coarser-, rather than finer-, grained towards the heat source. Also neither the wall rock of the Mount Desert Island "composite" dykes described by Chapman, nor the many gabbro xenoliths within these dykes, show any signs of fusion. A similar lack of evidence is seen in the Austurhorn net-veined complex, where fine-grained margins are absent around all gabbro and many basalt and dolerite inclusions as well as being absent in the basic rock alongside many cross-cutting acid veins.

(b) Concerning Reynolds "proof" of fusion, the writer agrees with Bailey and McCallien (1956, p. 494) who "are certain it is a mistake to suppose that the composition of glass stringers transversing bytownite crystals can be correctly determined by taking refractive index and assuming the glass to be made of pure feldspar-substance" and they recall (p. 470) "Holmes' demonstration that glass similarly veining quartz xenoliths enclosed in certain basic and ultrabasic lavas is far from being uncontaminated quartz substance (1936). He has quoted three microchemical analyses, the most siliceous of which may be summarised as follows: SiO_2, 79.99; Al_2O_3, 7.13; $Fe_2O_3 + FeO + MgO + CaO$, 1.51; Na_2O, 0.99; K_2O, 5.53; H_2O+, 2.71; H_2O-, 1.47; $T_1O_2 + P_2O_5 + SO_3 + M_nO$, 2.26; Total, 101.59."

(c) There is no evidence of abrasion, such as could be caused by fluidising gases, shown by any basic inclusions within the Austurhorn net-veined complex, nor by the basalt lavas alongside the intrusion on Hvalnesskridur, where the lavas are separated by just thin layers of granophyre from pillows within the net-veined complex. (There is a very marked contrast on Hvalnesskridur between the sharp angular contacts of the intrusion with the lavas, at which the lavas do not become finer-grained, and the cumulose, fine-grained and often diffuse contacts of the basic pillows less than 1cm. away.) Chapman (1962) has shown that evidence of abrasion is also absent in the Mount Desert Island composite dykes, and such evidence appears to be lacking in the other net-veined complexes.

(d) As has been pointed out by Chapman (1962, p. 560), the irregular and cumulose contacts of the pillows are not fluted or single curved surfaces and cannot be explained by fluidisation, nor can such a process account for some acid layers between pillows having sharp contacts on one side and diffuse contacts on the other side, as are so often seen within the Austurhorn net-veined complex.

(e) Elwell (1958), finds that fluidisation cannot account for certain acid pipes he has described from a dolerite layer at Slieve Gullion, a type area for Reynolds' fluidisation theory. These acid pipes have also been examined by the writer. They are connected downwards with an acid vein system, and are commonly bordered by finer-grained dolerite in their lower parts, while they appear to grade upwards into the dolerite. "Thus (Elwell, 1958, p.67) it would appear that the pipes cannot represent channels along which there was a sustained flow of gas ......". Some acid veins cutting pillows in the Austurhorn complex similarly grade into the dolerite of the pillow interior.

From these objections, the writer considers that the fluidisation theory of pillow formation is untenable in the Austurhorn net-veined complex.

Objections to the replacement theory

The theory of metasomatic replacement, proposed by Chapman to account for the dolerite pillows in the composite dykes of Mount Desert Island, appears to be based fundamentally on the interpretation of the fine-grained pillow margins, of whether these are due to recrystallisation, as claimed by Chapman, or to chilling, as claimed for similar fine-grained basic margins by Reynolds (1937), Wager and Bailey (1953), Bailey and McCallien (1956), Elwell (1958), Bailey (1959) and Elwell, Skelhorn and Drysdall (1960, 1962). Chapman states (1962, p.555) that "diminution of grain-size, variolitic pattern and skeletal crystals are not in themselves reliable criteria for true chilling" and that "a progressive decrease in grain-size has long been recognised as an effect by re-crystallisation ". As positive evidence against the origin by chilling of the fine-grained pillow margins Chapman claims (1962, p. 554) that by using a First Order Red accessory plate a relict doleritic texture can be detected in many thin-sections, that the optical continuity within groups of tiny scattered feldspar grains as "revealed by interference color patterns is most striking; and one may clearly visualise relict plagioclase laths of a magnitude and disposition identical to those of a diabase block interior." To the writer such evidence appears highly subjective and inconclusive.

A number of objections to Chapman's metasomatic replacement theory as applied to the Austurhorn net-veined complex are considered below:

1. Perhaps the strongest argument is one based on the broader field relations of the rocks. It seems inconceivable to the writer that the process of metasomatism can account for the contact features of the net-veined complex as displayed on Hvalnesskridur (page 162) nor can it explain why some basic inclusions are completely unaffected while other inclusions, identical in composition and grain-size, show such marked textural changes at their margins.

2. Though a sub-variolitic texture may not necessarily be due to chilling, it is difficult to see how skeletal crystals of iron ore and apatite and swallow-tailed, 'H'-shaped, plagioclases, as found in the Austurhorn pillow margins, can be formed by some other process; such features are typically encountered in the margins of minor basic intrusions where chilling has undoubtedly occurred. For skeletal plagioclases, Chapman (1962, p. 554) claims that "Through recrystallisation in the pseudochilled zones they have come to resemble the skeletal crystals of genuine chilled zones". The writer cannot accept such a conclusion. Significantly, from experimental and petrographic evidence, Wyllie <u>et al</u> (1962) have shown that an elongate acicular habit is characteristic of apatite precipitated from a liquid during

quenching, such crystals being typical of extrusive and hypabyssal volcanic rocks and of some granophyre but unknown in metamorphic rocks, where apatite has an equant habit.

3. Richey (1937, p.274), like Chapman on Mount Desert Island, has suggested that at Slieve Gullion the fine-grained margins of basic rock against acid are entirely due to recrystallisation, and he mentions the granular habit of augite and hornblende in such rocks as being consistent with such an origin. Reynolds (1937, p. 275), however, has shown that in the examples quoted by Richey the feldspars still exhibit a lath-like habit, instead of also being granular, as in undoubted examples of complete recrystallisation, such as are found on Skye (Harker, 1904). Although it is admitted that some recrystallisation has taken place within many of the Austurhorn pillow margins, the feldspar here also often has a lath-like habit, and is rarely granular.

4. Conclusive evidence that the decrease in grain-size is primary and not due to secondary recrystallisation is shown by many of the larger Austurhorn pillows, where the coarse doleritic texture of the pillow interiors becomes progressively finer-grained, but still typically doleritic, towards the pillow margins, as shown in fig.42a (see also Elwell, 1958, plate 3).

5. Adoption of the Commingling Theory

For the reasons discussed above the writer rejects Chapman's granitisation theory as well as Reynolds' fluidisation theory and follows Wager and Bailey in regarding the pillows as being formed by injection of basic magma into acid magma, the fine-grained pillow margins being due to chilling of the basic magma against the cooler acid. Such an origin is capable of accounting for the typically irregular and cumulose contacts of the pillows, which is suggestive of an original liquid-liquid relationship, as well as explaining the progressive decrease in grain-size towards the pillow margins and the petrogrphy of the margins themselves. Undoubted examples of chilling of basic magma against acid are found in many composite extrusions and composite minor intrusions, where metasomatism or melting of the basic rock can hardly have taken place. A number of such occurrences are given in table 12. In many of these examples the chilled basic inclusions within the acid rock are similar in shape to the Austurhorn pillows and they also have sharp cumulose contacts with the acid rock, in spite of Chapman's opinion (1962, p.358) that such contacts "are not to be expected when basic melt chills against acid melt". The writer considers it probable that composite lavas and minor intrusions are high level equivalents of net-veined complexes. Further evidence for the commingling theory is given by the presence of flow-banding in some of the acid layers between basic pillows of the Austurhorn, in acid veins bordered by fine-grained basalt on Guernsey (Elwell <u>et al</u>, 1962), and in the marginal basic rock itself both on Guernsey and at Slieve Gullion (Elwell, 1962).

Table Examples, other than those of net-veined complexes, of basic magma chilled against acid magma.

A. Extrusions:

Iceland: Composite lava flows (Gibson and Walker, in press).

U.S.A. Gardiner River Complex (Wilcox, 1944; Hawkes, 1945; but see Fenner, 1938, 1944, for alternative view).

B. Minor Intrusions:

Scotland: Composite sheet of South Bute (Bailey and McCallien, 1956)
Composite intrusions of Skye (Skelhorn, 1959).

Northern Ireland: Glasdrumman Port composite sheet (Bailey and McCallien, 1956).

The commingling hypothesis has previously been applied to net-veined complexes at St. Kilda and at Slieve Gullion by Wager and Bailey (1953), Bailey and McCallien (1956), and Elwell (1958, 1962); at Carlingford by Bailey, (1959); at Guernsey by Elwell, Skelhorn and Drysdall (1960, 1962); and at Sara Fier, Nigeria, by Turner (1961). By this hypothesis the Mount Desert Island composite dykes can be accounted for if it is considered that the acid magma was intruded first into the dykes, closely followed by the basic magma which formed intrusive pillows in the acid. This is in contrast with normal composite dykes, where the marginal basic members are generally recognised as being intruded just before the central acid member.

The Commingling Theory applied to the Austurhorn net-veined complex.

The writer interprets the Austurhorn basic pillows as originally liquid inclusions of basic magma which were emplaced in liquid acid magma in a manner analogous to the extrusion of pillows of pillow lavas into water. The fine-grained pillow margins are considered to be true chilled margins: the basalt magma was chilled against the cooler acid magma, so forming a solid or semi-solid "skin" around the basic pillows which prevented more than a very small amount of mixing of the two magmas at the pillow contacts. Once the chilled skin was formed the basalt magma of the pillow interiors would be partly insulated against the cooler, still liquid, acid magma and internal crystallisation could proceed more slowly, with crystals progressively increasing in size towards the pillow centres.

Once formed the basic pillows probably remained sufficiently plastic, until their crystallisation was nearly complete, to be capable of changing shape when acted upon by external forces (c.f. pillows in pillow lavas), as is shown by the fact that closely spaced pillows often accommodate themselves to one another (fig.37,4a). Only very rarely, however, are two pillows seen to touch one another.

It is thought that the addition of the basic magma heated up the acid magma, especially adjacent to the basic pillows, and thereby rendered it more fluid (see page 173). The acid magma became less viscous than the basic magma and, when the chilled basalt skin became broken before the crystallisation of the pillow interior was complete, acid veins penetrated inwards, instead of basic magma flowing outwards. Near the pillow margins the pillow magma would still chill against the cooler vein magma, but further into the pillow the vein magma would have become heated until the acid and basic magmas were at roughly similar temperatures. As no chilling of the basic magma would then take place some mixing of the two magmas could occur, and the vein contacts would become diffuse. The degree of chilling of the basic rock bordering the veins is thought to depend on the amount and speed of the acid magma travelling though the vein. A small volume of acid rock passing slowly through a vein could not chill basalt magma (Elwell et al, 1962, p. 225). Other veins, formed after the basic pillows had completely crystallised, have sharp boundaries with no bordering chilled basalt.

The amount of veining of the pillows is very variable, and in extreme cases pillows are partly or completely broken up by acid veins, most of which formed after the pillows had nearly completed their crystallisation. In such cases, the pillow fragments tended to become isolated and formed normal basic xenoliths within the acid magma.

Locally, where there are concentrations of basic pillows, all the acid magma would have become much hotter than normal and some mixing of the two magmas could again have taken place. It is in such areas that the pillow contacts with the surrounding acid rock, even when still cumulose, tend to be diffuse and the very dense pillow margins, formed by more drastic chilling, absent.

As an objection to the commingling theory Chapman (1962, p.559), stated that the basic pillows, being heavier than the surrounding acid magma, should show evidence of gravity settling. Any such settling would be affected by the viscosity of the acid magma, which may locally have started to crystallise; by the shapes and sizes of the pillows themselves; and by any flow and turbulence within the acid magma. From the general lack of evidence to the contrary, it seems there was little turbulence within the acid magma of the Austurhorn net-veined complex, certainly insufficient to cause more than a minor distortion of shape of the pillows after their initial formation. (Possible exceptions to this are the dismembered "hollow" pillows found at Olneshofn, shown in fig. 35). Gravity settling in this complex may be shown by the thin quasi-horizontal acid layers which occur between many of the closely spaced tabular pillows: once a layer of such pillows becomes stationary in a horizontal position other pillows could settle on top, possibly causing slight flattening of the lower pillows. Gravity settling in the Austurhorn net-veined complex would also explain why many closely spaced pillows accommodate themselves; why acid layers between pillows often have roughly parallel, but never matching, walls; and why the amount of acid rock in the layers between the pillows often bears no relationship to the degree of chilling shown by the pillows - much of the acid magma originally present may subsequently have been squeezed out by the settling pillows.

The intimate net-work of acid veins in the net-veined complex, many of which are very thin and penetrate the basic rocks for long distances, is evidence that here the intruding basic magma was more viscous (because it became cooler?) than the acid magma. Hence the acid magma veined the basic magma and not vice versa. The thinness of the acid veins also indicates that the acid magma may have been more fluid than usual. This could be due partly to the acid magma being highly charged with gas (the occurrence of drusy cavities shows that gas was present) and partly to the acid magma being heated by the intruding basic magma (see page 173).

Although little detailed work has been done on the hybrid rocks of the net-veined complex, it seems probable that they can all be ascribed either to mixing of acid and basic magmas, or to reaction between acid magma and basic rock. In many cases partial recrystallisation has accompanied the hybridisation.

Some of the hybrid rocks, in particular those with a marscoitic aspect, such as the diorite at Hvalnes and the basic granophyres (including those outside the net-veined complex), probably represent a hybrid magma resulting from the mixing of acid and basic magmas at greater depths. The pillow-like masses of basic granophyre may be pillows of such hybrid magma analogous to normal basic pillows, though their lack of chilled, finer-grained, margins may indicate that they are inclusions of earlier granophyre. The nebulous pillows south of Olneshofn may also have been normal pillows of hybrid magma, the interiors of which became more acid by mixing with veining acid magma. As has already been described, mixing of acid and basic magmas in situ is considered to be the main cause of the feldspathic patches in the interiors of many basic pillows.

Some slight mixing of the acid and basic magmas may possibly have taken place at the initial intrusion of a basic pillow, before the pillow skin was formed, although the mineralogical changes in the pillow margins are most likely mainly due to reaction, by diffusion of ions, between the pillow margin and the adjacent granophyre magma. In the pillow margins the augite becomes partly or wholly replaced by hornblende and large poikilitic crystals of biotite and sometimes hornblende are often developed. These margins also commonly show evidence of partial recrystallisation, such as the occurrence of poikilitic crystals, the breaking up of the sub-variolitic plagioclase of the groundmass into a mosaic, and possibly the granulation of the groundmass pyroxene. The acid rock immediately adjacent to the pillows is often correspondingly enriched in hornblende and iron ore: it will only show such marginal modifications when there has been no relative movement between the basic pillow and the adjacent acid magma before the final complete solidification (c.f. the granite immediately surrounding xenoliths in the Tregastel-Ploumanac'h granite, described by Thomas and Smith (1932, p.291).

In many of the basic hybrid rocks the original basaltic texture has been preserved although there has been a change in mineralogy. The acid magma has reacted with the original minerals and made them over to new minerals with which the acid magma is saturated (Bowen, 1928, p. 197): the augite and calcic plagioclase have been made over to hornblende and sodic plagioclase.

Most of the acid hybrid rocks can be attributed to the processes envisaged by Nockolds (1935) for the junction hybrids at Barnavave, Carlingford. In some instances the acid hybrids have been formed almost entirely by the mechanical incorporation into acid magma of solidified basic material, the minerals of which have reacted to form new minerals in equilibrium with the acid magma. These are the exocontaminated hybrids of Nockolds (1935, p.303), and they are characteristically heterogeneous. The partly digested basic inclusions found throughout the granophyre of the Austurhorn intrusion, which are particularly prominent within the net-veined complex, are the result of such mechanical incorporation. Nockolds has shown that at Carlingford some of the more homogeneous acid hybrids have probably formed by the reciprocal reaction of acid magma with basic xenoliths, leading to crystallisation of new minerals direct from modified acid magma, with little or no mechanical incorporation of basic material. These are what Nockolds (p.303) called "endocontaminated" hybrids. Many of the acid hybrids of the Austurhorn intrusion were probably formed by a combination of both processes acting together.

The Relationship of the Net-veined Complex to the Austurhorn Intrusion as a whole.

It has been shown that the net-veined complex is made up chiefly of basic pillows or fragments of pillows enclosed in granophyre, and that the pillows represent injections of basic magma into acid magma. It now remains to show how the formation of the pillows is related to the Austurhorn intrusion in general. The following are pertinent to this question:-

1. The scarcity of intrusive basic sheets in the net-veined complex in contrast with their abundance in the Hvalnesfjall gabbro and in the granophyre on Vikurfjall and on the upper part of Austurhorn (fig. 25).
2. The occurrence of all gradations between tabular pillows(fig.38) within the net-veined complex, through sheets with cumulose contacts (as seen cutting the granophyre on Vikurfjall), to normal intrusive sheets cutting the Austurhorn intrusion outside the net-veined complex.
3. The similarity in composition of the basic sheets and the pillows - both include porphyritic and non-porphyritic varieties.
4. The common occurrence side by side of porphyritic and non-porphyritic tholeiitic pillows (with the addition of olivine basalt pillows at Krossanes).
5. The occurrence of sheet-like zones of pink granophyre within the net-veined complex.

It is thought that the acid component of the Austurhorn intrusion was emplaced before the basic pillows were injected into it, and that the pillows were formed more or less in their present positions. It is also thought that the basic pillows and basic sheets are roughly contemporaneous and come from the same magma sources; that the intruding basic magma formed pillows in the still molten interior of the acid intrusion and cross-cutting sheets where the acid magma had already crystallised. Such an explanation would account for the occurrence side by side of porphyritic and non-porphyritic pillows in the net-veined complex and for porphyritic sheets cutting and being cut by non-porphyritic sheets outside the net-veined complex. The intrusions of basic magma probably took place over a comparatively long period of time and the early formed pillows would tend to become more acidified (hybridised) than the later pillows, as they were longer in contact with acid magma. On Hvalnes the acid magma had completely crystallised before the final intrusions of basic magma formed sheets cutting across the net-veined complex.

Minor acid intrusions contemporaneous with the basic intrusions may be represented by the porphyritic felsite sheets associated with the granophyre on Vikurfjall. Any acid intrusions into the molten acid magma of the net-veined complex would most likely be unrecognisable, as they would become incorporated within the acid magma already in place. However, some acid minor intrusions may be represented by the narrow sheet-like zones of pink granophyre within the complex.

The general variable orientations of both the pillows and the basic sheets are perhaps due to the general low pressures to be expected in a high level intrusive stock of non-forceful type.

The recent work of Shaw (1963) and Friedman <u>et al</u> (1963) has shown that there is a very marked decrease in the viscosity of acid magma with increase in temperature and/or H_2O content: acid glass, raised 100°C in the range 700° to 1000°C experiences a ten-fold decrease in viscosity. Shaw's curves indicate that an acid magma at 1000°C containing 4% by eight of water, or one at 900°C containing 6% by weight of water, has a viscosity of about 10^5 poises, similar to that of a typical basic lava flow. Such a water content in an acid magma is reasonable: the solubility of water in acid magma at 900°C and at a depth of 1700m. (the maximum depth at which the Austurhorn granophyre was intruded - page 175) is around 4% by weight (Goranson, 1931).

CHAPTER 16

Contact Relationships of the Granophyre

One of the problems to which no definite answer can at present be given is why the granophyre at the margins of the Austurhorn intrusion generally appears unchilled. Concerning this problem it is probably significant that the country rocks have been thermally metamorphosed for 100m. or more away from the intrusion and that many thin and irregular granophyre veins penetrate the adjacent basalt lavas, often for considerable distances. In these respects the Austurhorn granophyre intrusion is similar to some of the boss-like Skye granophyre intrusions which also have unchilled margins (Harker, 1904, p.144). In contrast, other Skye granophyres, those which have markedly chilled margins, are described by Harker as having little associated contact metamorphism and no irregular vein offshoots.

The marginal features of high level acid intrusions are dependent on the amount of intruding acid magma, the method of its emplacement and whether the magma was intruded as a flowing liquid or as a very viscous crystal mush. The state of crystallinity of the acid magma on intrusion is known for some of the Skye granophyres. Wager <u>et al</u> (1953) showed that the Coire Uaigneich granophyre, which is markedly chilled at its margins, was intruded as a liquid. Brown (1963) has recently studied the melting relationships of this granophyre, and also of the Beinn Dearg Mhor granophyre, which appears unchilled at its margins, and he concludes that this latter granophyre was largely crystalline at the time of its emplacement. He states for this and similar granophyres on Skye that (p.551) "The scarcity of interstitial liquid would account for the absence of much evidence for 'chilling' (which can only be observed in a liquid) and intrusive veins at the contacts of the granophyres". There are, however, three main objections to the Austurhorn granophyre being similarly largely crystalline on intrusion: firstly, there would have been little heat of crystallisation to help compensate for the heat loss during the cooling of the magma, so the magma would have cooled quickly and contact metamorphism of the country rocks would only be very slight; secondly, gases would have been largely lost and drusy cavities would not occur; thirdly, the magma would be relatively immobile, so stoping would be very unlikely to have taken place and the acid magma would have been unable to vein the country rocks.

The evidence of zeolite zones suggests that the Austurhorn intrusion was formed under a maximum cover of 1700m (in eastern Iceland laumontite, which occurs in the lavas on top of Vikurfjall, normally forms 1,700m. below the top of lava pile - Walker pers. comm.) and it is possible that the acid magma may have reached the surface. Hence a very large amount of acid magma may have passed through the intrusion and this magma could have heated the adjacent country rocks so that the later acid magma arriving at the margin of the intrusion was not chilled. The effect of varying amounts of magma passing through different intrusions has been noted by G.P.L.Walker (pers. comm.) in Antrim, Northern Ireland. Here there are many dolerite plugs (Walker, 1959a), some of which are unchilled at their margins. The unchilled dolerites are associated with a very intense contact metamorphism of the country rocks (e.g. Scawt Hill), while the chilled dolerites hardly affect the country rocks. Walker considers that a very large amount of basic magma passed through the unchilled intrusions and heated the country rocks, which eventually became as hot as the intruding magma, so that the latest dolerite magma was not chilled at the margins of the intrusion. A similar effect to that of a great volume of magma passing through an intrusion could perhaps also be produced by the circulation of magma, by convection currents, in a large intrusion: such currents could erode any chilled margin originally developed.

A further possible explanation for the contact relationships of the Austurhorn intrusion is that initially a partly crystalline acid magma, like that of the Beinn Dearg Mhor intrusion, was forcefully intruded, up-doming the country rocks. This very viscous magma was then followed immediately by a much more fluid acid magma which veined and incorporated some of the earlier acid magma and also veined the country rocks, displacing them by piecemeal stoping. (That the acid component of the Austurhorn intrusion may be made up of several different, though closely related, acid magmas is indicated by the variety of granophyres present). The convection currents within the later fluid acid magma may have further heated the country rocks (which had already been heated by the earlier granophyre) and prevented any marked marginal chilling.

CHAPTER 17

The Relative Age of the Hvalnesfjall Gabbro, and the Sequence of Intrusion within the Austurhorn Mass

Although the contact features of the Hvalnesfjall gabbro appear at first sight to show that the gabbro was intruded before the adjacent granophyre, there is reason for believing that the intrusion of gabbro is, in fact, later than that of the granophyre.

At its margins the Hvalnesfjall gabbro is unchilled; moreover it is cut by granophyre veins and apophyses, and it has been thermally metamorphosed (as is shown by the development of epidote and the clouding of feldspar and pyroxene crystals), presumably by the granophyre. Such features would appear to indicate that the gabbro is earlier than the granophyre. However, the present position of the gabbro is very difficult to reconcile with such a view. The large and comparatively very heavy gabbro mass is almost completely surrounded by much lighter granophyre, which underlies the gabbro below Thufuhraunstindur and on Breithatindur, and the gabbro is nowhere seen in contact with the country rocks. If the gabbro was earlier than the granophyre it surely should have sunk to the base of the granophyre intrusion, as were the basalt lavas which were displaced by the granophyre, especially as there is evidence that the granophyre magma was very mobile when it was intruded.

That the gabbro might be later than the granophyre is also suggested by the relationships in a group of basic sheets (the 'Differentiated Sheets', described on pages 75 - 86)intruding the basalt lavas on the shore between Hvalnes and Vik farms (fig.25). These sheets come within the metamorphic aureole of the main intrusion but appear to have suffered less thermal metamorphism than the lavas they cut. A significant feature of the sheets is that they contain inclusions of granophyre and gabbro. The former are normal, angular xenoliths, possibly derived from the nearby granophyre of the Austurhorn intrusion, but the gabbro inclusions are loose aggregates of plagioclase, augite and iron ore crystals similar in size, shape and composition to those of the Hvalnesfjall gabbro. These inclusions show that the intruding sheet magma picked up fragments of solid granophyre and only partially crystallised gabbro, and this could imply that the Hvalnesfjall gabbro is younger than the Austurhorn granophyre, although it must be admitted that the gabbro and granophyre inclusions may also be derived from some other, concealed, intrusive masses.

If the gabbro is later than the granophyre, it is possible to account for the contact relationships of the gabbro by analogy with the contact relationships observed in the net-veined complex. Like the basic magma forming the pillows in the net-veined complex, the gabbro magma may have been intruded into previously emplaced but still hot and perhaps only partially crystalline acid magma. Immediately adjacent to the gabbro magma the acid magma would have been heated and thereby rendered more mobile (Shaw, 1963) and, as it would probably remain liquid after the gabbro had completely solidified, it would be able to vein the gabbro. Much of the marginal gabbro would then have been broken up and incorporated, as xenoliths, within the acid magma. The gabbro may initially have chilled against the cooler acid magma and formed a solid skin; at any rate the two magmas remained essentially seperate, although the hybrid zone at the gabbro contact on the western side of Hvalnesfjall may be due in part to some slight mixing of acid and basic magmas immediately after the gabbro intrusion.

As has already been described, the basic sheets cutting the Austurhorn mass and the basic pillows of the net-veined complex are considered to be of the same age and derived from the same magma sources; both postdate the emplacement of the gabbro. The general sequence of intrusion within the Austurhorn mass is therefore thought to be:-

1. Acid magma was intruded to form a stock, and the country rocks were displaced by stoping. This initial intrusion was closely followed by:

2. the intrusion of the Hvalnesfjall gabbro, perhaps more or less contemporaneous with the intrusion of the xenolithic basic sheets cutting the basalt lavas between Hvalnes and Vik farms.

3. Further intrusions of basic magma then took place which formed irregular sheets where they cut solid rock, outside the net-veined complex, and pillow-like masses where they were intruded into still liquid acid magma, within the net-veined complex. At this time hybrid magmas, formed by the mixing of acid and basic magmas at depth, may also have been intruded. The final acid magma to crystallise formed the leucocratic veins which cut all the other acid rocks of the intrusion. At Hvalnes a few later intrusions of basic magma formed sheets cutting across the net-veined complex.

CHAPTER 18

Summary of Conclusions

1. The Austurhorn intrusion is an irregular composite stock intruded into Tertiary lavas. Many of these lavas are younger than the youngest products of the Alftafjordur volcano, indicating that the intrusion was formed long after the Alftafjordur volcano had become extinct.

2. The intrusion thermally metamorphosed the country rocks, forming a metamorphic aureole up to 100m. wide.

3. The country rocks were updomed to some extent by the intrusion but were mostly displaced by magmatic stoping.

4. Acid magma was intruded first, and before it had completed its crystallisation it was itself intruded, first by the Hvalnesfjall gabbro and then by a group of basic sheets, some of which helped form the net-veined complexes.

5. The texturally-zoned pillow-like basic inclusions within the net-veined complex were formed by the intrusion of basic magma into acid magma, analogous to the formation of pillow lavas in water.

6. Other basic inclusions within the net-veined complex are either fragments of broken pillows, fragments of the Hvalnesfjall gabbro, or xenoliths of country rock.

7. The fine-grained margins of the basic pillows are true chilled margins, formed by the chilling of basic magma against cooler acid magma. Though the margins usually show some metamorphic effects, these are quite distinct from the chilling and do not obscure the progressive decrease in grain-size towards the

pillow contact. The acid rock is never chilled against the basic pillows.

8. There was relatively little mixing of acid and basic magmas at the level of the net-veined complex, as the chilled pillow margins effectively separated the two magmas. Mixing of the two magmas is least evident where the basic magma is most notably chilled.

9. During and after their crystallisation the basic pillows were veined by the acid magma which remained fluid long after the basic pillows had solidified.

10. The evidence in the net-veined complex indicates that the acid magma here was highly fluid and much less viscous than the basic magma forming the pillows.

11. The hybrid rocks in the net-veined complex were formed by a combination of two processes, the mixing of acid and basic magmas, and the reaction of acid magma on basic inclusions which had partly or wholly crystallised.

Appendix

An X-ray investigation of the alkali feldspars in the Austurhorn granophyre.

An X-ray study of the alkali feldspars in eight granophyre specimens from the Austurhorn intrusion was made in order to determine their compositions and to verify that they were unmixed.

The alkali feldspars used in the X-ray investigation were separated from the granophyre rock powders by means of the Frantz isodynamic separator and heavy liquids. The final fraction of each alkali feldspar contained less than 10% of impurities, the chief of which was quartz, although sometimes small amounts of plagioclase were also present.

The X-ray investigation was carried out on a Philips high angle diffractometer and X-ray diffraction patterns of the alkali feldspars were obtained using the powder method described by McKenzie and Smith (1956, p.408), but with $KBrO_3$ as the internal standard instead of quartz or Amelia albite. Smear mounts of the specimens with added $KBrO_3$ were made and diffraction patterns in the range 19.5° to 23° 2θ were produced, using CuKα radiation. Peaks representing the ($\bar{2}01$) reflections of alkali feldspars come within this range of $2\ \theta$, as also does the peak representing the (101) reflection of $KBrO_3$ (at 2θ +20.205° ± 0.010°). The use of $KBrO_3$ as an internal standard is recommended by Orville (1958) as it is readily obtainable in a pure form and the position of the (101) peak is not appreciably affected by variations in room temperature. The required X-ray pattern was scanned four or more times using a scanning speed which gave a change in 2θ of 0.25° per minute, and the recorder produced a chart in which one inch was equivalent to 1° in 2θ .

X-ray diffraction patterns of each of the unheated alkali feldspar specimens showed two peaks representing the ($\bar{2}01$) reflection for two separate phases present, and this indicated that all specimens were unmixed The positions of the two peaks for each specimen were measured in relation to the (101) peak of $KBrO_3$ (table 13). Small amounts of the alkali feldspars were then placed in separate gold charges, which were left unsealed, and heated for twelve days at 950° in an attempt to homogenise the feldspars. X-ray diffraction patterns were produced for the heated feldspars and these indicated that only two specimens, H308 and H680, had become homogeneous: both these had X-ray diffraction patterns showing a single well-defined ($\bar{2}01$) peak. The patterns of the other heated specimens showed very wide and poorly defined ($\bar{2}01$) peaks indicating incomplete homogenisation. The approximate Or content of the homogenised specimens H308 and H680, which are given in table 13 , were obtained from the curve shown in fig. 49 (reproduced from Orville, 1958, fig. 21). The position of the ($\bar{2}01$) peak is primarily a function of Or content and the weight per cent orthoclase of homogenised natural feldspars can be estimated to within about 5% using this method. The position of the separate phases in the unheated specimens, though, cannot be reliably estimated from the positions of either or both of their ($\bar{2}01$) reflections (Deer, Howie and Zussman, 1963).

Table 13

Specimen	Position of ($\bar{2}01$) peaks, measured in 2θ, relative to the (101) peak of $KBrO_3$				Or content (in wt. %)
	unheated		heated		
H308	0.767	1.808	1.220		54.5
H680	0.789	1.847	1.075		67.5
H187	0.714	1.829	1.511	average	-
H217	0.690	1.798	1.441	"	-
H304	0.730	1.823	1.418	"	-
H313	0.739	1.829	1.393	"	-
H416	0.795	1.823	1.341	"	-
H683	0.641	1.798	1.527	"	-

For key to specimen numbers, see page 117.

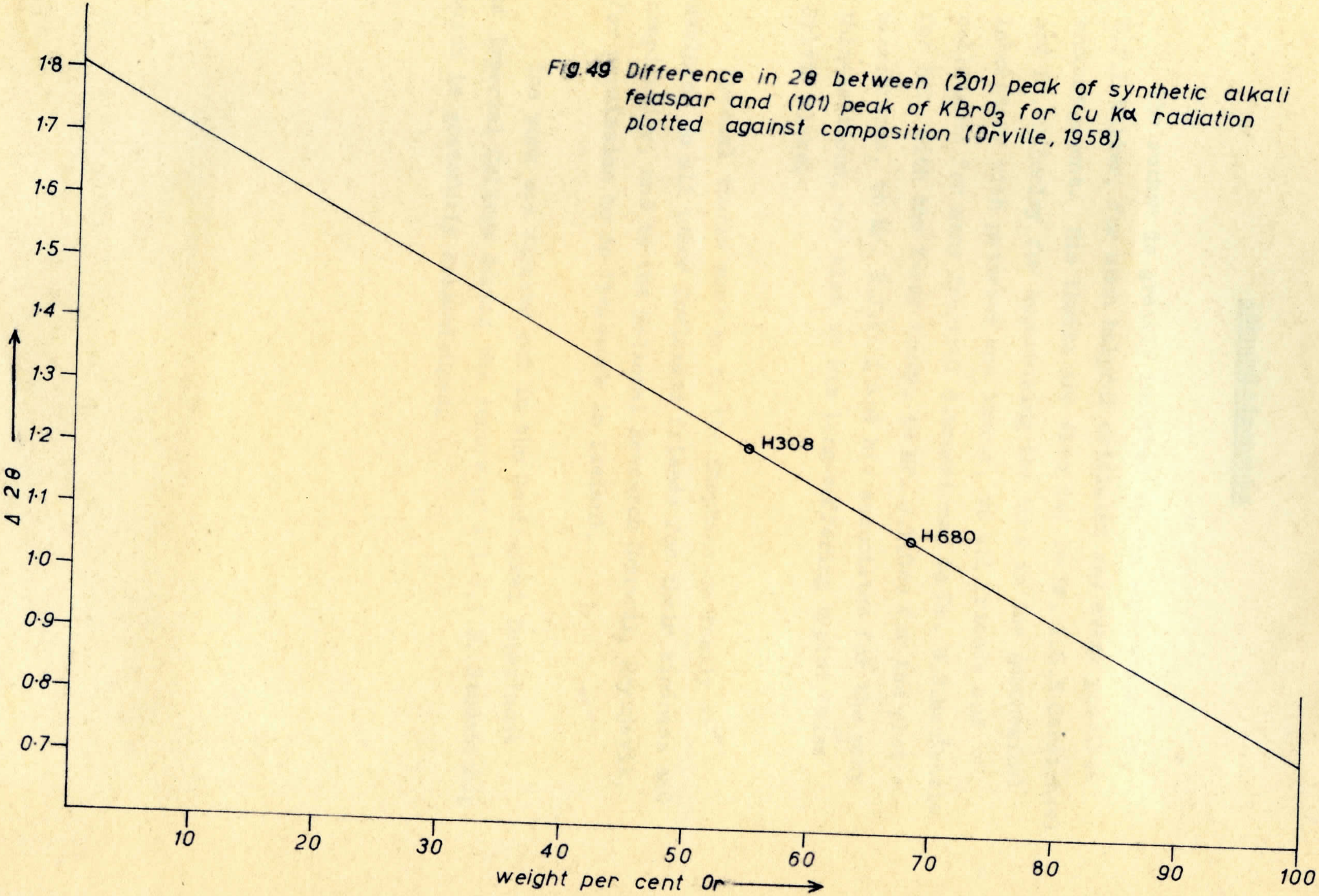

Fig. 49 Difference in 2θ between ($\bar{2}01$) peak of synthetic alkali feldspar and (101) peak of $KBrO_3$ for Cu Kα radiation plotted against composition (Orville, 1958)

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