Geology of Alftafjordur volcano, a Tertiary volcanic centre in South-Eastern Iceland

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I. INTRODUCTION

The Tertiary volcanic district of eastern Iceland consists partly of flood basalts erupted from regional fissures and partly of the more variable products of local volcanic centres (Walker, 1963, 1964), one of which is the Alftafjordur volcano (Fig. 1). Three of the other volcanic centres have already been described in detail; these are Breiddalur volcano (Walker, 1963), Thingmuli volcano (Carmichael, 1964), and Reydarfjordur volcano (Walker, 1959; Gibson, 1963; Gibson, Kinsman, and Walker, 1965). During their activity most of the local volcanic centres were at times capped by volcanic cones which stood above the surrounding flood basalts, but at other times the volcanic cones may have been completely overlapped and buried by contemporaneous flood basalts and lavas from other volcanic centres.

The products of Alftafjordur volcano crop out over 125 km² in south-eastern Iceland between Djúpivogur in the north and Lon in the south (Fig. 1). The total extent and thickness of the volcano are not known, since much of the volcano is hidden beneath Alftafjordur and open sea. However it must have been at least comparable in size to Breiddalur volcano.

This paper, which is based on part of a Ph.D thesis submitted in 1964 to the University of London (Blake, 1964), is concerned with that part of the Alftafjordur volcano and adjacent and overlying volcanics exposed between Alftafjordur and Lon (Fig. 2). This area was mapped in six months by the author during the summers of 1961, 1962 and 1963, using air photographs and a modified topographical map based on the 1:100,000 map of Iceland, sheet 104.

Most of the area mapped is mountainous, and peaks are connected by knife-edge ridges separated from one another by deep, steep-sided, glaciated valleys. The higher peaks rise over 750 m above sea level and were probably nunataks during the Ice Age. The only extensive tract of low-lying ground borders the southern shore of Alftafjordur. Here the land surface, partly covered by marsh, rises gently southwards for over 4 km to a raised beach 10 m above sea level. Remnants of this raised beach occur along the coast between the mouth of the Thvotta in the north, Hvalnes in the south, and the mouth of the Vikura in the south-west. The most prominent coastal features are off-shore bars cutting off Alftafjordur and Lon from the open sea. Exposures in most of the area are good, as the vegetation cover is generally thin or absent and superficial deposits are only locally developed.

Alftafjordur volcano was first identified as a Tertiary volcanic centre by Walker (1963), from the abundance of acid rocks exposed on the south side of Alftafjordur. The presence of acid rocks here had previously been indicated by Thoroddsen (1906).

II. GENERAL GEOLOGY

Like the other Tertiary volcanic centres in eastern Iceland, Alftafjordur volcano consists of basic, intermediate and acid lavas, pyroclastic rocks, minor sediments and numerous intrusions (Fig. 2). Acid and intermediate rocks are largely confined to such centres (Walker, 1963, 1966), and associated basaltic lavas tend to be much thinner than flood basalts of similar composition (Table 1). Five main lava types are recognized, olivine basalt (olivine tholeiite), tholeiite (olivine-free tholeiite), andesite (icelandite), rhyolite and porphyritic basalt, the field and petrographic characteristics of which have been discussed by Walker (1959, 1963), Carmichael (1964), and Gibson *et al.* (1965). The first four types from a continuous series from basic to acid.

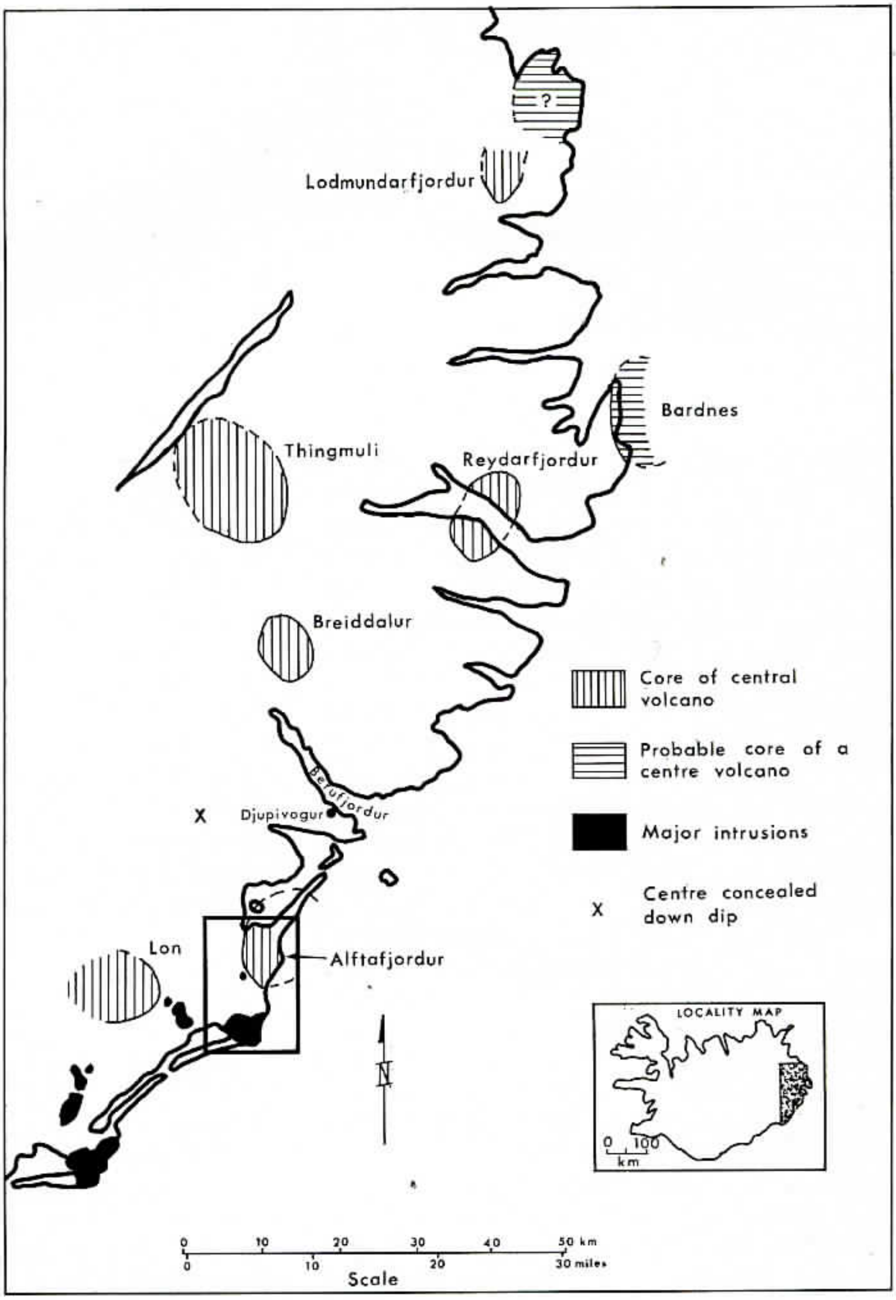


Fig. 1. Index map of eastern Iceland, showing positions of Tertiary volcanic centres and location of area mapped.

Thin red dust beds are commonly present between lava flows (Hawkes, 1916). Pyroclastic rocks, mostly agglomerates and welded tuffs, make up about 20% of the volcano; this is a much higher percentage than in the other Tertiary volcanic centres described to date. The approximate relative abundances of rock types making up Alftafjordur volcano are shown in Table 2; similar estimates for Thingmuli volcano and the Reydarfjordur area are also shown for comparison.

The core area of Alftafjordur volcano consists mostly of acid lavas and pyroclastics and has been mapped as a caldera. On the southern border of this caldera there is a separate small circular collapse area named the Maelifell

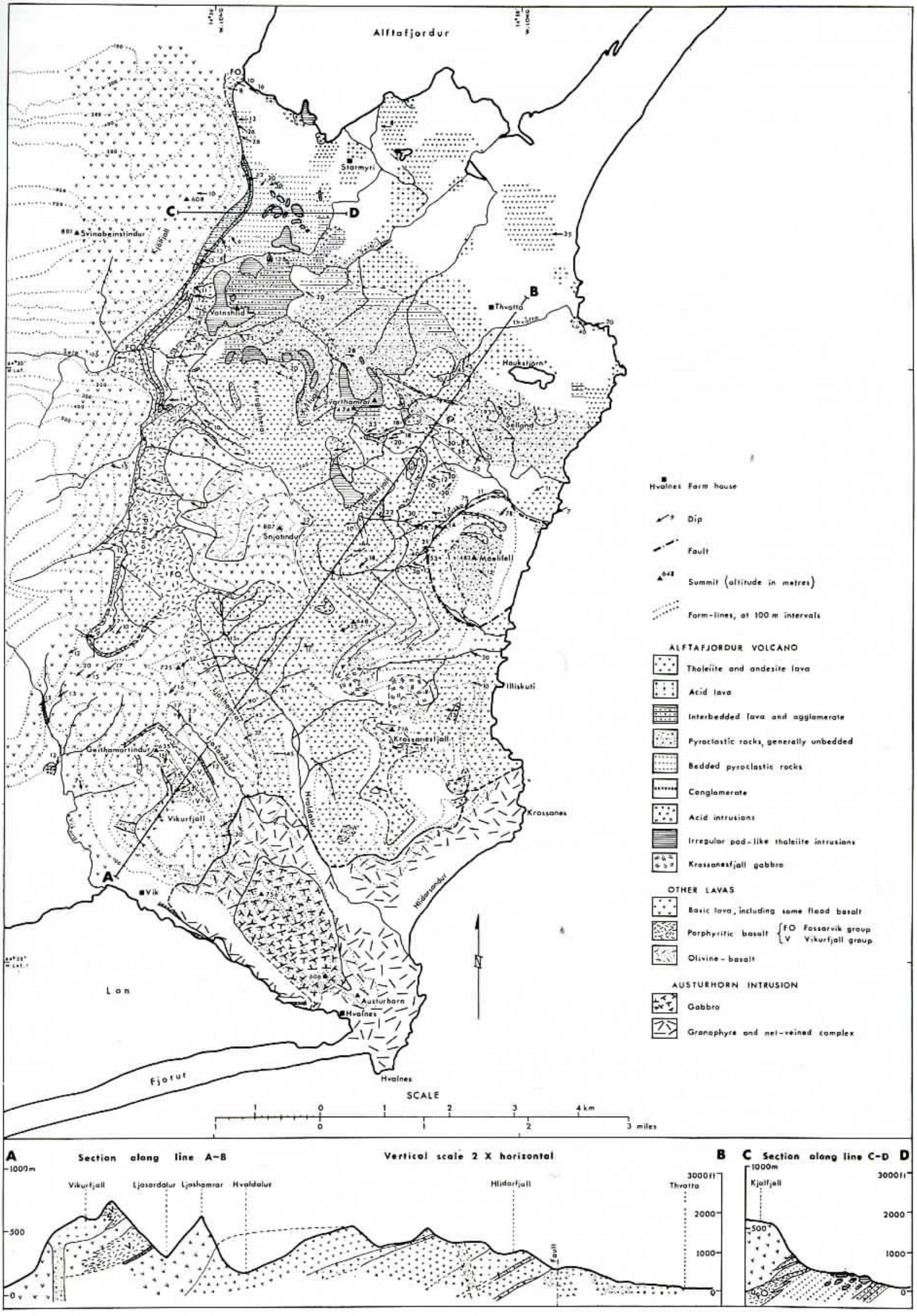


Fig. 2. Geological map of the area between Alftafjordur and Lon.

TABLE 1
AVERAGE THICKNESS OF THOLEIITE LAVAS

	Average thickness (m)
Flank Basalts:	
Alftafjordur volcano	3.5
Breiddalur volcano (Walker, 1962)	4.0
Thingmuli volcano (Carmichael, 1964)	6.0
Flood Basalts:	
Breiddalur area (Walker, 1963)	14.0
Reydarfjordur area (Walker, 1959)	10.0*

* Includes some flank basalts.

TABLE 2
RELATIVE ABUNDANCE (%) OF ROCK TYPES

Rock type	Alftafjordur volcano	Thingmuli volcano (Carmichael, 1964)	Reydarfjordur area* (Walker, 1959)
Olivine basalt	2	7	23
Tholeiite	48	50	48
Andesite	10	18	3
Rhyolite	18	21	8
Porphyritic basalt	1	1	12
Pyroclastic rocks	21	3	6

* Includes both flood basalts and the products of a central volcano.

caldera (Blake, 1970). The flanks of the volcano are made up mainly of tholeiite and andesite lavas, most of which dip outwards from the main caldera when corrections are made for the regional westerly dip (Fig. 3).

The lavas and proclastic rocks are intruded by dykes, sills, sheets and laccolithic masses, by irregular pod-like bodies of tholeiite, and by two plug-like bodies of gabbro; most of these intrusions are considered to be associated with the activity of Alftafjordur volcano. In addition, the youngest lavas on the southern flank of the volcano are intruded and thermally metamorphosed by the Austurhorn intrusion, a composite stock consisting of gabbro, ganophyre and a variety of intermediate hybrid rocks (Cargill *et al.*, 1928; Blake *et al.*, 1964; Blake, 1966).

The central part of Alftafjordur volcano coincides with an area of propylitic alteration, within which the volcanic rocks are rich in secondary calcite and chlorite. Outside the propylitized area lavas are affected by the regional zeolitization recognized elsewhere in eastern Iceland (Walker, 1960).

The youngest lavas on the western flank of Alftafjordur volcano are overlapped by flood basalts of the Fossarvik Porphyritic Group (Walker, 1963). These flood basalts thin out northwards against the southern flank of the Breiddalur volcano, indicating that Alftafjordur and Breiddalur volcanoes were active at the same time, as also was Thingmuli volcano (Walker, op. cit.). However, Alftafjordur volcano was probably the first of the three to become active and also the first to become extinct. (The age relationships of these and other volcanic centres in eastern Iceland are clearly shown in Fig. 1, of Walker, 1964.)

K-Ar age determinations by Moorbath *et al.* (1968) indicate that Alftafjordur volcano is probably of Upper Miocene age, as it is younger than an andesite from Oddsskard, Reydarfjordur, dated at 11.9 ± 0.3 m.y. and most of the volcano is probably older than an andesite from Thingmuli volcano dated at 9.5 ± 0.6 m.y. Flood basalts of comparable age occur in Profiles F, J and K of Dagley *et al.* (1967). K-Ar dates available for the much younger Austurhorn intrusion include 8.8 ± 1.3 m.y. for a specimen of granophyre (Gale *et al.*, 1966) and 6.6 ± 0.4 m.y. for biotite from a pegmatite vein cutting gabbro (Moorbath *et al.*, 1968).

III. MAIN CALDERA OF ALFTAFJORDUR VOLCANO

Part of the main caldera is exposed on the south side of Alftafjordur, but the remainder is hidden beneath the sea. The caldera coincides with an area of intense hydrothermal alteration and concentrations of acid volcanic rocks, especially pyroclastics, and minor intrusions. The abundance of pyroclastic rocks indicates that the caldera was the site of repeated explosive eruptions. Lavas and bedded tuffs within the caldera commonly have steep and abnormal dips which are probably due to collapse during caldera formation. The caldera is presumed to be bounded by faults, although these have been identified only in the south, on the west side of Maelifell and north-east of Hlidarfjall. The western margin of the caldera lies within a zone of coarse

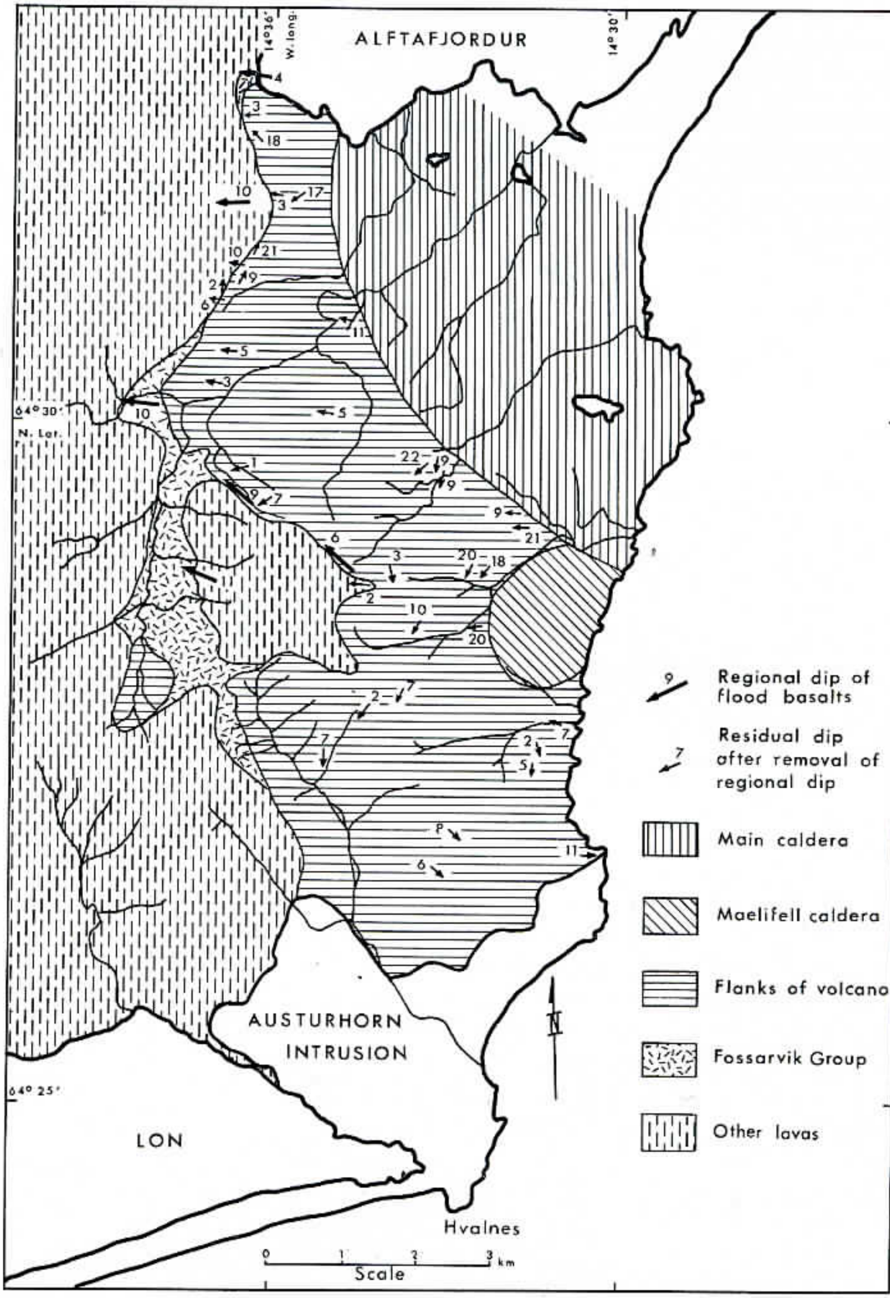


Fig. 3. Simplified geological map of the southern part of the Alftafjordur volcano showing the probable original depositional dips of the rocks.

agglomerate. No stratigraphical succession has been mapped within the caldera because of limited exposures, variable and commonly steep dips, and abrupt lateral changes in rock type attributed to differential collapse.

The acid rocks of the caldera comprise flow-banded rhyolite, agglomerate, and minor sediments. Most of the rhyolite is intimately associated with rhyolitic breccia and agglomerate, and forms undoubted extrusions, but some probably forms high level intrusions. The rhyolite is much altered and generally contains visible pyrite; it is white or pale bluish when unweathered, but when weathered it becomes orange, red or purple, due to iron-staining. Flow banding causes the rhyolite to split readily into thin plates.

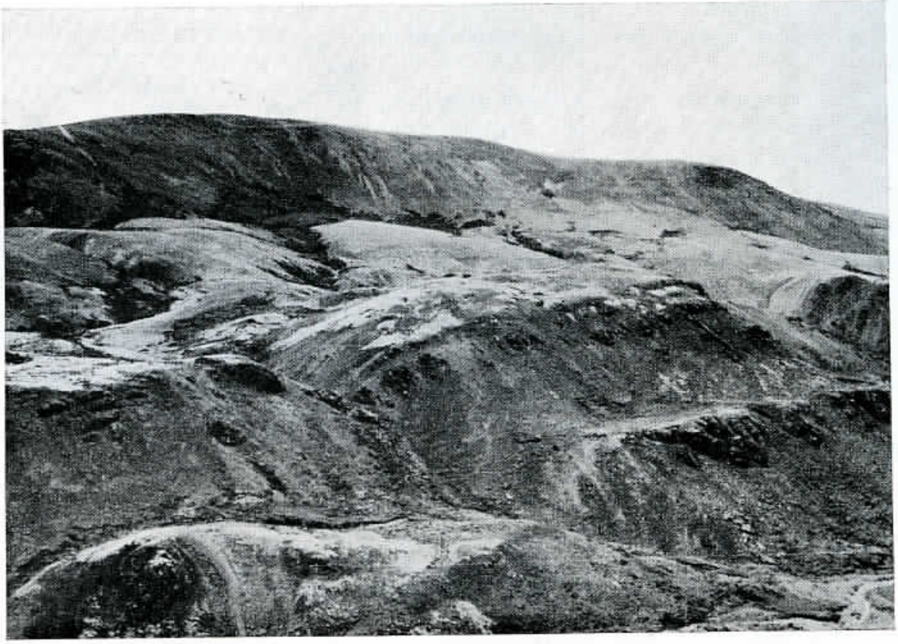


Plate 1a.
Steeply dipping basic lavas north-east of Hlidarfjall, from the west. The lavas lie just inside and dip away from the southern margin of the main caldera of Alftafjordur volcano. Behind the lavas are the agglomerate hills of Selland.

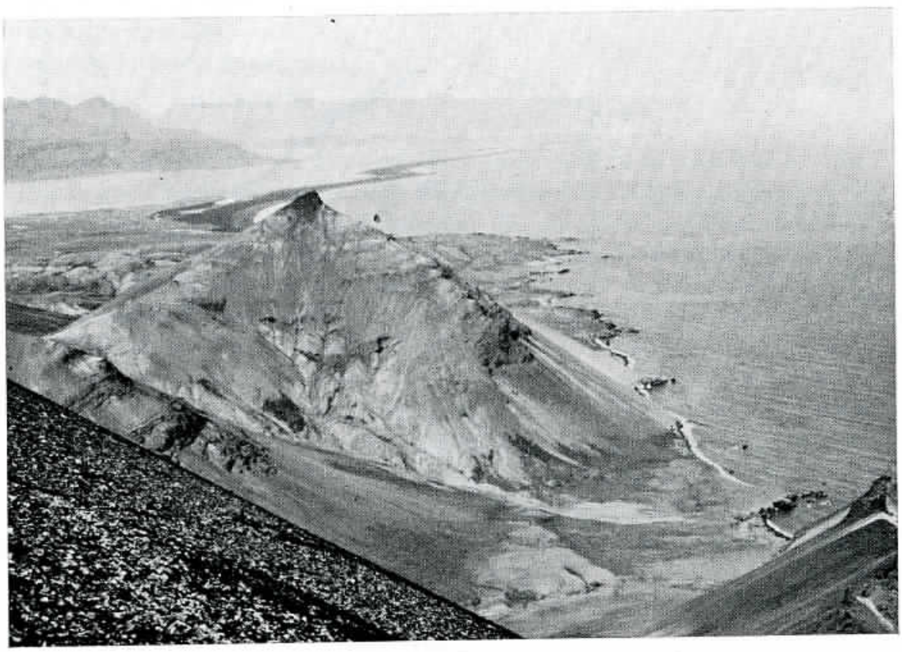


Plate 1b.
Maelifell from the south, showing exposures of inward dipping welded tuffs within Maelifell caldera on the mainly scree-covered slopes.

The agglomerate is typically unsorted and unbedded, and consists of angular to sub-angular fragments of flow-banded rhyolite up to 1 m across, and rounded fragments of basalt generally less than 3 m across, lying in a green or less commonly red tuffaceous matrix composed mainly of altered pumice. The largest fragments seen were slumped blocks of basalt over 30 m across in agglomerate on the north-west and south sides of the Sellond Hills. The general coarse chaotic nature of the agglomerate indicates the close proximity of eruptive sources, and some is probably true vent agglomerate.

In places buff and pale green water-lain tuffaceous sediments are associated with agglomerate. These sediments are generally fine-grained and thinly bedded and small scale cross-bedding is common. They were probably deposited in small temporary lakes. Dips are very variable, due to subsequent irregular collapse during caldera formation.

Basic and intermediate lavas form less than half of the total volume of rocks exposed in the caldera. Most of the basic lavas are tholeiites, although some porphyritic basalt lavas are also present, some being exposed 1 km south-west of Thvotta farm. The basic lavas are generally propylitized and are soft and greenish, whereas the andesite lavas are much less altered and are commonly hard and flinty. Most of the lavas have shallow dips, but dips of over 50° occur north-east of Hlidarfjall (Plate 1a) in a large tilted block of lavas surrounded by agglomerate near the edge of the caldera.

IV. MAELIFELL CALDERA

A detailed description of the Maelifell caldera is given in another publication (Blake, 1970) and only a brief synopsis will be given here. The structure is a circular fault-bounded collapse area 2 km in diameter situated on the southern border of the main caldera of Alftafjordur volcano (Figs. 2 and 3). Topographically it consists of a hill, Maelifell, which rises 487 m above sea level (Plate 1b). It is made up of inward dipping acid welded tuffs, agglomerate (including patches of welded agglomerate), tuffaceous sediments (Plate 2a), rhyolite and andesite lavas, and several intrusive sheets and dykes. Two kinds of welded tuffs are present, sheets of pitchstone less than 2 m thick and felsitic masses mostly over 30 m thick; the former, which were described as tuffo-lavas in Blake *et al.* (1965), contain inclusions of basalt glass and are examples of simultaneous eruption of acid and basic magmas.

The caldera is considered to represent the core of a parasitic volcano overlying a local high level acid magma chamber, the immediate source area of the acid rocks on Maelifell. It is thought that this magma chamber was intersected by numerous intrusions of basic magma coming from the main magma chamber of Alftafjordur volcano, and these caused explosive eruptions and the emission of mixed acid and basic magmas as thin pitchstone welded tuff sheets.

V. FLANKS OF ALFTAFJORDUR VOLCANO

The flank deposits of Alftafjordur volcano are distinguished from adjacent and overlying volcanics by their general residual dip outwards from the main caldera when the regional westerly dip of 6° to 11° is allowed for (Fig. 3).

The stratigraphical base of the flank succession south of Alftafjordur is not exposed. The top is taken as the base of the Fossarvik Porphyritic Group, a prominent group of flood basalts which overlap and interfinger with the youngest lavas on the western flank of Alftafjordur volcano. The overlapping relationship is exposed on the west side of Snjotindur (Plate 2b), where the plane of disconformity is marked by a layer of rubble. The angular difference here between the present dips of the flank lavas and flood basalts is less than 2°.

The southern and western flanks are built up of tholeiite, andesite, rhyolite, and porphyritic basalt lavas, agglomerates, tuffs (one of which is welded), volcanic sediments and numerous minor intrusions.

Tholeiite and andesite lavas make up most of the succession. Some of these lavas are exceptionally thin, such as on Ljoshamrar in the south, where lavas having an average thickness of only 3 m dip 35° to 45° south-west. The thinness of the lavas here indicates that they were probably laid down on relatively steep slopes, possibly over 10°; however the present steep dips must be due mainly to later tectonic tilting. At least five flow

Plate 2a.
Waterlain tuffaceous sands dipping 15° north at 400 m on the south side of Maelifell, within Maelifell caldera.

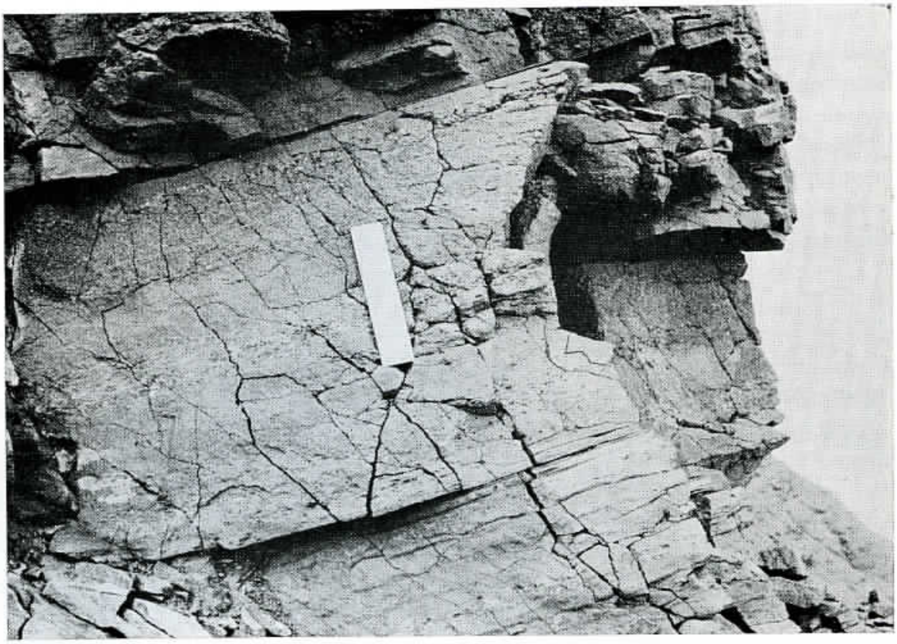


Plate 2b.
Disconformity (–c–) exposed on the north-west side of Snjotindur. Flood basalts to the west overlap more steeply dipping lavas on flanks of Alftafjordur volcano. Snjotindur, 807 m, is the peak in the left background.

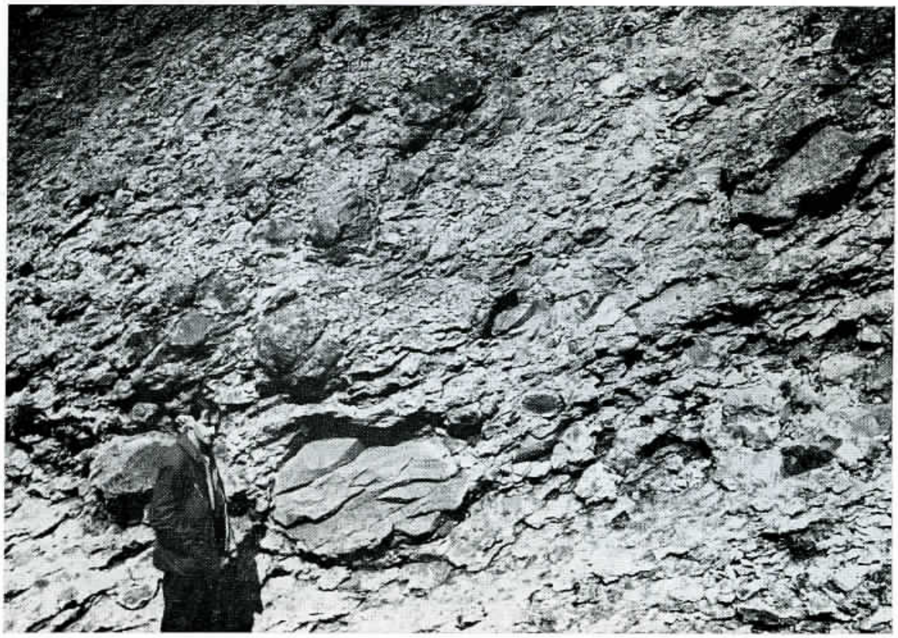


Plate 3a.
Coarse chaotic agglomerate in Kyrfugil on the western flank of Alftafjordur volcano.

Plate 3b.
Crude stratification in agglomerate, Kyrfugil, looking north.

banded rhyolite lavas occur on the southern flank of the volcano and one is present on the western flank; all of these are less than 5 km from the main caldera. These lavas form useful marker horizons, although they do not extend far along strike. Prophyritic basalt lavas are very rare and those that do occur may have been erupted from regional fissures rather than from the local magma chamber of Alftafjordur volcano.

Coarse chaotic acid agglomerates, some showing a crude stratification (Plate 3b), occur on the western and south-western flanks, close to the margin of the main caldera, where they are associated with tholeiitic lavas. Flattened rhyolitic bombs up to 50 cm long occur in agglomerate near the mouth of Kyrfugil. Elsewhere agglomerates are mainly restricted to four vents cutting through flank lavas, two on the north side of Krossanesfjall (both of which have been intruded by gabbro), one on the south-west side of Krossanesfjall and one on Hlidarfjall. Air-fall tuffs predominate on the western flank, where they are interlayered with both flank lavas and overlapping flood basalts. The tuffs range from dark brown to dark green or purple, and contain acid and basic rock fragments generally less than 1 cm across. An acid tuff 15 m thick, which may be an unwelded pyroclastic flow deposit, is exposed at 300 m on the south-west side of Kyrfugilsheidi. The only welded tuff found within the flank succession is a pitchstone sheet similar to those on Maelifell. It is 3 m thick and crops out 1.8 km north-west of Maelifell, where it is overlain and underlain by rhyolite lavas.

Volcanic sediments crop out at the northern end of Kyrfugil and on Ljoshamrar. At the former locality, near the western margin of the caldera, carbonized plant remains occur in tuffaceous sandstone, 10 m thick, overlying basic lavas and underlying coarse agglomerate. On Ljoshamrar two boulder beds, probably deposited by torrential streams, occur within the flank succession.

VI. THE ENVELOPE OF ALFTAFJORDUR VOLCANO

As stated previously, the youngest lavas on the western flank of Alftafjordur volcano are overlapped by and interfinger with flood basalts of the Fossarvik Porphyritic Group. These flood basalts and all overlying rocks have been mapped as the 'envelope', although some of the lavas may represent some of the youngest products of Alftafjordur volcano.

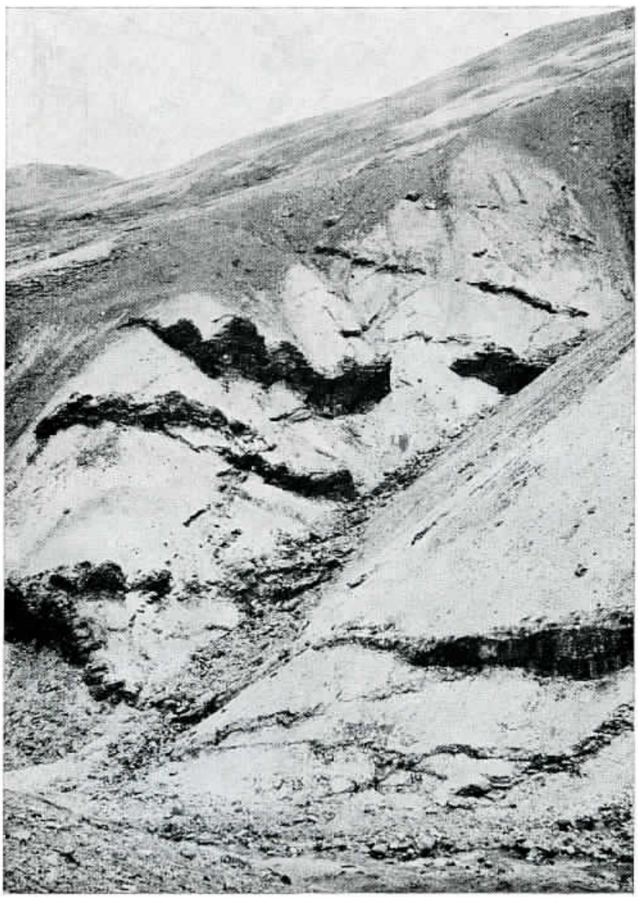
The Fossarvik Porphyritic Group has been traced southwards from Berufjordur, where it thins out against the southern flank of the Breiddalur volcanic centre (Walker, 1963, p. 38), to the south-west side of Alftafjordur volcano. The Group consists predominantly of olivine basalt lavas containing up to 25% of plagioclase phenocrysts. The maximum thickness of the group on the west side of Alftafjordur volcano is about 100 m, although it is locally less than 20 m thick at the base of Kolfjall in the north and it thins out completely when traced south-eastwards along Ljoshamrar in the south. The lavas of the group are typical flood basalts and are probably unrelated to the activity of Alftafjordur volcano.

The succession overlying the Fossarvik Porphyritic Group north of Vikurfjall mainly consists of both thick tholeiite lavas of flood basalt type and thin tholeiite lavas of the type associated with central volcanoes. Most of the latter may be derived from Lon volcano to the south-west and an unnamed volcano (labelled 'Y' in Walker, 1964) to the west.

On Vikurfjall in the south the succession overlying the Fossarvik Group is more varied, and includes a series of olivine basalt lavas, mostly porphyritic, which have been named the Vikurfjall Group, some andesite and rhyolite lavas, acid tuffs and two sedimentary horizons, as well as tholeiite lavas. The lavas of the Vikurfjall Group, which are probably flood basalts, thin out to the north-west against andesite and tholeiite lavas overlying the Fossarvik Porphyritic Group. The rhyolite lavas underlie the Vikurfjall Group and overlie tholeiite lavas and were probably erupted from an agglomerate-filled vent, 120 m in diameter, on the west side of Vikurfjall (Plate 4a). Acid tuffs containing rhyolite bombs are interlayered with the rhyolite lavas and also with some of the olivine basalt lavas immediately above. One of the two sedimentary horizons crops out on the north-east side of Vikurfjall: it is 40 m thick and consists of waterlain pumiceous sand and conglomerate containing carbonized plant fragments. The other, consisting mainly of basaltic conglomerate, crops out on the north shore

Plate 4a.
Volcanic vent, infilled with agglomerate, cutting nearly horizontal tholeiite lavas on the west side of Vikurfjall. At the base of the scree slopes tholeiite lavas are exposed on a raised beach, the top of which is about 10 m above sea level.

Plate 4b.
Thin basic dykes and sheets intruding rhyolite lava within the main caldera of Alftafjordur volcano. Exposure on the east bank of the Thvotta, 1 km east of Svarthamrar.



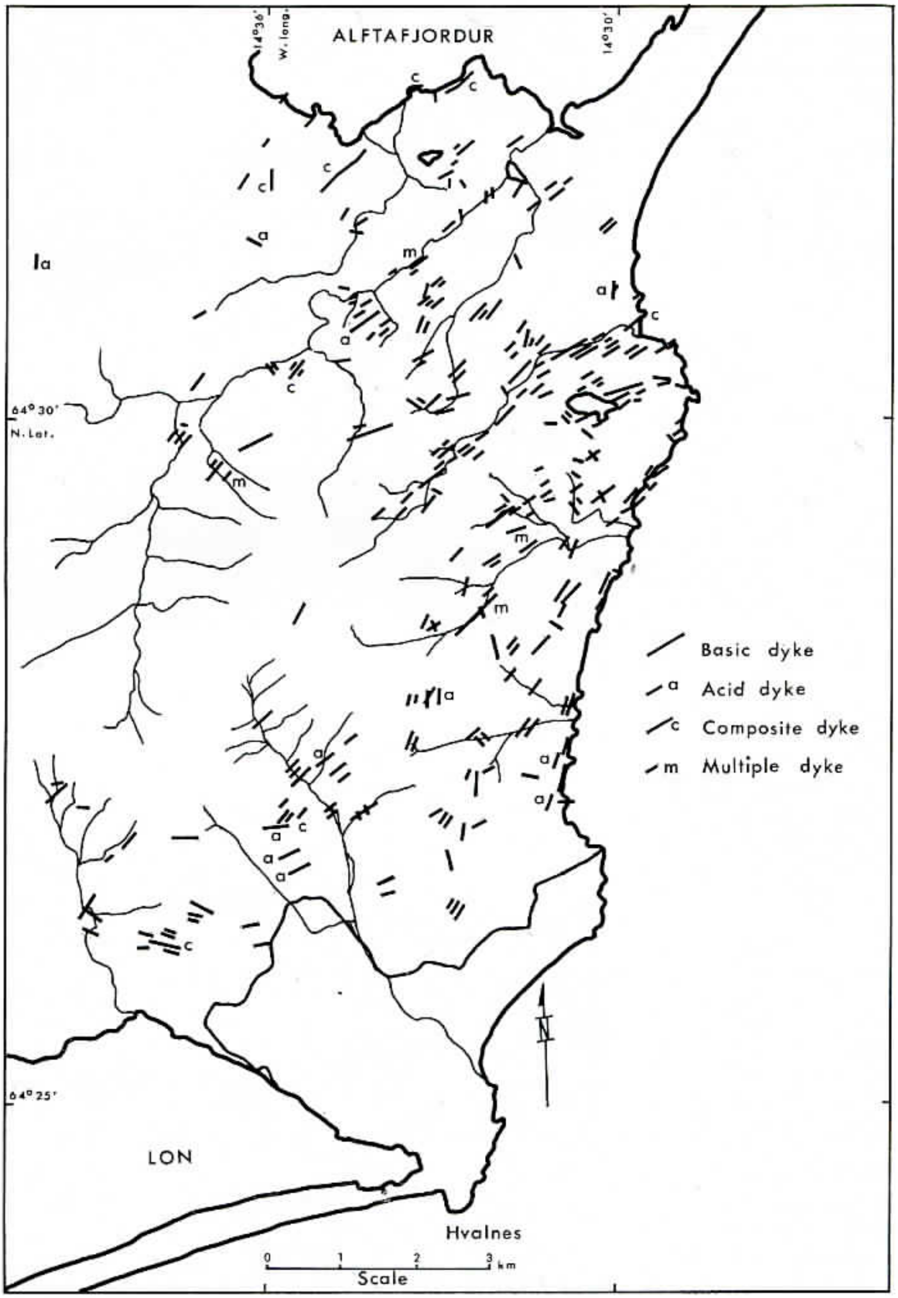


Fig. 4. Dyke distribution between Alftafjordur and Lon.

of Lon on the south and south-west sides of Vikurfjall.

VII. MINOR INTRUSIONS

The extrusive rocks in the area are cut by numerous dykes, sills, sheets, laccoliths, and irregular pod-like and plug-like bodies. These intrusions range in composition from olivine basalt to rhyolite. The great majority are considered to be directly associated with the activity of Alftafjordur volcano. The distribution of dykes is shown in Fig. 4 and that of the other minor intrusions is shown in Fig. 5.

Dykes.

Dykes have been mapped as either basic or acid, as no dykes of intermediate composition

Plate 5a.
Basic lavas (B) and intrusive sills and sheets (S) at Illiskuti, on the east coast. South flank of Alftafjordur volcano.

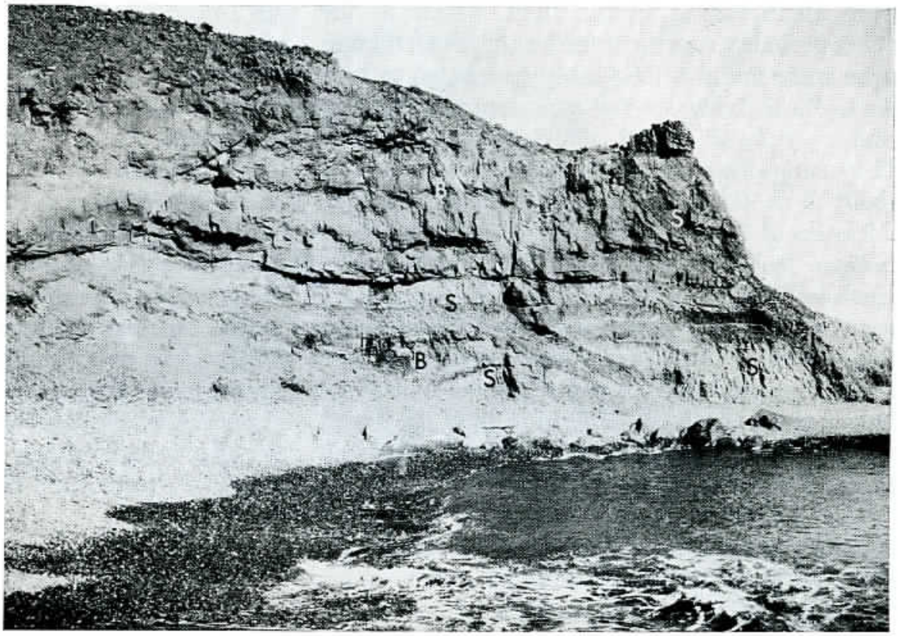
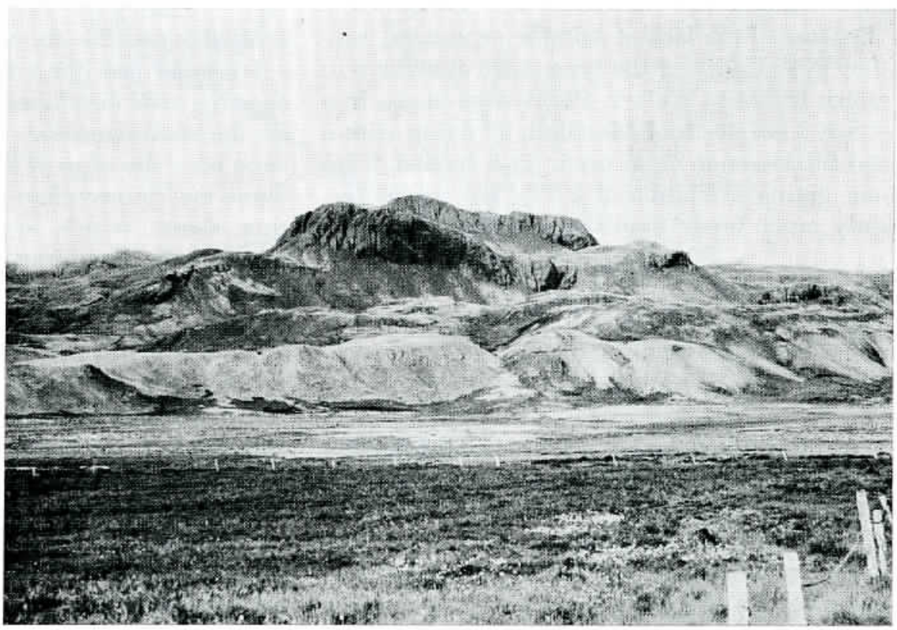


Plate 5b.
Svarthamrar from the north-east, showing a thick intrusive sheet of columnar jointed tholeiite capping the hill and one of two lower tongue-like intrusions forming prominent cliffs below. The lower pale toned hills in the foreground are formed of rhyolite and agglomerate lying within the main caldera of Alftafjordur volcano.



were distinguished in the field. Many of the dykes probably represent feeders of lavas, though none were found to be visibly connected to lava flows. Basic dykes are the most common, and include porphyritic and non-porphyritic types. They range from 0.3 m to 40 m but are mostly about 1 m thick, compared with the average thickness of 3 m for basic dykes further north in eastern Iceland (Walker, 1963). Acid dykes, much less abundant than basic dykes, range from less than 1 m to 6 m in thickness. In addition to single dykes there are also several multiple dykes, comprising from two to twelve individual intrusions ranging up to 60 m in total thickness, and six composite dykes, each possessing an acid centre flanked by basic margins.

The dykes appear to belong to two main swarms, one having a north-easterly trend, the other an easterly trend, although many dykes diverge from these two directions. Most of the dykes of the north-easterly swarm are probably related to Alftafjordur volcano, as also are many of the dykes with aberrant trends, especially those in the main caldera of the volcano. North of Alftafjordur the north-easterly dyke trend swings slightly to a north-north-easterly direction (Walker, 1959, 1963). Dykes of the east-west trend are most numerous in the south-west, on Vikurfjall, and many of these may be related to another major volcanic centre, such as Lon volcano.

Because of the lack of suitable exposures, only a few dyke counts of the type made elsewhere in eastern Iceland (Walker, 1962) were made. In a section 3 km north of Maelifell, 22 dykes with a total thickness of 25 m occur in a section 1 km long, giving a dilation of 2.5%, but this is certainly much lower than the maximum.

Sills and Sheets.

Sills are relatively rare in the area, although several basic sills occur on the east side of Krossanesfjall (Plate 5a) and on the south-west side of Vikurfjall.

Discordant intrusive sheets, with average dips less than 60°, are much more common than sills. They are mostly of basic composition and are generally less than 1 m thick. The sheets are found almost everywhere where exposures are good, and are especially abundant in and around the core area of Alftafjordur volcano (Plates 4b, 5a). They are commonly highly irregular and do not appear to be centrally inclined.

Of special interest is a series of unique porphyritic sheets which have been described in another paper (Blake, 1968). These are exposed on the north shore of Lon and do not appear to be related to Alftafjordur volcano, as the rocks they intrude are younger than the youngest recognized products of this volcano. The phenocrysts in the porphyritic sheets are arranged in two main layers, an upper layer of mostly plagioclase phenocrysts overlying a layer containing a concentration of augite and olivine phenocrysts. The phenocrysts are believed to have been gravitationally sorted during the passage through the sheets of a very fluid porphyritic basalt magma.

Laccoliths.

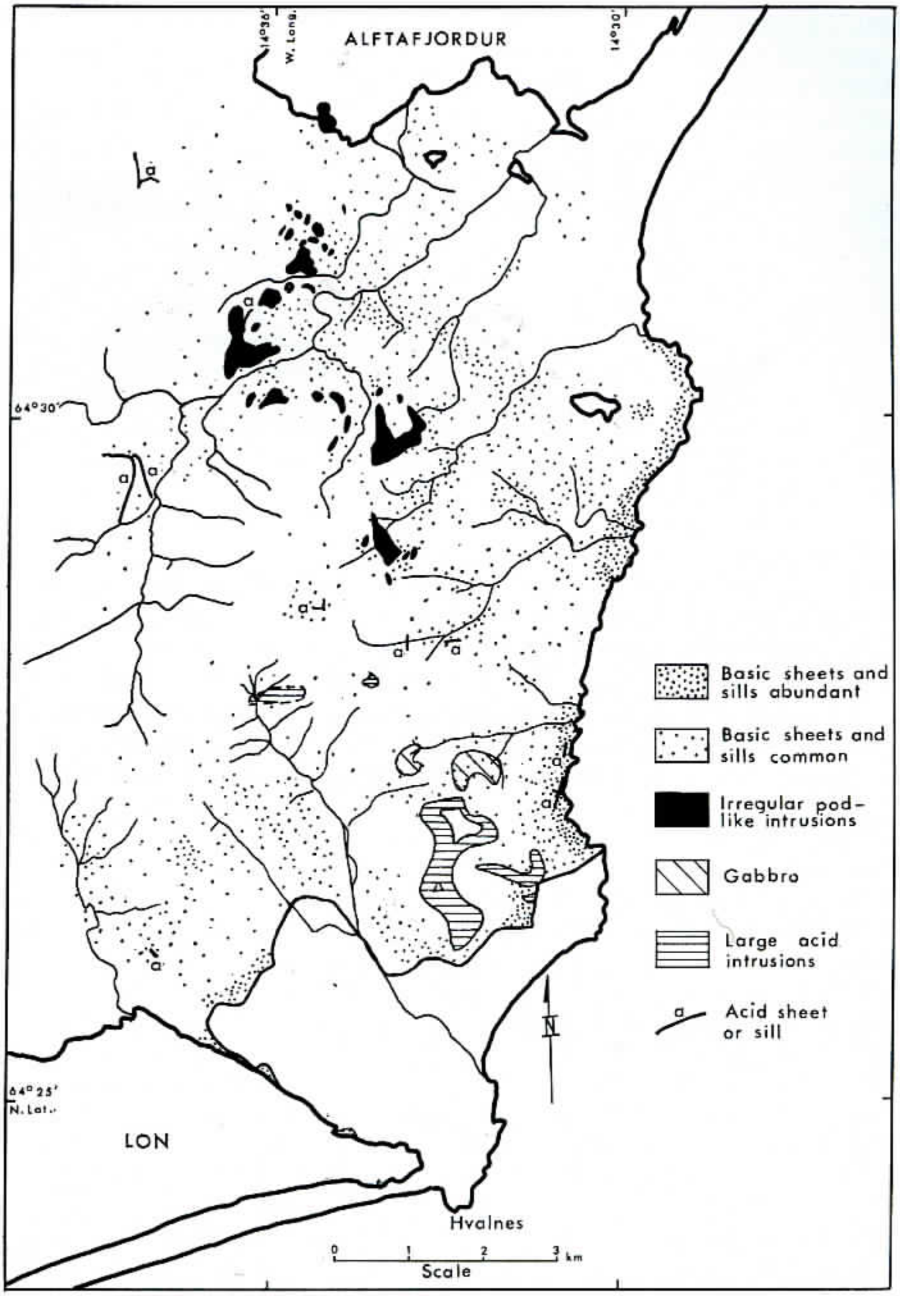
Several laccolithic intrusions of rhyolite are shown in Fig. 5. The largest of these intrusions occur near the top of Krossanesfjall, where at least three laccoliths may be connected to one another in cedar-tree fashion. The lavas on the east side of the summit of Krossanesfjall have been updomed by the uppermost laccolith (cf. the Sandfell laccolith, Faskrudsfjordur, described by Hawkes and Hawkes, 1933, and Gibson *et al.*, 1965); the upper margin of this laccolith consists of altered rhyolitic pitchstone flow-banded parallel to the intrusive contact.

Irregular pod-like intrusions.

Irregular pod-like intrusions of tholeiitic basalt showing well developed columnar jointing occur on the south-western flank of Alftafjordur volcano near the edge of the main caldera (Fig. 5). Some are connected to one another by irregular thin sheets which are also columnar-jointed. Most of the intrusions form prominent hills or scarps, as they are more resistant to erosion than the rocks they intrude. One such hill, Svarthamrar (Plate 5b), is capped by an intrusive sheet 30 m thick and two tongue-like intrusions of similar thickness occur below, together with a number of thin interconnecting sheets. Another hill, Vatnshlid (Plate 6a), consists of several intrusive pods.

The columnar jointing is developed perpendicular to the intrusive contacts (Plate 6a) and, because of the irregular shape of the intrusions, it is typically very variable in attitude. Most of

Fig. 5. Distribution of minor intrusions other than dykes between Alftafjordur and Lon.



the columns are between 15 cm and 1 m in diameter.

Most of the country rocks show little evidence of contact metamorphism apart from some baking of pyroclastic rocks at the intrusive contacts. The country rocks were nowhere seen to be structurally disturbed by the intrusions.

The tholeiitic basalt forming the intrusions contains sparse plagioclase and augite phenocrysts up to 2.5 mm long enclosed in a fine to very fine grained groundmass made up of plagioclase, pyroxene, iron ore, sparse olivine, and in many cases interstitial basaltic glass or altered glass; secondary calcite is also commonly present. The plagioclase phenocrysts are tabular and consist of weakly zoned bytownite (average An87) mantled by narrow zones of labradorite (average An65), the same composition as the groundmass plagioclase.

The irregular pod-like bodies are high level intrusions emplaced mainly within pyroclastic deposits on the upper flanks of the Alfafjordur volcano. All the intrusions are probably of similar age and are considered to represent a late stage phase of activity of the Alftafjordur volcano. Their irregular pod-like forms indicate that the magma was probably intruded while the pyroclastics were loose and unlithified; this implies that the intrusions followed closely on the eruption of the pyroclastics.

Gabbro intrusions.

Two small intrusions of gabbro crop out on the north side of Krossanesfjall (Plate 6b). Both are cut by veins of granophyre and by several acid and basic dykes and sheets. The larger gabbro mass is exposed along the northern lip and craggy side ridges of a northward facing corrie. It is an irregular steep-sided body intruded into agglomerate and basic lavas. Lavas within 20 m of the gabbro are hornfelsed and cut by granophyre veins, and the marginal gabbro is markedly finer-grained than the gabbro in the interior of the intrusion. The smaller mass intrudes agglomerate at the head of Maelifellshals, where it is intimately associated with porphyritic dolerite containing up to 50% of stumpy plagioclase phenocrysts. The actual shapes of the intrusions are not known, as contacts are generally poorly exposed.

Both gabbro bodies are considered to be high level plug-like intrusions which have been emplaced in volcanic vents partly infilled with agglomerate. As such, the gabbros were probably intruded during a late phase of activity of Alftafjordur volcano.

The gabbro making up the intrusions is a medium to coarse grained and locally pegmatitic rock containing less than 40% dark minerals. It consists mainly of plagioclase, augite and opaque minerals, although it also contains some interstitial quartz and alkali feldspar and, in some specimens, pseudomorphs after hypersthene and olivine: apatite is a common accessory mineral, in some specimens making up more than 1% of the rock, and calcite, chlorite, epidote, serpentine, amphibole and biotite are common secondary minerals. The texture ranges from granular to ophitic. Two modal analyses of the gabbro are given in Table 3.

The plagioclase crystals show marked normal zoning from calcic cores (An60–80) to sodic margins (An20–50). Some of the crystals are mantled by turbid alkali feldspar. The augite is commonly ophitic; measured optical properties are $\beta = 1.696–1.700 \pm 0.002$, $2V(+) = 44–50°$. Pseudomorphs after hypersthene and olivine occur in most gabbro specimens, the former of chlòrite commonly associated with pale green amphibole and green biotite, and the latter main-

TABLE 3

MODAL ANALYSES (VOL. %) OF INTRUSIVE ROCKS FROM KROSSANESFJALL

	Gabbro (H310)	Gabbro (H376)	Granophyric hybrid (H375)
Plagioclase	60 (An77–32)	73 (An75–40)	40 (An65–30)
Augite	16	14	9
Pseudomorphs after olivine	6	5 (olivine and hypersthene)	trace
Pseudomorphs after hypersthene	4		trace
Opaque minerals	7	5	6
Micrographic quartz and alkali feldspar	—	—	24
Non micrographic quartz	5 (quartz and alkali feldspar)	1.5	4
Non micrographic alkali feldspar		1.5	8
Other minerals	2	—	9*

* Chlorite, hornblende and biotite.

Plate 6a.
Contact between acid agglomerate (mainly scree-covered) and one of the pod-like volumnar-jointed tholeiite intrusions forming Vatnshlid. West flank of Alftafjordur volcano.

Plate 6b.
North side of Krossanesfjall, showing the two small gabbro intrusions (G) on the south flank of Alftafjordur volcano. B = basic lavas, A = agglomerate, C = exposed contact between gabbro and basalt lavas.

ly of chlorite, or less commonly serpentine. Quartz and alkali feldspar occur throughout the gabbro, locally as micrographic intergrowths but more generally as discrete grains with rectangular mutal contacts.

The gabbros are cut by numerous veins of granophyre and granophyric 'hybrid' rocks. The veins of granophyre have a colour index of less than 10 and consist of plagioclase (partly altered to calcite), turbid alkali feldspar (some mantling plagioclase), quartz, opaque iron ore, chlorite pseudomorphs, and minor apatite. Both the plagioclase and the chlorite pseudomorphs occur as euhedral elongate crystals, some over 1 cm long, lying in a partly micrographic groundmass of quartz and alkali feldspar.

A modal analysis of a granophyric hybrid vein cutting gabbro is given in Table 3. It consists mainly of plagioclase, alkali feldspar, quartz, augite, and iron ore, but also contains sparse pseudomorphs after hypersthene and olivine and minor apatite and zircon; chlorite, amphibole, biotite and calcite are present as secondary minerals. Plagioclase forms euhedral tabular crystals mostly less than 2 cm long, zoned from cores of labradorite (average An65) to margins of oligoclase-andesine (average An30), and mantled by turbid alkali feldspar. Interstitial quartz and alkali feldspar form micrographic to microgranitic intergrowths.

VIII. SECONDARY ALTERATION AND AMYGDALE MINERALS

The secondary alteration in the metamorphic enveloping volcanic rocks are affected by local metamorphic aureoles associated with Alftafjordur volcano and the Austurhorn intrusion and by regional zeolitisation. The metamorphic aureoles and localities at which amygdale minerals have been found are shown in Fig. 6.

Alftafjordur metamorphic aureole.

The secondary alteration in the metamorphic aureole of Alftafjordur volcano is of hydrothermal or propylitic type, similar to that associated with Breiddalur (Walker, 1963), Thingmuli (Charmichael. 1964), Reydarfjordur (Gibson *et al.*, 1963) and Lon (Johnson, 1969) volcanoes. It affects most of the products of the volcano and is most intense in the core area and in the lowest exposures along the east coast. Where propylitised the basalt and andesite lavas and minor intrusions, especially the amygdaloidal tops and bottoms of lava flows, are green and relatively soft; tuffs, agglomerates, and interlayered dust beds also are greenish. The green rocks are rich in calcite, chlorite, and locally, where the metamorphism is most intense, epidote and laumontite. Although the feldspar and pyroxene in the rocks are commonly entirely pseudomorphed, the original texture is generally preserved. Rhyolites when propylitised are rich in pyrite and have iron-stained weathered surfaces.

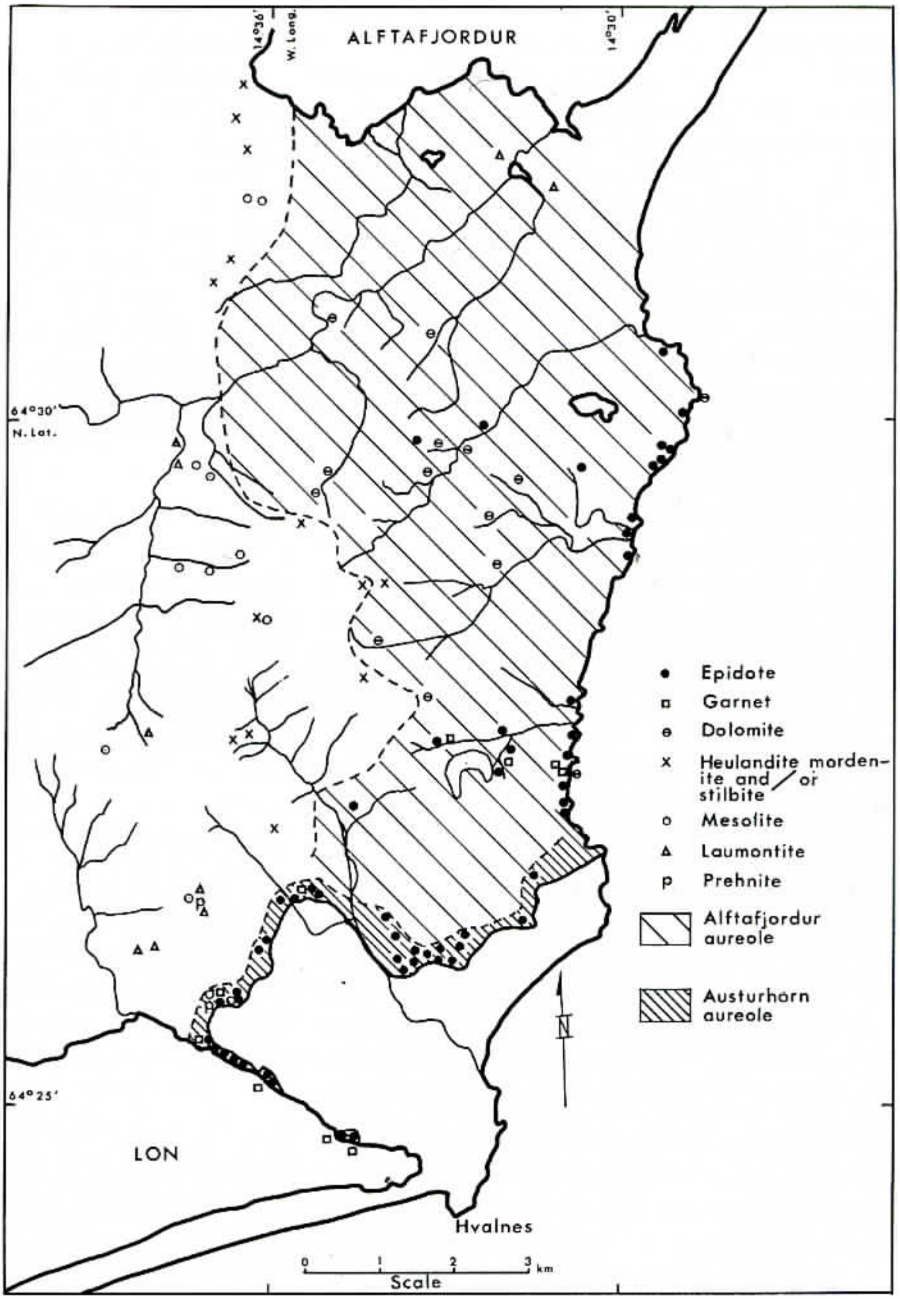
The chief minerals found in amygdales in the areas of most intense propylisation in the Alftafjordur aureole are calcite (commonly as crystals platy parallel to (0001)), chlorite, epidote, quartz and other silica minerals (opal, chalcedony), and in a few places laumontite. Where the propylitisation is less intense calcite predominates and is associated with dolomite, aragonite (very commonly paramorphed by saccharoidal calcite), chlorite and silica minerals. The dolomite in amygdales forms irregular rosettes made up of small and rather flat pale yellow rhombohedral crystals, with $\omega = 1.679 \pm 0.002$. The identification was confirmed by an X-ray powder photograph which indicated, as does the refractive index, that the dolomite is probably almost pure $CaMg(CO_3)_2$.

A narrow thermal metamorphic aureole characterized by epidote and locally garnet and brown biotite is associated with the larger of the two gabbro intrusions on Krossanesfjall. This aureole is superimposed on the main Alftafjordur aureole.

Austurhorn metamorphic aureole.

The Austurhorn intrusion south of Alftafjordur volcano has a well defined metamorphic aureole from 100 m to 1 km wide (Blake, 1966), within which the volcanic rocks appear hornfelsed. The most widespread of the amygdale minerals in the aureole are epidote, chlorite, calcite, quartz and alkali feldspar, less abundant are garnet, prehnite, scolecite, mesolite, actinolite, pyroxene, plagioclase and pyrite. The amygdales in the metamorphosed lavas are completely filled and some contain six or more different mineral species. Although the hornfelsed rocks are generally rich in epidote they are dark grey, unlike the epidotic rocks of the Alftafjordur aureole.

Fig. 6. Metamorphic aureoles of the Alftafjordur volcano and Austurhorn intrusion and the distribution of amygdale minerals.



Their original textures are commonly preserved. In the hornfelsed basic rocks the plagioclase is sometimes unaltered (apart from a certain cloudiness), but is generally partly or completely pseudomorphed by epidote, calcite, chorite and/ or zeolites, and the pyroxene is generally replaced by green amphibole.

Epidote, the characteristic mineral of the Austurhorn metamorphic aureole, has also been found in the aureole of the larger gabbro intrusion on Krossanesfjall and in the area of most intense propylitisation in the Alftafjordur aureole. The epidote forms elongate euhedral crystals up to 5 mm long which are dark green in hand specimen and colourless to lime yellow in thin section. It is optically negative, has a large 2V, a moderate birefringence, and a refractive index $\beta = 1.744 \pm 0.005$.

Alkali feldspar occurring in amygdales forms untwinned prismatic crystals up to 3 mm long which are white in hand specimen and turbid in thin section; the crystals generally line the edges of amygdales.

Calcic plagioclase is found associated with pale brown biotite in amygdales in the basalts on the north side of Krossanes; the plagioclase form an interlocking mosaic of anhedral crystals, each less than 1 mm long and showing albite twinning. There is a marked contrast here between the anhedral amygdaloidal plagioclase and the large euhedral plagioclase phenocrysts preserved in the same rock (cf. Le Bas, 1955).

Garnet is present in amygdales in the Austurhorn aureole and in the aureole around the larger gabbro intrusion on Krossanesfjall. It forms honey-coloured trapezohedral and rhombododecahedral crystals, mostly less than 2 mm across, which have a refractive index of 1.88 ± 0.01. A similar garnet occurs within the metamorphic aureoles of the Vesturhorn, Slaufrudal and Reydararfjall (Johnson, 1969) intrusions and of Thingmuli (Carmichael, 1964), Breiddalur (Walker, 1963) and Reydarfjordur (Gibson *et al.*, 1966) volcanoes, but has not been found in that of Alftafjordur volcano.

Prehnite occurs as an amygdale mineral within the Austurhorn aureole on Vikurfjall, where it is associated with scolecite, mesolite and calcite, and it is also present in olivine basalts within the laumontite zone on Geithamarstindur. It forms pale green globular aggregates made up of radiating crystalts up to 5 mm long. Prehnite has also been found in the aureole of the Slaufrudal intrusion (Walker, pers. comm.). Two specimens of prehnite from Vikurfjall have the following optical properties:

$\alpha = 1.618$, $\beta = 1.627$ $\gamma = 1.644$; 2V large, positive
$\alpha = 1.621$, $\beta = 1.630$ $\gamma = 1.646$; 2V large, positive
all refractive indices are ± 0.002.

Regional zeolitisation.

Outside the local metamorphic aureoles, zeolites and other amygdale minerals in the volcanic rocks occur in flat-lying zones cutting across the lava stratigraphy. These zones are inferred to lie approximately parallel to the original top of the lava pile, as they reflect the depth at which the lavas have been buried (Walker, 1960, 1964). Except in the north-west, on Svinabeinstindur, the basic lavas in the area come within the mesolite and laumontite zones. The top of the laumontite zone, which lies about 1700 m below the original top of the lava pile (Walker, pers. comm.), rises southwards from below the base of Kjolfjall in the north to over 750 m on Vikurfjall.

As described by Walker (1960, p. 516), the amygdale minerals in olivine basalts differ from those in tholeiites; minerals poor in silica are characteristic of the former and minerals rich in silica are characteristic of the latter. In olivine basalts within the laumontite zone the commonest amygdale minerals are laumontite, mesolite, stilbite, and calcite; in addition scolecite and prehnite occur within this zone at 600 m on the south side of Geithamarstindur. In the overlying mesolite zone mesolite is the dominant amygdale mineral. Analcite, garronite and unidentified fibrous zeolites are present in olivine basalts within the overlying analicite zone on Svinabeinstindur. The main amygdale minerals in the tholeiites within the mesolite and laumontite zones are mordenite, stilbite, heulandite, calcite, celadonite, quartz and chalcedony. Epistilbite occurs in amygdales in tholeiite lavas of the mesolite zone at 100 m on the east side of Kjolfjall.

IX. SUMMARY OF VOLCANIC HISTORY

Alftafjordur volcano is of Upper Miocene age. During its activity it consisted of a broad volcanic cone built up by lava flows, pyroclastics, and intrusive dykes, sills, irregular sheets, laccoliths, and pod-like and plug-like bodies, ranging in composition from olivine basalt to rhyolite. The immediate source of most of the volcanic rocks is presumed to have been a high level magma chamber situated beneath the volcano.

Acid rocks, mainly agglomerates and rhyolite lavas, were largely restricted to the central part of the volcano, and tholeiite and andesite lavas formed most of the flank succession. The majority of the lavas and pyroclastics were erupted from vents situated in the summit area of the cone, although some were erupted from small parasitic vents, now infilled with agglomerate, on gently sloping flanks; two of these were later intruded by plug-like bodies of gabbro. The lavas on the lower flanks interfingered with contemporaneous flood basalts and lavas from other volcanic centres.

The main caldera of the volcano was formed when the summit area of the cone foundered, probably due to the withdrawal of magma at depth during a late phase of volcanic activity. This caldera became the site of numerous explosive eruptions of acid magma. The smaller Maelifell caldera is probably slightly younger than the main caldera and is thought to represent the collapsed core of a parasitic volcano.

The youngest flank deposits of Alftafjordur volcano in the west were overlapped by flood basalts of the Fossarvik Group, which were erupted from regional fissures, and by younger lavas. The succession above the Fossarvik Group consists mainly of tholeiites but also includes some andesites and rhyolites.

The rocks in the core of the volcano were affected by hydrothermal alteration — propylitisation — caused by either hot fluids emanating from the local magma chamber or circulating meteoric water heated by intrusions. This type of alteration probably continued to take place long after other forms of volcanic activity had ceased.

On becoming extinct Alftafjordur volcano was buried by over 1000 m of younger lavas, and the unpropylitised products of the volcano and adjacent volcanic rocks of the same age became affected by regional zeolitisation, a form of depth metamorphism. During the Pliocene the Austurhorn intrusion was emplaced south of Alftafjordur volcano and the adjacent country rocks were thermally metamorphosed by it. This intrusion does not appear to be part of the Alftafjordur volcano nor of any other volcano.

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