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The Hurry Inlet granite and related rocks of Liverpool Land, East Greenland

by

Kenneth Coe

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Abstract

The Hurry Inlet granite, a late Lower Palaeozoic mass was emplaced into a basement complex which had been metamorphosed and deformed in an earlier period of plutonism. The host rocks were brittle at the time of emplacement and the granite made space for itself in part by stoping. Contacts are frequently faulted. Internal faulting is of a similar kind showing that the final movement was of a rigid granite mass which rose to a very high crustal level and was soon unroofed, the debris from unroofing being itself affected by similar faulting.

The homogeneity of the mass is shown by petrography and chemistry and the chemistry indicates that it was generated at deep crustal levels.

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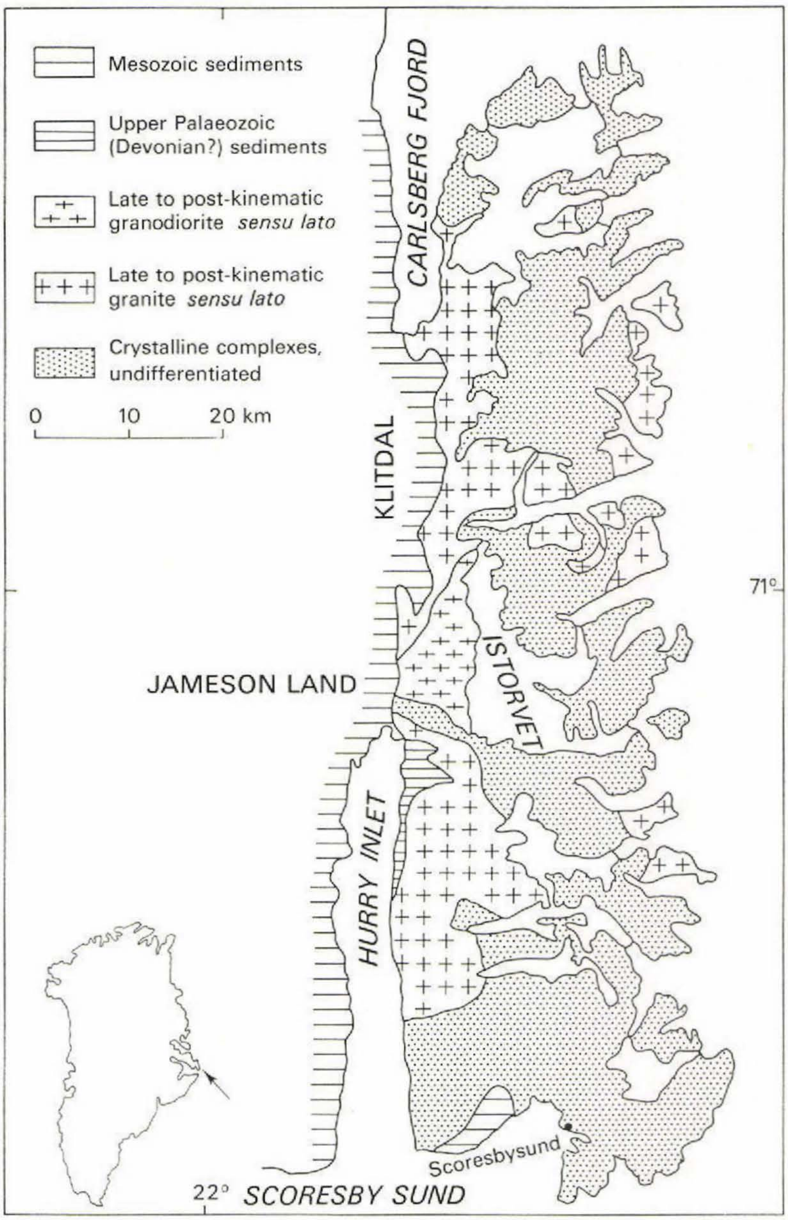

Fig. 1. Position of the Hurry Inlet granite in Liverpool Land.

INTRODUCTION

Mapping in Liverpool Land was carried out in the summers of 1969 and 1971 as part of the GGU programme in central East Greenland. Most of the area described in this paper was mapped by the author in 1969. The mapping of the northern part of the Hurry Inlet granite was completed in 1971, in which season N. Henriksen mapped an area east of Klitdal which included a similar granite mass. The extreme south of the Hurry Inlet granite was mapped by R. F. Cheeney in 1969 (fig. 1).

Previous work in the area was of variable assistance. Observations by Nathorst (1901) and Nordenskjöld (1907) were superficial, but Kranck's general survey (1935) proved very valuable, and Bütler (1957) using a more modern approach made a valuable contribution, but restricted himself to the younger non-metamorphosed sediments. This younger group has also been mentioned but in no great detail by Callomon *et al.* (1972) and the significance of faulting in these sediments has been demonstrated (Coe, 1971).

A preliminary account of the geology of Liverpool Land has been published (Coe & Cheeney, 1972). This describes a sequence of stratified metamorphic rocks of varying origin and composition, ranging from granitic augen gneisses and amphibolites probably of igneous parentage, to quartzites, marbles and biotite-rich garnet gneiss certainly of sedimentary origin. A series of granitic rocks is very abundantly developed and this ranges in temporal position from pre- to post-kinematic and in composition from leucocratic mica granite *sensu stricto* to mesocratic monzo-diorite. Overall the relations of the granitic rocks to the deformation are complicated but it is hoped that a programme of isotope work, currently in hand, will help to elucidate problems. So far, only two dates are available, 434 ± 10 m.y. (RB/Sr on biotite) for the Hurry Inlet granite (Hansen & Steiger, 1971) and 1183 ± 55 m.y. (K/Ar on hornblende from a gneiss) (Hansen, Frick & Steiger, 1973). The significance of the time gap between these two results is discussed below.

Within the gneiss series there is an important thrust which can be traced over a large area in central Liverpool Land. In terms of the development of the gneisses this was a very late event, post-dating the granites west of Istorvet where it (or a very similar fault) brings together two granite masses, both known to be late.

Post-granite rocks are of three categories: first there is a sequence of non-metamorphosed clastic sediments clearly derived principally from the breakdown of the granites and believed to be Upper Palaeozoic in age; secondly, sediments of Mesozoic age which correlate with strata of Jameson Land (Surlyk & Birkelund, 1972);

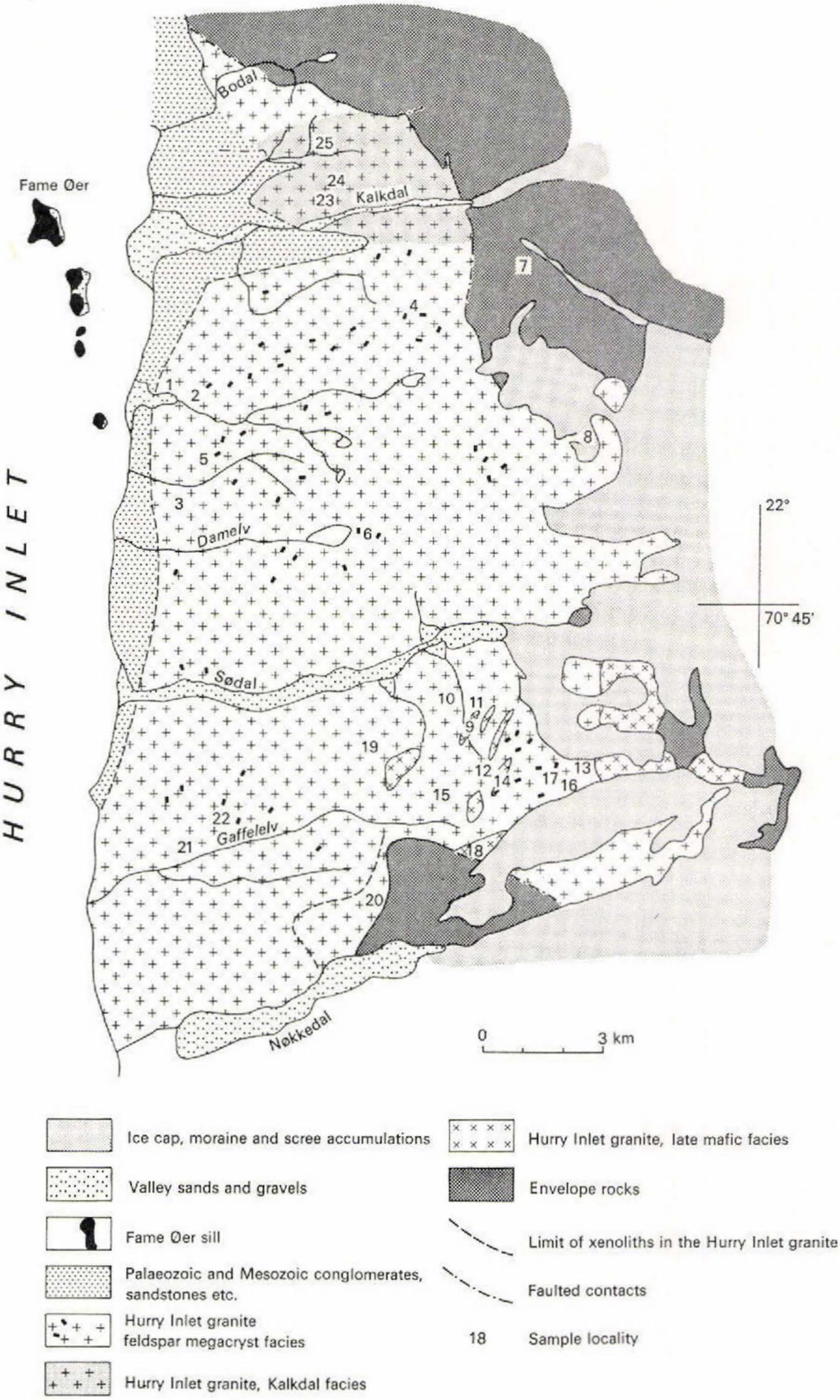

Fig. 2. Geology of the Hurry Inlet granite and its envelope rocks. The 25 samples used in the petrographic study are marked.

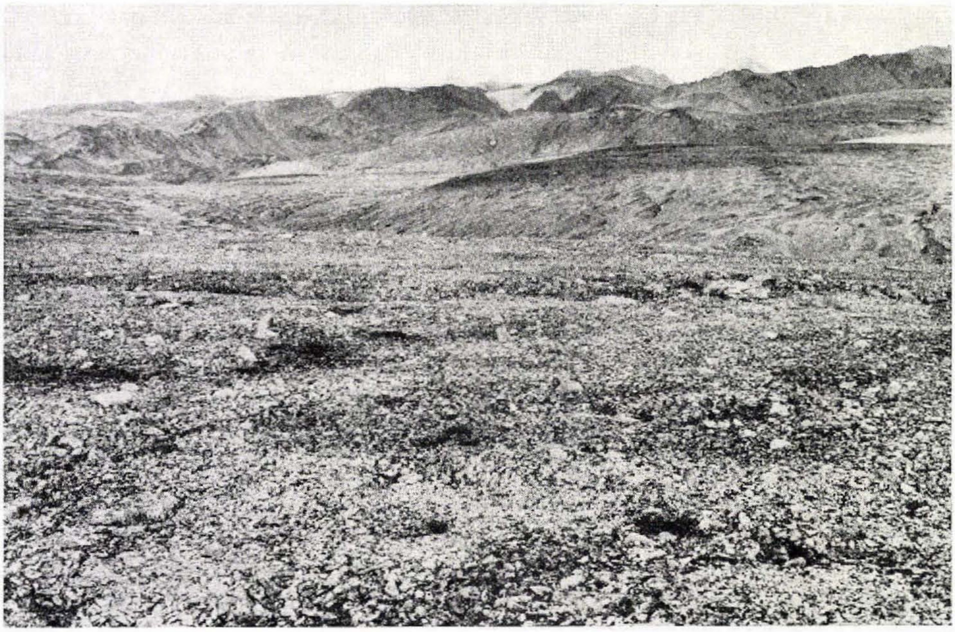

Fig. 3. Felsenmeer over lower slopes of the Hurry Inlet granite.

and thirdly, minor intrusions of lamprophyric and basaltic aspect which are late Cretaceous or Tertiary in age.

The present contribution is concerned with what on field evidence is considered to be the youngest member of the granite sequence, its enveloping rocks and the sedimentary rocks derived from its unroofing. The genesis of these suites collectively seem to constitute a cycle but it will be seen that a much closer relationship exists between granite and sediment than between the granite and its host rocks.

The granite was called the Hurry Inlet granite by Kranck in 1935 and he attributed a Devonian age to it. Kranck also recognised it to be the biggest of the granite masses in Liverpool Land with an outcrop over an area of about 400 km^2. Recent mapping confirms this; its dimensions exceed 30 km from north to south and 14 km from east to west (figs 1, 2). Its eastern margin is in part concealed by an ice cap but from the ice to the coastal plain the exposure is good, though the granite is not always fresh in its exposure. The land surface, falling to the west, is possibly an old erosion surface and it has been suggested that the slope, subsequently dissected by glaciers and west flowing streams, is parallel to the gentle westwards dip of the Mesozoic strata of Jameson Land. No traces of the Jameson Land strata occur in central Liverpool Land but the topographical configuration may be that of a Mesozoic erosion surface and to this may be attributed the local alteration of the granite and its red coloration. A comparable and much more obvious surface has been recognised by Henriksen (personal communication) further north, where modern erosion of red beds is exposing a weathered granite surface.

In places between Sødal and Kalkdal the topography is steep and some north-south scarps strongly suggest faulting. Throughout the area there are tor-like outcrops—occasionally with a reticulate distribution again suggesting control by faulting, and this is further indicated by an excess of reddening of the rock in depressions between castellated tors. Over vast areas frost shattering has produced a spread of granite debris or felsenmeer and on steep slopes there are treacherous screes (fig. 3).

ENVELOPE ROCKS

The host rocks to the granite consist of an assemblage of more or less stratified gneisses together with a migmatitic granodiorite gneiss in which amphibole is conspicuous. The northern contact is against a distinctive siliceous garnet gneiss which is overlain by marble horizons and some amphibolites. The migmatitic granodiorite structurally overlies this, and itself contains metasedimentary units including impure marbles. The significance of relations with carbonate bands is dicussed below.

A petrographic comparison has been made of rocks of similar lithologies from very close to the granite contact (in some cases xenolithic within the granite) and from far removed. The comparison shows the minimal effect of contact metamorphism, usually restricted to retrogression. The siliceous garnet gneiss demonstrates amounts of both plagioclase and potash feldspar. Sillimanite is rarely developed. The minerals are fresh but there is evidence of strong brittle deformation. Near to the granite the mineralogy is little changed, but feldspars, both plagioclase and potash feldspar are clouded. Very close to the contact there is greater breakdown of feldspar and the replacement of both biotite and garnet by chlorite. Similar effects were found in the migmatitic granodiorite in which hornblende and biotite are reduced to chlorite in close proximity to the granite. In the carbonate rocks there is great variation in the assemblages from different localities irrespective of their situation in relation to the granite. Further work is in hand on these rocks and although they are not considered to be temperature sensitive assemblages it seems possible that certain minerals like diopside and garnet are better developed near to the contact or in xenolithic material.

Very abundant aplite veins and acid veins of granitic texture are found in the migmatitic envelope rocks close to the granite. In certain localities such veins are cut off by the granite suggesting that they belong to a previous cycle of plutonic activity. Proof of this lies in the observation that the veins do not decrease in abundance nor change in style as the rocks are traced to the east.

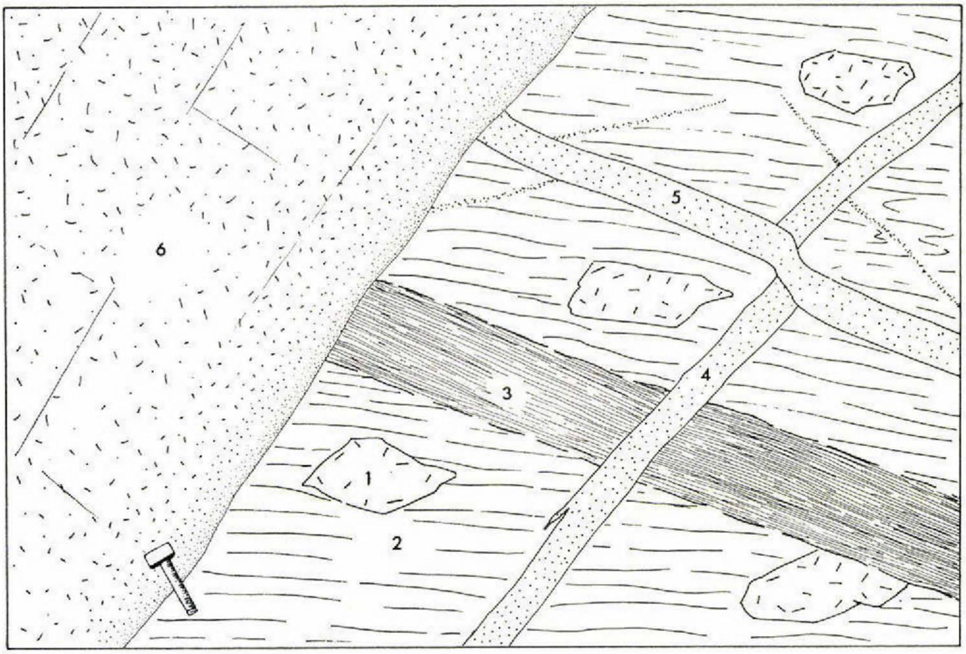

Fig. 4. Sequence of events shown diagrammatically, drawn from photographs of a locality at the head of Sødal. 1 enclaves of amphibole granite, 2 banded gneiss, 3 strongly foliated discordant amphibolite dyke, 4 early aplite vein, 5 later aplite vein emplaced dilatationally, 6 Hurry Inlet granite.

Structural elements of the gneisses appear not to have been affected by the granite emplacement, and the variations in dip and strike remain unchanged both close to and far removed from the contact.

In three localities there are metamorphosed and migmatised basic dykes which are discordant to the gneiss. An important example lies in a confined outcrop north of Sødal. Most of the outcrop is of a coarse grained amphibole-rich gneiss with abundant enclaves of biotite amphibolite. This is cut discordantly by the basic dyke which has a strong foliation parallel to its trend. All these rocks are cut by aplite and pegmatite veins and these in turn by the margin of the Hurry Inlet granite. The relations are shown in diagrammatic form (fig. 4). Similar relations at the head of Nøkkedal also indicate a long and complex history to the area before the emplacement of the granite (fig. 5).

From the features described it is clear that the granite has no prograde aureole and that its effects on the host were very limited in both areal extent and intensity. Apart from local crushing they amount to minimal mineral retrogression. The significance of this is twofold. First, it indicates that the metamorphism of the host rocks, though long and complicated, was completed at the time of emplacement of

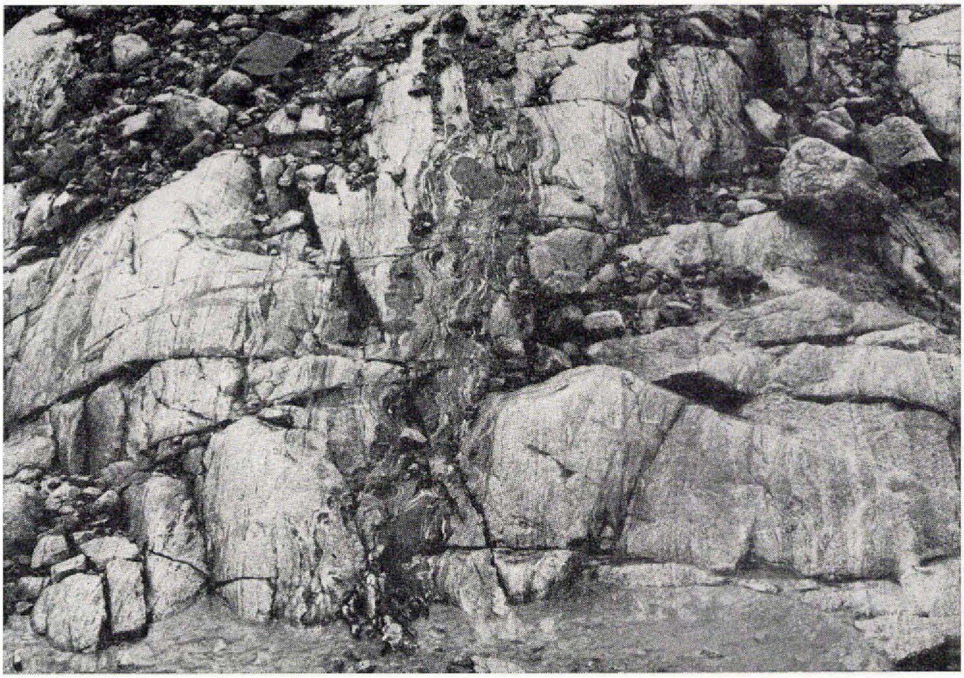

Fig. 5. Migmatised discordant amphibolite. North side of Nøkkedal.

the granite. The antiquity of the gneiss was thus deduced and a pre-Caledonian and hence Precambrian age predicted. It was not unexpected then that the mineral K/Ar age from the host indicating the *latest* event is 1183 m.y., whilst the granite age is 434 m.y. Secondly, the relations between granite and host are those of a high level granite in Read's sense (Read, 1949). It is clear that the granite was magmatically dead during its final movement into place.

FIELD CHARACTERISTICS OF THE GRANITE

Major divisions of the granite

A field and macro-study of the granite justifies sub-division into five main lithological types:

(a) a more or less homogeneous granular biotite granite

(b) a variation of (a) characterised by the presence of megacrysts of perthite

(c) a variation of (a) characterised by an aplitic texture (although not deficient in biotite)

(d) a facies which in hand sample appears to be relatively poor in quartz. It is characterised by an abundance of pink potash feldspar and by a range in grain size of the feldspar
(e) an even textured rock which usually appears more mafic than the rest of the granite

With all these there are local variations, in some cases attributable to contamination, to late-stage processes and to post-granite processes, although, as will be emphasised below, these effects are largely textural. Late-stage granite veins and dykes of aplite and pegmatite are probably related to the main types.

(a) In hand sample the granular facies is typically composed of two feldspars and quartz plus a ferro-magnesian mineral. Both biotite and an amphibole occur and in many cases these have been replaced by chlorite. Sphene and magnetite are occasional macro-accessories. The texture is variable, from granular and even to seriate, feldspars varying in length from 1 to 5 mm. The degree of freshness is variable, but usually feldspars are milky and somewhat soft.

(b) The feldsparphyric variety is somewhat similar to that described above except for the presence of conspicuous flesh coloured perthite crystals, up to about 25 mm in length. Some of the more feldspathic varieties appear also to be the richest in biotite.

(c) An aplitic facies of this granite has been recorded. This is again similar to type (a), but very even in texture and somewhat finer grained. Biotite is relatively abundant and sometimes is the coarsest phase present. The matrix of this facies is usually pinkish and from macro-observations is judged to be relatively quartz-poor.

These three types are clearly minor variations of each other. In no case can a line on the map be drawn between any two, and frequently there is a gradation from one type to the other. This is particularly true of types (a) and (b). In most areas where type (a) outcrops, patches can be found which contain feldspar megacrysts. No distribution can be shown, therefore, on the map, and the symbol for feldspar megacrysts has been superimposed where there is an abundance of well developed (i. e. large) crystals. Similarly the aplitic facies is of local occurrence only and rapidly grades into one of the other principal types. Its genesis will be discussed later; there are no indications that this is a primary type from which other facies have been derived.

(d) On the other hand, variety (d), whilst certainly petrogenetically related to the other facies, has a mappable distribution. It is confined to the area north of Kalkdal and a small strip on the south side of that valley. Because of this distribution, it has been referred to as the Kalkdal granite. Characteristically it is a pink, feldspar-rich granite with only minor quartz. The ferro-magnesian mineral seems always to be chlorite, almost certainly derived from biotite. The texture is seriate-granular with subhedral feldspars ranging from 3 to 7 mm in length and chlorite finely divided as an interstitial mineral.

(e) The fifth facies of the Hurry Inlet granite, like the Kalkdal granite, has both distinctive macro-characteristics and a mappable distribution. It is limited in its outcrop to the south-east part of the main mass and occurs in two main masses and in a number of sheets and irregularly shaped intrusions. The sheets range in size from a few metres in length to about 1.3 km. Their distribution is such as to suggest that they are cupolas or stocks (apophyses) from the main mass, and it could well be that more of this facies lies further to the south-east.

The rock has been referred to as a diorite (Henriksen & Higgins, 1970). In hand sample it is typically more mafic than the other facies of the granite, and has a somewhat finer and more even grained texture. Biotite is the principal ferro-magnesian mineral, and although the rock is usually mesocratic there is clearly no deficiency in quartz.

There are no doubts on the evidence of field relations that this facies was an intrusive rock. In a large number of cases a sharp junction can be seen between it and other facies of the granite. (The only contact between it and the gneiss is faulted). In the case of the sheet intrusions the contacts are usually steep and where exposure permits observation it is seen to be not planar but stepped. Examples are illustrated (fig. 6). Evidence for the relative age of it and other facies of the granite can be seen from a number of localities. In places the sharp line of junction cuts across feldspar megacrysts in the host granite, and at other localities xenoliths of the granite occur in the more mafic rock, and veins in the granite are

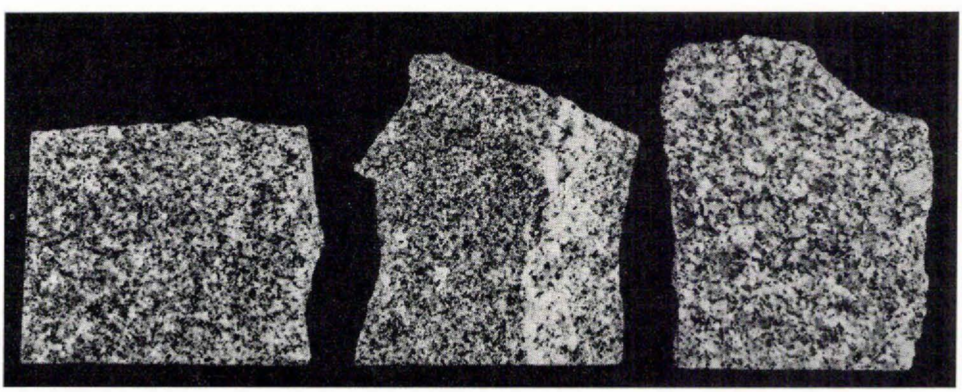

Fig. 6. Contact between two facies of the Hurry Inlet granite. The late mafic type at the left x 0.8.

cut off at contacts. In places there is a concentration of mafics to give a dark selvedge in the younger rock at its contact with the granite.

This facies is therefore demonstrably a late member of the granite series, post-dating veins in the other facies. The orientation of the sheets is parallel to one of the joint directions in the granite.

Margin of the granite

The original contact between granite and host on the west side is nowhere exposed. Granite crops out on the Hurry Inlet coast at the mouth of Gaffelelv and 2 km north of there, where there is a faulted contact between it and the younger sedimentary series. To the north the granite is overlain by sandstones and conglomerates. Elsewhere the contacts between the main granite and its host are reasonably well exposed. North of Kalkdal the contact trends east-north-east and in part is faulted against garnet gneiss.

In the north-east corner a remarkable junction can be seen between granite and a mass of marble of sedimentary origin. Viewed from the south side of Kalkdal the marble appears to be xenolithic but in fact it is part of the gneiss sequence penetrated by tongues and veins of granite on the west side but passing into gneiss on the east. The three-dimensional view obtained from the side of Kalkdal indicates that the granite underlies the marble which it penetrates by a series of veins, particularly of aplite. Here there is a primary contact between granite and host showing the classic features of stoping. Very abundant xenoliths of marble in the granite are consistent with this interpretation. Immediately south of the marble mass on the steep north side of Kalkdal the granite/host relations are somewhat more complex. Traversing across the strike of the foliation in the gneiss, veins of aplite are found suggesting that the gneiss is underlain by granite. Near the exposed contact with the granite there is a series of gullies in which the gneiss is variously mylonitised. Nearer the granite the alteration is greatest. In some of the gullies it is apparent that there has been fault movement and there are slivers and pods of disrupted gneiss. Pegmatite and aplite dykes occur and (of great significance) there is a strong development of large (up to 20 mm) porphyroblasts of potash feldspar giving a protoclastic texture. The crystals show no signs of deformation themselves and hence clearly post-date the faulting in the gneiss. The contact with the granite mass is gradational over a zone 10 m wide. In this the feldspars become even in distribution and on the western side the rock has the appearance of the Hurry Inlet granite and contains xenoliths of marble. Thus it seems that the contact is partly fault controlled but the granite remained active after a period of faulting, partially obliterating the tectonic features. The relations are important from the point of view of the late history of the granite, indicating first that the feldspar megacrysts form very late and, secondly, that they may be localised in fault zones and hence belong to a volatile stage of the granite. The significance of the absence of similar feldspars in the marble is discussed later. Direct observations of the contact cannot be made immediately to the south in the Kalkdal valley. Further south there are again indications that the junction is a fault. The granite itself is somewhat deformed and a 100 m broad clitter filled depression lies between good outcrops of granite to the west and folded gneiss to the east. The most easterly granite exposures are however xenolithic and xenoliths of marble occur slightly out of the line of a prominent marble horizon in the gneiss.

Slightly farther to the south the line between granite and gneiss, though again not distinct, has been mapped swinging somewhat to the east. In this area the rock has a hybrid aspect. It is not homogeneous granite as observed to the west, neither does it contain the characteristic banding of the gneiss. In parts of the outcrop there are relics of banding but for the most part this has disappeared, presumably during a process of homogenisation. Ghost remains of banding show that parahomogenisation but not mobilisation was achieved. Mafic blocks are abundant and the whole zone is shot through with aplite veins.

The granite has contacts with a small area of gneiss near the head of Sødal. These are imperfectly exposed as the gneiss is partially covered by moraine, ice and scree. Veins of granite can be observed penetrating the gneiss and a sharp contact exists between gneiss and granite. In view of the occurrence of granite further east in ridges north and south of this locality the older material may best be regarded as a large xenolith. Near the head of Nøkkedal there is a rather sharp junction between granite and older rock and in places this has been replaced

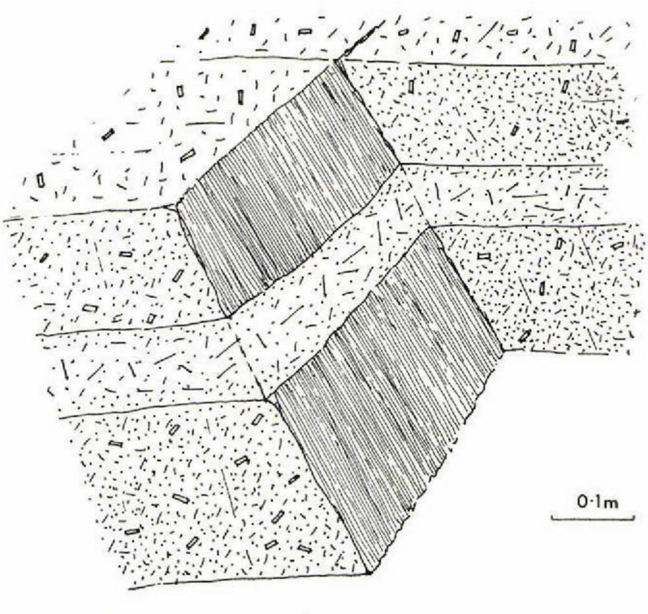

Fig. 7. Undeformed pegmatite vein cutting across shear zone in Hurry Inlet granite.

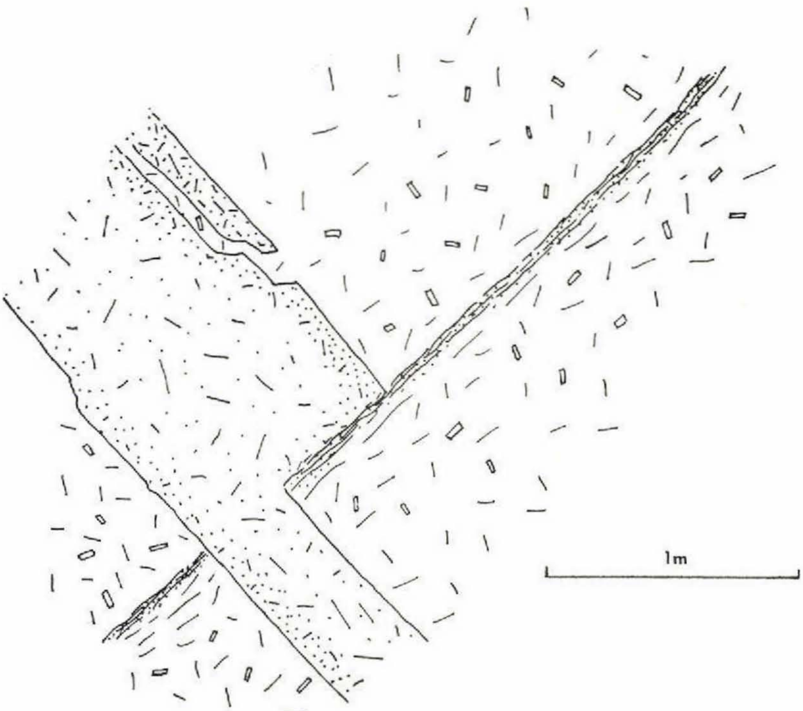

Fig. 8. Pegmatite vein with emplacement synchronous with shear, Hurry Inlet granite.

by a fault. To the north-west the junction is an intrusive contact with homogenised gneiss forming a zone between the granite and normal gneiss. Evidence for stoping is positive in this area, where a traverse shows a progressive increase in xenolith size and abundance in the granite, to a point where the older material is dominant, broken and intruded by granite and aplite veins.

From two localities there is direct evidence that faulting took place between the main period of crystallisation and the formation of pegmatite veins. In Damelv, grey granites are veined by thin sheets of pegmatite and aplite. There is a single but unequivocal case of an undeformed, subhorizontal pegmatite sheet cutting across a slickensided surface in the granite. The pegmatite is not displaced on the fault (fig. 7).

Relations to the east are slightly different. A shear plane in the granite along which there are quartz and chlorite developments partially terminates a broad pegmatite. The vein is of injection rather than replacement type and its emplacement must have been covered by the period in which the shear was active (fig. 8).

The features described are those of a high level granite in Read's sense (Read, 1949). In places the mass made space for itself by stoping its walls and roof, although there is no reason to suppose that this was more than a local phenomenon resulting in more than local modification of the shape of the body. The main part of the granite clearly crystallised whilst movement was taking place, so that there is a gradation between true magmatic injection (liquid and crystal into solid) and movement between plastic or rigid material into solid. In part the deformation produced by crystalline material being injected into its host has been obliterated by late stage processes. Finally, in places the junction is a true fault: that is the movement was between two solid and brittle substances. Thus the emplacement period extended beyond the time of magmatic crystallisation of the granite.

Xenoliths in the granite

Small xenoliths or segregations of mafics into clots are very widespread. The individuals are not usually more than about 0.1 m long; they may be spindle-shaped or angular and are usually well spaced in the outcrop. Amphiboles are the most abundant constituents of these clots but as with the dark minerals in the granite these have frequently been down-graded to chlorite. Locally xenoliths control the composition of the granite, but amphibolite xenoliths are occasionally found in biotite granite. In Damelv amphibolitic migmatite occurs as xenoliths and here the granite contains amphibole as its principal ferro-magnesian mineral. In the north-eastern part of the granite and at other localities near the eastern margin, xenoliths of amphibole-rich granite have been recorded. These are angular blocks with straight sharp contacts with the host granite.

The last mentioned examples may be somewhat exceptional; the others presumably represent the more refractory portions of the rock from which the granite was derived. They are best regarded simply as primary inhomogeneities in the granitic melt and their wide distribution is consistent with this.

In two areas in the granite, xenoliths occur in dimensions and abundance which justify special interpretation. These are in a zone parallel to the contact with the gneisses north of Nøkkedal and north of Kalkdal.

Near Nøkkedal a broken line has been drawn on the map (fig. 2) showing the limit in which xenoliths are abundant in the Hurry Inlet granite. In the south-western part of this zone angular amphibolite blocks and blocks of amphibolitic granite are abundant. Some of these represent portions of a migmatite complex and were cut by aplite veins prior to their inclusion in the granite mass. Adjacent to this are smaller but similar masses almost all veined by aplite and some by tongues of normal textured granite. To the north and east the most abundant xenolith is marble. In places there are good cliff exposures of migmatite and marble forming composite xenoliths. These are veined by aplites up to 3 m broad which clearly have penetrated from below with a tendency to break up the metasediment. Extensive patches of marble occur as xenoliths in the granite. The marble shows relics of bedding and the granite in contact is aplitic in texture

Fig. 9. Pods of granite in marble. North of Kalkdal. The biggest pod in the picture is about 0.1 m long.

and pink in colour. In the lower part of the outcrop there is a 10 m wide vein of granite which is feldsparphyric and which cuts across the migmatic and aplite carrying with it inclusions of aplite.

The conclusion to be drawn from these relations is that the xenoliths are close to the contact between granite and host, and hence that here the contact plunges at a relatively low angle to the south-east.

North of Kalkdal there are marble xenoliths and also detached masses of amphibole-rich rock which may be derived from pre-existing carbonate rock. The marble xenoliths are abundantly exposed in a small stream north of Kalkdal and to the north of there. The material and its relations with the granite are slightly different from areas further south since here few calc-silicate minerals have developed. In this respect the marble is different also from the mass which lies in contact with the granite only about 1 km to the east.

Unlike most marble xenoliths seen in the south, this retains no trace of bedding but has a very strong fabric. In it are numerous veins of granite and granite blocks and pods. The superficial similarity to migmatite is obvious, and it was this term that was used for similar rocks by Kranck (figs 9, 10). Close inspection

Fig. 10. Pods and veins of granite in marble. North of Kalkdal.

however reveals the phenomenon to be one of rheomorphism and clearly the marble xenolith has been (at least partially) mobilised by the granite and has retained its ability to flow longer than the granite. The structure in the marble referred to above non-committally as a strong fabric was produced by flow as a result of partial melting. Similar relations were recorded at a number of localities in the area north of Kalkdal and it is of obvious importance that such rheomorphism took place in relatively pure marbles, i. e. where few calc-silicate minerals have formed. Chemical reaction between granite and marble is limited. The marble appears not to have been affected mineralogically by the granite but it is apparent that textural variations have been produced in the granite which in proximity to the marble xenoliths is always aplitic. This may be the result of rapid crystallisation stimulated by the increasing P_{CO_2} as the calcite dissociated.

The possibility of both rheomorphism of marble by granite injection and the chilling of granite melts has been shown by several experimental workers. Wyllie & Tuttle (1959a) showed that partial melting of calcite could take place at temperatures below the solidus of granite. A melting temperature of 650°C was declared to be reasonable in the presence of water and it was pointed out that this could be achieved under regional metamorphic conditions. In another contribution (Wyllie & Tuttle 1959b) the effects of CO_2 on granite magma were considered and it was shown that dehydration takes place which in turn raises the temperature of the solidus. These results were confirmed (Wyllie & Tuttle, 1960) when melting of calcite was described at 740°C and 1 kbar, in the presence of water vapour. The minimum liquidus for the system $CaO–CO_2–H_2O$ was 640°C, well below the possible temperature of the solidus for the Hurry Inlet granite. Watkinson & Wyllie (1969) pointed out that dissociation of calcite and incorporation of the cation also raises the temperature of the granite liquidus, inducing rapid (isothermal) crystallisation. Thus the total effect must be one comparable to chilling and a fine-grained texture is likely to be produced. The very regular occurrence of aplitic granite in all areas where marble xenoliths are found is significant. Comparable textures have been found at other granite–marble contacts, one of the best described being that of the Beinn an Dhubaich granite in Skye (Harker, 1904; Tilley, 1949), but rheomorphism seems to be rare.

On the steep slopes of Kalkdal a basic facies of the granite occurs which is best interpreted as almost completely digested xenolithic material. There are three separate masses, the biggest being almost 2 km long. All are surrounded by the normal Kalkdal granite. The material looks like an amphibolite having a deep greenish hue. At the highest level of exposure the rock consists of an extremely coarse aggregate of feldspar, each grain poikilitically including amphibole, biotite and possibly a little quartz. The feldspar crystals have grown to a large size (50 mm) and have fairly straight crystal boundaries against each other. In patches there are amphiboles in clots between the feldspars as well as being poikilitically included. Lower on the valley side, the feldspars, whilst still sieved with inclusions, become separated from each other by zones of amphibole. Finally this passes into a hornblende granite in which the feldspars are unusually large and which appears to be deficient in quartz.

GRANITE PETROGRAPHY

A thin section study of the granite types recognised in the field showed that differences are largely textural. The essential minerals are always plagioclase, quartz and potash feldspar, usually with biotite but occasionally hornblende. Accessory minerals commonly occurring include muscovite, zircon and sphene.

Modal analysis shows a small range in the proportions of the three major components and a remarkably small range in the colour index. A plot of the result on the diagram proposed for classification by Streckeisen (1967) has already been published (Coe & Cheeney, 1972). This shows the suite occupying a small field lying across the granite–granodiorite boundary; the term adamellite would have been appropriate.

The potash feldspar is microcline-perthite where it occurs as megacrysts, and either microcline or orthoclase as a groundmass mineral. Megacrysts frequently have inclusions of other minerals. Occasionally the inclusions are in optical continuity. The megacrysts reach 12 mm in length when they have a very irregular lobate margin. Plagioclase crystals are usually zoned, in most cases with a simple form from core to rim, though repeated or oscillatory zoning is locally present. Because of this inhomogeneity determinations are not easy, but a composition in the range An_{27} to An_{33} for twinned crystals has been measured. Twin types are variable and frequently complex. Albite rims to complex crystals are not uncommon. An obvious feature of the whole suite is that the alteration of the plagioclase components is more advanced than that of the potash feldspar. Alteration products, rarely absent, are white mica and epidote.

Quartz has the greatest range in abundance of the major minerals, from a minimum of 16.9 % to a maximum of 33.2 %. It occurs with considerable range in grain size but larger grains are usually fractured. There is abundant evidence for the granulation of this mineral, but occasionally limpid crystals appear to be rewelded from small grains. Biotite varies from fresh crystals with strong pleochroism from dark brown to straw yellow, to completely chloritised grains. Pleochroic haloes occur but are not abundant. Muscovite is rarely absent from a slide but it is always subordinate to biotite and indeed rarely reaches 1 %.

The low range in mineral composition is confirmed by chemical composition and indicates that the divisions erected in the field are superficial and this in turn explains the rapid variation in type. Variation in texture can be accounted for in some but not all cases. For instance, the megacrysts of microcline-perthite represent a late-stage low-temperature growth of alkali-rich phases compared with more rapid total crystallisation of orthoclase in adjacent areas. This is consistent with a view of the final stages of crystallisation being synchronous with irregular movement into place of the whole mass. The Kalkdal facies can be attributed to contamination effects as has been detailed earlier. On the other hand no explanation can be offered for the facies described in the field as dioritic. It differs from the main part of the mass in being somewhat finer grained and even in texture. Megacrysts are wanting, but synneusis aggregates of plagioclase occur. The melanocratic appearance is in fact entirely due to texture since the average measured colour index is not higher than that of the main granite mass. The sum of the evidence proves this facies to be truly magmatic and late in the sequence. For this reason it was selected for isotopic dating.

A structural feature of this rock, which may be of some significance, is the local development of orbicules. Such structures have now been described from a number of localities and in rocks of widely ranging ages but mostly in dioritic types. In this particular case there are some unusual features. As stated above the quartz diorite is commonly very even in texture and hence the orbs are conspicuous on a rock face (fig. 11). They are surprisingly uniform in size and composition, being

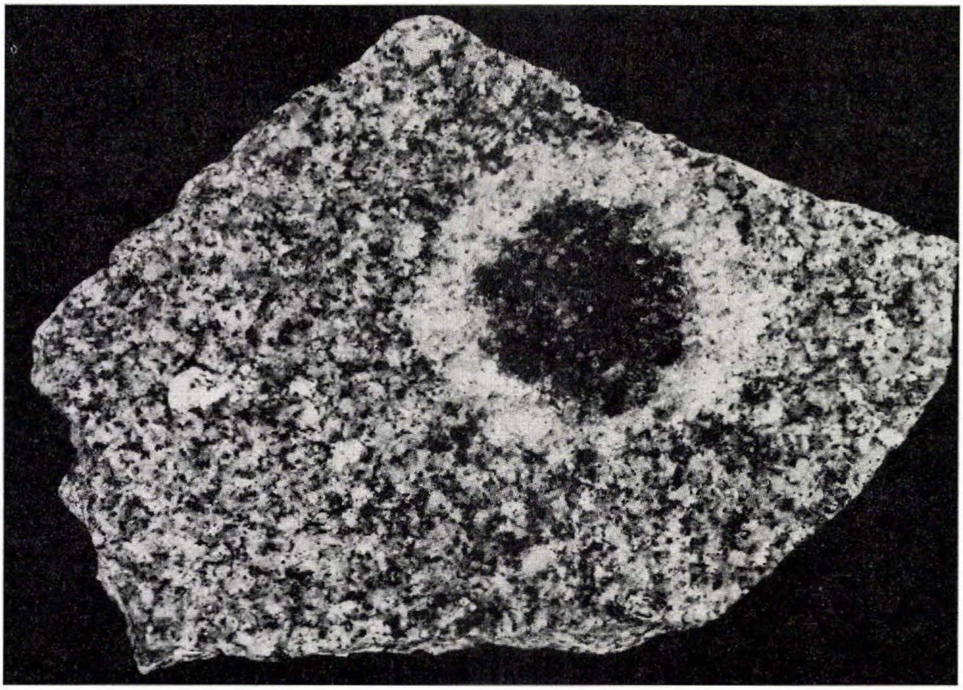

Fig. 11. Orbicule in the late mafic facies of the granite.

35 to 50 mm in total diameter and consisting of an outer rim (5 to 8 mm wide) of almost biotite-free quartz/plagioclase aggregate and an inner core consisting of these minerals plus a greater proportion of biotite than is found in the whole rock. Thus the structure seems to be due to a migration of dark minerals from the outer shell to the core. Unlike some orbicular diorites there are no further zones. The margin of both core and outer part of the shell is sharp, and in hand sample no textural change can be seen. The orbs are widely distributed in the quartz diorite and of sporadic occurrence; in areas where they occur a normal distribution is about three per square metre on any surface. It is unusual to see two orbs in contact, and there have been no observations of growth interference.

The 'type' sample of the facies containing orbicular structure has the following mode:

K-feldspar	19.4 vol.%
Plagioclase	42.6
Quartz	29.1
Biotite	7.6
Muscovite	0.6
Opaque minerals	0.3
	99.6

In computing this mode from three slices cut mutually at right angles from a large sample some variation was found in the ratio of potash feldspar to plagioclase, but the leucocratic total was consistent for all slides at 91 %. The rock has an igneous texture with plagioclase a dominant mineral in crystals which are usually zoned, subhedral and complexly twinned. Synneusis texture, which is occasionally developed, is acclaimed by Vance (1965) to indicate a magmatic origin. The plagioclase crystals have maximum dimensions of 2.2 mm by 0.3 mm.

Potash feldspar and quartz reach up to 4 mm in diameter.

The rim and core of the orbicular structure together with the host were designated *a, b* and *c* from outside to core and attempts were made to compute modes for each. The areas available in thin section were small but the following aggregated results were obtained:

	K-Feldspar	Plagioclase	Quartz	Biotite	Muscovite	Opaque minerals	Quartz + feldspar
a (host)	29.0	32.8	31.3	5.1	1.4	0.3	93
b (rim)	25.4	37.3	33.4	0.8	2.5	0.5	96
c (core)	0.2	32.4	36.8	7.0	19.2	0.4	69

Thus the rim *b*, although leucocratic in hand sample, differs from the host *a* by only a minor increase in leucocratic minerals and some exchange of muscovite for biotite. The significant difference is between rim *b* and core *c*, brought about by almost complete elimination of potash feldspar, some increase in biotite and a very pronounced increase in muscovite. Thus the chemical differences could easily amount to little more than an increase in water in the core. From this it is concluded that the structure is of primary origin and results from very local hydration of the melt but not at high vapour pressure. The temperature of 700°C suggested for formation of the magma is within the stability range for primary muscovite determined by Yoder & Eugster (1955).

GRANITE CHEMISTRY

Major elements

Twenty-five random samples were used for an initial chemical study. These come from different parts of the body and include all the main facies established in the field together with associated veins. In each case about 4 kg of clean material were crushed and a representative sample powdered. Ten major oxides, plus P_2O_5, H_2O^+ and H_2O^- were determined. Major elements except for FeO and Na_2O were determined by X-ray fluorescence on fused pellets using the techniques of Norrish & Hutton (1969) and Harvey *et al.* (1973). Na_2O was determined by standard

Table 1. Chemical analyses of the Hurry Inlet granite

	1	2	3	4	5	6	7	8	9	10	11	12	13
Sample	105006	105007	105016	105017	105028	105036	105038	105049	105055	105056	105057	105061	105062
Major elements													
SiO_2	70.18	62.83	68.06	64.39	72.56	63.31	69.60	60.10	70.57	70.13	70.55	71.77	72.84
TiO_2	0.47	0.88	0.54	0.79	0.46	0.85	0.38	1.06	0.37	0.40	0.38	0.30	0.23
Al_2O_3	14.44	16.70	14.89	16.21	14.43	17.18	16.65	17.59	15.48	15.92	15.33	14.82	14.75
Fe_2O_3	1.73	2.51	1.77	2.04	0.76	2.35	0.66	2.37	1.22	1.39	1.53	1.00	0.80
FeO	1.02	2.02	1.43	2.36	1.53	2.34	1.33	3.09	1.25	1.21	1.07	1.03	0.75
MnO	0.09	0.10	0.08	0.09	0.07	0.09	0.07	0.10	0.08	0.08	0.08	0.08	0.07
MgO	0.76	2.05	1.20	1.35	0.79	1.40	0.68	2.04	0.60	0.50	0.56	0.34	0.40
CaO	1.06	3.10	1.86	3.63	0.60	3.52	2.54	4.41	1.93	1.87	1.53	1.57	1.29
Na_2O	4.23	3.84	4.32	3.77	2.80	4.22	4.50	3.73	4.45	4.30	3.62	4.15	4.34
K_2O	4.80	4.16	4.37	3.07	4.99	3.25	3.68	3.46	3.75	3.85	3.78	4.38	4.78
P_2O_5	0.21	0.41	0.23	0.30	0.18	0.34	0.13	0.45	0.13	0.15	0.15	0.17	0.11
Trace elements (data in ppm)													
Ni	40	44	41	42	43	42	34	47	38	37	35	36	38
Zn	69	111	87	109	42	106	50	116	69	73	67	60	42
Ga	22	26	19	27	27	27	24	28	21	22	20	21	18
Rb	138	82	125	54	162	78	84	93	90	94	96	111	118
Sr	979	1389	815	1269	373	1160	718	1613	640	619	591	491	424
Y	20	29	18	20	18	9	17	25	18	16	18	17	14
Zr	244	394	249	352	207	363	239	351	246	271	253	218	153
Nb	10	18	12	8	11	6	4	3	5	8	5	7	10
Ba	1679	3202	1877	2224	1641	2314	1678	3120	1844	2120	1778	1630	1064
Ce	70	116	89	121	104	148	79	174	82	85	90	71	66
Pb	36	35	46	37	47	36	47	31	42	45	39	40	62

14	15	16	17	18	19	20	21	22	23	24	25	
105064	105067	105085	105086	105091	105095	105098	105103	105105	105114	105116	105124	*Sample*
												Major elements
71.03	52.49	70.53	69.53	70.68	73.86	66.17	68.77	73.07	55.31	68.65	69.40	SiO_2
0.34	1.80	0.35	0.43	0.45	0.12	0.68	0.44	0.35	0.65	0.57	0.55	TiO_2
15.78	18.72	15.66	16.21	15.00	13.83	16.24	15.55	14.44	10.29	14.98	14.68	Al_2O_3
0.93	3.03	0.97	1.25	0.94	0.46	1.79	1.81	0.86	1.55	1.26	1.25	Fe_2O_3
1.29	3.16	1.17	1.34	1.46	0.48	1.68	1.34	1.35	2.81	1.25	1.68	FeO
0.09	0.11	0.08	0.08	0.08	0.06	0.09	0.09	0.07	0.12	0.09	0.09	MnO
0.34	2.89	0.64	1.09	0.27	0.20	0.89	0.54	1.04	6.01	1.27	0.87	MgO
2.05	5.72	2.07	2.67	1.91	0.58	2.55	1.95	1.52	11.26	1.60	1.22	CaO
3.99	4.40	4.47	4.57	3.87	4.75	4.42	4.64	3.83	1.66	4.33	4.58	Na_2O
3.88	3.73	3.92	3.34	4.11	4.37	3.84	3.87	4.61	5.55	5.02	4.21	K_2O
0.13	0.69	0.13	0.16	0.11	0.12	0.24	0.15	0.17	1.52	0.25	0.23	P_2O_5
												Trace elements (data in ppm)
35	73	33	37	36	37	32	34	38	192	56		Ni
62	130	57	70	65	23	91	76	72	89	96		Zn
19	26	21	23	19	19	22	21	17	16	24		Ga
99	69	107	86	100	178	104	101	117	122	185		Rb
588	1773	707	779	549	173	789	792	380	969	1000		Sr
16	15	14	11	17	15	18	25	23	41	19		Y
220	496	218	264	241	73	308	254	231	104	300		Zr
12	16	4	5	4	17	8	8	8	5	16		Nb
1546	2800	1711	1886	1672	541	1878	1743	1749	1063	1313		Ba
71	145	72	89	87	34	121	61	89	167	158		Ce
37	30	42	31	37	41	40	31	41	20	59		Pb

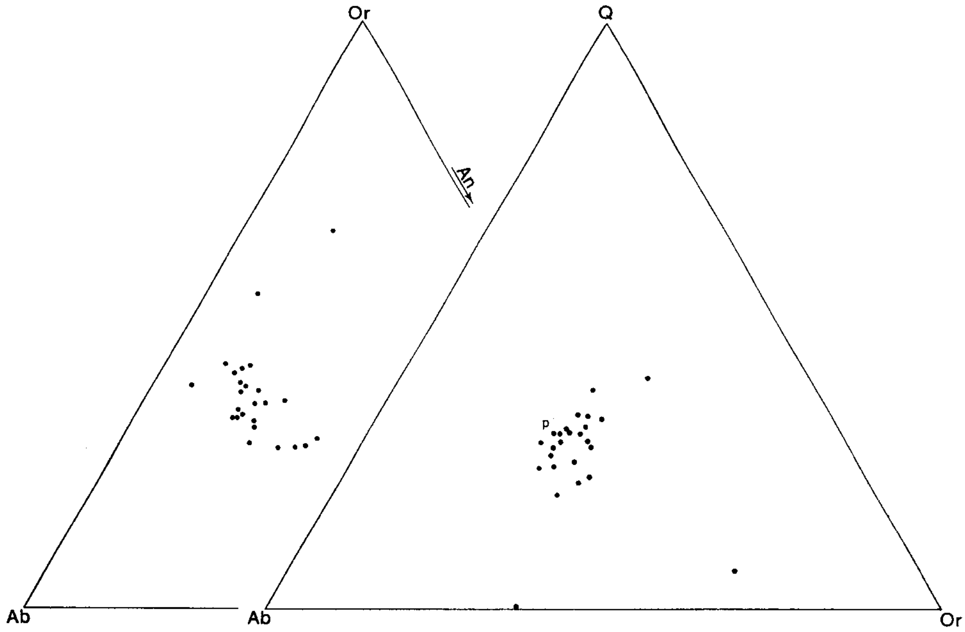

Fig. 12. Plots of normative quartz–albite–orthoclase and orthoclase–albite–anorthosite from 25 samples of Hurry Inlet granite.

XRF method on powder pellets and FeO by rapid wet methods. In addition 11 selected trace elements were determined by XRF on powder pellets. The full results are tabulated in table 1.

From the analyses CIPW norms were calculated and normative minerals plotted in groups on triangular diagrams. A close clustering of points resulted in most cases (fig. 12). It is interesting to compare the normative Qtz, Alk, Plag field with the diagram for modal Q–Or–Ab for a wide range of samples (extending beyond sample points for chemically analysed rocks). The close clustering confirms the original field observation on the homogeneity of the granite mass. To test this further, the major elements were subjected to cluster analysis using techniques described by Davis (1973). The results are presented in the series of dendograms (figs 13, 14).

Dendograms represent in diagrammatic form the similarity between variable groups where large amounts of data are involved. In this case the groups are rock samples and the variables their chemical components. For each group, variables are compared with all other groups and the correlation coefficient (i. e. the measure of the similarity) is calculated. The correlation coefficient by definition takes values from 1.0 to −1.0, that is, high positive values represent high positive correlations. Compared samples with correlation coefficients close to 1.0 are highly correlated positively, i. e. similar. In the construction of a dendogram groups of

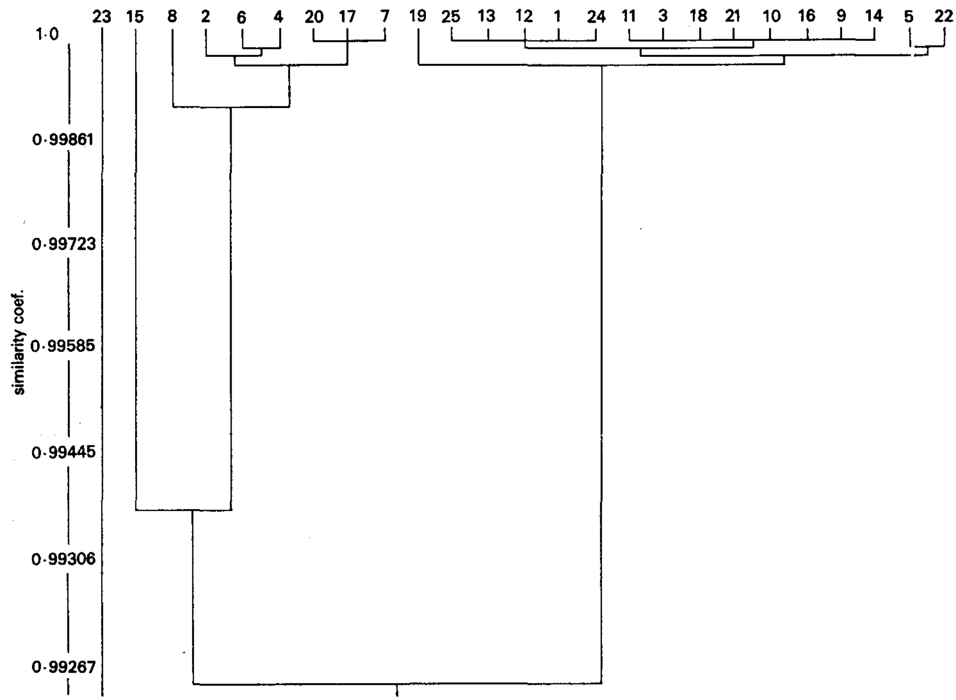

Fig. 13. Dendogram to show grouping of major elements in 25 samples of Hurry Inlet granite. The samples are marked on fig. 2.

variables are linked in the order of their correlation coefficient. When two or more groups are linked, they are then treated as one group and compared with the remainder of the groups.

Figure 13 shows a breakdown into three clusters, with variations drawn to scale. Figure 14 shows the small range between most of the members of the principal groups by reducing the scale. A point of considerable significance emerging from this exercise is that the groups determined are in no way related either to the geographical grouping of samples or to the macro characteristics described above. Thus rocks grouped by being closely similar chemically have crystallised into different facies of the granite. The most striking individual results are the close grouping of 9 to 16 and 21 respectively, 'diorite', biotite granite with pink feldspar megacrysts and an aplite vein.

The lack of diversification confirms field observations that whatever the condition of the material at the time of emplacement it was a homogeneous mass. There are no indications of magmatic differentiation nor of subsequent significant metasomatic changes. An absence of late potash metasomatism, so common in granite masses, is indicated by the Or–Ab–An plot (fig. 12b) in which the points are well clustered. The long axis of the field of distribution is normal to the Ab–Or line. Only in the AFM diagram (fig. 15) is there any distinct trend, and this, near to the FA side line reflects the slight variation in the mafic content of the granite. The point cluster on the Q–Or–Ab diagram (fig. 12a) is good except for two aberrent samples. The centre of the concentration lies in the feldspar field of the ternary diagram for low values of P_{H_2O} (Tuttle & Bowen, 1958) but must be near to the minimum value for the system with added An at values of P_{H_2O} in excess of 3 kilobars (von Platen, 1965). The average An content of plagioclase computed from the norm is 22, a figure which differs from that obtained by direct measurement, presumably because of the difficulty of measuring in zoned crystals and in perthite and other mixed crystals.

The most obvious explanation of this high pressure value is that the 'magma' was generated at a depth corresponding to a pressure in excess of 3 kilobars and injected to higher level. Almost certainly it never achieved the condition of total melt. This is consistent with evidence from other sources that there was in Liverpool Land no major Caledonian metamorphism at the present erosion level. Ideas on the cause of the generation of the granite magma at depth must be

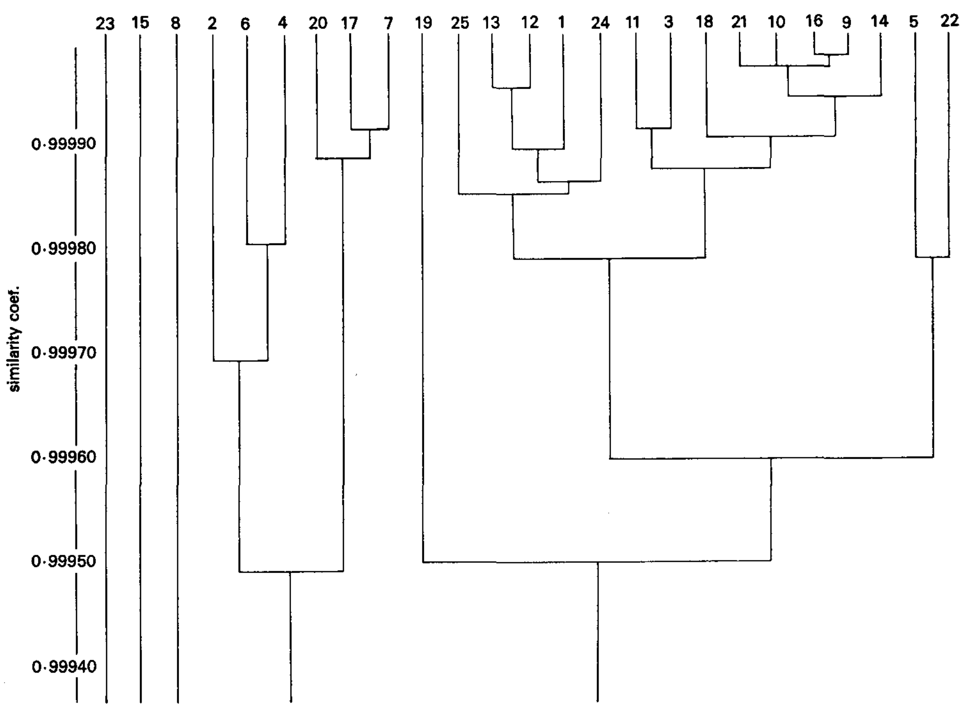

Fig. 14. Dendogram of the same data presented in fig. 13, but with scale reduced so as to show the linkage of the two main groups.

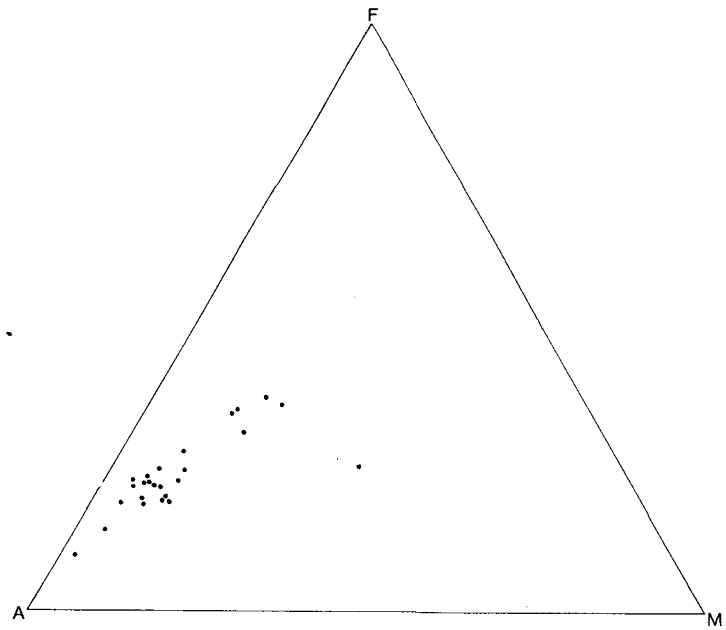

Fig. 15. AFM plot of 25 samples of Hurry Inlet granite.

speculative, certainly this cause had no effects at the present erosion level. The system probably indicates a low thermal gradient. Assuming water saturation, at 3 kilobars and a temperature of 700°C the melt may hold 9% H_2O.

In the event of water undersaturation, a situation considered to be likely by Brown & Fyfe (1972) and indicated by the fact that the granite has apparently risen a long way from its source (Harris *et al.*, 1970) then the temperature pressure conditions are likely to be much higher, up to 850°C at P_{total} = 10 kilobars. This possibly corresponds to a depth of 30 km and hence a thermal gradient slightly less than 30°C per kilometre. Comparison with the statistical results of Hall (1971) also suggests a low thermal gradient.

Trace elements

Cluster analysis of the trace elements from the same suite of samples also yields two main groups (of 7 and 17) but the groups do not entirely overlap with the grouping for major elements. Greater significance is attached to the major element analysis because of the extremely small variation shown. The dendogram for trace elements is included (fig. 16) for completeness.

Values for trace elements are not considered to be extreme. Comparisons are shown with two granite masses which have similar structural environments and are of about the same age.

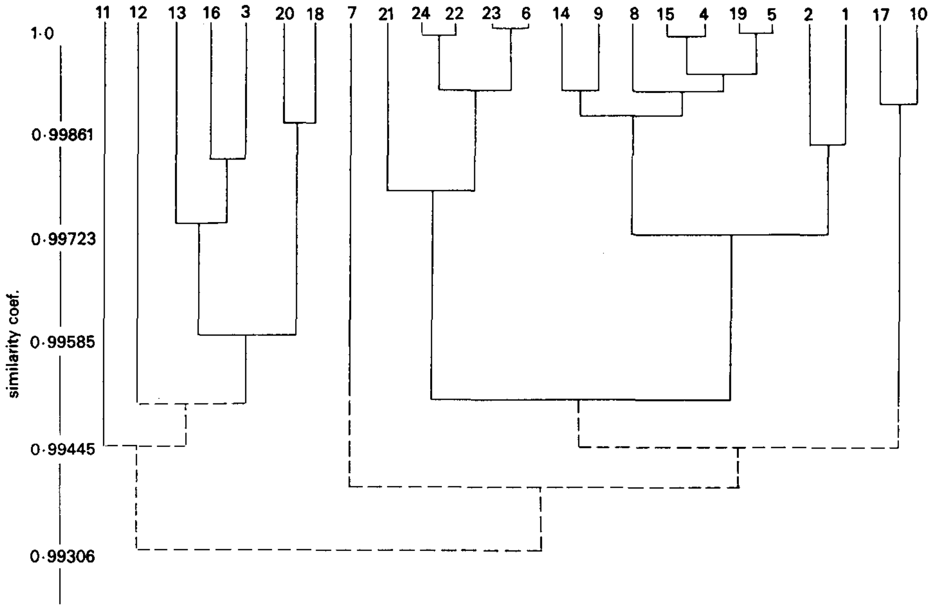

Fig. 16. Dendogram to show grouping of trace elements from 25 samples of Hurry Inlet granite.

	Hurry Inlet granite	Palmer granite (White *et al.*, 1967)	Loch Doon (Higazy, 1954)	Crustal average (Taylor, 1965)
K/Rb	180	225	160	232
Ba/Rb	21	2.4	11.1	4.7
Rb/Sr	0.14	2.1	0.12	0.24

Attention is drawn to the relatively low value of rubidium in the Hurry Inlet granite but very high values of barium.

YOUNGER SEDIMENTS

Rocks included in this category are distinguished by being unmetamorphosed. They are all clastic, mostly coarse grained and in many cases clearly of local derivation. They can be divided into three groups on lithological grounds, but the same grouping holds for a division on a structural basis.

3. Marls and sandstones
2. Sandstones, siltstones etc.
1. Conglomerate

A fault always separates groups 1 and 2. It is clear that the conglomerates are the older, yet they dip at a lower angle (to the west) than the beds of group 2. No contact is seen between groups 2 and 3 but from the attitudes of bedding in outcrops on the adjacent Fame Øer an unconformity can be inferred. The significance of these relations has been discussed earlier (Coe, 1971).

The exposure in the area underlain by the sediments is variable. The broad coastal plain is covered by glacial and fluvio-glacial deposits and only in some of the deeper cut river valleys (e. g. Damelv) are rocks exposed. Patches of good coast exposure are interrupted by barren zones, with gravel banks facing the sea. In the northern part of the area mapped conglomerates are found on high ground and also in Kalkdal, and there the exposure is good.

Conglomerate

The conglomerate lies on the Hurry Inlet granite. In the high ground north of Kalkdal it can be seen lying on a planar granite surface which has a gentle dip to the west. It has an irregularly shaped outcrop with a small outlier at the eastern end (fig. 2). On the sides of Kalkdal and the high ground to the south the contact is faulted, but the eastern extremity must have a similar form to the more northerly patch. The western limit is marked by a north–south fault which brings younger sediments against the conglomerate. The fault surface is well exposed and the conglomerate much crushed.

The conglomerate, especially the lower parts, is massive and composed of boulders, cobbles, pebbles and grains of Hurry Inlet granite. Most of this is as fresh as the parent in outcrop and in consequence the conglomerate looks in the field very much like the rock from which it was derived. This is particularly the case when it is compared with the granite from the fault zones. However, the outline of cobbles and boulders can usually be determined and the fragmentary origin revealed. The grain size ranges from sand composed of broken crystals of the granite up to cobbles 0.25 m in diameter, although occasional larger boulders may occur. The cobbles and boulders vary in shape but the majority are subangular. Sedimentary structures are usually lacking, but in the lower part of Kalkdal what appears to be a large scale wash-out can be seen. Sandstone bands are involved in this structure. In some places the conglomerate is faulted against the granite. The granite is somewhat broken in a zone close to the fault, but the conglomerate is not. The fault does not appear to affect the dip of the conglomerate, and it is suggested that whilst faulting clearly post-dates deposition of the sedimentary rock it may represent renewed movement along an older break. In some places the base of the conglomerate is seen resting on the granite, but it is likely that in many places the derived rock was banked against an irregular topographical surface and many of the irregularities may have been produced by fault movement. Faulting within the conglomerate can also be seen.

Sandstones, siltstones, etc.

Whereas the conglomerates are uniform in character, the suceeding group is highly variable, consisting of sandstones, some of which are very coarse-grained siltstones and mudstones. Some of the bands are calcareous. The group is characterised by a rapid variation both along and across the strike, so that precise correlation is impossible.

The Damelv section was recorded in detail, as it is the most complete cross-section exposed. Apart from that there are good exposures in a stream section north of Kalkdal and at isolated coast localities. The nature of the outcrop rarely permits beds to be traced in the strike direction over more than a few metres— but where this is possible, e. g. in some coastal sections, then the lenticular nature of the bedding is apparent.

In the stream section north of Kalkdal the lowest members of the group exposed are purple, well-bedded mudstones with small granite pebbles and pink feldspar grains. The purple rocks show ripple marks. Above these beds are fine sandstones and grits. The bulk of the material forming these beds is quartz and feldspar; this is angular and the rock is bound by a slightly calcareous matrix. These horizons have been tested unsuccessfully for conodonts. Higher in the succession are coarse-grained arkoses, usually well bedded and alternating with siltstones or mudstones. This part of the succession frequently shows small scale scour marks, usually

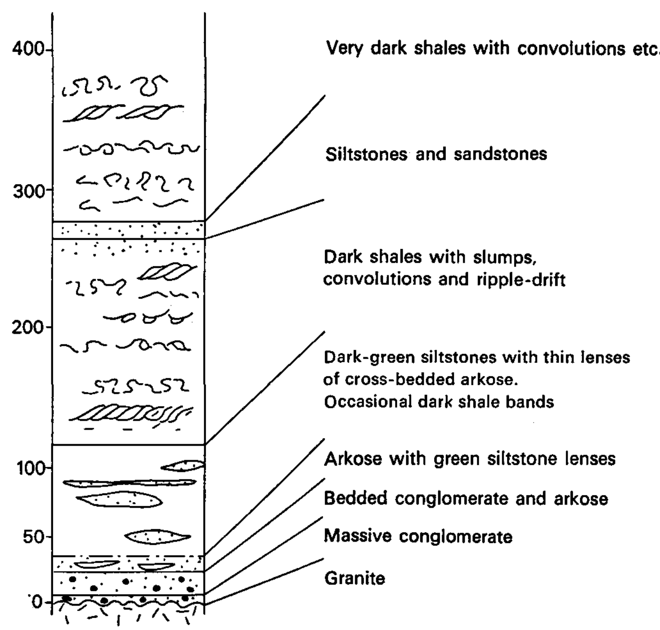

Fig. 17. Diagrammatic profile of the succession in the Damelv section.

at the interface between mudstones and overlying sandstones. Shales succeed, usually grey in colour and with signs of contemporaneous slumping, cross-bedding and wash-outs. Occasional calcareous bands occur but these do not exceed 40 mm in thickness and are lenticular. Above this the exposure is patchy and the succession seems to be mainly in sandstones and conglomerates in which feldspars and granite pebbles are abundant. The sequence is always well bedded, frequently cross-bedded, and sometimes shows other sedimentary structures.

The Damelv section has been described by Bütler (1957) whose account cannot be exactly confirmed. A schematic section is presented as fig. 17. The total thickness of sediment exposed is about 420 m and the horizontal length of the exposure 450 m.

The coast exposures, usually very clean, vary from small outcrops protruding through beach deposits to extensive rocky headlands. The biggest of them is in the extreme south, where the sedimentary rocks are faulted against the granite. There and at other localities arkoses, arkosic conglomerate, and shales are exposed. They have the same characters as were recorded west of Kalkdal. Arkosic conglomerates which make up the greater part of the succession contain an abundance of fresh pink feldspars. There are usually more or less isolated granite pebbles often bigger than 1 m in diameter. Frequently these are rounded. Cross-bedding is common. Interbedded with these are flagstones and shales in which ripple drift is prominent. Plant fragments commonly occur in the shale horizons. Throughout these coastal localities the dip is to the west at a fairly high angle. At the southern extremity of the series, beds are either overturned or vertical, but all are west facing and the exaggerated dips are due to proximity to the boundary fault.

The provenance and conditions of deposition of these rocks must be related to those of the underlying conglomerate. The material could all be derived from the Hurry Inlet granite (although in one thin section a small pebble of spherulitic rock—?acid lava—was noted) either direct or by reworking of the conglomerates. Some degree of sorting has taken place and the nature of the bedding, other sedimentary structures and the occurrence of mica indicate a fluviatile environment. The freshness of the feldspar and especially the occurrence of euhedral crystals indicate either very short transportation or possibly local derivation from granite pebbles. The indications are of shallow-water accumulation probably near to an upland area.

Marls and sandstones

Marls and sandstones have a very limited occurrence, outcropping only on the northernmost Fame Øer and in Klitdal. The obvious differences between these strata and members of the older group are, first, the colour which is bright red and reminiscent of the British New Red Sandstone and, second, the friable nature of the rock. Medium to coarse-grained, cross-bedded sandstones and arkoses outcrop together with some conglomerates. There are also interbedded marls, and the whole succession is a distinctive brick red colour except where reducing conditions have produced green spots or bands. The beds dip to the west at 6° and must lie unconformably across the older group. Rocks of similar colour crop out at the base of the cliff on the north-western shore of Hurry Inlet, and it is likely that they are the same horizons.

Correlation of these three units with strata (even of very similar lithologies) from other areas must be made with caution. The conglomerate lies unconformably on the Hurry Inlet granite from which it is derived. Evidence of faulting persisting during the period of emplacement of the granite, during its unroofing and within conglomerate horizons, suggests an age for the clastic rocks close to that of the granite itself. A Devonian age is therefore reasonable and possibly justified by comparison with similar rocks in areas to the north. The environment of deposition was different for the next series. The sandstone and siltstones were subjected to faulting, steep-up-thrusts rotating the strata to give high-angled dips to the west compared with the gentle dips of the conglomerate. The faulting was completed by the time of deposition of the third series which lies unconformably on all older rocks and structures. A Lower Triassic age has been suggested for the youngest series (Perch-Nielsen *et al.,* 1972) and hence an Upper Palaeozoic age, probably late Devonian is indicated for the sandstones and shales. Bütler's suggestion that the whole sequence be assigned to the Eotrias (1957) is not acceptable, nor that of Kranck (1935) who thought that a lower Palaeozoic age was appropriate for some parts of the succession.

CONCLUSIONS

The evidence presented here shows that the Hurry Inlet granite was emplaced to a high crustal level in lower Palaeozoic times. It shares none of the plutonic history of its host rocks and in this respect it is different from other granitic bodies in Liverpool Land.

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REFERENCES

Brown, G. C. & Fyfe, W. S. 1972: Experimental and electron microprobe studies of granite melting phenomena. *In* Progress in experimental petrology. *Nat. Envir. Res. Coun. Publ. ser.* D **2,** 34–37.

Bütler, H. 1957: Beobachtungen an der Hauptbruchzone der Küste von Zentral-Ostgrönland. *Meddr Grønland* **160,** 1, 79 pp.

Callomon, J. H., Donovan, D. T. & Trumpy, R. 1972: An annotated map of the Permian and Mesozoic formations of East Greenland. *Meddr Grønland* **168,** 3, 35 pp.

Coe, K. 1971: Faulting in the western part of Liverpool Land, East Greenland. *Bull. geol. Soc. Denmark* **20,** 260–264.

Coe, K. & Cheeney, R. F. 1972: Preliminary results of mapping in Liverpool Land, East Greenland. *Rapp. Grønlands geol. Unders.* **48,** 7–20.

Davis, J. C. 1973: *Statistics and data analysis in geology.* New York: John Wiley.

Hall, A. 1971: The relationship between geothermal gradient and the composition of granitic magmas in orogenic belts. *Contr. Mineral. Petrol.* **32,** 186–192.

Hansen, B. T., Frick, U. & Steiger, R. H. 1973: The geochronology of the Scoresby Sund area. Progress report 5: K/Ar mineral ages. *Rapp. Grønlands geol. Unders.* **58,** 59–61.

Hansen, B. T. & Steiger, R. H. 1971: The geochronology of the Scoresby Sund area. Progress report 1: Rb/Sr mineral ages. *Rapp. Grønlands geol. Unders.* **37,** 55–57.

Harker, A. 1904: The Tertiary igneous rocks of Skye. *Mem. Geol. Surv. U.K.*

Harris, P., Kennedy, W. Q. & Scarfe, C. M. 1970: Volcanism versus plutonism – the effect of chemical composition. *In* Newall, G. & Rast, N. (edit.) *Mechanism of Igneous Intrusion.* Liverpool. 187–200.

Harvey, P. K., Taylor, D. M., Hendry, R. D. & Bancroft, F. 1973: An accurate fusion method for the analysis of rocks and chemically related materials by X-ray fluorescence spectrometry. *X-Ray Spectrometry* **2,** 33–44.

Henriksen, N. & Higgins, A. K. 1970: Preliminary results of mapping in the crystalline complex of Renland, the southern Stauning Alper and south-west Liverpool Land, Scoresby Sund, East Greenland. *Rapp. Grønlands geol. Unders.* **30,** 5–17.

Higazy, R. A. 1954: The trace elements of the Plutonic complex of Loch Doon (southern Scotland), and their petrogenetic significance. *J. Geol.* **1962,** 172–181.

Kranck, E. H. 1935: On the crystalline complex of Liverpool Land. *Meddr Grønland* **95,** 7, 122 pp.

Nathorst, A. G. 1901: Bidrag till nordöstra Grönlands geologi. *Geol. Fören. Stokh. Förh.* **23,** 275–306.

Nordenskjöld, O. 1907: On the geology and physical geography of East Greenland. *Meddr Grønland* **28,** 5, 151–284.

Norrish, K. & Hutton, J. J. 1969: An accurate X-ray spectrographic method for the analysis of a wide range of geological samples. *Geochim. cosmochim. Acta* **33,** 431–453.

Perch-Nielsen, K., Bromley, R. G., Birkenmajer, K. & Aellen, M. 1972: Field observations in Palaeozoic and Mesozoic sediments of Scoresby Land and northern Jameson Land. *Rapp. Grønlands geol. Unders.* **48,** 39–59.

Platen, H. von 1965: Experimental anatexis and genesis of migmatites. *In* Pitcher, W. S. & Flinn, G. W. *Controls of Metamorphism.* Edin. & London: Oliver & Boyd. 203–234.

Read, H. H. 1949: A contemplation of time in plutonism. *Q. Jl. Geol. Soc. Lond.* **105,** 101–156.

Streckeisen, A. 1967: Classification and nomenclature of igneous rocks. *Neues Jb. Miner. Abh.* **107,** 144–240.

Surlyk, F. & Birkelund, T. 1972: The geology of southern Jameson Land. *Rapp. Grønlands geol. Unders.* **47,** 61–74.

Taylor, S. R. 1965: Application of trace element data to problems in geology. *Phys. Chem. Earth* **6**, 133–213.

Tilley, C. E. 1949: An alkali facies of granite at granite-dolomite contacts in Skye. *Geol. Mag.* **86**, 81–93.

Tuttle, O. F. & Bowen, N. L. 1958: Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8 - KAlSi_3O_8 - SiO_2 - H_2O$. *Mem. Geol. Soc. Amer.* **74**, 153 p.

Vance, J. A. 1965: Zoning in igneous plagioclase: Patchy Zoning. *J. Geol.* **73**, 636–651.

Watkinson, D. H. & Wyllie, P. J. 1969: Phase equilibrium studies bearing on the limestone assimilation hypothesis. *Bull. geol. Soc. Amer.* **80**, 1565–1576.

White, A. J. R., Compston, W. & Kleeman, A. W. 1967: The Palmer granite – a study of a granite within a regional metamorphic environment. *J. Petrol.* **8**, 29–50.

Wyllie, P. J. & Tuttle, O. F. 1959a: Melting of calcite in the presence of water. *Amer. Min.* **44**, 453–459.

Wyllie, P. J. & Tuttle, O. F. 1959b: Effect of carbon-dioxide on the melting of granite and feldspars. *Amer. J. Sci.* **257**, 648–655.

Wyllie, P. J. & Tuttle, O. F. 1960: The system $CaO - CO_2 - H_2O$ and the Origin of Carbonatites. *J. Petrol.* **1**, 1–46.

Yoder, H. S. & Eugster, H. P. 1955: Synthetic and natural muscovites. *Geochim. cosmochim. Acta* **8**, 225–280.

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