hundreds of feet of horizontal and relatively undisturbed basalts. The southern contact of the intrusion dips southwards at about 20°. The upper cliffs of the plateau are composed of horizontal basalts; below which are the intrusive rhyolites, almost obscured by the extensive scree deposits.

The greater part of the area covered by the intrusion lies within the valleys of the Fjarðará, Þverá, Mosdalsá and Hrafná rivers, although towards the east higher ground occurs, with the mountains of Bálkur and Skjöldur, which appear to have a basalt capping. These areas were not visited but from photographic examination it is reasonably certain that Bálkur (731 m) has a basalt

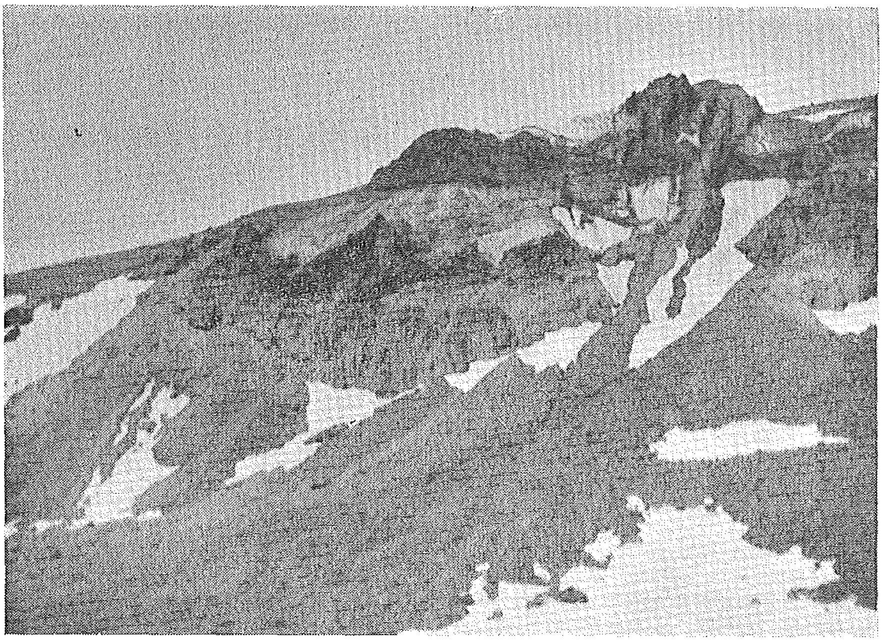

Photo: M. Murray.

Fig. 4. Skúmshattardalsbrík Cliff. — Part of the rhyolite intrusion below horizontal basalts. For explanation see text.

summit. The north-western limit of the intrusion may be seen formed by the horizontal basalts of the Dyrfjöll Montains (1136 m), 14 km to the north; the western limit, the Beinageitarfjall Range, lies 10 km to the west.

Other isolated basalt areas forming the capping of high peaks on the Loðmundarfjörður watershed may be seen on Skúmhöttur (778 m), Flatafjall (868 m), and the Miðfjall—Þriggjahnúkafjall ridge.

At Skúmhattardalsbrík (Fig. 3), 751 m, a 250 m section of the intrusion is exposed in the cliffs, half a mile long and forming the western ridge of the mountain. Horizontal basalts make up the main cliff and are intruded at the base by strongly banded spherulitic rhyolites giving, at first sight, the appearance of small-scale imbricate structure. The Skúmhattardalsbrík cliffs form the only exposed contact between the basalts and the rhyolites south of the watershed which shows the large scale features of an intrusive

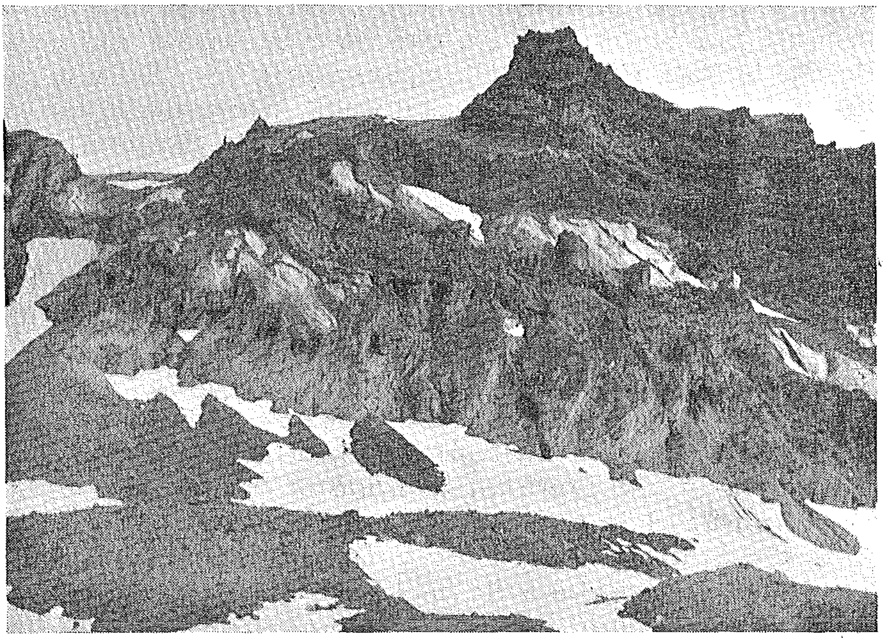

Photo: M. Murray.

Fig. 5. Skúmhattardalsbrík Cliff. — Continuation of Fig. 4.

contact (Figs. 4 and 5). There is a gradual passage at the western end of the ridge, from horizontal, massive-bedded, spherulitic rhyolite to the highly dipping banded series on the east. Passing eastwards there is a gradual upward splay of the rhyolites culminating in upturned, vertical units.

A bed of basalt, just above the latter, continues across the outcrop and is folded and thrust eastwards, and at the eastern end the thrust plane along which movement took place may be discerned, dipping to the west at about 30°. A second, almost horizontal thrust occurs a little higher up the cliff with contorted basalts above. In front of these thrusts a number of buckles are developed in the basalts due to compression by the force of the eastward moving, intruding rhyolite mass, but little or no large scale displacements of the basalts are to be seen, and no updoming occurs.

Dolerite and basalt dykes cut the whole cliffs in great profusion, notably along the almost vertical lines of weakness between the highly dipping rhyolite "units" and form irregular ramifying veins. Weathered "pitchstone" outcrops occur at various levels in the cliff face and an upward passage from banded spherulitic rhyolite to black pitchstone takes place within 50—100 cm at the top of the steeply dipping vertical units. Where the dykes cut these weathered outcrops a thin margin of black, glassy rock may be seen, the significance of which will be discussed later (p. 24).

The dyke at the western end of the section appears to have been injected along a line of movement as the basalt is displaced by it and shows an isoclinal fold and small thrust to the east. This dyke is a trachyte similar to the one cutting the whole series a little further east, and has numerous ramifying small dykes of dolerite associated with it and branching from it.

The large dyke cutting through the whole series of basalts (Fig. 3) is 10—15 m in width, has typical trachytic texture and consists almost entirely of close packed microliths of orthoclase, with flow structure parallel to the walls of the dyke. A few small clinopyroxenes occur and magnetite is a common accessory. Numerous thin dykes and veins of dolerite and basalt cut through the trachyte in an irregular manner.

At the margins of the dyke an intrusion breccia is developed up to a foot or more in thickness, consisting of angular trachyte fragments cemented by chalcedony.

Owing to the extensive snow and scree cover the junction of the dyke with the intrusive mass below is not seen, but it is probably similar to that observed at the west end of the cliff, which cuts the upper part of the intrusion and is a post-intrusion phase.

The top of the dyke cuts a 5—10 m thick sill of trachyte within which and near to its junction with the dyke, flow-structures may be seen and the underlying basalts show contortion. Petrologically the sill is almost identical with the trachyte of the dyke, and it is assumed that the latter does, in fact, act as a feeder to the sill.

The sill may be seen also below the summit basalt capping of Flatafjall (868 m), where it is at least 60 m thick; the vertical jointing of the sill is conspicuous and is developed extensively on the Skúmhattardalsbrík—Flatafjall col where it strikes east-west. South of Skúmhattardalsbrík the sill rapidly thins out and does not occur on the summit of Bungufell (732 m).

Within the area covered, the predominant rock type of the intrusion is a spherulitic rhyolite, with a tendency to develop a more coarsely crystalline ground mass than the extrusives of "North Hill" for example, where a marginal type is developed with a thickness in the region of 15 m. This type is a well developed spherulitic and flowbanded thyolite, with phenocrysts of albite and sanidine, which passes down into a finer banded rhyolite series with a texture suggesting trachyte. Zeolite and quartz-filled vesicles are common and numerous alkali-felspar phenocrysts occur.

Skúmhattardalur River Rhyolite-Basalt Contact

In the river which flows from the Skúmhattardalur corrie, 300 m south from the eastern end of the Orustukambur cliffs a rhyolite basalts contact is exposed. It occurs near to the extrusion centre and possibly constitutes the upper part of a magma chamber covered by a thin series of basalts, above which the surface flows may be seen.

Exposures in the river gorge show shattered sub-horizontal basalts penetrated by a network of quartz and green rhyolitic veins in advance of the irregular rhyolite junction. Within a few metres a passage occurs from normal rhyolite, through a zone of basalt blocks traversed by rhyolitic bands to the relatively undisturbed basalts penetrated by veins of rhyolite. The junction is extremely irregular and may be seen cutting across the individual basalt flows. In the river bed large blocks of banded pitchstone or obsidian, and blocks showing bands of green rhyolite alternating with darker basic material formed from xenoliths occur in great profusion. A continuous variation may be seen in the rhyolite magma from large angular blocks of basic material, through more rounded and lenticular inclusions, to almost completely assimilated and drawn out filaments, which give the rock a banded appearance.

The effects described above form a close parallel to the Gardiner River rhyolite basalt contact of Yellowstone Park, as stated by *Fenner* (1938, pp. 1442—1483) where the basalts are locally penetrated ". . . . in the most intricate and irregular manner by more or less contaminated rhyolite. This injected material is in small to minute veinlets. Both the rhyolite and the hybrid rock contain numerous vesicles lined with tridymite crystals and the passage of gases is indicated by open pockets and pipes of irregular shape. The vertical zone of basalt penetrated in this manner by rhyolitic liquids and gases has a width of 1 or 2 up to 4 or 5 feet." (*Fenner*, 1934, p. 119).

Fenner (1934, p. 120), states that the "penetration of veins of rhyolite into solid basalt for long distances indicates a remarkable mobility of the rhyolite magma, even if .... it was forced into seams of the basalt under great pressure of .... magma," and further goes on to say that, "This mobility may be ascribed to its high content of volatiles."

In thin section the darker bands and the lighter rhyolitic bands may be distinguished, the latter being similar to the spherulitic rhyolites of Skúmhattardalsbrík, the darker areas, of partly assimilated basic inclusions, form irregular areas around which the rhyolite shows flow structure. Within an area of dark material the ground mass consists of alkali felspar but contains phenocrysts of oligoclase, occasional biotites, associated with wisps of chlorite, and many small crystals of hornblende. Small zircons are common, often enclosed in the biotite crystals and magnetite is scattered throughout the groundmass. The borders of the basalt inclusions are corroded , and fragments can be seen to have broken from the larger masses and to be in the action of floating away in the rhyolite. Very thin veins (0,1 mm) of tridymite pass from the rhyolitic liquid and penetrate the more basic areas. Felspar phenocrysts show signs of corrosion and fusion along the borders, especially when they occur as phenocrysts within the fragments which have broken away from the larger basic inclusions. The basic portion has been greatly altered and although numbers of labradorite and bytownite phenocrysts are still present the groundmass has gone over into an almost irresolvable, uniform-textured, crystalline aggregate with orthoclase. No olivine is present and all the pyroxene appears to have gone over into hornblende. Phenocrysts of albite occur along with andesine-labradorite felspars in the rhyolitic portion of the rock and magnetite is scattered throughout the more basic areas in small crystals.

Fenner (1938, Pl. 7, Fig. 2) shows a photomicrograph with dark portions of "soaked" basalt in rhyolite which is almost identical with the features described above. "In most places in the section all evidence of xenolithic inclusions has disappeared, though here and there traces persist in small, dimly perceptible areas which are a shade darker than the rest" (*Fenner*, 1934, p. 121).

It appears to be reasonably well established then, that the Loðmundarfjörður (Skúmhattardalur river) basalt-rhyolite contact shows evidence of the ability of the rhyolite intrusion to dissolve basaltic material. This, of course, is contrary to what might be expected from the theory of differentiation by crystal separation since, ".... the magma that begins to differentiate is basic, probably basaltic. As this cools, crystals separate, and by their separation the composition of the remaining liquid is caused to change progressively. In the normal sequence the liquid passes from basalt through increasingly siliceous andesitic types to a very siliceous rhyolite. The points to be noted are that rhyolite is the coolest liquid of the series, and that basic constituents have been eliminated by a freezing out process. It follows necessarily that if rhyolitic magma should engulf fragments of basic rock it should not be able ordinarily to melt them or take them into solution, as the minerals of such basic rocks are almost wholly of the sort that, theoretically, have already been frozen out of the magma in the process by which rhyolite has been generated." (*Fenner*, 1934, pp. 113—114).

The importance of the presence of volatiles in the rhyolite has been stressed (*Fenner*, 1938, p. 1481 etc.) and this feature is shown by the effects produced on the wall rocks of the Loðmundarfjörður intrusion, and by the characters of the extrusive facies of rhyolite. In many places within the margins of the rhyolite, and penetrating the basalts nearby, irregular veins of siliceous residue from the acid magma, chalcedony, agate and opaline breccias may be found, e.g. at Skúmhöttur (778 m) and in the cliffs to the west.

The vesicular nature of the extrusive rhyolites suggests prolonged evolution of gases.

In the Skúmhattardalur river contact the abundance of quartz veins penetrating the basalts and the presence of tridymite veins passing into the basic portions of the hybrid rocks indicates the presence of a highly gaseous rhyolite magma, together with tenuous liquid and gaseous rhyolitic solutions.

IV. MINOR INTRUSIVES

The third phase of the Tertiary igneous activity in the region is marked by the presence of a large series of dykes (Fig. 1). Within the east coast areas of Loðmundarfjörður and Seyðisfjörður many hundreds of dykes occur, with an average direction of N30°E to S30°W, although individual variations up to a maximum of 20° from this trend may be found. The limits of this particular swarm are not known but occasional dykes of the same trend are to be found as far south as Eskifjörður and the occurrence of a dense dyke swarm trending NE-SW to NNE-SSW cutting the plutonic masses of south-east Iceland have been noted by *Hawkes* (1928, p. 505).

The apparent absence of dykes from areas of the map does not preclude their occurrence, but in view of the nature of the reconnaissance no detailed plotting of all the dykes was attempted.

Within the Loðmundarfjörður area the dykes are predominatly vertical and constant in direction, cutting across all the rocks of the region. They are cut however by two well exposed sills of crinanite and olivine-dolerite on Kerling and "North Hill" respectively. In general the sills occur after the intrusion of the dykes.

The various rock types of which the dykes and sills are composed may be divided into the following groups: —

1. Crinanite.
2. Olivine-dolerite.
3. Porphyritic dolerite and basalt.
4. Trachybasalt.
5. Trachyte.

A description of representative examples of each of these types is as follows: —

1. *Crinanites*

3—6 m thick N25° E-S25°W crinanite dyke occurs at the western end of the Orustukambur cliffs and projects above the intrusive rhyolites as a high wall, which can be traced for almost a mile. The rock is an ophitic, analcite-dolerite containing numerous large phenocrysts of fresh olivine, many of which show biaxial negative interference figures, thus indicating a high iron content (fayalite). The groundmass consists of labradorite, augite and accessory magnetite, with a large amount of interstititial analcite filling the polygonal spaces between the felspars and frequently containing needlelike apatite inclusions. A picrite trend is indicated by the large number of olivine phenocrysts present.

The sills which occur east of point 877 m on Miðfjall and just below point 926 m on Karlfell are almost identical, being olivine-analcitedolerites but with brown iron-rich rims characteristically altered to brownish iddingsite. The amount of olivine is less than in the other crinanites and the analcite portion is greater. According to *Tyrrell's* classification (1923, p. 252) this type should be termed a teschenite.

2. *Olivine-dolerites*

Three specimens have been studied from the sill forming the summit plateau of "North Hill." Olivine is not common in any of these rocks, but some degree of concentration of clinopyroxenes occurs in the specimen from 15 feet above the base of the sill where large plates of pyroxene enclose small labradorite crystals. Between these large ophitic plates ilmenite and small crystals of olivine are found. The top of the sill is a typical ophitic dolerite with only a small amount of olivine while the base is made up of a fine-grained basaltic rock with a very small amount of olivine.

3. *Porphyritic dolerites*

This type forms the dyke at the waterfall in Hraundalur, due south of "North Hill." The rock has a basaltic groundmass with numerous, large and zoned phenocrysts of bytownite and labradorite, with an outer rim of albite-oligoclase. The pyroxene is greatly altered into uralite; olivine, which is present in only small amounts, is confined to the matrix. The rock forming part of the vertical pipe of the Hraundalur vent (p. 7) is almost identical.

Both these types correspond to the "Dykes of Porphyritic Central Type" of the *Mull Memoir* (1930, pp. 351—352), and the crinanite dykes of this paper correspond to the "Dykes of Plateau Basalt Type" (*Mull Memoir*, 1930, pp. 350—351).

4. *Trachybasalts*

A vertical 2,5—3 m wide dyke occurs, together with many others, in the western cliffs of Bungufell with a N25°E — S25°W trend. Small pyroxenes, with alkali-felspar and labradorite laths and accessory magnetite occurs as a fine-grained trachytic groundmass. Olivine is present in small crystals and plagioclase phenocrysts, mantled with orthoclase are common.

5. *Trachyte*

Represented by the vertical dyke and the sill of the Skúmhattardalsbrík cliffs.

Note on the Developement of Glassy Rocks at Dyke Margins

As mentioned previously, glassy margins are invariably associated with the dolerite dykes or sills wherever they cut either the ignimbrites or the intrusive rhyolites.

Microscopically the margins of a dolerite dyke, which cuts the rhyolites of the Orustukambur cliffs, show the chilled phase of the basalt dyke passing into a darker (tachylytic) zone, containing labradorite phenocrysts, orientated parallel to the margin of the dyke which in turn passes irregularly into flow-banded, lighter coloured rhyolite. In hand specimen this marginal rock has a pitchstone lustre and is black or greenish and glassy. A specimen from a dyke margin on the Flatafjall-Skúmhöttur col shows similar flow-banding parallel to the dyke and contains phenocrysts of albite, traversed by hematite veins, which give them a red colour in hand specimens.

The margin of a dolerite dyke cutting the ignimbrites of Karlfell, and a similar rock from below the Kerling crinanite sill at its contact with the ignimbrites at the western end of the plateau, both appear, at first sight, to be flow-banded pitchstones. Microscopically they are clearly fragmental deposits exactly similar to the ignimbrite of Karlfell but having undergone fusion followed by relatively quick cooling during the intrusion of the dyke or sill.

A deposit of perlitic pitchstone in the Fitjar area runs in a line approximately parallel to the dyke swarm and is here interpreted as a refused margin where dolerite dykes cut the near-surface rhyolites. Some dolerite dykes of the regional swarm may be seen 'in situ' with margins of perlitic pitchstone. The relatively straight line taken by the pitchstone outcrops over the irregular ground suggests its verticality, which in turn tends to confirm the view that the pitchstone is merely a refused and quickly cooled margin to the dykes.

Thoroddsen (1899, p. 503) suggested that the mass of jumbled blocks of spherulitic rhyolite which cover large areas of the corrie floor was a lava flow. *Hawkes* (1917) ascribed them to a "rock-stream."

The actual nature of the rocks hereabouts seems to indicate a cover of moraine over actual outcrops of rhyolite. The fact that at least some of the rhyolite blocks are 'in situ' is proved by the occurrence of dolerite dykes with pitchstone margins cutting them, within some of the so-called morainic areas.

Tectonics of the Dyke Swarm

"Thoroddsen's map of the north-western peninsulas shows 62 dykes in the southern half of the area, the dykes trend NE—SW, but in the northern part they mostly run NNW—SSE. Thoroddsen says that a few of the dykes are older than the "surtarbrandur", but by far the greater number cut through all the Tertiary basalts up to the highest summits, but are older than the 'Palagonite Formation' and the intrusions of glaciated dolerite and, in large part, older than the late Miocene faulting" (*Tyrrell*, 1949, p. 437). In the Loðmundarfjörður east areas the dykes of the regional swarm are certainly later than the rhyolitic intrusion and may thus be associated with the faulting of the Héraðsflói rift-valley, of late Miocene age. Fig. 1 shows the line of the fault forming the eastern margin of the Héraðsflói rift and its continuation out to the sea, as marked by the line of the 100 m sub-marine contour line. The fault has a trend of north 35° east.

The average strike of the dykes comprising the swarm is N30°E (see Fig. 1) and it would seem to be more than a pure coincidence that the two directions are so closely parallel.

In addition it may be noted that the general elongation of the intrusion (marked in outline) is roughly parallel to the fault direction.

The WNW — ESE tensional force may have had some degree of control in the determination of the trend of the elongated dome of the intrusion, and may, at a later date, have been active in the production of the Héraðsflói rift-valley and the initiation of the Loðmundarfjörður dyke swarm. Further, it would appear that this tensional force was active over the whole of the eastern areas of Iceland to produce the NE — SW swarms of the south-east coast associated with the earlier plutonic intrusions of these regions.

The basalts of the eastern areas dip inland (to the west), at an angle, from 3°—5° and the western basalts of Iceland similarly dip inland (to the east), thus giving the form of a shallow trough in the central areas of which the post-glacial deposits are to be found.

If the eastern and western areas thus began to warp into elongated, gently sloping (NE—SW) swells with a trough between, in pre-Miocene times, intrusions would tend to occur below the upwarps. Tensional forces acting at right angles to the trend of the swells would initiate the faulting and the dyke swarms, the latter being more pronounced in the areas of plutonic intrusions.

The outpouring of the basalts would possibly cause the central downwarping and the corresponding marginal swells and the second phase would comprise the localised intrusions below the upwarped margins of the present island, to be followed by the faulting and dyke swarm intrusion caused by tension in the swells as final phases of the sequence.

V. SUMMARY AND CONCLUSIONS

An account of the geology of the Loðmundarfjörður region may conveniently be sub-divided into three parts.

1. (a) Period of outpouring of plateau basalts, with local explosion vents and associated sills and dykes.
   (b) Temporary pause in volcanism and a period of explosive activity giving rise to great quantities of rhyolitic welded-tuff (ignimbrite) deposits. This activity probably represents the initial stages of the intrusion of the rhyolite 'dome,' below the rising swell of the present eastern areas of Iceland postulated above.
   (c) Renewal of plateau basalt eruptions.

The age of Stage 1 is uncertain, but probably lies between Pre-Miocene or Early Miocene and Pliocene (?).

2. Intrusion of the rhyolite 'dome,' comparatively near to the surface (suggested by the previous explosive activity in Stage 1b), and giving rise to surface vents and flows.

3. Regional series of dykes in a N30°E — S30°W swarm covering a large area and extending to the south of Loðmundarfjörður and Seyðisfjörður. The swell had by this time developed tensional lines of weakness and these would become more concentrated in the region of the intrusions. A Late Miocene or Post Miocene age is suggested.

Petrology

Petrologically the Loðmundarfjörður rocks can be divided into two Magma Series, the Tholeiitic Magma Type and the Olivine-Basalt Magma Type. According to *Kennedy* (1933, p. 240 etc.), the relationships of these types is as follows: —

Note Square brackets indicate rock types present in the area.

Olivine-Basalt Magma Type
(Plateau Type)

[Olivine-basalts.]

↓

Alkaline Series

[Crinanites, Trachy-basalts & Trachytes]

↙

Eucrite-Allivalite Series
[Olivine-hypersthene-dolerites]

Tholeiitic Magma Type
(Nonporphyritic Central Type)

↙

Acid Magma Series
[Rhyolites]

↓

Porphyritic Central Magma Type

[Porphyritic basalts and dolerites]

Consequently within the Loðmundarfjörður area of Tertiary igneous rocks, the Olivine-Basalt Magma Type and the Tholeiitic Magma Type were simultaneously available but at any given period the tendency was for one Magma Type to predominate.

During the First (regional) Phase the flood basalts were erupted. The basalts have not been examined and it is not known whether the series as a whole conforms to the Olivine-Basalt Magma Type or to the Tholeiitic Magma Type.

The explosion vents however are associated with dykes and sills of the Tholeiitic Magma Type, corresponding to the Porphyritic Central Magma Type (porphyritic dolerites and basalts) and the Eucrite-Allivalite Series (olivine-hypersthene-dolerites with basic plagioclase). This fact suggests that a study of the basalts would reveal alternations of predominently Tholeiitic or Olivine-Basalt Types.

An overlap between the First (regional) Phase and the Second (local) Phase is evidenced by the rhyolitic tuff series preceding the intrusive rhyolites of the Acid Magma Series. The Second Phase is thus predominently of the Tholeiitic Magma Type.

The Third (regional) Phase shows a reversion to the Olivine

Basalt Magma Type with the formation of dyke swarms of Alkaline Series affinities.

The sequence developed then bears a close resemblance to that of Greenland (*Tyrrell*, 1949, p. 425 etc.) and to that of the Scoto-Irish region. The rock types present in the Loðmundarfjörður area of eastern Iceland show a close parallel to these areas suggesting the "petrological unity of the great Thulean region."

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R. D.

University of Leeds.
February, 1953.

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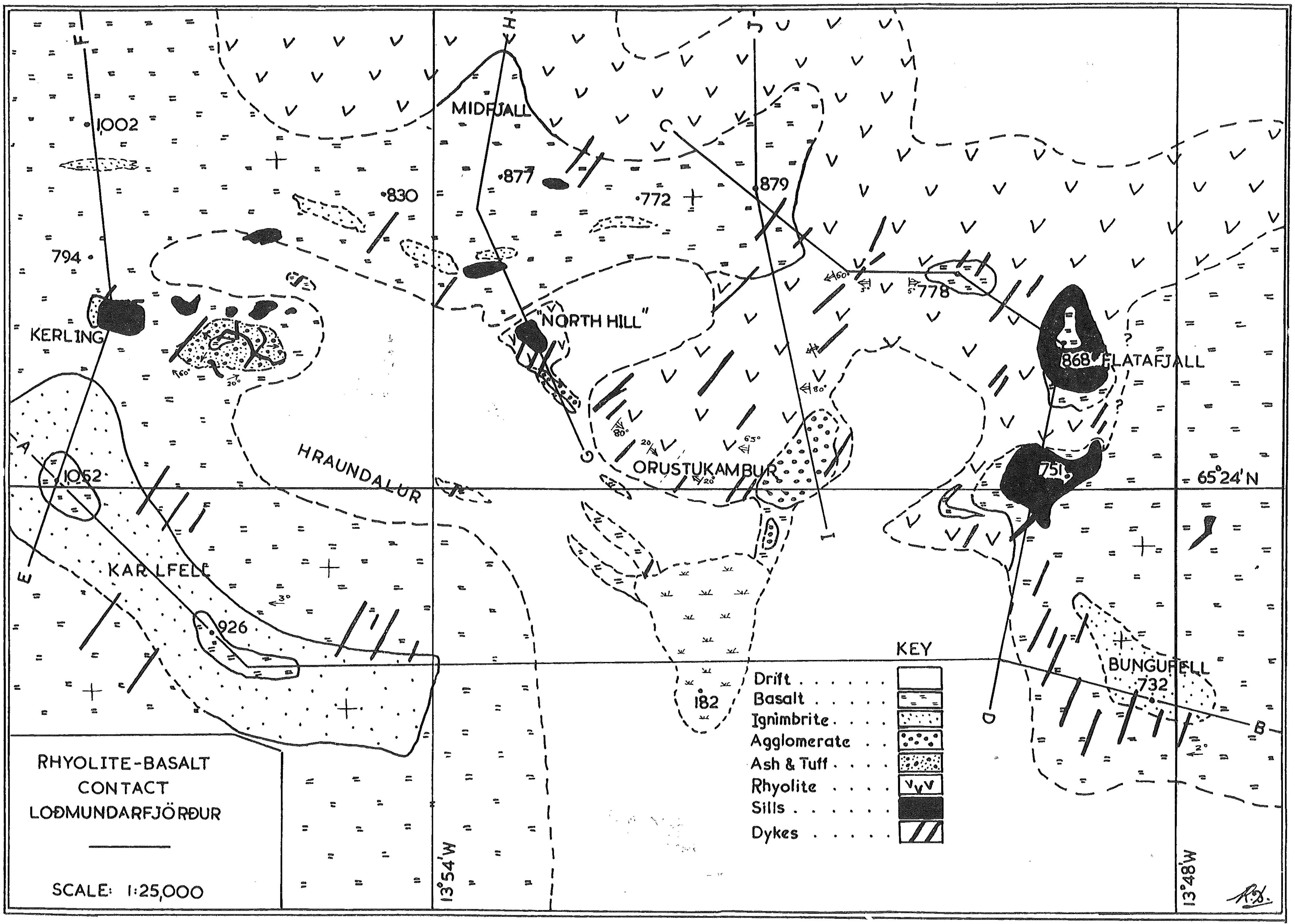
Geological Sketch Map and Sections of Rhyolite-Basalt Contact, Loðmundarfjörður, East Iceland (Pl. I and II).

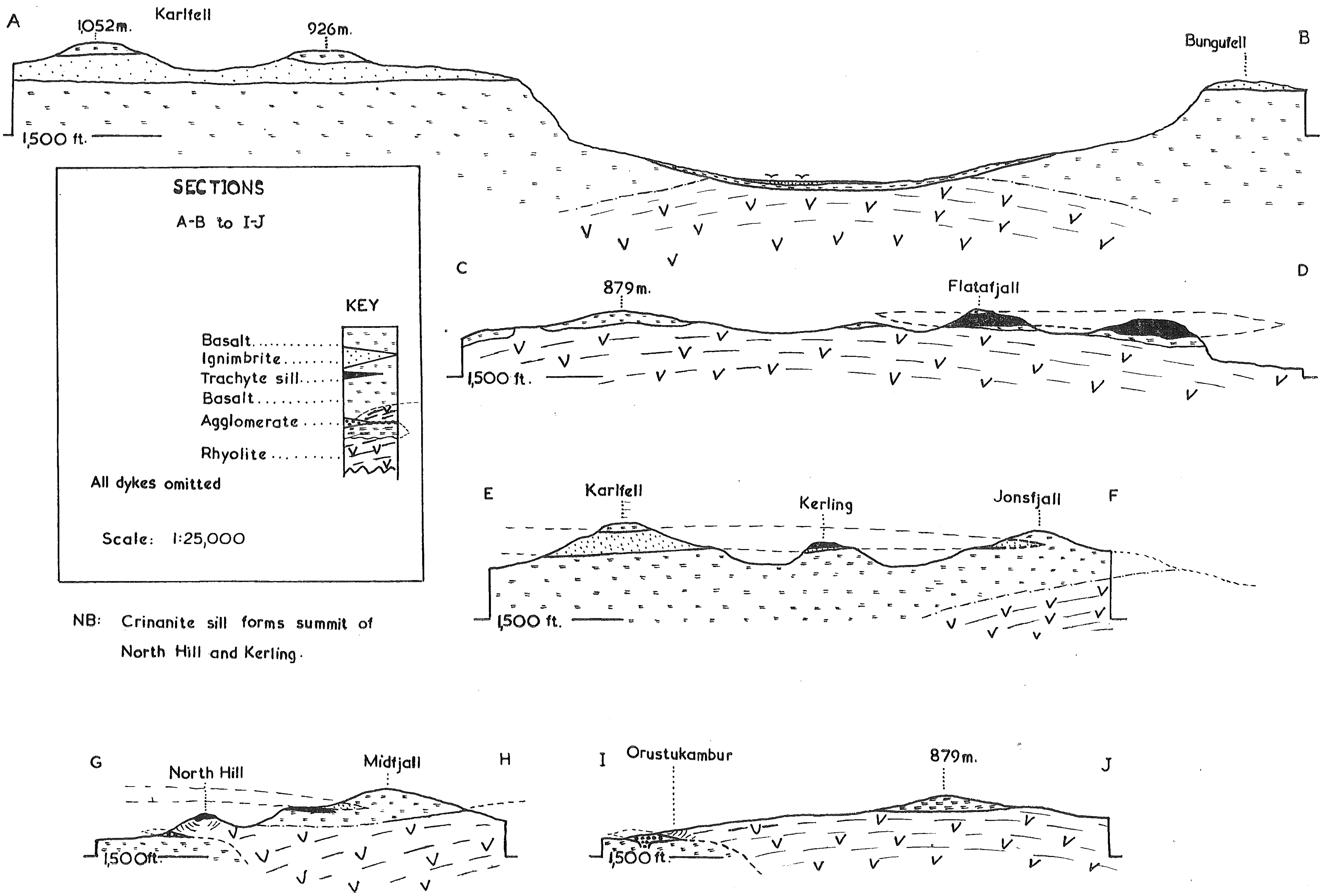
The map Pl. I was produced by plane tabling, using the fixed points of the Danish Geodetic Institute map on the scale of 1:100,000 Sheet 113 (Dyrfjöll), Copenhagen, 1945.

Contours could not be surveyed in the time available and all the sections (Pl. II) have been prepared with the aid of photographs. All estimates of distances and heights are as accurate as possible but the survey is to be regarded as an approximate one, carried out in a limited time for the purpose of indicating the general geological structure of the region.

The map is drawn on a scale of 1:25,000 and includes a portion of the southern margin of a large liparite intrusion.



RHYOLITE-BASALT
CONTACT
LOÐMUNDARFJÖRÐUR
SCALE: 1:25,000
KEY
Drift
Basalt
Ignimbrite
Agglomerate
Ash & Tuff
Rhyolite
Sills
Dykes
MIDFJALL
"NORTH HILL"
KERLING
HRAUNDALUR
ORUSTUKAMBUR
FLATAFJALL
KARLFELL
BUNGUFELL
1002
830
877
772
879
794
778
868
751
1052
926
182
732
65°24'N
13°54'W
13°48'W



A
Karlfell
1,052m.
926m.
Bungufell
B
1,500 ft.
SECTIONS
A-B to I-J
KEY
Basalt
Ignimbrite
Trachyte sill
Basalt
Agglomerate
Rhyolite
All dykes omitted
Scale: 1:25,000
NB: Crinanite sill forms summit of North Hill and Kerling.
C
879m.
Flatafjall
D
1,500 ft.
E
Karlfell
Kerling
Jonsfjall
F
1,500 ft.
G
North Hill
Midfjall
H
1,500ft.
I
Orustukambur
879m.
J
1,500 ft.