groundmass plagioclase: they may be partly or completely pseudomorphed by uralitic green hornblende or, less commonly, chlorite. Unaltered olivine is present only in the cores of some olivine phenocrysts; such phenocrysts are always marginally and usually completely pseudomorphed by talc (confirmed by X-ray powder photograph), chlorite, actinolite and/or serpentine, with granules and cross-cutting veins of opaque ore.

The groundmass in which the phenocrysts lie and the non-porphyritic margins have basaltic textures and consist of laths of plagioclase; sub-ophitic augite, often pseudomorphed; olivine, always pseudomorphed; iron ore; and sometimes altered basaltic glass. The grain-size of the matrix of the porphyritic zone increases towards the centre of the zone. The markedly chilled contact of the non-porphyritic marginal zones against the country rocks is usually a tachylite. Small amygdales are quite common in the groundmass and contain epidote, chlorite and sometimes actinolite.

The gabbro inclusions in the porphyritic zone of the sheets have a typical coarse gabbroic texture except that they contain a number of angular patches of fine-grained basalt similar to that surrounding the inclusions. The inclusions are made up of weakly zoned labradorite, augite, iron ore and sometimes pseudomorphs after olivine: when they become schistose their igneous texture is replaced by a cataclastic texture, but no new minerals are developed. They appear to be fragments of partially crystallised gabbro.

Discussion

The differentiated sheets of the Austurhorn area are interpreted by the writer as multiple intrusions in which non-porphyritic basalt magma was first intruded, closely followed by a pulse of porphyritic magma. The multiple character of the sheets is indicated by the sharp contacts often seen between the porphyritic centre and the non-porphyritic margins. During and after the injection of the later pulse the phenocrysts are thought to have been sorted by gravity, so that the heavier pyroxene and olivine phenocrysts became concentrated towards the base of the sheets.

The initial pulse is represented by the non-porphyritic marginal zones of the sheets. These margins were chilled to a glass against the country rocks. In places, however, the original contact tachylite has been eroded by succeeding basalt magma which did not become drastically chilled against the country rocks.

The first intrusion, while still very hot, was closely followed by the second intrusive pulse, now occupying the centre of the sheets, which is unchilled at its contacts. The phenocrysts of this central zone are thought to have been formed prior to intrusion although they may have continued to grow after the sheets were formed. Unlike the enclosing groundmass, the phenocrysts do not, in general, show a gradual increase in size towards the centre of the sheets, and this, with the very variable relative thicknesses of the feldspar and mafic layers, is evidence against a post-intrusive origin for the phenocrysts.

The arrangement of the phenocrysts in the sheets can only be due to gravitational sorting during and after their intrusion, within a very fluid magma, into already hot country rocks. The heavier phenocrysts became concentrated in the lower part of the magma stream and tended to become preferentially deposited in hollows in the lower surface of the sheets, forming olivine- and pyroxene-rich "puddles". The absence of any flow-banding of the phenocrysts may be due to post-intrusive movement of the phenocrysts. This would be possible in a slowly cooling, highly fluid, basic magma, as is envisaged here.

As well as containing phenocrysts, the magma also contained inclusions of granophyre and felsite and gabbroic crystal clots. Frequently the gabbroic inclusions are schistose, as when they have been wedged into constrictions in the sheets, and it seems probable that only a very rapid flow of magma would be able to force the "spongy" (and hence able to be squeezed) gabbroic inclusions into and sometimes through such constrictions. A very rapid flow of magma could also account for the erosion of parts of the earlier non-porphyritic sheet margins.

The writer has observed another example of gravitational sorting of phenocrysts in Iceland. This is shown by a group of pillow lavas of Pleistocene age at Stapafell, on the Reykjanes peninsula. The individual pillows here are porphyritic but the phenocrysts, of olivine and feldspar, are found only in the lower part of each pillow, the upper part being essentially non-porphyritic. Here the settling of the phenocrysts in the individual pillows must have occurred in situ. Other possible examples of gravitational sorting of phenocrysts are the many feldspar porphyritic lavas in eastern Iceland in which the feldspar phenocrysts are concentrated in the middle and top of the individual flows (G.P.L. Walker, pers. comm).

No examples closely comparable to the differentiated sheets have been found in the literature, although Drever (1956, p.35) mentions an intrusive sheet on the Isle of Soay, Scotland, which may have a similar distribution of phenocrysts. One of the picritic sheets of Ubekendt Ejland, West Greenland, described by Drever (1956, sheet 2), is interpreted by Bailey (1959) as a multiple sheet, similar to the differentiated sheets of the Austurhorn area, but this particular sheet does not appear to show any gravitational sorting of the phenocrysts.

The age of the differentiated sheets is uncertain. They may be related to the activity of the Alftafjordur volcano, 12Km. to the north, but on the other hand they may be more or less contemporaneous with the much later Austurhorn intrusive stock (although affected by the metamorphic aureole of this intrusion) as is suggested by the inclusions they contain. The magma which formed the sheets picked up, en route, inclusions of partially crystallised gabbro, which may be derived from the gabbro of the Austurhorn intrusion before this gabbro had completely solidified, and fragments of granophyre and felsite, which may also be derived from the Austurhorn intrusion

CHAPTER 8

Secondary Alteration and Amygdale Minerals

In eastern Iceland Walker (1960) has established a regional zoning of the zeolite and other amygdale minerals in the basalt lavas: the zeolite zones are flat-lying and cut across the stratigraphy, and it is inferred that they lie approximately parallel to the original top of the lava pile. Besides the zeolitisation, which is a form of very low grade regional metamorphism (c.f. Coombs et al 1959), there are also local areas of secondary alteration unrelated to the zeolite zones. These are the metamorphic aureoles about the Tertiary volcanic centres and major intrusions. In the Austurhorn area there are both local metamorphic aureoles, associated with the Alftafjordur volcano and the Austurhorn intrusion, and normal zeolite zones, outside these aureoles (fig. 23).

The Alftafjordur aureole

The secondary alteration in this aureole is of propylitic type , similar to that associated with the Breiddalur (Walker, 1963), Thingmuli (Carmichael, 1962) and Reydarfjordur (Gibson, 1963) volcanoes. Most of the products of the Alftafjordur volcano are affected by the propylitic alteration, which is most intense in the core area and along the east coast. The basalt and andesite lavas and intrusions, and particularly the amygdaloidal tops and bottoms of the lava flows, become pale green and relatively soft when propylitised due to the development of much carbonate and chlorite in the rocks. Tuffs and dust beds also become green. These green altered rocks are rich in calcite, chlorite and sometimes epidote and laumontite, the latter two minerals being found where the metamorphism is particularly intense. The original feldspar and pyroxene in the lavas are often entirely pseudomorphed. Rhyolites in

Fig.23 The Alftafjordur and Austurhorn metamorphic aureoles & the distribution of some amygdale minerals

this propylitic zone are very closely jointed and, as they contain much pyrite, their weathered surfaces are iron-stained.

Where the propylitisation is most intense the chief amygdale minerals are calcite (often as crystals platy parallel to (0001)), chlorite, epidote, quartz and other silica minerals, and also sometimes laumontite. Where the rocks are less altered calcite is the dominant secondary mineral with dolomite, aragonite (usually paramorphed by saccharoidal calcite), chlorite and silica minerals.

<u>The Austurhorn Aureole</u>

The Austurhorn intrusion is surrounded by a metamorphic aureole which is generally about 100m. wide, although it is rather wider at sea level (fig.23). The basalt lavas within this aureole appear hornfelsed in the field, and, although they are usually rich in epidote, they do not have the green colour of the propylitised basalts in the Alftafjordur aureole. Under the microcrope the original texture of the metamorphosed basalt lavas is seen to be preserved. The plagioclase is sometimes unaltered except for a certain cloudiness, but is often partly or completely pseudomorphed by epidote, calcite and/or zeolite, and plagioclase phenocrysts are often crossed by chlorite veins. The pyroxene is usually replaced by green hornblende.

The suite of amygdale and vein minerals in the Austurhorn aureole is very similar to that in the Tertiary lavas around Ben More, Mull (M'Lintock, 1915), and in the basalts near the Skye granophyres (Harker, 1904). Epidote, chlorite, calcite, quartz and alkali feldspar are the most abundant amygdale minerals, while less abundant are garnet, prehnite, scolecite, mesolite, actinolite, pyroxene, plagioclase and pyrite. All amygdales in the aureole are completely filled and many contain six or more different minerals.

Regional Zeolitisation

Normal zeolite zones occur outside the Alftafjordur and Austurhorn aureoles. Except on Svinabeinstindur in the north-west all the basalt lavas come within the mesolite zone. In the lower part of this zone laumontite is the characteristic mineral and, as elsewhere in south-eastern Iceland, a separate laumontite zone, below the mesolite zone, can be mapped, the top of which comes at about 1700m. below the original top of the lava pile (Walker, pers. comm.). In the Austurhorn area the top of the laumontite zone rises from below the base of Kjolfjall in the north to over 750m. on Vikurfjall.

As has been described by Walker (1960, p. 516) the amygdale minerals in olivine basalts differ from those in tholeiites, silica poor minerals being characteristic of the former and silica rich of the latter. In the olivine basalts of the Austurhorn area within the laumontite zone laumontite, mesolite, stilbite and calcite are the chief amygdale minerals and prehnite and scolecite have also been found, apparently within this zone, at 600m. on the south side Geithamarstindur. In the mesolite zone mesolite is the characteristic mineral, while analcite also occurs. Analcite, garronite and fibrous zeolites occur in the olivine basalts within the analcite zone which outcrop along the ridge west of Svinabeinstindur. The characteristic amygdale minerals in the tholeiites within the laumontite and mesolite zones are mordenite, stilbite, heulandite, calcite, celadonite, quartz and chalcedony, and epistilbite occurs in tholeiites at 100m. on the east side of Kjolfjall.

Certain Amygdale Minerals

Dolomite

This mineral has not previously been recorded in print from eastern Iceland. It is common in the outer part of the Alftafjordur aureole, where it is associated with calcite and quartz. The dolomite occurs as irregular rosettes made up of small and rather flat rhombohedral crystals, with ω = 1.679, which are pale yellow when unweathered. The identification of the dolomite was confirmed by an X-ray powder photograph which indicated, as does the refractive index, that the dolomite is probably almost pure $CaMg(CO_3)_2$.

Epidote

Epidote is the characteristic mineral of the Austurhorn aureole, and it also occurs in the basalts adjacent to the main Krossanesfjall gabbro intrusion and locally within the Alftafjordur aureole where the alteration is most intense (fig.13); in addition epidote also occurs in the gabbro and granophyre within the Austurhorn intrusion. The epidote typically forms elongate euhedral crystals, up to 5mm. long, which are dark green in the hand specimen, with a bright lustre. In thin section the epidote varies from lime yellow (when it is pleochroic) to colourless. It is optically positive, with a large 2V, moderate birefringence and β = 1.744 $\pm$ 0.005.

Feldspar

Both alkali feldspar and plagioclase occur as amygdale minerals within the Austurhorn aureole. Alkali feldspar forms untwinned prismatic crystals, up to 3mm. long, which are white in the hand specimen and turbid in thin section: these crystals usually occur at the edges of the amygdales. Calcic plagioclase is found associated with pale brown biotite in amygdales in the basalts on the north side of Krossanes: the plagioclase forms an interlocking mosaic and the individual crystals, less than 1mm. long, show fine albite twinning. The contrast between the small anhedral amygdaloidal plagioclase crystals and the much larger thermally metamorphosed but still euhedral plagioclase phenocrysts in the same rock is very marked (c.f. Le Bas, 1955).

Garnet

The distribution of garnet is shown in fig.23 . In the Austurhorn area garnet is found within the Austurhorn aureole, where it occurs as honey-coloured trapezohedral or rhombdodecahedral crystals, usually less than 2mm. in diameter. The refractive index, n = 1.88 ± 0.01, indicates that the garnet is probably andradite. Elsewhere in eastern Iceland garnet occurs within the metamorphic aureoles of the Vesturhorn, Slaufrudal and Reydarafjall intrusions and in the aureoles of the Thingmuli (Carmichael, 1962), Breiddalur (Walker, 1963, p.46) and Reydarfjordur volcanoes.

Prehnite

This mineral has not previously been recorded from Iceland. Prehnite has been found at two localities on Vikurfjall (fig2), where it is associated with scolecite, mesolite and calcite. It occurs as pale green globular aggregates of radiating crystals up to 5mm. in diameter. Prehnite has also been found within the metamorphic aureole of the Slaufrudal intrusion (Walker, pers. comm.) and in interstices of the Krossanesfjall gabbro. The optical properties of the prehnite are as follows:-

α = 1.618, β = 1.627, γ = 1.644; 2V large, positive; Vikurfjall
α = 1.621, β = 1.630, γ = 1.646; " " "
α = 1.619, β = 1.627, γ = 1.645; " " Slaufrudal

CHAPTER 9

Summary of Conclusions

The existence of a volcanic centre south of Alftafjordur in Tertiary times has been confirmed. The products of this centre, the Alftafjordur volcano, cover the greater part of the area mapped and consist of tholeiitic, andesitic and rhyolitic lavas and associated pyroclastic rocks, with many minor intrusions. The intrusion of gabbro and granophyre at the Austurhorn does not appear to be related to the actigvity of this volcano.

The core of the volcano occurs in the northern part of the area, where acid rocks, both lavas and pyroclastics, are particularly voluminous. From the evidence of dips, which are often steep and abnormal in direction, it is concluded that a form of caldera collapse has taken place here. The centripetal dips on Maelifell indicate that this hill represents a separate collapse "cone" on the southern border of the main caldera. The extrusive xenolithic acid rocks which outcrop on Maelifell are interpreted as tuffolavas, some of which, the Maelifell Sheets, are thought to have been erupted as mixtures of acid and basic magmas.

The lavas on the flanks of the Alftafjordur volcano can be distinguished from flood basalts and other lavas as they dip outwards from the core area (when corrections are made for the regional dip, fig. 2). Most of the flank lavas were probably erupted from within the core although some, such as the Hestabotnar rhyolites, issued from parasitic vents on the flanks.

The lavas which are not products of the Alftafjordur volcano include both flood basalts and thin basalt lavas of central type (probably derived other Tertiary volcanoes). The Fossarvik group of flood basalts, which terminates against the southern margin of the Breiddalur volcano, partly overlaps the highest flank lavas of the Alftafjordur volcano and indicate that both volcanic centres were active at the same time, although that of Alftafjordur probably became extinct first.

The majority of the minor intrusions in the Austurhorn area are related to the activity of the Alftafjordur volcano, and there is an associated dyke swarm similar to that associated with the other volcanic centres in eastern Iceland.

The Alftafjordur volcano has its own aureole of hydrothermal alteration which is marked by an extensive zone of propylitic alteration affecting most of the products of the volcano. Calcite, dolomite, aragonite and chlorite are the characteristic amygdale minerals within this aureole: epidote also appears locally.

The Alftafjordur volcano is a "cedar-tree" type of volcano (Walker, 1963, p.56) and is closely comparable to the three other Tertiary volcanic centres in Eastern Iceland, Thingmuli (Carmichael, 1962), Breiddalur (Walker, 1963) and Reydarfjordur (Gibson, 1963), which have been described in detail. The Breiddalur volcano is probably the most comparable: Thingmuli is much larger and has a more intense associated hydrothermal alteration, while the Reydarfjordur volcano is the smallest and is the only one that appears never to have formed a topographical volcanic cone. These volcanic centres are considered by Walker (1963), to be due to local high level magma chambers, in contrast to the flood basalts which are fed from a deep-seated magma source of very wide horizontal extent. Both types of vulcanicity are still taking place in Iceland at the present time.

PART II

The Austurhorn Intrusion

Chapter 10

Introduction

The Austurhorn intrusion is one of a number of major intrusions (fig. 24) known in south-eastern Iceland (Thoroddsen, 1905; Cargill, Hawkes and Ledeboer, 1928; Anderson, 1949; Jonsson, 1954). The intrusions are made up largely of gabbro and/or granophyre and both rock types are present at the Austurhorn.

The occurrence of gabbro and granophyre at the Austurhorn was first recorded by Thoroddsen (1896), who suggested that the mass had a laccolithic form. Hawkes (Cargill et al 1928) later gave a more detailed account of the shape of the intrusion and discussed the petrography of the rock types, and the present author agrees with Hawkes' interpretation of the intrusion as an irregular composite stock rather than a laccolith. No other work appears to have been done in the Austurhorn area.

The intrusion (fig. 25) forms the eastern part of the Austurhorn Ridge, including Hvalnesfjall and eastern Vikurfjall, and also outcrops on the south-east side of Krossanesfjall. The scenery here contrasts strongly with the sub-horizontal trap-featuring characteristic of most of eastern Iceland: the gabbro and granophyre instead form a rugged steep-sided mass which abruptly cuts across the adjacent basalt lavas. Screes are extensively developed below the granophyre outcrops, as the granophyre is closely-jointed and readily frost-shattered. Similar screes are characteristic of the other granophyre masses of south-east Iceland, including those at the Vesturhorn, Slaufrudal and Reydaratindur (Rauthafjall). The gabbro is less susceptible to erosion and screes are less well developed below the precipitous gabbro mass of Hvalnesfjall.

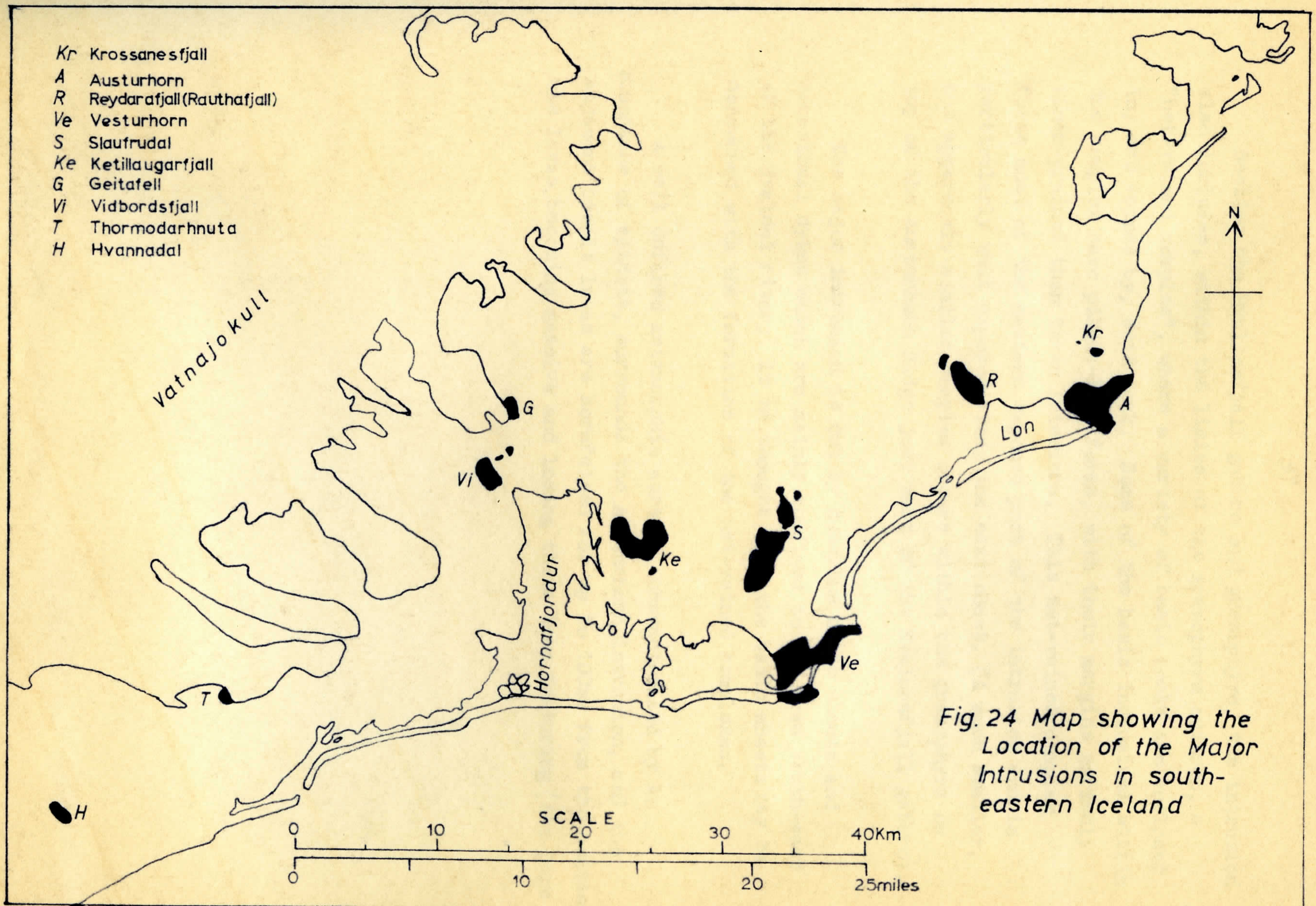

Fig. 24 Map showing the Location of the Major Intrusions in south-eastern Iceland

Besides the Hvalnesfjall gabbro and granophyre, the intrusion also includes, within the limits of the granophyre outcrop, a "net-veined complex", where a variety of basic rocks are enclosed in, and veined by, acid rock. Some of the basic inclusions within the complex have pillow-like forms, with their margins markedly finer-grained than their interiors. This net-veined complex forms most of the eastern exposed part of the intrusion and is particularly well exposed along the east coast. (A much smaller, but apparently similar complex occurs within the granophyre on top of the Austurhorn Ridge just west of the Hvalnesfjall gabbro).

The major intrusion is cut by numerous basic sheets and occasional dykes which are mainly confined to the area south-west of the Hvaldal river; it is thought that the basic sheets may be concerned with the formation of the net-veined complexes.

A well defined metamorphic aureole, characterised by an abundance of epidote, surrounds the Austurhorn intrusion, and the adjacent basalt lavas are hornfelsed for up to 100m. from the contact, the lavas becoming massive and losing their trap featuring (see page 89).