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Bulletin No. 151

The geology of the Qôrqut granite complex north of Qôrqut, Godthåbsfjord, southern West Greenland

by

C. R. L. Friend, M. Brown, W. T. Perkins
and A. D. M. Burwell

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Abstract

The late Archaean (*c.* 2550 Ma) Qôrqut granite complex post-dates the major part of the geological evolution of the Godthåbsfjord region of southern West Greenland.

The complex is composed of a variety of granites intruded as a multitude of individual sheets. The granites are divided into three groups according to their age relations and overall characteristics: leucocratic granites, grey biotite granites, and composite granites. Moreover, the complex can be divided into three zones: upper, intermediate and lower. These zones have different proportions of the three granite groups and included country rocks.

Textures and structures typical of partial melting are found in highly modified gneiss enclaves contained in the leucocratic granites of the lower zone. All stages of the transition from gneiss to granite are present. Field evidence suggests that much of the biotite contained in the granites may be derived from the parent gneiss. Petrographic and mineral data are presented to support this contention.

In some parts of the complex in the area studied extensive mineral and lithological layering is present. This most commonly occurs in the leucocratic granites and consists of biotite-rich versus biotite-poor granite. Otherwise seams and thin layers of biotite are found which, in part, may be derived from the partially melted enclaves. Lithological layering may also be produced by intrusive effects of thin sheets of granite of slightly different characteristics.

Using mesonormative components the granites approximate to minimum melts in the granite system and appear to have crystallised under conditions where P_{Total} was less than 5 kbar.

The melting zone for the leucocratic granites was not far below the present level of exposure. The grey biotite granites were probably derived from slightly deeper levels. The tectonic regime under which the Archaean crust was partially melted allowed small, discrete batches of magma rapid access to higher levels of the crust. Once at this higher level emplacement was constrained to a sheet form. The complex was thus built up by successive intrusions of small batches of magma.

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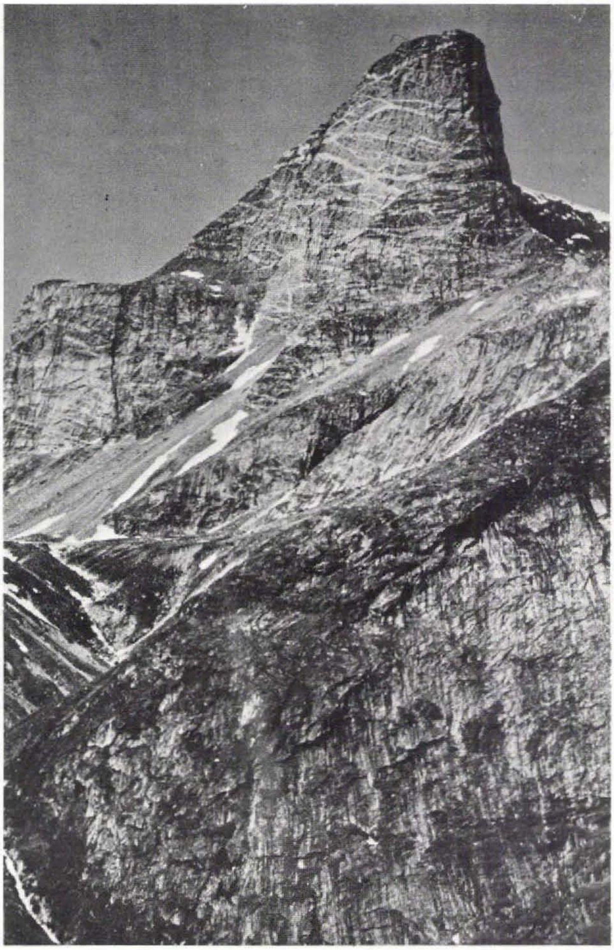

Fig. 1. Section through the Qôrqut granite complex of about 1500 m, view of the 1493 m mountain with the upper zone occupying the top of the peak. Underneath this is the intermediate zone which occupies the rest of the cliff face down to sea level. Looking east from Ūmánap suvdlua.

And though the shadow of a sigh
May tremble through the story,
For 'happy summer days' gone by,
And vanished summer glory
It shall not touch with breath of bale
The pleasance of our fairy tale.
Lewis Carroll

INTRODUCTION

The Qôrqut area is situated some 40 km east-northeast of Nuuk/Godthåb in the Archaean block of southern West Greenland (pl. 1). The Godthåbsfjord area is composed mainly of various gneisses with supracrustal rocks and plutonic rocks of several ages and origins (McGregor, 1973, 1979), including the Qôrqut granite complex (Brown *et al.*, 1981), cut by Proterozoic dykes (Bridgwater *et al.*, 1976).

Reports of a body of granite occurring in the Godthåb region are given by Giesecke (1878) and Noe-Nygaard & Ramberg (1961). During reconnaissance mapping by McGregor in 1965 and 1966 granites were found to be the dominant lithology in an elongate zone between Ameralik and Kapisigdlit kangerdluat; later McGregor (1973) used the name Qôrqut granite for this suite of rocks. Subsequent mapping has established that the Qôrqut granite and associated pegmatite extends from the vicinity of Færingehavn some 150 km northeast through Qôrqut to the Inland Ice at Ivisârtoq (Sharpe, 1975; Gibbs, 1976; Walton, 1976; Friend & Hall, 1977; Burwell & Friend, 1979; Brown & Friend, 1980b).

In the Qôrqut area there is a maximum thickness of granite exposed and here the granitic rocks are seen to be markedly polyphase and to form a sheeted body; because of this variety in granite type and the internal structure of the granite body, Brown & Friend (1980b) proposed that the name *Qôrqut granite complex* should be used for the suite as a whole. The granitic rocks making up the Qôrqut granite complex are divided into three lithological groups and a threefold zonal division of the complex has been established, each zone comprising a different proportion both of the various granite types and of the country rocks (Brown & Friend, 1980b). A detailed account is given of the field occurrence and characteristics of the granites which make up the Qôrqut granite complex in the area north of Qôrqut, coupled with a petrographical study of the granites and an account of the major element geochemistry of samples collected during the field seasons 1978 and 1979.

The age of the Qôrqut granite complex has been established by the following isotopic methods: 2530 ± 30 Ma, Rb-Sr whole rock isochron (Moorbath *et al.*, 1981); 2530 ± 30 Ma, U-Pb on zircons (Baadsgaard, 1976); and 2580 ± 80 Ma, a Pb-Pb whole rock isochron (Moorbath *et al.*, 1981). All of these methods give good agreement within analytical error and for the purposes of this account the age of the Qôrqut granite complex is taken to be 2550 Ma (cf. Moorbath *et al.*, 1981).

OUTLINE OF THE INTERNAL RELATIONSHIPS IN THE QÔRQUT GRANITE COMPLEX

The Qôrqut granite complex between Qôrqut and Sulugssugutip kangerdlua (pl. 1) is composed of a polyphase association of granitic rocks (*sensu* Streckeisen, 1976). The constituent granites have been divided into three main groups (cf. Brown & Friend, 1980b; Brown *et al.*, 1981):

(1) leucocratic granites,	often containing biotite schlieren and lamellae.
(2) grey biotite granites,	essentially homogeneous granites
(3) composite granites,	comprising granite with pegmatite and composite aplogranite – granite pegmatite.

These three groups of granites are not evenly distributed throughout the complex. An approximately 1500 m vertical section is available through the complex in the area mapped (fig. 1) which has allowed a diagrammatic section to be constructed (fig. 2) illustrating the division of the complex into three zones (cf. Brown & Friend, 1980b; Brown *et al.*, 1981):

Lower zone:	composed of dominantly leucocratic granite which contains modified gneiss enclaves and some unmodified rafts of country rock all cut by sheets of biotite granite and recut by a few thin sheets of composite granite.
Intermediate zone:	composed of dominantly grey biotite granite of various types which occur as cross-cutting sheets, some of which include subordinate rafts of country rock and with occasional horizons dominated by country rock, all of which are cut by composite granites, which are more common than in the lower zone.
Upper zone:	composed largely of country rock as angular rafts enclosed within a network dominantly of sheets of grey biotite granite, the whole forming the host for numerous anastomosing sheets of composite granite which break up this country rock – grey biotite granite host into lozenge-shaped blocks.

COUNTRY ROCKS

A general description of the lithological characteristics of the Amîtsoq (*c.* 3750 Ma) and the Nûk (*c.* 3000 Ma) gneisses, which form the bulk of the country rocks, can be found in Bridgwater *et al.* (1976). More detailed aspects of the occurrence of the gneisses are given by McGregor (1973, 1979). The field characteristics that are used to distinguish between the Amîtsoq and Nûk gneisses (e.g. the presence of amphibolite strips which are interpreted as the remnants of Ameralik dykes) have been used to assign many of the enclaves and rafts contained within the granite complex to either the Amîtsoq or the Nûk gneisses. Thus a reconstruction of the geology of the area prior to its invasion by the various granites can be made. It is clear from such a reconstruction that the majority of the country rocks at the present level of erosion are Amîtsoq gneisses with only a minor component of Nûk gneiss. However, in the north of the area, around the shores of Sulugssugutip kangerdlua and along the eastern shore of Ũmánap suvdlua, there are units of Nûk gneiss which contain enclaves of anorthosite, related gabbroic rocks and amphibolite (pl. 1). Fragments which may be attributed to other lithological units such as the Akilia association (McGregor & Mason, 1977) and the Malene supracrustal rocks (McGregor, 1973) are found as enclaves within blocks of the Amîtsoq and Nûk gneisses respectively (see Bridgwater *et al.,* 1976). The mineral assemblages present in these enclaves are typical of the amphibolite facies of metamorphism. The Qôrqut granite complex is located within amphibolite facies Amîtsoq and Nûk gneisses and has not been subjected to either major regional metamorphism or deformation. No relics of any granulite facies assemblages, which are known to occur in other parts of the Godthåbsfjord region (Wells, 1977, 1979; Griffin *et al.,* 1980), have been found.

Throughout most of its *c.* 150 km length the Qôrqut granite complex is oriented sub-parallel to the regional structure. However, in detail the granite complex is markedly discordant (Brown *et al.,* 1981; McGregor, 1984).

STRUCTURE OF THE QÔRQUT GRANITE COMPLEX

The Qôrqut granite complex is emplaced into a broad antiformal structure (Bridgwater *et al.,* 1976; Brown *et al.,* 1981) and is occasionally cut by shear zones of unknown age. A foliation, picked out by an alignment of biotite, is sometimes present, and it is not unusual to find a sheet of unfoliated granite cut by a foliated granite. This foliation is parallel to the margins of the sheets and is attributed to flow during emplacement and not to subsequent deformation. From a study of the country rock enclaves and rafts, particularly those in the upper parts of the complex, it seems that the orientation of the foliation in the country rocks was largely undisturbed during dilation as the sheets of granite were emplaced, indicating that the granite magma intruded passively into a zone of brittle or semi-brittle behaviour (see pl. 1, figs 1 & 2). Thus the complicated pre-existing structure of the country rocks is preserved from raft to raft, and the country rocks now occur in a large-scale agmatite structure. Poles to the foliation in the country rocks concentrate along a great circle interpreted to indicate a fold plunging to the south-southeast (Burwell & Friend, 1979). This interpretation is in accord with an observed large-scale synform, with measurements made on linear structures and with rare fold hinge lines preserved in the gneiss rafts. Measurements of the orientation of the margins of individual sheets of granite in the lower portion of the complex show that there is generally no consistent orientation. It is concluded that the pre-existing structure of the host rocks has not been a significant influence in controlling the disposition of the sheets of granite which make up the lower part of the complex.

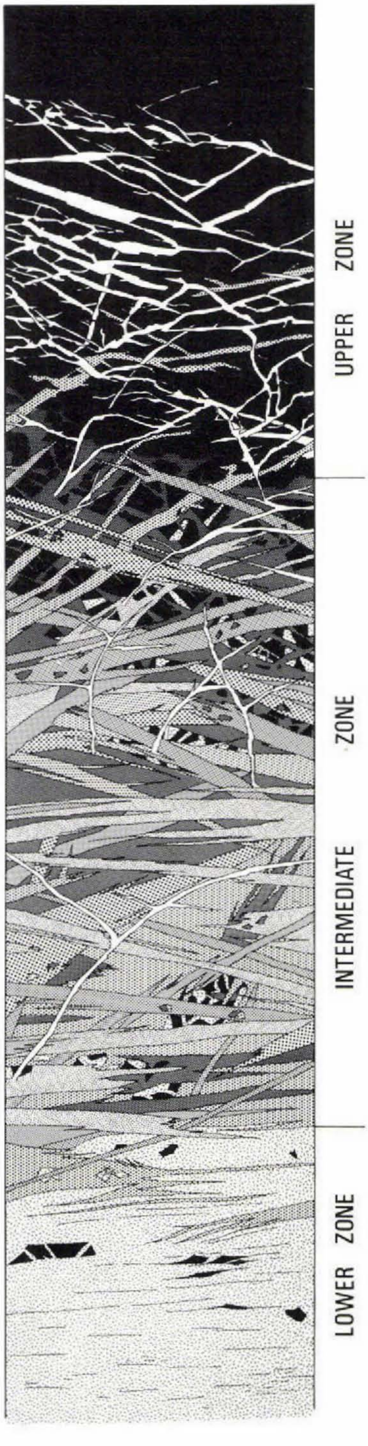

Fig. 2. Vertical section through approximately 2000 m of the Qôrqut granite complex to demonstrate the components of the three zones. Jackstraws (bottom part) = leucocratic granite; various stipples = grey biotite granite; white = composite granites; black = undifferentiated country rocks. Section prepared from field photographs.

The upper parts of the Qôrqut granite complex contain many of the composite granite sheets. These sheets have a much more regular orientation, in contrast to the earlier granite sheets forming the bulk of the complex. A stereographic plot (fig. 3a) of poles to the composite granite sheets occurring to the west side of Nigsik shows that they invariably have a low to moderate westerly dip. To the east of Nigsik the number of easterly dipping sheets increases as the granite complex dies out laterally into the country rocks.

The joints developed within the granite form a regular pattern. Four distinct sets of joints are discernable (fig. 3b):

(1) strike 050°, steeply dipping
(2) strike 110°, steeply dipping
(3) strike 160°, steeply dipping
(4) gently dipping, no preferred orientation.

The fourth set may be interpreted either as cooling joints developed parallel to the margins of the gently dipping granite sheets or as joints which have developed due to the static unloading of the granite during the recent glacial retreat (cf. Ollier, 1969; Sugden & John, 1976). The first three joint sets, which have clearly defined orientations, are unlikely to be related to the orientations of the randomly disposed granite sheets. These three sets are geometrically related to the axis of the south-

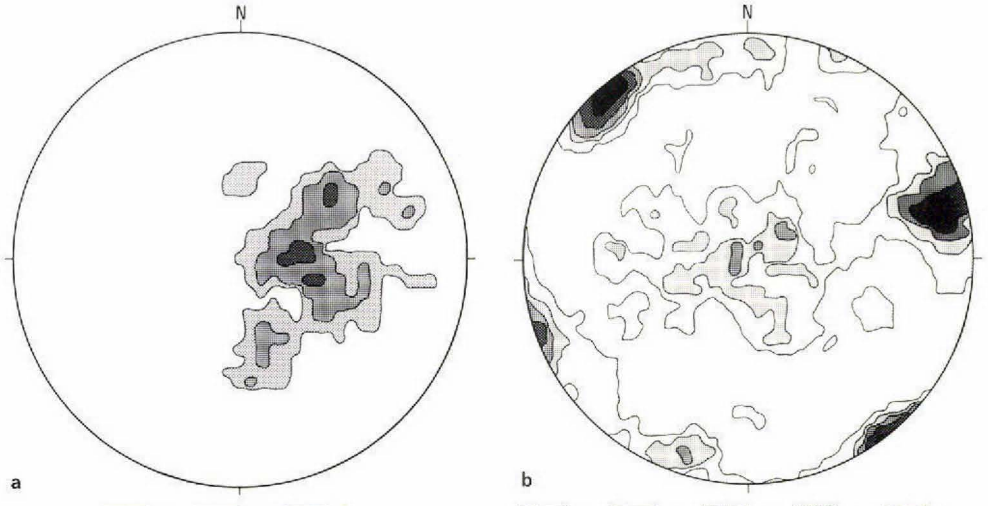

Fig. 3. Contoured lower hemisphere stereographic projections, contour values given as percentages per 1% area. (a) 109 poles to the orientation of composite granite sheets in the upper zone of the Qôrqut granite complex west of Nigsik and north of Qôrqut. (b) 301 poles to joint surfaces in the Qôrqut granite complex west of Nigsik and north of Qôrqut.

southwest plunging antiformal structure into which the body is intruded. Those striking 050° and 160° are symmetrical about the axis of this regional antiformal fold whilst the set which strikes 110° is sub-parallel to the fold profile. Because of this relationship Brown *et al.* (1981) concluded that these three joint sets are cooling joints which exhibit a controlled development. Additionally, the joint set striking approximately northeast is sub-parallel to a majority of the later shear zones which cut the granite. There is evidence that some of these joints have been reactivated, and bleached zones, suggesting the passage of volatiles, are developed on either side of some joints.

In the upper zone of the complex the host rocks, comprising country rocks which have previously been cut by granites, are broken up into lozenge-shaped blocks by composite granite sheets (pl. 1, figs 1 & 2). This configuration of blocks and anastomosing sheets is similar to the pattern developed when micro-joints are produced during extension (Wise, 1964).

GRANITES

Leucocratic granites

The leucocratic granites are the earliest members of the Qôrqut granite complex and form the dominant component of the lower zone. They crop out mainly in the deeper levels of the complex exposed along the north and south shores of Qôrqut, around the point Ujarâ and along the coast of Sagdlia (pl. 1). In the north of the area, leucocratic granites are also found around the point Alángorssûp nûa (pl. 1). At shallower levels within the complex, corresponding to increasing topographic elevation, the leucocratic granites decrease in abundance giving way to an ever increasing volume of grey biotite granite sheets. At high levels leucocratic granites form only a very small portion of the complex and become rather difficult to distinguish from some of the later composite granite sheets.

The leucocratic granites vary from white to pinkish in colour and exhibit a range of internal structures from inhomogeneous to homogeneous depending upon the distribution of biotite. A characteristic variety is a leucogranite with biotite seams which in some instances grades into an inhomogeneous leucogranite containing schlieren of biotite. The leucocratic granites are best displayed near Ujarâ and in the floor of the hanging valley to the west of the mountain Qáqarssuaq on the northern side of Qôrqut (pl. 1).

To the west of Qáqarssuaq there is very little exotic material present within these granites, and only occasional enclaves of country rocks are found. Below this level (*c.* 400 m) and down to the shores of Ũmánap suvdlua, enclaves of country rock become more common and may be divided into two types: rare enclaves which are unmodified, angular to sub-angular rafts; and more common enclaves which are modified and have the characteristics of migmatites.

Unmodified gneiss enclaves

Throughout the Qôrqut granite complex there are many enclaves of unmodified gneiss (Brown *et al.*, 1981). A large proportion of these are identified as Amîtsoq gneisses. Evidence for this interpretation includes, for example, remnants of amphibolite strips preserved in several of the enclaves which are regarded as Ameralik dykes and fragments lithologically identical to the Akilia association. Additionally, the gneissic component of many of these enclaves has lithological characteristics not typical of the Nûk gneisses. Since these enclaves have an angular appearance, the simplest conclusion is that they have been derived from the marginal zone adjacent to the intruding leucocratic granites. Structurally these rafts appear to have been unaffected by their incorporation in the leucocratic granites and there has been virtually no modification of their mineralogy or texture. Where modification can be seen it is limited to either a thin rind of biotite formed around the basic enclaves or the development of biotite concentrations at the contacts of basic layers in the gneiss where they are truncated by the granite. In both cases this minor modification is easily explained in terms of a simple chemical replacement of hornblende by biotite which is a reflection of activity of K in the enveloping magma.

Modified gneiss enclaves

The occurrence of occasional migmatised enclaves and rare biotite-rich partial melt residues was reported by Burwell & Friend (1979). In the vicinity of Ujarâ, many modified enclaves occur in the leucocratic granite exhibiting features typical of partial melting. These enclaves led Brown & Friend (1980a) to propose that the leucocratic granites had originated by partial melting of gneisses, probably of Amîtsoq type, not far below the present level of erosion, and that the modified enclaves had been carried up from the margin of the zone of melting. At several places within the leucocratic granites there are enclaves of amphibolite, in some cases preserved as horizons of boudin trains (fig. 4). These are thought to be the remnants of Ameralik dykes from around which all of the Amîtsoq gneiss has been removed during the process of melting (fig. 5).

The modified enclaves and the leucocratic granites, including the development of biotite schlieren and seams, are best seen in a rockfall north of Ujarâ (locality 457 in Friend, unpublished field notes). Here copious fresh surfaces are available for examination, and the textures and structures present are described with reference to Mehnert (1968), Brown (1973) and Johannes & Gupta (1982). The leucocratic granites are extensively layered and often contain schlieren and seams of biotite. In the area around Ujarâ there is convincing evidence as to the origin of at least some of these schlieren and seams (see below). It is concluded that much of the biotite in the leucocratic granites could be derived from the disaggregation of such schlieren rather than by precipitation from a wholly liquid granite melt, i.e. much of the biotite could be relict. Throughout the outcrop of the lower zone of the

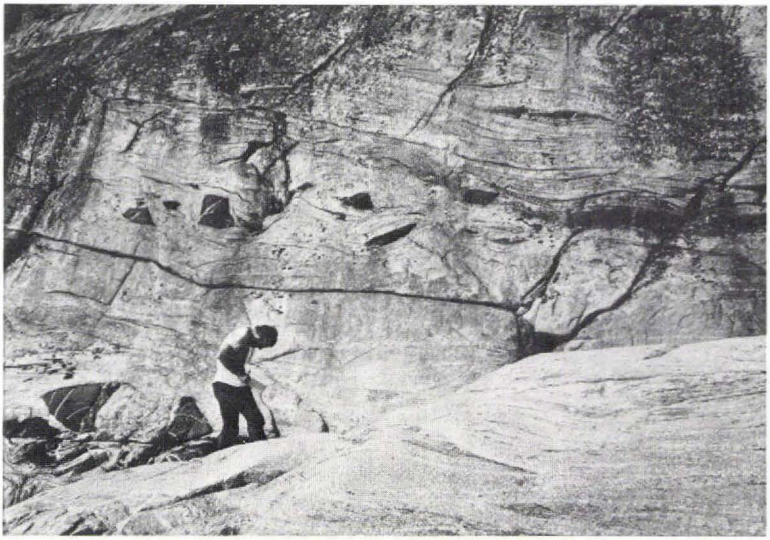

Fig. 4. Crude horizons of amphibolite enclaves within leucocratic granite, the gneissic material in which they were originally contained having been removed by partial melting. North shore of Qôrqut, west of Angmagssivît.

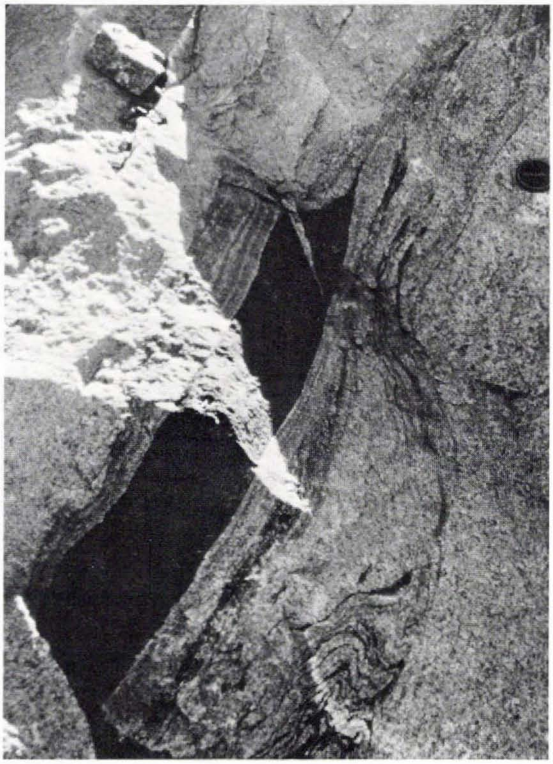

Fig. 5. An enclave of modified Amîtsoq gneiss with an Ameralik dyke. This enclave demonstrates the stages of partial melting and the release of the amphibolite into the granite. Rockfall north of Ujarâ.

complex around Ujarâ and along the shores of Qôrqut there are many other enclaves of gneissic material which exhibit the progressive change from layered, foliated biotite gneiss into a metatexite. The gneiss first undergoes an alteration by which the felsic layers lose their gneissic texture (fig. 6). The layering is a relic from the gneiss, but the textures present in the neosome are a hypidiomorphic granular texture in the felsic layers (leucosome) and a lepidoblastic texture in the biotite-rich layers (melanosome). The next stage involves the enlargement of the leucosome at the expense of the mesosome to produce a more pronounced biotite-rich melanosome. Eventually the melt generated begins to disrupt the layering in places, and the metatexite becomes broken up to result in smaller enclaves of metatexite in inhomogeneous granite (fig. 6). This type of process, whereby melt gradually accumulates first along foliation surfaces and then becoming more and more disruptive, no longer being contained within the layering, is similar to that postulated by Hyndman (1981) for the widespread accumulation of granitic magma.

As described above, at least some of the biotite schlieren and lamellae in the leucocratic granite are derived from the metatexite melanosomes. The development of melt may take place to such an extent that the biotite-rich melanosome is reduced to a seam no more than a few crystals thick. It is evident from this that there is a continuum present, and some of the early leucocratic granites may be termed inhomogeneous or homogeneous diatexites (Mehnert, 1968; Brown, 1973). Amongst the numerous enclaves in the early leucocratic granites there are many examples which have undergone this next stage of accumulation of melt which results in disrupted banding and the formation of a diatexite. Some of these rocks still

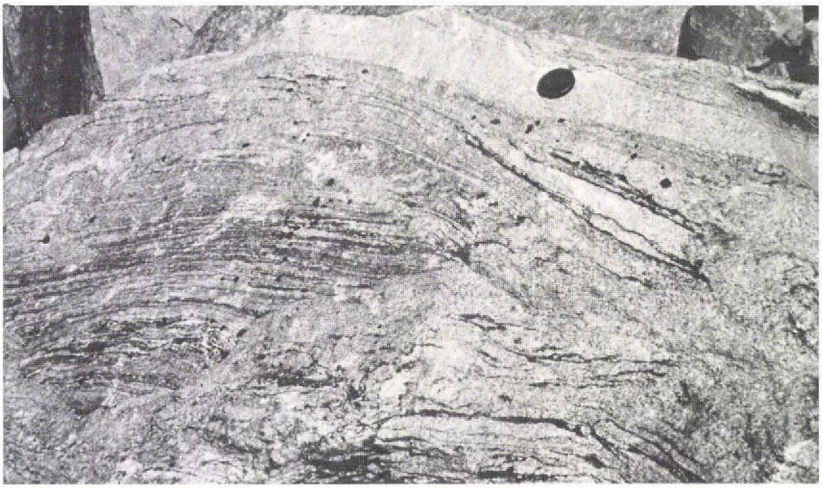

Fig. 6. A highly modified enclave of gneiss, now metatexite, showing the derivation of biotite schlieren from the break up of the melanosome. This process can be traced in many areas and may give rise to much of the biotite present in the leucocratic granites. Rockfall north of Ujarâ.

preserve structures from their gneissic parent such as relict foliation, sometimes still folded, which are picked out by concentrations of biotite (fig. 5). Both to the south of Qôrqut, beneath the mountain Qáqarssuaq, and to the north, around Ujarâ, areas of gneissic material may be encountered with the foliation parallel to a similarly oriented weak banding in granite.

Layering

Compared with basic and ultrabasic rocks, reports of layering in granitic rocks are relatively uncommon, for example: Barrière (1977, 1981), Emeleus (1963), Harry & Emeleus (1960), Smith (1975) and Wilshire (1969). Summaries of the types of layering occurring within granitic bodies and their possible origins have been given by Wilshire (1969) and Barrière (1981). Layered structures in the leucocratic granites can originate in several ways and are divided into two types, as follows.

Lithological layering

The simplest form of layering is a crude intercalation of granites with slightly different characteristics of grain size, biotite content or colour of the felsic phases. It generally extends over several tens of metres laterally and for several metres perpendicular to the layers. The thickness of the individual layers is usually less than about 50 cm, but is normally quite variable and layers frequently appear to interfinger and wedge out laterally. In the kind of melting environment described above it is likely that batches of broadly similar magma will be available in close proximity to each other. Thus, in such a situation, a batch of magma could be at any stage in its crystallisation when another batch of magma is intruded into it. That this situation occurred is suggested by the variety of contact relationships observed in the field which indicate either brittle behaviour (angular xenoliths or sharp contacts) or ductile behaviour (lobate contacts) or the meeting of two viscous liquids (lobate and convolute contacts with flow structures).

Other examples of lithological layering are slightly more complex and are the result of early phases of the grey biotite granites emplaced into still soft leucocratic granite. Again, some of the contacts are lobate and indicate that, at least locally, members of both groups of granites were available at about the same time.

Mineral layering

One type of mineral layering present is formed by biotite lamellae which are often seam-like or semi-continuous over a distance of several metres. These are derived in the main by smearing out schlieren in the inhomogeneous diatexites. It is quite common to find that mineral layering defined by biotite may bifurcate or form a group of curved laminae (fig. 7) which is attributed to flow. Similar bifurcating and arcuate biotite laminae and layering have been attributed to con-

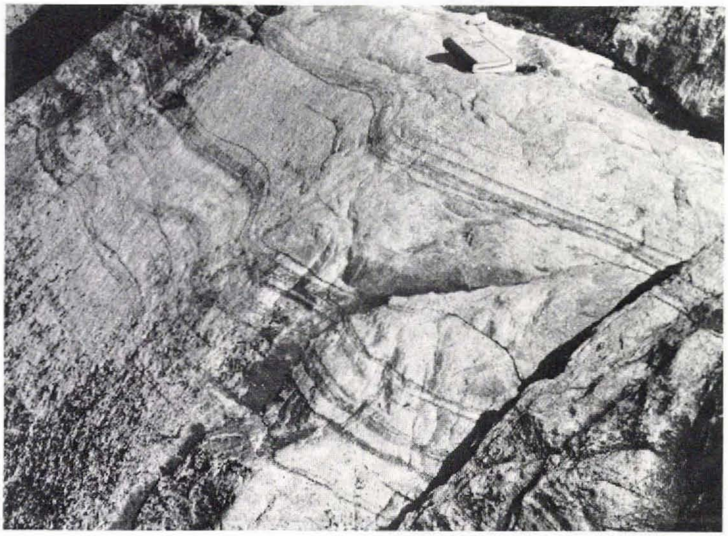

Fig. 7. Detail of biotite-rich versus biotite-poor layers showing the bifurcation of biotite seams. Leucocratic granite between Ūjarâ and Sagdlia.

vection currents (Grout, 1926; Mayo, 1941; Barrière, 1977, 1981) or to episodic shearing flow (Smith, 1975), perhaps during emplacement (Wilshire, 1969). Experimentally it has been shown that the shear flow mechanism can produce not only a concentration of crystals (Bagnold, 1954) but also both bifurcating and branching layers (Bhattacharji & Smith, 1964). This mechanism may explain some of the layering in the rocks of the Qôrqut granite complex since during the emplacement of laterally extensive sheets of granite shear flow sub-parallel to the margin is quite likely to have occurred.

Within the leucocratic granites around Alángorssûp nûa and the south side of Sulugssugutip kangerdlua there are several features which are not seen in the rocks further to the south around Ujarâ. The most striking is the frequency and variety of mineral layering. The present orientation of the layering is sub-vertical (fig. 8). Unfortunately, because of the intrusion of a large volume of later granite, it is not known whether this present sub-vertical orientation of the layering represents its original disposition. The layers, which consist of both regular and irregular types, can be up to 25–30 cm or more thick, but more normally are 5–10 cm thick. This layering closely resembles that described from granites in south Greenland (Harry & Emeleus, 1960; Emeleus, 1963; Ferguson & Pulvertaft, 1963) and northwestern France (Barrière, 1977, 1981).

Locally the layering is very regular (figs 8 & 9) and consists of many biotite-rich and biotite-poor layers. Some of the layers consist of homogeneous granite with an even distribution of biotite. Sometimes there is a sharp biotite-rich cut-off between layers which marks the presumed base or margin of the next succeeding layer. In

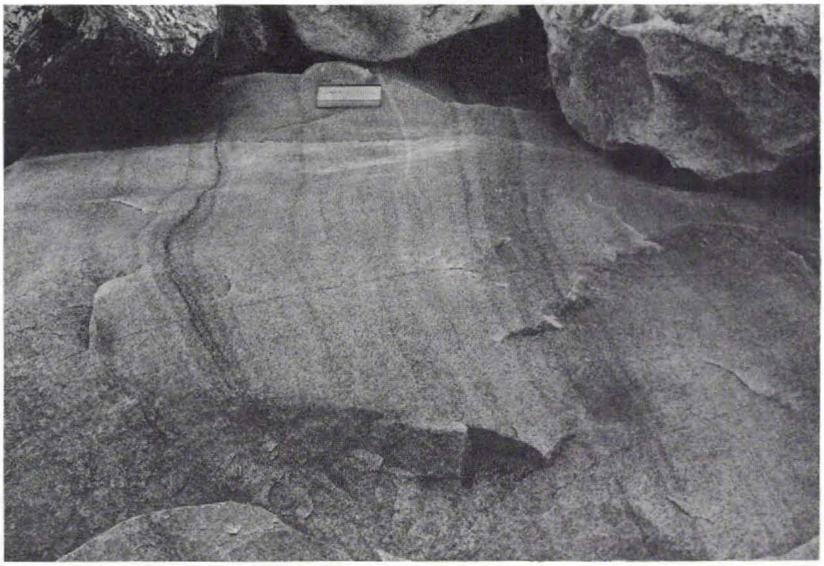

Fig. 8. Graded mineral layering of biotite-rich versus biotite-poor granite orientated sub-vertically. Leucocratic granite southwest of Alángorssûp nûa.

these examples there is a strong resemblance to igneous cumulate layering. However, since it can be demonstrated that some of the layering originated from the assimilation of modified enclaves, there is no unequivocal evidence that this particular type of layering did originate by crystal accumulation.

Several modes of origin of such layering have been discussed in the literature: shearing out of inhomogeneities in the magma, segregation and convection concentration of biotite (Wilshire, 1969), *in situ* differentiation (Ferguson & Pulvertaft, 1963), double density diffusion (McBirney & Noyes, 1979) and variation in

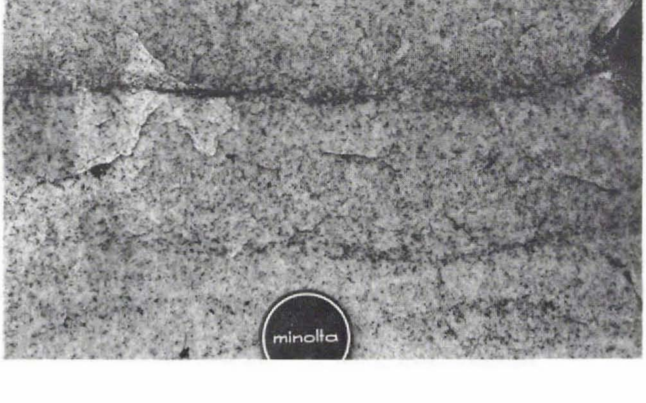

Fig. 9. Detail of regular mineral layering showing two biotite-rich 'bases' to individual layers which grade into more normal biotite-poor granite. Leucocratic granite southwest of Alángorssûp nûa.

the rates of nucleation of the mafic phases (Naney & Swanson, 1980). Field evidence in the Qôrqut granite complex does not permit an unequivocal choice between these alternatives. However, the proposal of Naney & Swanson (1980) that border zones of granitic plutons, which are often rich in mafic phases, may have resulted from a more rapid nucleation of these phases from the magma merits attention. They give experimental results suggesting that the precipitation of alkali feldspar, quartz and to a lesser extent plagioclase, is suppressed in such instances. In the case of the Qôrqut granite complex, the only mafic phase present is biotite which we believe to be in part derived from the source rock.This could have had the effect of seeding the magma and leading to the formation of sets of mineral layers. The conditions that Naney & Swanson (1980) suggest for cooling are interesting in that the body must cool from its margins inwards, allowing the formation of mafic layering at the contacts. This sort of process could explain biotite concentrations found along both contacts of some of the grey biotite granite sheets. Alternatively (or simultaneously) the model of McBirney & Noyes (1979) may be applicable to the Qôrqut granite complex, particularly since there is clear evidence that there were different liquids present at the same time.

Flow folds occur in one sheet of leucocratic granite which crops out near Alángorssûp nûa (fig. 10). Since the rocks show no evidence of major regional ductile strain, these structures cannot be of tectonic origin, and they are interpreted as having formed in a viscous medium that was not fluid enough to disrupt the biotite-rich layers as the fold developed. Additionally, along the eastern side of this sheet

Fig. 10. A flow fold disrupting biotite-layered leucocratic granite. The fold has no fabric associated with it and consequently is attributed to magmatic flow in a viscous liquid. Alángorssûp nûa.

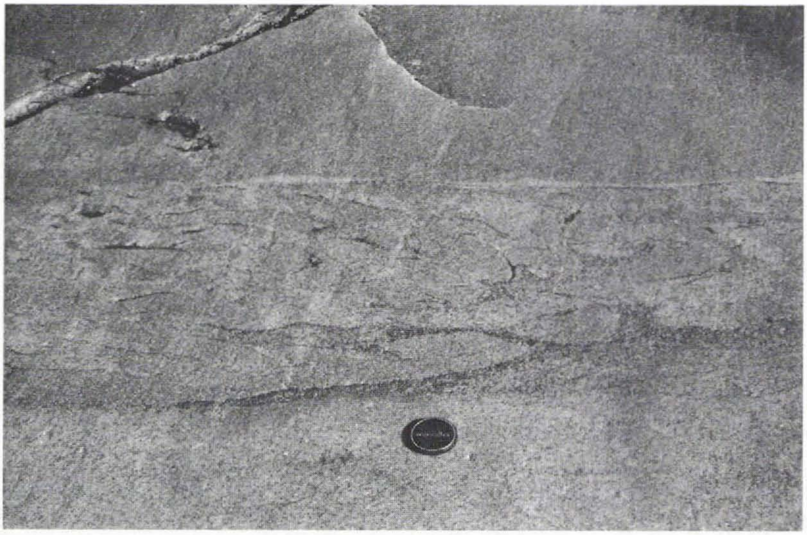

Fig. 11. Contact of two sheets of leucocratic granite showing the results of viscous flow. Such structures are found along the contacts, or more rarely, in the centres of sheets. They consist of lobed areas of essentially homogeneous granite outlined by margins of more biotite-rich granite, such as those illustrated, or rarely, biotite schlieren. Alángorssûp nûa.

of leucocratic granite there are balled stuctures preserved in the granite (fig. 11). These structures consist of lobate or rounded areas of biotite-poor granite which are surrounded by an envelope of more biotite-rich granite. The turbid nature of the biotite-rich layers suggests that flow along the interface was impaired and that these lobate areas were developed as a result. It is possible that these biotite-rich and biotite-poor types of granite could have developed by flow segregation.

Another group of structures, which again imply current activity and which we attribute to flow in the magma, are features which strongly resemble sedimentary troughs and cross laminations with biotite forming the laminae (fig. 12). The concentration of biotite into laminae gives a layered appearance to these rocks.

Grey biotite granites

The grey biotite granites form the main component by volume of the Qôrqut granite complex. Throughout most of the area north of Qôrqut these grey biotite granites are the dominant rock type of the intermediate zone of the complex (fig. 2) which largely comprises the middle portions of the mountains. Whilst they are not the dominant component of the upper and lower zones, the grey biotite granites are, none the less, important constituents of these zones. In most cases the sheets are between 1 and 10 m thick, rarely thicker, although they also occur as abundant thinner veins and apophyses. Occasionally, however, particularly at intermediate

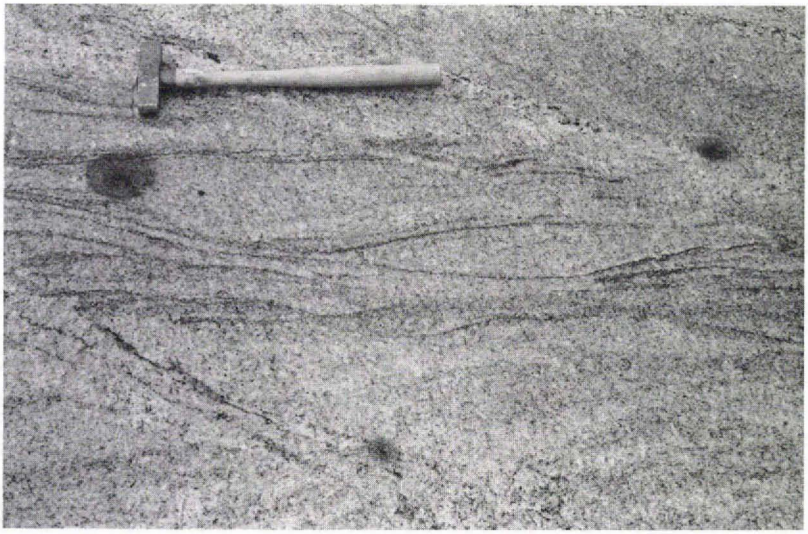

Fig. 12. General view of an area of layered leucocratic granite. Here the layers are irregular and resemble sedimentary cross laminations. The layers consist of thin biotite-rich layers versus thicker layers of normal granite. Southwest of Alángorssûp nûa.

levels of the complex, outcrops occur of individual sheets which are free of enclaves of country rock and, due to the coincidence of the orientation of such sheets and the slope of the topography, they appear as larger areas of grey biotite granite.

These granites are quite variable, in any one area of outcrop comprising cross-cutting sheets of up to five different types of grey biotite granite. These different phases of grey biotite granite may contain frequent xenoliths of the leucocratic granites, any of the earlier phases of grey biotite granite and several generations of pegmatitic granite. Usually, it is not possible to follow an individual sheet for more than a few tens of metres. Occasionally, in some of the cliff faces, sheets of granite can be seen to be laterally much more extensive. An additional complication is the apparently random succession of intrusion of the different phases of grey biotite granite. Usually it is possible to establish a sequence of intrusion at one locality. However, throughout the complex, different sequences appear to be present at different localities, and it has not proved possible to establish a common sequence of intrusion of the different phases of grey biotite granites. Occasionally it is impossible, even locally, to establish a completely unambiguous sequence of emplacement.

In some instances, individual sheets appear to have been the result of more than one intrusive phase and in this respect are similar to dykes which have been formed by multiple intrusion. There are also examples which show the marginal portion of the emplaced granite magma solidified against the host rocks only to be cut by apophyses of the same magma which have intruded the crystallised marginal zone from the still mobile central portion of the sheet. Usually, chilled margins to the sheets are not seen and it may be concluded that the granites have been intruded into an environment that has allowed them to cool relatively slowly. Miarolitic cavities have not been found. Lateral mineralogical, and hence colour variations occur in some sheets and these usually involve differing amounts of plagioclase and biotite and, as might be expected, the finer-grained varieties are generally darker in colour. Inhomogeneous types, which contain clots of biotite and feldspar crystals and aggregates (up to 5 cm long), rarely occur. Petrographic evidence suggests that the feldspar crystals and the biotite clots have originated as xenocrysts, being relics from the parental material.

Concentrations of biotite can usually be found locally along parts of some contacts of individual sheets or located at the tips of fingers of grey granite into earlier rocks. Evidence for the origin of these concentrations is sometimes ambiguous. In some instances they may be interpreted as flow concentrations, alternatively, they could be the result of a contact reaction. Other possible explanations are that they were produced either by cooling induced along the intrusion walls or by wall-rock contamination, both mechanisms proposed by Naney & Swanson (1980).

An interesting sporadic, but widespread, feature of the grey biotite granites is the irregular development of a spotted texture (fig. 13). At their simplest, the spots consist of an aggregate of feldspar + quartz, which may be up to 3 cm in diameter, with a dark core. The distribution of these aggregate structures is irregular, and in areas of continuous exposure patches with a spotted texture can be seen to pass into normal granite which may have a higher biotite content. In the field the most common minerals identified in the cores of the spots are euhedral to rounded magnetite (fig. 13), often with a biotite corona, or aggregates of biotite occasionally with epidote. Sometimes, where the aggregates are more densely developed, there may be amalgamation of the spots to form irregularly shaped felsic patches or short, irregular veins containing magnetite and biotite.

Layering in the grey biotite granites is restricted to a lithological banding of granites of slightly different compositional and textural characteristics (fig. 14). The size and extent of this layering is extremely variable but is most usually encountered on a scale of several tens of centimetres thick by some tens of metres laterally. No mineral layering of any sort has been found. However, biotite foliation is a widely distributed feature of the grey biotite granites and can be demonstrated to be of magmatic origin. The structure is usually sub-parallel to the margins of the sheets, and in consequence it may be found with many different orientations; additionally, instances of foliated sheets cutting non-foliated sheets of granite are a common occurrence.

The contact relationships between the individual granite sheets are well displayed. In many examples there are lobate and diffuse contacts to some of the sheets, which suggests that different batches of magma were available at about the

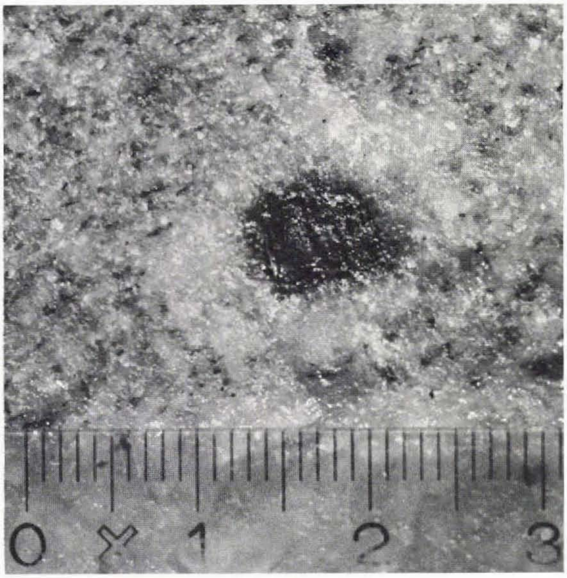

Fig. 13. Spotted texture in grey biotite granite showing the structure of the magnetite-cored, felsic-haloed spots. South shore of Sulugssugutip kangerdlua.

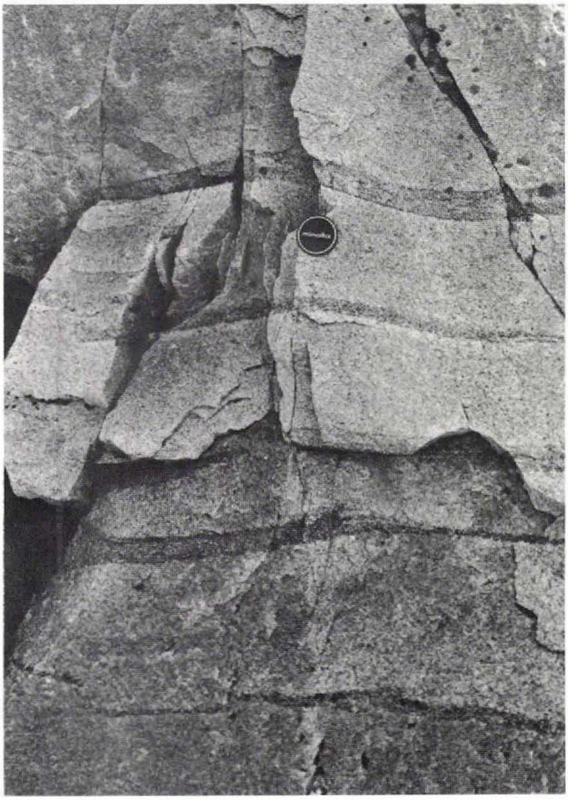

Fig. 14. Layering as a result of grey biotite granite (dark layers) intruded into leucocratic granites. This type of layering is also produced by the intrusion of grey biotite granite sheets which have slight differences in composition and texture. Near Ujarâ.

same time. It is evident that whilst in some areas the granite was able to behave in a ductile manner, elsewhere it behaved in a brittle manner.

Pegmatite is often associated with the grey biotite granites. Much of this is coarse-grained quartz + feldspar pegmatite with variable amounts of biotite and is attributable to segregation during crystallisation.

Throughout the whole of the area studied north of Qôrqut the grey biotite granites, unlike the leucocratic granites, are generally free of enclaves interpreted as restite after partial melting. The homogeneous appearance and the absence of such modified enclaves leads us to the conclusion that the grey biotite granites have moved some distance from their zone of generation before emplacement. From field evidence the volume of each individual batch of magma which gave rise to a sheet of grey biotite granite is relatively small in relation to the complex as a whole and, when intruded, was geographically not very extensive. A plausible mechanism of accumulation and intrusion of the grey biotite granites might be as follows. Each batch of magma was allowed free access upwards as soon as it became sufficiently buoyant, rather than being confined long enough to permit accumulation of a much larger pulse of magma which might, in consequence, have formed a sizeable plutonic body able to rise diapirically (cf. Hyndman, 1981).

Composite granites

The granitic rocks making up this group may be found at all levels within the complex. They form a significant component of all three zones and are distinguished from the earlier granites by cross-cutting relationships. However, some of them bear a strong resemblance to some of the coarser, more homogeneous, leucocratic granites. Thus, where clear evidence from cross-cutting relationships is absent, these composite aplogranite – granite pegmatite sheets are difficult to distinguish from some of the earlier pegmatitic rocks.

Rocks of this group constitute the most voluminous component of the upper zone of the complex. They occur as sheets cutting the highest levels of intrusion reached by the grey biotite granites and further extend the complex to higher levels in the crust (fig. 2). Thin sheets of pegmatite belonging to the composite granites are also found far from the main area of the granite complex, for example to the east of Nigsik. For the most part the composite granites form an anastomosing network and, since the pre-existing country rock/granite complex is split up into angular, lozenge-shaped rafts, they are interpreted as having been intruded into rocks which were behaving dominantly in a brittle manner. Individual sheets of composite granite can be followed for considerable distances, often several hundreds of metres, in many of the cliff faces (fig. 1). The composite granites may be divided into two main types.

Composite aplogranite – granite pegmatite sheets

This type (fig. 15) varies from sheets consisting of coarse-grained granite containing numerous segregations and irregular veins of coarser-grained pegmatite with some aplite to sheets consisting only of coarse-grained pegmatite with feldspars in excess of 5 cm long. Development of this facies of the complex occurs, for example, on the summit of Sagdliata portornga. In some examples this type has a simple layered structure consisting of clearly defined pegmatitic or aplitic border zones up to 15 cm thick with the opposite lithology in the centre of the sheet up to several tens of metres thick. Generally the granitic rocks are all leucocratic, containing little biotite. In this respect they resemble some of the leucocratic granites; however, they may be distinguished by the pegmatitic segregations which are not found in the leucocratic granites. In addition, the composite granites do not contain biotite schlieren.

Occasionally a sheet may be found to consist of an anstomosing network of smaller sheets and veins of a composite nature, usually pegmatite and aplite. These interconnected veins are separated by small screens of country rock, which may be either Amîtsoq gneiss or grey biotite granite.

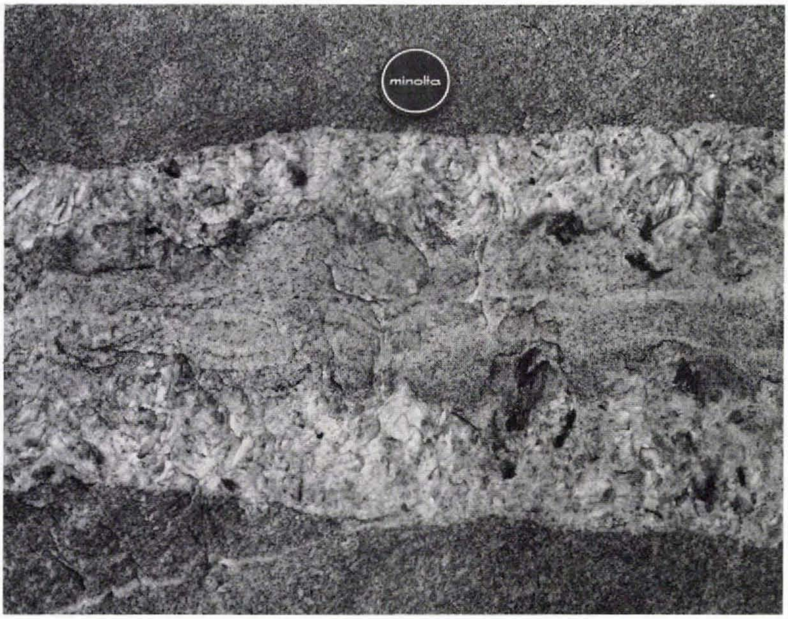

Fig. 15. Composite aplogranite – granite pegmatite.

Composite biotite granite – granite pegmatite sheets

These sheets are far more complex than the previous type and comprise banded granite interlayered with granite pegmatite. The best examples are found in the upper levels of the complex in the mountains west of Nigsik forming the ridge to the 1493 m peak (fig. 1) and Talorssuit. Here there are sheets containing bands of biotite-rich and biotite-poor granite, which in many respects have a strong resemblance to the regular layering found in the leucocratic granites near Alángorssûp nûa. However, at the former location the sheets may be distinguished from the leucocratic granites as they cut not only the Amîtsoq gneisses but the grey biotite granites as well. The sheets are normally 1.5–2 m thick, with a sub-horizontal attitude. A laterally extensive internal layering sub-parallel to the margins of the sheets may be present. This layering may be repeated several times across the thickness of the sheet with the individual layers normally less than 5 cm thick. The layers consist of a biotite-rich granite with a sharp base, which often passes up gradationally into a leucocratic granite or pegmatitic layer with a homogeneous texture which is terminated by the sharp base of the next layer. Within the sheets the contacts between the constituent types of granite are frequently lobate or undulating and in some instances there is little, if any, grading within a layer.

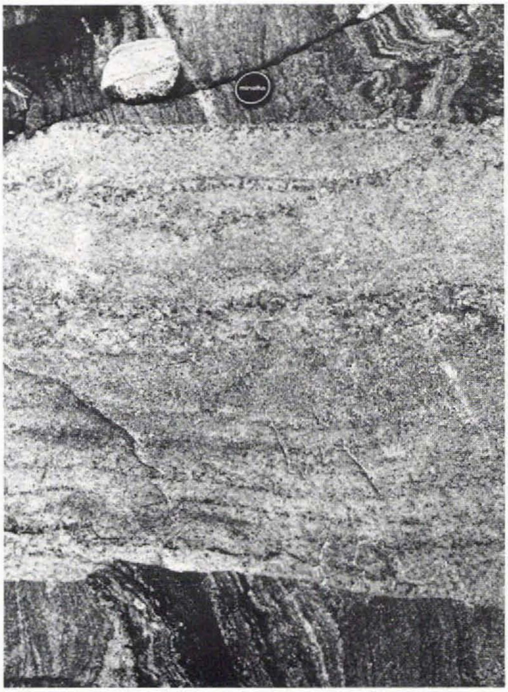

Fig. 16. Detail of a pegmatite-aplite layered composite granite sheet cutting Amîtsoq gneiss. Southeast side of Nigsik, beneath 1530 m mountain.

Some of the thinner sheets contain a lower portion consisting of biotite layered granite which is laterally persistent over some 10 m. This shows varying degrees of mineral segregation with biotite being concentrated towards the base of each layer. In some of the layers the biotite is concentrated in a thin selvedge at the base. The upper portion of the sheet is essentially biotite-free consisting of pegmatite-aplite layered granite, with irregular layers between 3 and 10 cm thick (fig. 16). As this type of layering has a more mafic base passing up to a more leucocratic top an obvious comparison can be made with rocks of basic composition which contain layers attributed to igneous processes which are graded both in terms of mineralogy and bulk rock chemistry (cf. Wager & Brown, 1967).

PETROGRAPHY

Granites

The granite types forming the Qôrqut granite complex are petrographically fairly uniform, the main difference being the variable biotite contents: 0.25–6% in the leucocratic granites, 2–12% in the grey biotite granites and 1–2% in the composite granites. Especially in the leucocratic granites in the lower part of the complex and in some of the composite granites the distribution of biotite is characteristically inhomogeneous (figs 4–6). This sometimes makes meaningful modal analysis difficult. Representative modes for the various granites, where these could be satisfactorily determined, are given in table 1. Quartz, plagioclase and K-feldspar occur in subequal amounts, and with few exceptions all samples plot in the granite field in the QAP triangle (Streckeisen, 1976).

Textures vary from hypidiomorphic granular (most common in the leucocratic granites) to allotriomorphic granular (mainly in the composite granites). Most of the granites are medium grained, with a range from 1–2 mm to 4–5 mm in individual samples. Some of the composite granites are coarse grained to locally pegmatitic. Where an order of crystallisation can be deduced, biotite appears to have been the first phase present in the melt. However, as discussed earlier, part of the biotite appears not to have crystallised from the melt, but to have been derived from the source rock. Subhedral plagioclase followed by quartz, or quartz followed by plagioclase, formed after biotite but preceded the crystallisation of microcline, which occurs largely interstitially and poikilitically encloses biotite, quartz and plagioclase. Some samples show aphyric granophyric textures with microcline enclosing areas of quartz which are in optical continuity suggesting simultaneous crystallisation of these two phases (fig. 17). In the composite granites the plagioclase is often anhedral, and appears to have crystallised simultaneously with the microcline.

The plagioclase varies in composition from An_{22} to An_{16}, frequently with rims of albite. Often it is weakly sericitised. The K-feldspar is a perthitic (string perthite)

Table 1. Modes of granites from the Qôrqut granite complex

	Quartz	Plagioclase	Microcline	Biotite	Epidote	White mica	Opaques	Others*	No. of points
195332(1)	32.1	29.1	35.5	2.6	-	-	-	0.8	1500
195337(1)	28.9	34.5	32.1	1.9	0.7	-	-	2.0	1500
195352(1)	32.2	30.5	34.3	2.3	-	-	-	0.6	1500
195360(1)	33.8	32.7	29.0	4.1	-	-	-	0.3	1500
195361(1)	27.3	45.9	23.4	1.3	1.1	1.1	-	0.1	1500
195362(1)	27.6	41.2	27.8	1.1	0.9	1.1	-	-	1506
195380(1)	25.3	31.2	36.8	3.5	1.7	1.0	0.4	0.3	2000
195385(1)	27.1	31.0	31.4	6.0	1.7	1.7	0.5	0.7	1500
195391(1)	30.9	33.0	35.6	0.3	0.4	-	0.3	-	1500
195304(2)	26.5	42.9	20.8	9.3	-	-	-	0.5	1500
195309(2)	30.9	32.3	30.4	4.9	0.9	0.3	-	0.4	1500
195317(2)	20.5	49.0	18.2	12.0	-	-	-	0.4	1500
195325(2)	34.0	36.0	24.1	4.7	0.6	-	-	0.6	1500
195329(2)	30.0	29.5	30.4	6.4	2.9	-	-	0.8	1500
195338(2)	31.5	40.4	19.5	6.8	0.9	-	-	2.0	1500
195339(2)	29.5	31.9	31.5	5.7	-	-	-	1.4	1500
195344(2)	26.1	35.2	32.0	4.3	1.8	-	-	0.8	1500
195350(2)	28.3	35.4	28.5	6.8	-	-	-	0.9	1500
195363(2)	26.7	37.4	26.8	6.3	0.6	1.7	-	0.7	1500
195364(2)	33.0	31.9	26.3	7.8	0.1	0.3	0.2	0.4	1500
195365(2)	24.9	32.6	33.3	6.6	2.1	0.1	-	0.5	2000
195370(2)	29.9	32.5	31.3	4.8	0.9	0.4	0.2	0.1	1510
195372(2)	28.1	30.2	35.1	3.7	0.9	0.8	0.7	0.5	1500
195374(2)	26.8	30.7	34.8	7.0	0.1	0.1	0.1	0.4	1000
195381(2)	21.6	36.5	30.7	9.0	1.4	0.5	0.2	0.2	2000
195382(2)	26.8	31.4	34.9	5.4	0.5	0.2	0.7	0.2	1500
195390(2)	29.5	35.0	23.1	7.4	0.7	3.2	-	1.1	1500
195396(2)	25.7	33.4	33.8	5.1	1.1	-	0.1	0.7	1500
195398(2)	36.2	29.3	29.5	3.8	0.3	0.8	-	0.1	1500
195359(3)	32.5	30.6	34.0	1.1	1.1	-	-	0.7	1500
195377(3)	32.0	26.0	39.1	1.5	-	-	1.0	0.3	1000
195397(3)	33.9	34.5	27.5	1.9	1.6	-	0.1	0.7	1500

* Others include allanite, zircon, apatite and sphene.
Numbers in brackets refer to the granite groups to which each sample is assigned.

microcline. Especially in the leucocratic granite it commonly shows bimodal grain size distributions, occurring both as anhedral, equant, medium-sized and as coarse anhedral crystals. The biotite, with pleochroism α = greyish yellow to straw, $\beta = \gamma$ = olive green to green brown, is often embayed along cleavage edges (fig. 18) and appears to have undergone re-equilibration with the melt. Common accessory minerals are allanite, apatite, zircon, magnetite and, more rarely, sphene. Late replacive epidote and white mica occur locally in the leucocratic granite.

Many of the investigated samples contain myrmekite. Most commonly this is a rim myrmekite within marginal albitic rims of plagioclase. In the grey biotite granite, however, two other types of myrmekite also occur: bulbous replacive myr-

Fig. 17. GGU 195320. Aphyric granophyric texture in microcline containing optically continuous quartz grains. Cross polarised light.

mekite and intergranular myrmekite. The rim and intergranular types have been attributed by Philips (1980) to diffusion redistribution of the components of potassium feldspar, whereas the bulbous myrmekites are attributed to intergranular introduction of sodium and calcium and the subsequent removal of potassium. The myrmekites within the grey biotite granites are, therefore, polygenetic.

A spotted texture (fig. 13) occurs sporadically in the grey biotite granites. The spots often have opaque cores which are primarily magnetite but, in one example (195344), there is a partial rim of ilmenite (see table 2). The biotite within these eye-like structures is distinct from the biotite distributed throughout the rock, being generally more cloudy, inclusion-free and having a very distinct pleochroism (α = pale yellow brown, $\beta = \gamma$ = dark greyish brown). In sample 195345, biotite + epidote clots occur which show no evidence of an opaque core. However, the biotites in the clots within this specimen are morphologically distinct from the biotites in clots from other rocks; the individual grains are considerably larger, and are chemically similar to those in the matrix. Three possible origins for these textures (fig. 13) might be considered. First, some of the spots could have formed as a result of derivation of magnetite xenocrysts from Amîtsoq gneisses during partial melting, since similar magnetite-cored felsic aggregates are present in some of the gneissic enclaves. Second, all of the varieties could be formed wholly as a result of magmatic processes within the granite, although in this case the magnetite-cored aggregates in the Amîtsoq gneiss enclaves become difficult to explain. Third, it is conceivable that some of the spots are a late-stage replacement phenomenon (cf. Brown *et al.*, 1972).

Within the grey biotite granites there is also a number of examples which contain aggregates of biotite, plagioclase, microcline or quartz. The biotite in these specimens is morphologically distinct from those in the eye-like structures being larger

Table 2. Representative microprobe analyses of opaque minerals from granites of the Qôrqut granite complex

	magnetites							ilmenites	
	195337	195385	195391	195308	195344		195350	195344	195363
SiO_2	1.27	1.20	0.74	0.35	0.22	0.20	0.50	0.51	0.68
TiO_2	nd	nd	nd	0.16	0.23	nd	nd	51.8	49.6
Al_2O_3	nd	0.47	0.31	nd	nd	nd	nd	nd	0.27
Cr_2O_3	nd	0.21	nd	nd	nd	nd	0.17	nd	nd
V_2O_5	nd	nd	nd	nd	0.22	0.29	nd	0.33	nd
$Fe_2O_3^*$	69.08	68.70	67.89	67.92	68.40	68.00	67.66	-	-
FeO	30.89	30.80	30.33	30.77	30.99	30.83	29.93	43.0†	44.8†
NiO	nd	0.23	nd	nd	nd	nd	nd	nd	nd
MnO	nd	nd	nd	nd	nd	nd	nd	4.06	1.76
CoO	1.05	1.15	0.97	nd	nd	nd	0.92	nd	0.48
	102.29	102.76	100.24	99.20	100.06	99.32	99.18	99.70	99.79
Cations to 32(0)								*Cations to 6(0)*	
Si	0.379	0.356	0.226	0.108	0.068	0.062	0.155	0.026	0.035
Ti	-	-	-	0.037	0.053	-	-	1.969	1.933
Al	-	0.164	0.112	-	-	-	-	-	0.016
Cr	-	0.049	-	-	-	-	0.042	-	-
V	-	-	-	-	0.045	0.059	-	0.013	-
Fe^{3+}	15.519	15.333	15.599	15.827	15.796	15.833	15.766	-	-
Fe^{2+}	7.712	7.640	7.745	7.968	7.953	7.978	7.751	1.816	1.941
Ni	-	0.055	-	-	-	-	-	-	-
Mn	-	-	-	-	-	-	-	0.174	0.077
Co	0.251	0.273	0.237	-	-	-	0.228	-	0.028

* ΣFe computed as FeO. Fe_2O_3 calculated from the total FeO assuming spinel stoichiometry of $R^{2+}R_2^{3+}O_4$.
nd Not detected, other elements sought but not found were Mg and Ca.
† All Fe expressed as FeO.

in grain size, having sub-parallel alignment and no associated magnetite. These larger crystals may be either the products of early crystallisation or they may be derived during partial melting.

Migmatites

Most of the country rock gneisses that occur as rafts and inclusions in the Qôrqut granite complex are unaffected by their inclusion in the granite. However, in the lower zone of the complex (pl. 1, fig. 2) it is possible to trace a progressive change in gneissic enclaves from unmodified biotite gneisses through metatexite into inhomogeneous leucocratic granites (inhomogeneous diatexites) over a distance of less than one metre. Petrographic study of these modified gneisses, here referred to as migmatites, reveals textures of both metamorphic and igneous origin (cf. Johannes & Gupta, 1982).

Metamorphic textures

In the zones where metamorphic textures are dominant the rocks display two distinct compositional layers: biotite-rich layers in which the micas are aligned sub-

Fig. 18. GGU 195373. Photomicrograph of an optically continuous biotite showing evidence for instability. Note the ragged terminations partly controlled by the 001 cleavage planes and embayments. Opaque dust and small remnants indicate the former extent of the grain. Width 1.5 mm plane light.

parallel and felsic layers in which quartz and plagioclase are the dominant phases and granoblastic polygonal textures are prevalent.

Biotite-rich layers

Within these layers the biotites have a sub-parallel alignment and in some cases enclose augen composed of felsic phases. These augen structures often contain microcline whereas microcline is virtually absent from the remainder of the rock, including the more homogeneous granitic portions. The cleavage ends of the biotites are frequently embayed where they are adjacent to either the homogeneous granitic material or the felsic augen. However, where the biotites are in contact with the felsic layers there is no evidence of reaction. Apart from the augen structures, the biotite layers also contain minor quartz, apatite, and allanite which is sometimes overgrown by epidote and zircon.

Felsic layers

In the felsic layers a granoblastic polygonal texture is usually developed between plagioclase grains and to a lesser extent with and between the co-existing quartz grains. Potassium feldspar is virtually absent from the felsic layers being restricted to small intergranular areas.

Igneous textures

Within the zones of more homogeneous granitic material the texture is typically hypidiomorphic granular with a medium grain size. Subhedral plagioclase (*c.* An_{20}) frequently shows marginal zonation to albite. Medium-grained, anhedral quartz occurs as well as larger crystals, up to 5 mm in diameter, which poikilitically enclose subhedral plagioclase. The quartz grains often show scalloped grain boundaries and microcline occurs only sporadically as small interstitial areas.

Within the granitic portion of the metatexites the biotite usually has two modes of occurrence. First, as discrete grains which are homogeneously distributed throughout, and second, as clusters of biotites which retain a sub-parallel alignment. These clusters are interpreted as being derived from the biotite-rich layers of the metatexite. In some outcrops of migmatite the derivation of granitic material from the original gneiss can be demonstrated beyond reasonable doubt, whereas in other examples the relationship is less obvious and the granitic material may have been introduced.

MINERAL CHEMISTRY

Mineral analyses were carried out on the energy dispersive electron microprobe at the Department of Earth Sciences, University of Cambridge. Operating conditions and data reduction techniques are explained in Sweatman & Long (1969) and Statham (1976). Mineral analyses were obtained from 22 samples: four leucocratic granites, thirteen grey biotite granites, two composite granites and three migmatites. The composition of biotite was analysed in each of the samples. The compositions of plagioclase and the perthitic alkali feldspar were examined in a representative selection. Opaque minerals were examined in order to establish their origins and to investigate their relationships with the biotite + epidote + opaque clots. The secondary phases such as epidote and white mica were analysed in a few of the samples. The other components of some of the clots and eye-like structures, sphene, garnet and green biotite were also analysed. Some mineral data are presented in tables 2, 3 & 4.

Biotite

In the migmatites biotites were analysed from both the biotite-rich layers and the dispersed grains within the granitic portions. These data are compared on an AFM plot in fig. 19a. The analyses of the biotites from the migmatites fall in two groups, one at a slightly higher Fe/(Fe+Mg), which also has higher tetrahedral Al (from sample 195393) whilst those with a slightly more iron-rich composition were obtained from samples 195383 and 195392. Thus within any one migmatite specimen there is no chemical difference between the biotites within the biotite-rich layers and those occurring as dispersed grains in the granitic portions. This supports the hypothesis that at least some of the biotites in the granite are relics.

Biotite analyses from the leucocratic granites show a range in composition of Fe/(Fe+Mg) from 75 to 61 and tetrahedral Al from 2.51 to 2.34, which at the more magnesium-rich end is close to the composition of the biotites from the migmatite samples 195383 and 195392 (fig. 19a). These chemical data support the field observations that at least some of the biotites occurring in the leucocratic granites may

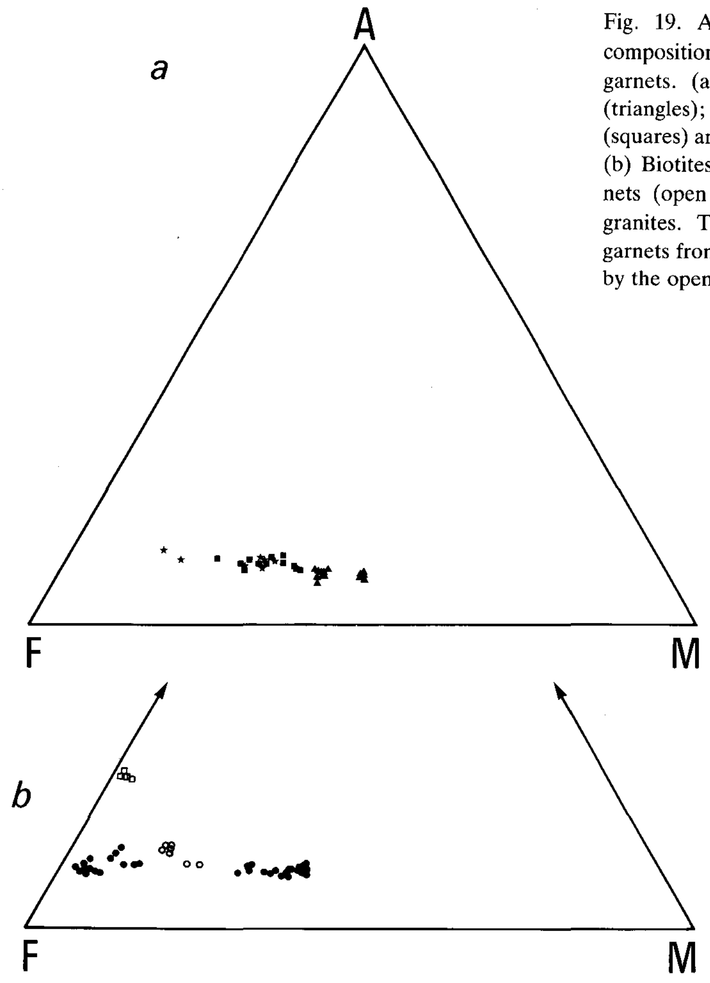

Fig. 19. AFM diagrams showing the composition of the analysed biotites and garnets. (a) Biotites from migmatites (triangles); leucocratic granites (squares) and composite granites (stars). (b) Biotites (circles and dots) and garnets (open squares) from grey biotite granites. The co-existing biotites and garnets from GGU 195398 are indicated by the open symbols.

have been derived from the migmatites and that these biotites may have subsequently undergone re-equilibration towards more iron-rich compositions.

Within the grey biotite granites biotite crystals occur either as discrete grains or in intergrowths with epidote and white mica. These differences in mode of occurrence are reflected in the mineral chemistry. The dispersed biotite grains show a variation in ratio of ionic Fe/(Fe+Mg) from 70 to 59, and tetrahedral Al from 2.53 to 2.31. The magnesian end of this trend is close to the composition of the biotites found in the migmatites and therefore, like those in the leucocratic granites, could in part be derived from a gneissic parent. There is some textural evidence to support this hypothesis, but the origin of the biotites in the grey biotite granites cannot be demonstrated in the field.

Table 3. Representative microprobe analyses of biotites from the Qôrqut granite complex

	LEUCOCRATIC GRANITES						GREY BIOTITE GRANITES												COMPOSITE GRANITES		MIGMATITES				
	195337	195361		195385	195391		195304		195308			195309	195344		195352		195394		195316	195397	195383		195392		195393
SiO_2	36.69	37.77	36.49	37.03	36.75	36.14	37.47	37.86	33.56	37.07	35.59	35.87	33.14	37.10	34.02	36.27	36.32	34.89	35.69	36.40	36.34	37.13	37.04	37.45	38.09
TiO_2	2.80	2.07	2.04	2.23	2.89	3.08	2.74	2.83	2.82	1.85	2.12	2.03	3.18	1.39	1.70	1.77	1.94	2.36	2.65	2.09	2.27	2.30	2.24	2.18	1.87
Al_2O_3	16.62	17.27	16.66	16.36	16.42	16.39	16.52	17.05	15.75	16.38	16.91	16.61	15.47	16.73	17.07	16.75	15.78	15.45	16.61	16.83	15.28	15.44	15.91	16.05	16.37
FeO*	26.78	25.38	25.95	23.44	23.72	25.92	22.80	22.39	34.02	22.61	30.59	25.72	34.65	22.45	33.81	23.85	26.70	34.56	24.21	24.24	21.94	22.79	22.07	22.28	19.02
MnO	0.52	0.18	0.26	0.24	0.15	0.14	0.16	0.19	0.43	0.24	0.21	0.33	0.32	0.15	0.17	0.26	0.14	0.16	nd	0.29	0.26	0.27	0.29	0.21	0.29
MgO	5.10	7.45	7.36	8.20	7.86	6.06	8.33	8.49	0.72	8.10	2.56	6.32	0.97	8.68	1.53	7.88	6.34	0.71	6.53	7.35	9.36	9.43	9.04	9.23	10.66
CoO	0.26	0.27	nd	0.38	0.23	0.18	0.26	0.25	nd	nd	nd	0.49	nd	nd	0.34	0.24	nd	nd	0.27	0.19	0.34	0.30	0.36	0.25	0.14
ZnO	nd	nd	nd	nd	nd	nd	nd	nd	0.44	nd	nd	nd	0.40	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.20
CaO	0.18	0.15	0.17	nd	0.16	0.12	0.10	0.20	nd	nd	nd	nd	nd	nd	nd	nd	0.13	nd	0.11	0.15	0.13	nd	0.13	0.21	0.11
Na_2O	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.42	nd	nd	nd
K_2O	9.10	9.15	9.21	9.61	9.24	9.34	9.59	9.50	9.23	9.73	9.58	9.65	8.84	9.45	9.05	9.62	9.17	9.17	9.37	9.32	9.25	9.58	9.58	9.41	10.00
	98.05	99.69	98.14	97.49	97.24	97.37	97.94	98.76	96.97	95.98	97.56	97.02	96.97	95.95	97.69	96.64	96.52	97.30	95.44	96.86	95.17	97.80†	96.66	97.27	96.75
Cations to 22(0)																									
Si	5.62	5.62	5.56	5.63	5.59	5.56	5.64	5.62	5.46	5.69	5.60	5.56	5.40	5.68	5.44	5.58	5.65	5.62	5.57	5.58	5.63	5.62	5.65	5.66	5.71
Al^{iv}	2.38	2.38	2.44	2.37	2.41	2.44	2.37	2.38	2.54	2.31	2.40	2.44	2.60	2.32	2.56	2.42	2.35	2.38	2.43	2.42	2.37	2.38	2.35	2.34	2.29
Al^{vi}	0.62	0.65	0.55	0.56	0.54	0.54	0.56	0.61	0.48	0.66	0.74	0.60	0.37	0.70	0.66	0.61	0.55	0.55	0.62	0.63	0.43	0.38	0.51	0.52	0.60
Ti	0.32	0.23	0.23	0.26	0.33	0.36	0.31	0.32	0.35	0.21	0.25	0.24	0.29	0.16	0.20	0.20	0.23	0.29	0.31	0.24	0.27	0.26	0.26	0.25	0.21
Fe	3.43	3.16	3.31	2.98	3.02	3.34	2.87	2.78	4.63	2.90	4.02	3.34	4.72	2.87	4.52	3.07	3.48	4.66	3.16	3.11	2.84	2.89	2.81	2.82	2.38
Mn	0.07	0.02	0.03	0.08	0.02	0.02	0.02	0.02	0.06	0.03	0.03	0.04	0.04	0.02	0.02	0.03	0.02	0.02	-	0.04	0.03	0.04	0.04	0.03	0.04
Mg	1.17	1.65	1.67	1.86	1.74	1.39	1.86	1.88	0.17	1.85	0.60	1.46	0.23	1.98	0.36	1.81	1.47	0.17	1.52	1.70	2.16	2.13	2.05	2.09	2.38
Co	0.03	0.03	-	0.05	0.03	0.02	0.03	0.03	-	-	-	0.06	-	-	0.04	0.03	-	-	0.03	0.02	0.04	0.04	0.04	0.03	0.02
Zn	-	-	-	-	-	-	-	-	0.05	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	0.02
Ca	0.03	0.03	0.03	-	0.03	0.02	0.02	0.03	-	-	-	-	-	-	-	-	0.02	-	0.02	0.02	0.02	-	0.02	0.03	0.02
Na	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.12	-	-	-
K	1.78	1.74	1.79	1.86	1.79	1.83	1.84	1.80	1.92	1.91	1.92	1.91	1.84	1.85	1.85	1.89	1.82	1.88	1.87	1.82	1.83	1.85	1.87	1.81	1.91
Mg/Mg+Fe	25.4	34.3	33.5	38.4	36.6	29.4	39.3	40.3	3.5	39.0	13.0	30.4	4.7	40.8	7.4	37.1	29.7	3.5	32.5	35.3	43.2	42.4	42.2	42.6	50.0

* All Fe as FeO.

† Includes 0.14% Cr_2O_3, Cr = 0.02.

nd Not detected, other elements sought were V, Cr and Ni.

Table 4. Representative microprobe analyses of the feldspars from the migmatites and granites

	MIGMATITES						LEUCOCRATIC GRANITES						GREY BIOTITE GRANITES							COMPOSITE GRANITES			
	195383		195392		195393		195337		195385		195391		195304	195345			195350			195316		195397	
	†P	P	P	P	P	P	K	Ab	K	Ab	P	K	K	P	K	Ab	Ab	K	P	P	K	P	K
SiO_2	63.2	62.6	63.0	63.3	60.9	63.3	65.6	65.4	66.0	67.2	63.1	64.9	65.3	62.5	65.3	69.0	66.4	63.8	63.2	64.8	64.5	63.7	64.9
Al_2O_3	22.7	23.4	22.8	23.1	24.0	23.2	18.4	21.6	18.4	20.5	22.7	18.0	18.5	23.1	18.4	19.1	18.9	18.1	22.7	21.7	18.0	22.6	18.4
CaO	4.10	4.57	4.27	4.33	5.93	4.66	nd	2.36	nd	1.09	3.80	nd	nd	4.59	nd	0.24	0.13	nd	4.13	3.11	nd	3.78	nd
Na_2O	9.18	9.14	8.94	8.69	8.35	8.93	nd	10.3	4.13	11.5	9.28	nd	0.43	9.06	0.31	10.8	10.1	0.39	9.35	9.81	nd	9.39	nd
K_2O	0.21	0.08	0.14	0.10	0.13	0.16	16.4	0.22	11.1	nd	0.16	16.1	16.1	0.11	15.9	1.35	2.06	15.6	0.12	0.07	15.9	nd	16.1
FeO*	0.18	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
TiO_2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.17	nd	0.18	nd	nd	0.13	nd	nd	nd	nd	nd
	97.57	99.79	99.05	99.52	99.31	100.25	100.4	99.88	99.53	100.29	99.04	99.0	100.50	99.36	100.19	100.49	97.59	98.02	99.50	99.49	98.4	99.47	99.4
Cations to 32(0)																							
Si	11.226	11.101	11.224	11.217	10.898	11.172	12.055	11.527	12.023	11.756	11.245	12.080	11.991	11.139	12.022	12.049	11.977	11.999	11.232	11.465	12.075	11.288	12.039
Al	4.757	4.899	4.783	8.827	5.069	4.821	3.979	4.484	3.953	4.228	4.773	3.957	4.005	4.845	3.991	3.922	4.019	4.014	4.749	4.528	3.969	4.728	4.014
Ti	-	-	-	-	-	-	-	-	-	-	-	-	0.023	-	0.024	-	-	0.019	-	-	-	-	-
Fe^{2+}	0.027	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca	0.780	0.869	0.815	0.821	1.137	0.881	-	0.445	-	0.204	0.726	-	-	0.877	-	0.044	0.024	-	0.787	0.589	-	0.718	-
Na	3.162	3.145	3.089	2.985	2.896	3.052	-	3.502	1.460	3.883	3.209	-	0.155	3.130	0.109	3.648	3.512	0.142	3.221	3.362	-	3.226	-
K	0.048	0.017	0.032	0.022	0.028	0.036	3.841	0.050	2.590	-	0.037	3.809	3.773	0.024	3.731	0.300	0.473	3.745	0.027	0.016	3.793	-	3.802
Ab	79.3	78.0	78.5	78.0	71.3	76.9	0	87.6	36.0	95.0	80.8	0	3.9	77.7	2.8	91.4	87.6	3.7	79.8	84.7	0	81.8	0
An	19.5	21.6	20.7	21.5	28.0	22.2	0	11.1	0	5.0	18.3	0	0	21.8	0	1.1	0.6	0	19.5	14.8	0	18.2	0
Or	1.2	0.4	0.8	0.6	0.7	0.9	100	1.2	64.0	0	0.9	100	96.1	0.6	97.2	7.5	11.8	96.3	0.7	0.4	100	0	100

* All Fe calculated as FeO.
† P = Plagioclase; Ab = Albite; K = Alkali feldspar (microcline).
nd Not detected. Other elements sought were Mg, Mn, Cr and Ni, but were all below detection limit.

The most iron-rich biotites occur as overgrowths on opaque minerals in the spotted texture, or associated with clots of epidote and white mica. Their origin is attributed to a reaction between magnetite and granitic liquid. One specimen of grey biotite granite is garnet-bearing (195398); it has replacive biotites which are compositionally intermediate between the dispersed grains and those occurring as overgrowths on opaque minerals (fig. 19b).

Biotites from the various composite granites are much more similar to each other and reveal a smaller range in composition from Fe/(Fe+Mg) 70 to 65. Most of the granites studied in thin section show epidote and white mica replacing biotite. The biotites which are replaced by these minerals commonly have an intermediate chemistry (fig. 19b) and have undergone reaction in the solid state rather than with a granitic liquid.

Plagioclase

For all the granites the composition of the plagioclase feldspar is dominantly oligoclase, although any one group of granites may show variation within this compositional range. Zoning to more sodic compositions is also present. For example, in a leucocratic granite (195385) oligoclase (An_{20}) with a marginal albite (An_5) rim was analysed whilst the composition of most of the plagioclase is confined to the range An_{20} to An_{18}. Analyses of plagioclases from the grey biotite granites and the composite granites all fall in the compositional range of oligoclase, and normal zoning has also been observed in several specimens (e.g. 195397, table 4). Solution of the orthoclase molecule within plagioclase is limited (fig. 20a, b).

In the migmatites the plagioclases in both the metamorphic and the igneous layers have compositions in the middle of the oligoclase range. However, in sample 195393 plagioclase occurring within an augen structure has a more calcic composition (An_{28}) than the plagioclase in the granitic portion (An_{22}).

Microcline perthites

In some instances string perthites are sufficiently well-developed to allow analysis, and their compositions are plotted in fig. 20c.

Opaque minerals

During petrographic study of the granites it was noted that the opaque minerals had two distinct modes of occurrence. Microprobe analysis (table 2) has demonstrated that the more common type, subhedral to euhedral grains up to 5 mm diameter, is magnetite, whilst the less common type, small anhedral grains usually enclosed within biotite and frequently rimmed with sphene, is ilmenite. In sample 195344 a large magnetite grain is partially rimmed by ilmenite.

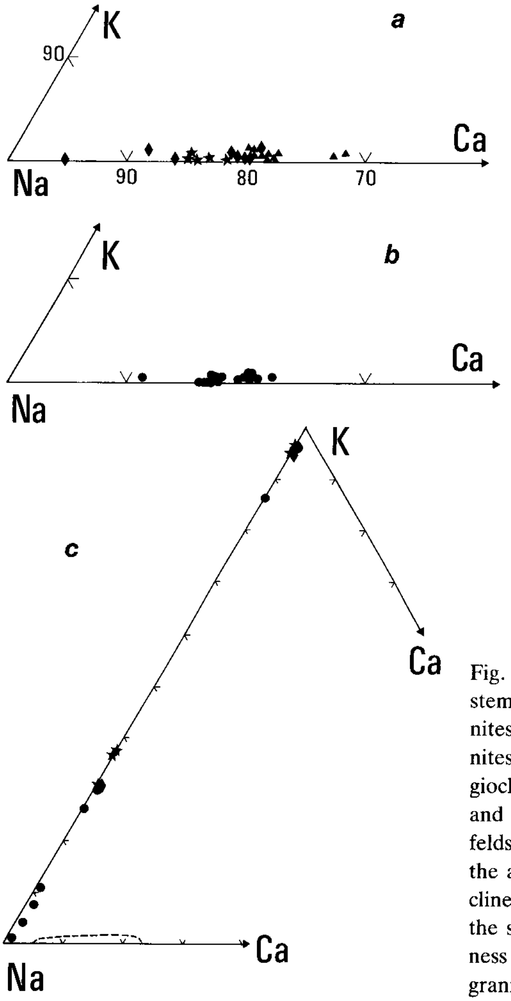

Fig. 20. Composition of the analysed feldspars in the system Na-Ca-K. Symbols: diamonds = leucocratic granites; dots = grey biotite granites; stars = composite granites; triangles = migmatites. (a) Composition of the plagioclase feldspars in the leucocratic, composite granites and the migmatites. (b) Composition of the plagioclase feldspars in the grey biotite granites. (c) Composition of the alkali feldspars and the perthite strings from microcline. Some of the analyses clearly represent mixtures of the sodium and potassium feldspars due to the narrowness of the perthite lamellae. Field of plagioclase in the granites is enclosed by dashes.

GEOCHEMISTRY

Analytical techniques. The major element composition of a representative suite of the samples collected during 1978 and 1979 has been determined utilising the following analytical techniques. A Perkin-Elmer 460 atomic absorption spectrophotometer with a flame source was used to determine all elements except FeO and P_2O_5. Ferrous iron was determined by the metavanadate method of Wilson (1955) and phosphorous was analysed using UV spectrophotometry (Riley, 1958). All analyses were carried out at Oxford Polytechnic by WTP, and a detailed discussion of sampling and analytical techniques together with a statistical study of the data may be found in Perkins (1984). A study of the precision and accuracy of the analytical data using sample 195359, an in-house standard SH4, and international standards, is available on request.

Major elements

Major element concentrations together with calculated mesonormative mineralogies (Barth, 1955) are presented for 19 samples selected from a set of 59 representative samples of the Qôrqut granite complex from the area north of Qôrqut (table 5). The Barth mesonorm was selected in preference to either the CIPW or the Niggli molecular norms because the mesonorm provides the option of assigning the ferro-magnesian molecular proportions to biotite and amphibole, rather than to pyroxene, as appropriate. In the rocks from the Qôrqut granite complex biotite is the only ferro-magnesian mineral phase to appear in the mesonorm (table 5). This is in agreement with the observed petrography since amphibole has not been recorded in any of our samples, nor has it been reported from any of the other studies of the Qôrqut granite complex (Friend & Hall, 1977; McGregor, 1973; Moorbath *et al.*, 1981). Additionally a differentiation index (DI), computed as the sum of the components Qz+Ab+Or, is given.

The major element concentrations of all 59 samples analysed are plotted against DI in fig. 21. It may be seen that analyses of samples from the leucocratic granites and the composite granites plot exclusively at high values of DI, while the migmatitic samples plot at low values of DI. The samples from the grey biotite granites span most of the range between these two extremes. For all the major elements the suite defines more or less linear trends on the diagram, with the notable exception of the migmatites on the following plots: TiO_2, Al_2O_3, CaO, Na_2O and K_2O vs. DI. The explanation for this deviation lies in the method of the mesonorm calculation and hence the computation of the index of differentiation. A low DI value is not simply a reflection of low SiO_2 concentration. In terms of SiO_2 content the migmatites would, if they fell on a linear trend, have a DI of *c.* 85 rather than 75. However, a combination of relatively high MgO + FeO and low K_2O results in high mesonormative biotite being formed at the expense of orthoclase, and hence low DI values. This assignment of molecular K_2O to biotite as opposed to orthoclase receives support from the petrographic study which revealed very low modal percentages of K-feldspar in the migmatitic rocks.

All of the major elements with the exception of Na_2O and K_2O decrease with increasing DI. K_2O increases consistently up to a DI of about 86 to which point Na_2O decreases. From DI 86 to 95 the trend of both elements flattens and remains essentially constant. These trends reflect the overall decrease in the proportion of mafic minerals with increasing DI.

The data for the samples are plotted in the granite system of Winkler *et al.* (1975) and Winkler (1979) for the condition P_{H_2O} = 5 kbar (fig. 22). This value is chosen because it is the lowest P_{H_2O} for which there are good experimental data. There is no initial implication that these were the conditions under which the Qôrqut granite complex evolved, although the P_{H_2O} is unlikely to have been in excess of 5 kbar. In fig. 22a, all of the granite data plot within the projection of the 685°C iso-

Table 5. Representative major element geochemistry and Barth mesonormative components for the Qôrqut granite complex

	195360	195361	195380	195378	195383	195392	195307	195311	195325	195339	195345	195352	195353	195357	195382	195390	195316	195334	195359
	*1	1	1	M	M	M	2	2	2	2	2	2	2	2	2	3	3	3	3
SiO_2	74.10	72.72	75.10	72.84	70.41	71.28	66.55	69.88	74.88	72.38	72.66	75.80	74.11	73.26	71.50	71.51	77.31	74.97	75.59
TiO_2	0.24	0.19	0.11	0.22	0.48	0.48	0.40	0.33	0.22	0.17	0.27	0.15	0.16	0.26	0.19	0.40	0.10	0.07	0.14
Al_2O	13.35	14.65	12.88	15.25	14.59	14.51	17.62	15.10	13.37	14.11	14.05	13.42	14.05	14.17	14.05	14.63	13.92	13.28	13.32
Fe_2O	0.17	0.12	0.55	0.27	0.84	0.53	0.56	0.39	0.22	0.21	0.16	0.02	0.11	0.33	0.45	0.49	0.00	0.29	0.05
FeO	1.20	1.11	0.79	1.41	2.80	2.68	1.93	1.97	1.07	1.33	1.43	0.57	0.91	1.33	1.35	1.54	0.67	0.41	0.62
MnO	0.02	0.02	0.02	0.03	0.06	0.06	0.03	0.03	0.04	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.01	0.02
MgO	0.34	0.28	0.24	0.77	1.60	1.18	0.97	0.79	0.29	0.50	0.53	0.12	0.30	0.39	0.40	0.68	0.05	0.07	0.10
CaO	1.42	1.61	1.13	2.81	2.59	2.57	2.62	1.91	1.29	1.75	1.65	0.97	1.26	1.26	1.43	1.84	1.32	1.01	1.09
Na_2O	3.10	3.49	2.96	4.78	4.51	4.16	5.04	4.70	3.66	3.98	3.55	3.34	3.61	3.69	3.19	3.46	4.06	3.86	3.31
K_2O	4.59	4.74	5.50	1.17	1.86	1.79	2.85	4.05	4.39	5.19	4.78	5.38	5.03	5.03	5.27	4.47	3.51	5.14	5.05
P_2O_5	0.05	0.03	0.08	0.07	0.11	0.15	0.14	0.10	0.05	0.08	0.04	0.02	0.08	0.01	0.10	0.11	0.01	0.01	0.03
	98.58	98.96	99.36	99.62	99.85	99.39	98.73	99.25	99.48	99.73	99.14	99.80	99.63	99.75	97.95	99.16	100.96	99.12	99.32
Barth mesonormative components																			
Q	34.05	29.26	32.81	32.51	29.98	33.37	19.85	21.85	32.26	24.63	28.69	31.72	29.47	28.10	28.76	29.14	34.69	29.09	32.84
C	1.26	1.29	0.37	1.60	1.45	2.25	2.53	0.19	0.72	-	0.53	0.64	0.85	0.79	1.10	1.70	1.30	-	0.75
Or	25.53	26.41	31.84	3.46	4.12	4.70	12.57	19.84	24.30	28.01	25.63	31.10	28.17	27.50	29.57	23.48	19.70	30.25	29.29
Ab	28.59	31.87	27.11	43.16	40.72	37.89	45.46	42.39	33.33	35.90	32.36	30.31	32.73	33.42	29.50	31.57	36.37	35.14	30.22
An	6.04	7.25	4.79	12.79	10.52	10.25	10.74	7.71	5.38	5.33	7.09	4.20	5.22	5.33	5.95	7.13	6.12	3.78	4.80
Wo	-	-	-	-	-	-	-	-	-	0.91	-	-	-	-	-	-	-	0.39	-
Mt	0.18	0.13	0.59	0.28	0.88	0.56	0.59	0.41	0.23	0.22	0.17	0.02	0.12	0.35	0.48	0.52	-	0.31	0.05
Bi	3.71	3.31	2.09	5.59	11.08	9.65	7.13	6.71	3.20	4.48	4.87	1.64	2.93	3.95	4.00	5.38	1.59	0.87	1.67
Tn	0.52	0.40	0.23	0.46	1.01	1.02	0.84	0.69	0.47	0.36	0.57	0.32	0.34	0.55	0.41	0.85	0.21	0.15	0.30
Ap	0.11	0.06	0.17	0.15	0.23	0.32	0.29	0.21	0.11	0.17	0.08	0.04	0.17	0.02	0.22	0.23	0.02	0.02	0.06
D.I.	88.18	87.55	91.75	79.12	74.82	75.96	77.88	84.08	89.89	88.54	86.68	93.14	90.37	89.01	87.83	84.19	90.76	94.48	92.36

* The granite group to which each sample belongs: 1 = leucocratic granites; 2 = grey biotite granites; 3 = composite granites; M = migmatites.

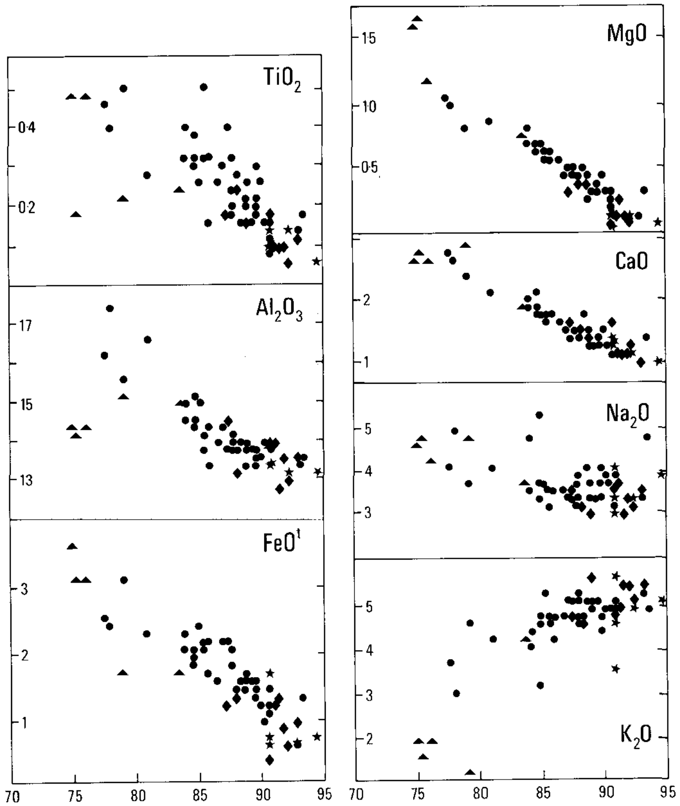

Fig. 21. Selected major elements of the analysed granites from the Qôrqut granite complex in the area north of Qôrqut plotted against DI (normative Qz+Ab+Or). Symbols as for fig. 22.

therm and close to the cotectic curve Pl+Af+Qz+H_2O for P_{H_2O} = 5 kbar. Those points shown in open symbols plot below but close to the cotectic surfaces Qz+Pl+L+V and Af+Pl+L+V. Those granites which plot in the plagioclase volume lie close to the cotectic curve as constrained by their An content. The migmatites, however, are clearly separated plotting close to the 700°C isotherm and are obviously not near the cotectic surface. The trend of the data points across the projection form Qz onto the Ab–An–Or face (fig. 22b) follows the trend defined by the data of Brown *et al.* (1981) which included samples from outside the current area of study. Again the migmatites are clearly separated from the granite data points. In this system the data points for the granites do not deviate significantly from the cotectic surfaces quartz – plagioclase or plagioclase – alkali-feldspar with only a few samples plotting in the primary phase volume of potassium feldspar. However, the petrographic data for the samples in this study correspond with the data of Brown *et al.* (1981), which suggests that after biotite either quartz or plagioclase next appears and that potassium feldspar is later in the order of crys-

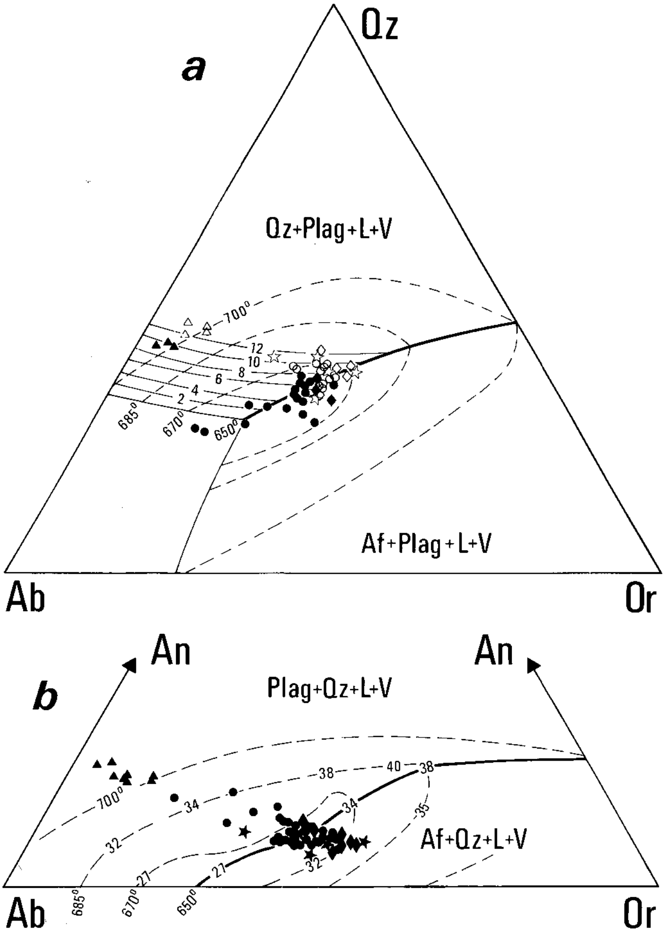

Fig. 22. Data for the Qôrqut granite complex plotted in the projections Qz–Ab–Or and Ab–An–Or from the granite system of Winkler (1979) and Winkler *et al.* (1975). Symbols: triangles = migmatites; diamonds = leucocratic granites; dots = grey biotite granites; stars = composite granites. (a) The projection Qz–Ab–Or for the condition $P_{(Total)} = P_{H_2O} = 5$ kbar. Solid symbols are those data points plotting in the plagioclase primary phase volume above the cotectic surfaces Af+Plag+L+V and Qz+Plag+L+V, open symbols plot below these surfaces. Isotherms for 670°C, 685°C and 700°C are indicated as dashed lines. Contours indicating the An content of liquid compositions are given as solid lines on the Qz+Plag+L+V cotectic surface. (b) The projection An–Ab–Or for the condition $P_{(Total)} = P_{H_2O} = 5$ kbar. The projection from Qz of the 670°C, 685°C and 700°C isotherms are shown together with Qz values of liquid compositions lying on the cotectic surfaces or along the cotectic curve formed by the intersection of the two cotectic surfaces.

tallisation. No samples of the granite show potassium feldspar to be early in this order. Lowering P_{H_2O}, to say 3 kbar, has the effect of expanding the plagioclase volume and reducing in size the potassium feldspar volume. Also, the quartz volume decreases slightly (Wyllie, 1977) which has the effect of causing more of the data points to plot in the plagioclase volume, thus conforming to the petrographic data. The implication of this is that at the time of crystallisation of the granite, P_{H_2O} must have been lower than 5 kbar.

CONCLUSIONS

The field relationships of the Qôrqut granite complex with the surrounding country rocks demonstrate that the complex forms a discrete lithological unit which may be clearly separated from both the earlier and the later geological lithologies of the Godthåbsfjord region. The field data presented here, together with the geochemical data, support the suggestion made previously that the granites forming the complex were produced by partial melting of earlier sialic crust (Brown & Friend, 1980a; Brown *et al.*, 1981; Moorbath *et al.*, 1981).

The granites forming the complex can be divided into three groups, broadly equating with the sequence in which they were intruded, although some overlap occurred. Evidence for overlap consists of the lobate nature of some of the contacts between granites of different groups and the fact that occasionally some granites from one group appear out of place in a sequence of intrusion. Turbulent flow appears to have taken place within the batches of granitic magma, and this mechanism is responsible for some of the types of layering observed. A tripartite division of the complex into lower, intermediate and upper zones may be recognised according to the proportions of the different groups of granites and country rocks present.

Pegmatite in the complex increases in abundance upwards and forms the dominant granite component in the upper zone. However, throughout the lower portions of the complex there is a significant volume of pegmatite which cannot be assigned unequivocally to any particular group.

The level of generation of the leucocratic granites was not very far below the present level of exposure, whilst the grey biotite granites were derived from somewhat deeper levels. The tectonic environment allowed the free upwards access of small batches of magma; thus the complex was intruded as sheets into country rocks which behaved in a brittle or semi-brittle manner. Although this must indicate a fairly high level of emplacement in the crust, no miarolitic cavities or true granophyric intergrowths have been found in the granites implying that their emplacement was not at very shallow depths.

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PLATE 1 1:50 000 scale geological map of the Qôrqut area.

Geological map of Qôrqut

by C. R. L. Friend

1:50 000