G E U S
Report file no.
22460

GRØNLANDS GEOLOGISKE UNDERSØGELSE
RAPPORT NR. 123

The Geological Survey of Greenland
Report No. 123

The plutonic igneous and high-grade metamorphic rocks of southern Liverpool Land, central East Greenland, part of a supposed Caledonian and Precambrian complex

by

R. F. Cheeney

KØBENHAVN 1985

Grønlands Geologiske Undersøgelse

(The Geological Survey of Greenland)

Øster Voldgade 10, DK-1350 Copenhagen K

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Abstract

Layered metamorphic formations in southern Liverpool Land are disposed in dome-shaped structures with inclinations everywhere gentle. Meta-igneous and meta-sedimentary rock types are represented as well as formations of less clear affinities. Rocks of eclogitic character comprise part of one of the formations which, together with others of the layered succession, passes laterally into a less-deformed complex containing discordant contact relations of plutonic igneous type. The Hurry Inlet granite is a post-tectonic, post-metamorphic formation cropping out in the extreme north-west of the area.

The earliest detectable events indicate emplacement of granodiorite into sedimentary or metasedimentary formations. Subsequently, these rocks of igneous and sedimentary origin were raised to upper amphibolite or granulite facies with some deformation leading to the prominent layering and including, perhaps, their juxtaposition with eclogitic rocks originating at great depth. Retrogression to 'normal' amphibolite facies followed, with widespread development of hydrous minerals, pegmatites, etc. The position of limited cataclasis with respect to this later stage of metamorphism is not abundantly clear. Emplacement of the Hurry Inlet granite entirely post-dates all of these events.

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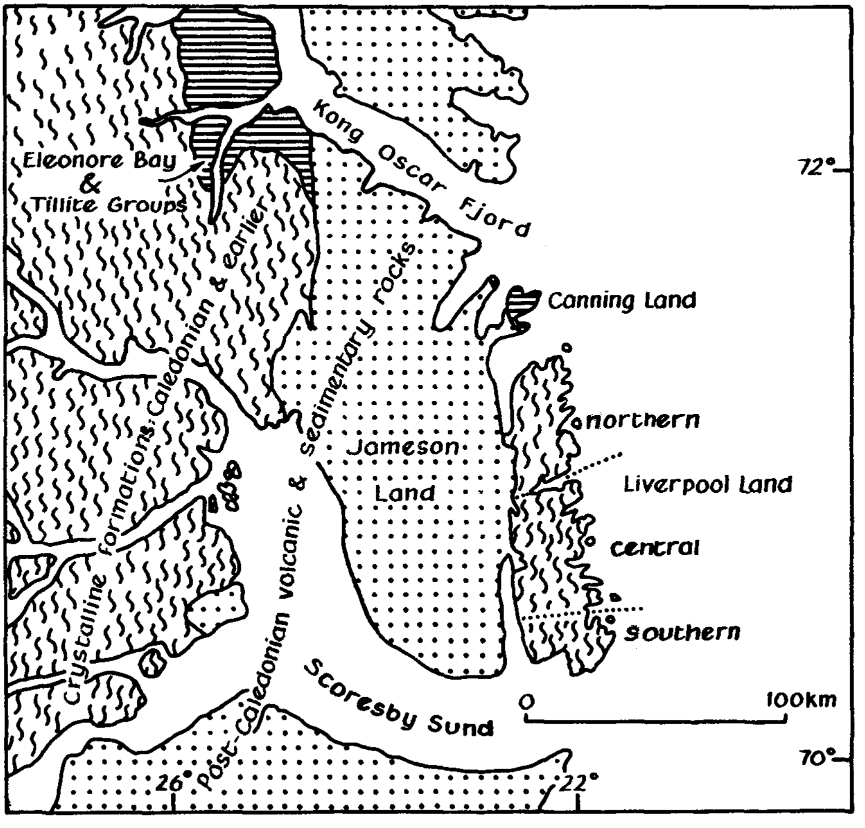


Fig. 1. The relative isolation of Liverpool Land from the Caledonian and earlier complexes of central East Greenland. The three-fold division of Liverpool Land (northern, central, southern) serves the purposes of geological description only and has no administrative significance. Southern Liverpool Land is described here.

INTRODUCTION

The area of Liverpool Land treated in this report includes the settlement of Scoresbysund (figs 1 & 2), and was mapped by the author in the summer seasons of 1969 and 1971 as a part of the Grønlands Geologiske Undersøgelse's (GGU) five-year expedition to Scoresby Sund 1968 to 1972 (GGU, 1969, 1970, 1971, 1972, 1973). Liverpool Land lies within the East Greenland Caledonian fold belt, of which general geological accounts have been given by Haller (1971), Henriksen & Higgins (1976), and Higgins & Phillips (1979). Most of Liverpool Land is covered by two 1:100 000 geological map sheets produced by the Survey (GGU, 1980, 1981).

In scope, this report will be confined to presenting an account of the lithology and structure of the crystalline bedrock of southern Liverpool Land, together with a brief interpretation of their metamorphic, igneous and tectonic histories. No further remarks will be expended on the unconformably overlying Mesozoic and Quaternary deposits for which see Rosenkrantz (1942) and Funder (1972, 1978) respectively. These Phanerozoic formations occupy very small outcrops.

The crystalline rocks of Liverpool Land form a strip approximately 30 km west to east and 120 km north to south which is isolated across-trend from the principal crystalline complexes of central East Greenland by distances of 90 to 110 km, occupied by younger sedimentary formations (fig. 1). This isolation renders comparison and correlation difficult.

The likely absolute ages of the various components of the crystalline complex of Liverpool Land as a whole must remain in doubt as preliminary Rb-Sr whole-rock isochrons proved to be severely ill-conditioned, providing a range of apparent ages from 400–1500 m.y., but all with large errors of estimation (O. van Breemen, personal communication). K-Ar mineral ages of 1183 and 1124 m.y. were obtained from Liverpool Land by Hansen *et al.* (1973) on hornblende from a gneiss and an amphibolite sample respectively, while the Hurry Inlet granite has yielded a Rb-Sr biotite age of 434 m.y. (Hansen & Steiger, 1971).

Previous work

It is of interest to note that some of the earliest recorded geological observations in the whole of Greenland appear to have been made in southern Liverpool Land. These are included in the accounts of Scoresby (1823) who forced landings at Kap Lister and Kap Hope (fig. 3) in late July, 1822. Scoresby noted (1823, p. 185) the rocks consisted chiefly of hornblende, in angular, irregular masses (cf. agmatite?) as well as in "slaty kind" (i.e. schist). Abundant mica and veins of feldspar were also noted. Amongst the specimens collected and returned to Edinburgh, Jameson (*in* Scoresby, 1823, p. 400) identified mica "slate" (i.e. schist), various gneisses and granite-like correlatives, syenite and "secondary greenstone" (i.e. dolerite).

The earliest attempt at systematic mapping was that of Kranck (1935), who also mentions a number of isolated observations by earlier visitors to the region. Kranck (1935, plate 3)

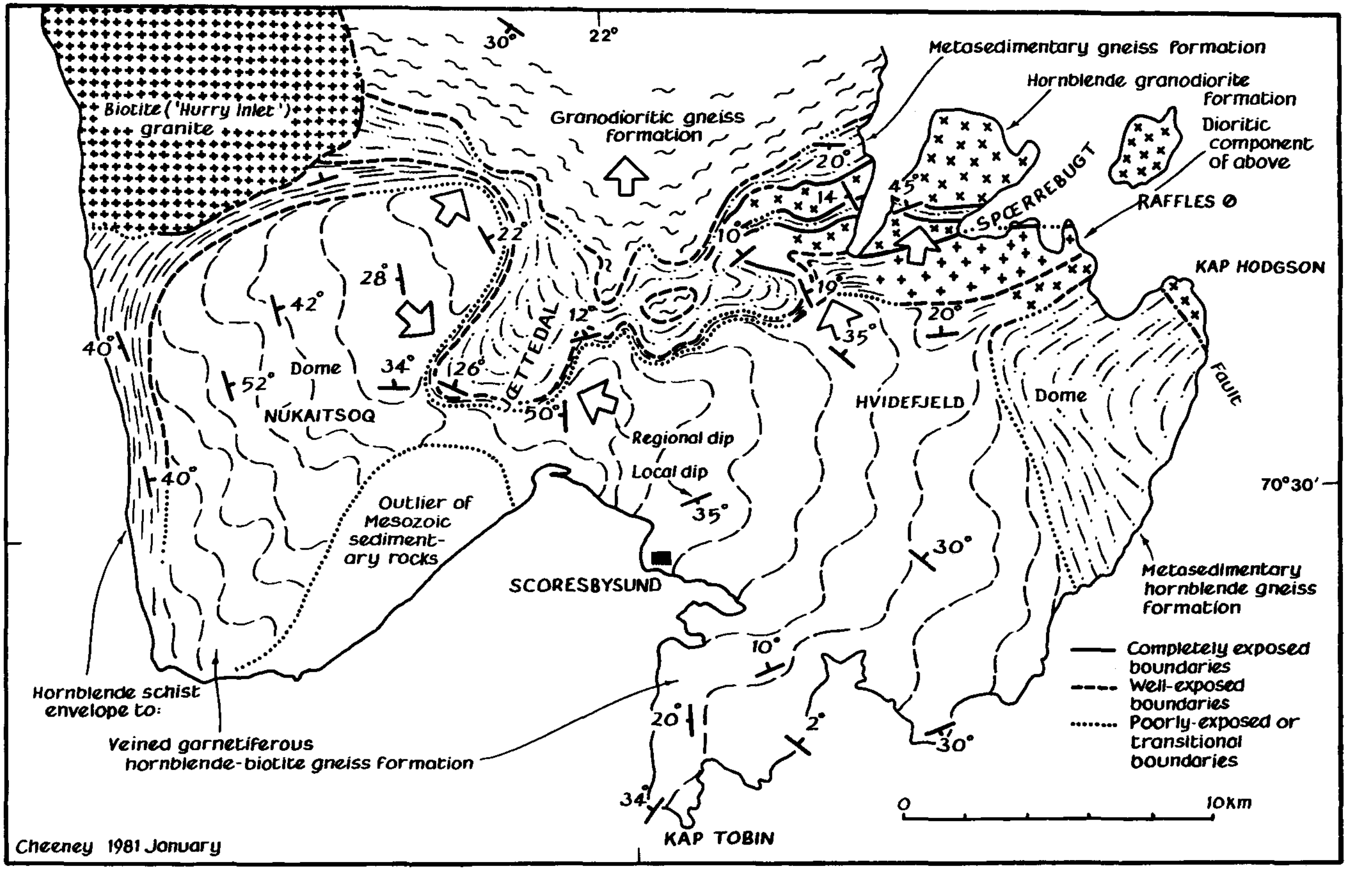


Fig. 2. Outline geological map of southern Liverpool Land showing boundaries of formations and both generalised (regional) and local dips of compositional layering. The positions of two domes are indicated approximately.

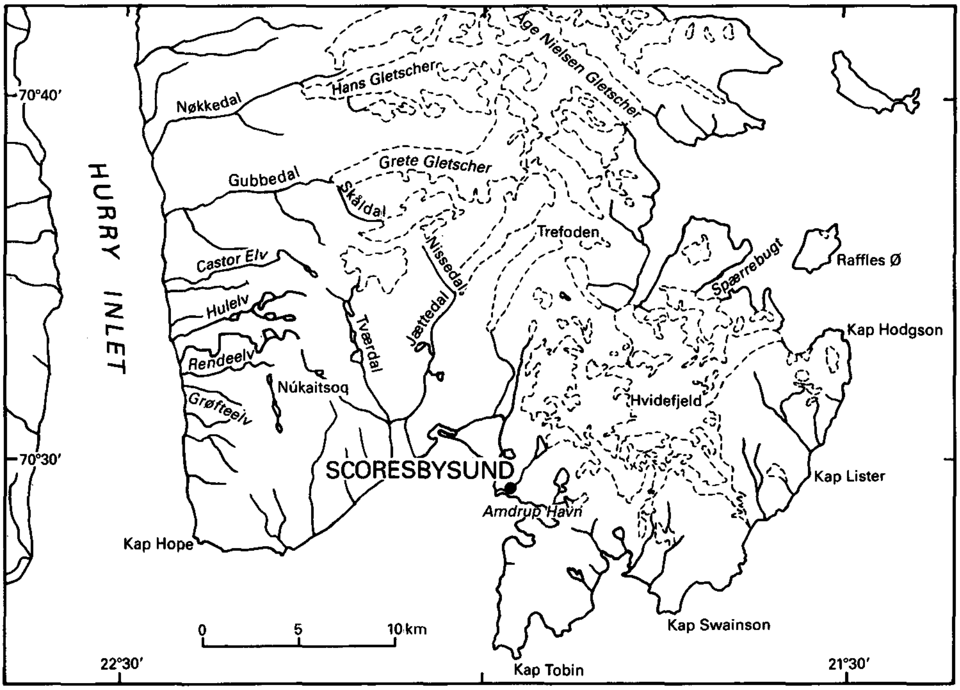


Fig. 3. Place names referred to in text and captions. Based on Geodetic Institute 1:250 000 map sheet number 70 Ø.1.

completed an outline geological map of much of the coastal areas of Liverpool Land and recognised a number of crystalline formations. However, being denied access to the interior, some of his inferences regarding field relationships are understandably tentative.

Kranck (1935, pp. 9–10) summarised the geology of southern Liverpool Land as consisting largely of migmatitic gneisses, probably mostly paragneisses, with a prominent granitic component in the form of pegmatite and aplite sheets. In the west, on the Hurry Inlet coast, rather different grey gneisses and darker garnetiferous gneisses with abundant eclogitic inclusions were encountered (Sahlstein, 1935). Amongst these darker gneisses, granitic material was less prominent. North-east of Kap Hope, Kranck found a mylonite zone which he supposed formed the boundary between these two gneiss types. North of the 'Hurry Inlet type gneisses', Kranck reported migmatitic gneisses with amphibolite inclusions increasing in abundance northwards, then a large area of granite, the Hurry Inlet granite. Whereas the latter was found to be unaffected by tectonic movements, the gneisses were generally interpreted as having been conspicuously deformed.

Regarding the age of the rocks, Kranck appears to have followed the prevailing concensus in alloting their origins to Caledonian events although evidence is not clearly stated. Koch (1929) had suggested that the Liverpool Land crystalline rocks, previously thought to be Archaean, represented a deep-seated level of the Caledonian fold belt. Within a few years, a similar Caledonian origin was being proposed for all the metamorphic crystalline rocks of East Greenland. The concept of a Caledonian stockwerke genesis for the crystalline rocks is most clearly presented by Haller (1971). In recent years the ready availability of refined isotopic age-dating techniques has made it possible to demonstrate that Caledonian orogenic events are superimposed on a complex of Proterozoic and Archaean orogenic events in East Greenland (see e.g. Steiger *et al.*, 1979; Higgins & Phillips, 1979; Higgins *et al.*, 1981; Rex & Gledhill, 1981). However, as stated above, these techniques have not yet been successfully applied to the rocks of Liverpool Land, and the likely absolute ages of the various rock components remain speculative.

Methods of the present work

In the absence of suitable topographic sheets at the time of this geological survey, mapping proceeded on transparent overlays to vertical aerial photographs (approximate scale 1:50 000) supplied by the Geodetic Institute, Copenhagen. Subsequently, standard photogrammetric procedures were used to construct a planimetrically more precise geological map on the scale 1:50 000 (fig. 2). Latitude/longitude coordinates quoted here are based on that map, and compare favourably with the more recent 1:250 000 map sheet (70 Ø.1 – 1978) published by the Geodetic Institute, on which fig. 3 is based.

The work was supported by boat in the 1969 season, with penetration inland from the coast camps rendered difficult underfoot by the large, angular bedrock blocks that litter much of the west and south of the area. Helicopter transport and reconnaissance in the 1971 season facilitated work in the rugged north and east of the area and enabled rapid consolidation of understanding of regional geology. A preliminary account and map of the whole of Liverpool Land is given by Coe & Cheeney (1972), and Coe (1975) provided a special study of the Hurry Inlet granite.

Outline of results

In the area described here, which lies south of a line through Gubbedal and Grete Gletscher, and south of the Aage Nielsen Gletscher (i.e. south of latitude 70°38′N) (fig. 3), metasedimentary, igneous and gneissic rocks are found of which the last are clearly oldest and clearly of both igneous and sedimentary origin. In the north-west of the area, near Hurry Inlet, a body of granite has cut the metamorphic formations, which are also unconformably overlain by Mesozoic sedimentary rocks in a small outcrop near Kap Hope in the extreme south-west.

Nearly all of the metamorphic rocks are prominently layered and over most of the area described, the layering is of shallow inclination, thus defining broad domes and saddles. Consequently, the metamorphic formations are disposed in a structural succession:

'Top' not seen
- Granodioritic gneiss formation
- Metasedimentary gneiss formation with schists, quartzites, amphibolites and marbles
- Thin hornblende schist
- Veined garnetiferous hornblende-biotite gneiss formation
- Metasedimentary hornblende gneiss formation with marble layers

'Bottom' not seen

The total 'thickness' is perhaps 2 to 3 km. The first and third from the top of this succession both grade laterally north-east into a hornblende granodiorite formation (with subsidiary dioritic rocks) from which they have been derived, in part, by processes involving strong deformation. These relatively less-deformed igneous rocks belong to Kranck's 'Granodiorites of Kap Hodgson and Raffles Ø' while their gneissic derivatives constitute his remaining metamorphic formations. He seems not to have encountered in bulk the marble-bearing formations which crop out entirely inland, although he does mention an isolated exposure of this rock type.

Within the veined garnetiferous hornblende-biotite gneiss formation, there appears to be west and east facies variation, as a consequence of which relatively unmigmatised gneisses in western exposures contain bodies of eclogitic affinity while relatively migmatised equivalents in eastern exposures carry bodies of mafic hornblende-biotite gneiss.

At its earliest decipherable stage, the crystalline complex contained igneous (granodioritic and dioritic) and sedimentary (mixed carbonate and argillaceous plus perhaps volcanic) rocks. Subsequently, these were raised to upper amphibolite or perhaps granulite facies of metamorphism while processes of deformation and migmatisation appear to be later. The origin of the eclogitic and associated inclusions remains undecided: field relations suggest they are not obviously tectonic, instead, they show certain gradational features towards their host gneisses, so they could be co-genetic. Alternatively, if assimilation has played a role, then they may be truly exotic (Smith & Cheeney, 1981). The emplacement of the Hurry Inlet granite marks the most recent event of significance.

Although no specimens collected in the area described here were used in the preliminary Rb-Sr whole-rock dating programme, certain formations that crop out further north are thought to be co-genetic with some in southern Liverpool Land. Thus, the ill-conditioned isochrons (O. van Breemen, personal communication) suggest an age of 430±80 m.y. for the Hurry Inlet biotite granite which is in accord with a Rb-Sr biotite age of 430±10 m.y. (Hansen & Steiger, 1971). However, others of the ill-conditioned isochrons are not similarly corroborated. The bulk of the veined garnetiferous hornblende-biotite gneiss formation may be co-genetic with gneisses near Kap Greg (Kranck, 1935) from which specimens furnish a poorly defined isochron suggesting an age of 1530±160 m.y. while the hornblende granodiorite formation perhaps belongs to a pre- or syn-tectonic suite with an 'isochron' age of 600±160 m.y. *If* these ages are real, their relation to K-Ar hornblende ages of 1124±50 m.y. and 1183±55 m.y. (Hansen *et al.*, 1973) is not clear.

STRUCTURE

Because of extreme deformation at an earlier stage, all compositional layering and most inter-formational bounding surfaces are paraconcordant. Consequently, the overall structure is simple. Minor tectonic structures are few, giving rise to another, perhaps deceptive, kind of structural simplicity. A brief account of major and minor tectonic structures follows immediately while further details of the internal structures of formations are given in a later section.

Major structural features

Principal layering in the metamorphic formations, together with the contact surfaces between these formations, generally dips at angles not exceeding about 30°, although the small-scale, internal structure of formations may exhibit greater complexity. Consequently, the major structural features may be presented quite adequately as in fig. 2. The dominating features here are the two large domes developed within the outcrops of structurally lower gneiss and metasedimentary formations, from which the structurally higher formations dip away to the north. The two domes are separated by a saddle located approximately along the line of Jættedal.

The Núkaitsoq dome in the west seems clearly defined, apparently with almost circular symmetry but perhaps elongate towards the north-east. It has marginal dips up to 30°–40° although its southern parts are largely obscured by Mesozoic and later deposits. The Hvidefjeld dome in the east is much less well defined, not only on account of more indifferent exposures but also because of shallower dips. Between the domes is developed a saddle, the west side of which seems to exhibit a smooth profile while the east side seems complicated by a number of gentle folds with approximately north-east trending hinges. Locally, in this zone of folding, dips are much steeper.

Northwards, amongst the structurally higher formations, dips are very gentle and there is no manifestation of the dome and saddle arrangement of the south.

Minor structures

Minor tectonic structures developed within formations are few, indicating perhaps a deceptive structural simplicity.

Small folds are developed in abundance only within the veined garnetiferous hornblende-biotite gneiss formation, but even there the regional significance remains obscure. Lineation, appearing as an inhomogeneous distribution of quartzo-feldspathic material taking the form of bands lying on foliation surfaces, is more widespread in the eastern outcrops of the veined garnetiferous hornblende-biotite gneiss formation and in the schistose sheath to that formation. Elsewhere, it is absent. The trend is simple, north to north-east with very little variation, save some contortion at one locality.

Description of the formations

The formations named and described here are those of the preliminary map (Coe & Cheeney, 1972, map 1); nearly all are prominently foliated and flat-lying, rendering the structural succession given above, and described from lowest to highest below. A unit of hornblende granodiorite grading into two of the gneiss formations is described first, and the later granite and dolerite intrusions last.

Hornblende granodiorite formation, grading into gneiss

This formation crops out on Raffles Ø (fig. 2) and immediately adjacent parts of the mainland.

The formation comprises rocks of granodioritic aspect and dioritic to pyroxenitic rocks in about equal proportions, while other rock types are rare. At only one locality (70°34'N, 21°47'W), does a notably different rock type occur: a greenish-brown weathering dunite in angular blocks separated by thoroughly serpentinised veins having dark-green micaceous rims.

The outcrop is divided into a series of west to east trending stripes which, from north to south, comprise: granodiorite to the north of Spærrebugt trending towards Raffles Ø, a narrow strip of a metasedimentary formation, a narrow strip of granodiorite, a wider strip of dioritic and pyroxenitic rocks (commonly mis-identified as amphibolite in the field), and a very narrow strip of granodiorite at the contact with another metasedimentary formation. Separate small, fault-bounded outcrops of granodiorite are found to the south-east of Kap Hodgson, and a small outcrop to the north-west of Jættedal (70°37'N, 22°08'W) not shown on fig. 2, sheathed by the granodioritic gneiss formation, is believed also to belong to this formation.

The striping of the outcrops can be attributed to strong deformation, despite which the overall igneous origin of the formation is clearly displayed at a number of localities although the details of the igneous history are difficult to assemble. Even though igneous structures are apparent at the exposures, the rocks can be shown to be in a highly metamorphosed state and schistosities and major lithological boundaries are paraconcordant to those of neighbouring formations.

Internal structure

The least deformed parts of the formation are found on Raffles Ø and on the peninsula north of Spærrebugt where igneous textures are clearly visible in hand specimens of the leucocratic plutonic rocks. Thus in the south-west of Raffles Ø (70°36'N, 21°32'W) is a coarse-grained rock, principally of fresh, pink, Carlsbad-twinned feldspars and lesser hornblende with phenocrysts developed. Nearby, the proportion of ferromagnesian minerals ranges between wide limits and inclusions are present.

Structures characteristic of igneous rocks, namely discordant contact relations, are especially well displayed at two localities. At the first (70°34'N, 21°49'W) the most prominent feature is the mafic dyke that has cut the more leucocratic host rock (fig. 4). Both dyke and host rock are heterogeneous in composition with amphibolite and hornblende pyroxenite in the former and hornblende pyroxenite and hornblende monzonite in the latter. In addition to this compositional inhomogeneity of the host rock, a weakly developed schistosity is present, and nearby, an interlayering of pyroxenite and monzonite is seen.

The second locality (70°34'N, 21°45'W) shows foliated granodiorite resting upon foliated pyroxenite. Foliation surfaces and contact surfaces are all paraconcordant but diligent searching reveals some discordant relationships at which schistose granodiorite is cut at acute angles by offshoots from a sheet of biotite pyroxenite, as shown in fig. 5a, and disorientated xenoliths of schistose granodiorite are found in the pyroxenite, as shown in fig. 5b. Nearby, the igneous history is further complicated in that an intrusion, now of biotite pyroxenite, contains xenoliths of an earlier pyroxenite as well as of granodiorite.

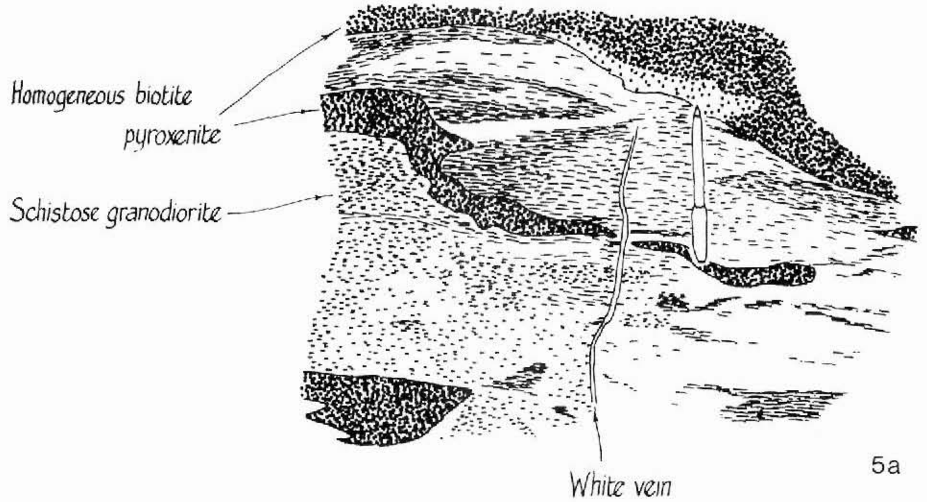
An isolated outcrop of rocks of granodioritic aspect, about 1 km long and situated at 70°37'N, 22°05'W, may be grouped with this formation on the basis of rock type and field relations. The outcrop is of grey hornblende granodiorite cut by pegmatites, aplites and a few

Fig. 4. (a) Discordant mafic sheet (now hornblende pyroxenite) emplaced in hornblende monzonite (also now metamorphosed). (b) Detail of the contact. Unnamed locality 70°34′N, 21°49′W.

sheets of dark, fine-grained micromonzonite. Contacts with the surrounding granodioritic gneiss formation are gradational, with the foliation of the latter becoming more prominent towards the margins of the granodiorite outcrop.

Contact relations

In spite of the clear evidence of an igneous origin of this formation, the strong deformation it has suffered, especially near its contacts, has brought about the parallelism of structure that is so well displayed in the field. Only in a few localities is there any preservation of original discordant relations with host formations. On the regional scale, therefore, *transverse* contacts, perpendicular to the strike of the schistosity, are to be distinguished from *lateral* contacts parallel to the strike of the schistosity. The former tend to be quite sharp and clearly displayed on valley sides; the latter are much more gradational and emerge only as a result of detailed mapping. Only near Kap Hodgson is a different kind of contact developed: homogeneous granodiorite is separated from a metasedimentary formation by a steep fault.



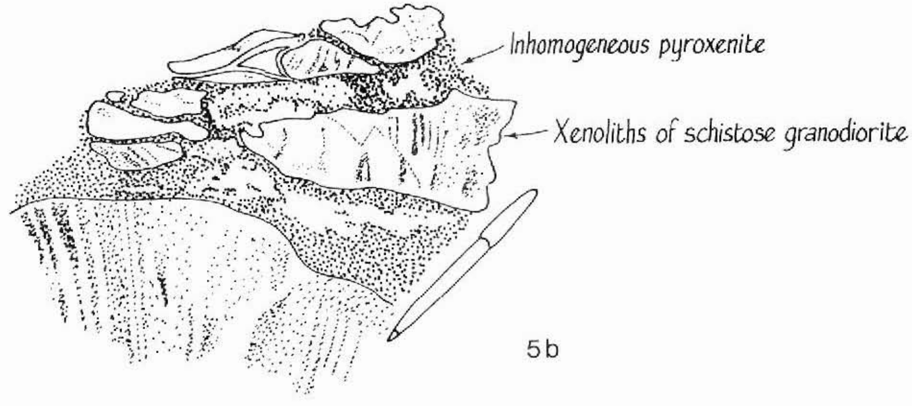


Fig. 5. Internal relations in the hornblende granodiorite formation. (a) Discordant contacts between biotite pyroxenite and schistose granodiorite. (b) Xenoliths of already schistose granodiorite in pyroxenite. (Both drawn from transparencies: the length of the pen is approx. 15 cm). Un-named locality 70°34′N, 21°45′W.

There are three transverse contacts, two bounding a strip of metasedimentary formation cropping out west of Spærrebugt and a third forming the structural base of the formation and cropping out on the mainland to the south-west of Raffles Ø.

West of Spærrebugt there lies a narrow outcrop of a metasedimentary formation, prominent on aerial photographs, confined between two outcrops of the hornblende granodiorite formation. The bounding surfaces of the metasedimentary rocks are approximately parallel and dip north at about 40°. Within short distances of both the upper and lower contacts, the granodiorite is relatively massive but schistosities developed in both formations are sensibly

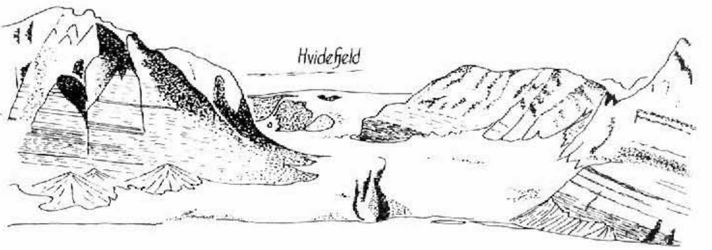


Fig. 6. Contact relations of formations between Kap Hodgson and Spærrebugt, with schistose hornblende granodiorite overlying a metasedimentary formation. (Drawn from a transparency: width of section 2.5 km).

parallel. The principal interest is that the metasedimentary formation is cut discordantly by a sheet of granodiorite and that both granodiorite sheet and metasedimentary rocks share a common schistosity.

On the mainland south-west of Raffles Ø, the structural base of the hornblende granodiorite formation is spectacularly exposed over a distance of 5 km along the northern side of the glacier draining the snowfield Hvidefjeld (fig. 6). The surface separating the granodiorite from the underlying metasedimentary formation dips to the north-west or north-north-west at about 25°. At the top of the cliffs is relatively massive pink granodiorite grading downwards into a schistose form. This schistose granodiorite overlies dark-coloured members of the metasedimentary formation in a perfectly concordant contact.

Detailed descriptions of the lateral relations, along the regional strike, of the hornblende granodiorite with the other formations are given below in the description of those formations, since they are clearly derived from the hornblende granodiorite formation as a result of combined deformational and metamorphic processes. Thus, the diorite/pyroxenite member of the hornblende granodiorite formation grades laterally into hornblende schist, the granodiorite itself passes into granodioritic gneiss and hornblende-biotite gneiss.

Mineralogy and textures

Thin-section study of this formation clearly reflects the leucocratic/melanocratic subdivision that was recognised in the field: predominantly quartzo-feldspathic rocks are most abundant, followed by rocks rich in the hydrated ferromagnesian phases hornblende and biotite. A third, smaller sub-group contains rocks rich in clinopyroxene, commonly misidentified in the field as a second amphibole.

Some of the salient features of the mineralogical composition include the following: (1) sphene is present in accessory amounts in many of the rocks and is often prominent in the field; (2) clinopyroxene is absent from the quartzo-feldspathic types, being ousted, apparently, by garnet, listed only in one thin section but prominent in the field; (3) there is a wide variation of quartz-feldspar proportions amongst the quartzo-feldspathic types; (4) in the mafic rocks, clinopyroxene is nearly always accompanied by hornblende except in one case where olivine, mostly serpentinised, is developed; (5) some of the mafic rocks are almost bimineralic clinopyroxene-hornblende associations with only accessory amounts of other phases.

The quartzo-feldspathic rock types show a wide overall variation in grain size while individual samples may be even-grained or not. Quartz grains almost invariably have undulose extinction, as do many of the feldspars, and albite twin-lamellae are commonly bent, as in samples 142637 and 142638. Nearly all of the feldspars are clouded to a greater or lesser extent with sub-microscopic particles which in a few cases may be identified as clay mineral/epidote mixtures. In sample 142657, feldspar boundaries are heavily sutured, and in this rock, and sample 142637, the feldspars show well developed undulose extinction. Hornblende tends to occur as large, irregularly shaped crystals, partly altered to chlorite in some cases and accompanied by profuse small epidote crystals in sample 142638. Sphene forms large crystals, commonly aggregated.

The mafic rock types, in general, are granoblastic, consisting of an equant aggregate of crystals of uniform grain size with simple grain boundaries, of which sample 142660 is a good example. Only rarely, as in sample 142645, is the texture indeterminate.

Clinopyroxene is the principal phase in nearly all of the rocks and simple twins are abundant. Sample 142642 is unusual in that clinopyroxene twinning is lamellar. In nearly all of the rocks in which hornblende is also present, there is a tendency for this mineral to form inclusions in the pyroxene in optical continuity with each other and sub-parallel to the pyroxene host.

The hornblende has two, not entirely separate, modes of occurrence. First, as inclusions in the clinopyroxene crystals, as above. Second, as individual crystals, some with simple twins developed. In the rocks where the hornblende occurs as aligned inclusions in the pyroxene, examples can be found of discrete hornblende crystals in optical continuity with the inclusions of neighbouring pyroxene crystals.

Plagioclase occurs as an interstitial phase, invariably clouded with alteration products. Other minerals occur in accessory amounts only.

In addition to the mild cataclastic features mentioned above, namely undulose extinction in quartz and feldspar and bent twin-lamellae in the latter, there are rarer examples in which grain reduction is much more advanced. Thus, sample 141910 is a highly schistose rock and sample 142636 has a well developed fluxion structure with plagioclase, alkali feldspar and hornblende porphyroclasts.

Metasedimentary hornblende gneiss formation with marble layers

This formation, the lowest in the structural sequence, crops out over a small area near Kap Hodgson (fig. 2), where it is principally confined to the lower slopes of valleys to the west and south-west of the cape. The outcrop is bounded on the east by hornblende granodiorite, with a faulted contact running south from Kap Hodgson. Elsewhere, the formation is overlain conformably by higher units in the structural succession so that the base is not seen. A minimum thickness of about 700 m of foliated rocks is exposed.

A strong colour contrast between individual layers is a very pronounced feature of the formation; these layers are as much as several metres thick and can be traced laterally for several hundreds of metres. Darker hornblendic gneisses make up most of the succession but there are abundant lighter layers of both pink and white marbles. Biotite and garnet appear to be very minor constituents of the gneissic rocks.

Some black, ultramafic sheets, only a few centimetres thick, are slightly discordant to the foliation of the gneisses in localities west of Kap Hodgson. A few of these sheets contain xenolithic inclusions of the country-rock. The presence of these sheets especially, but the overall characters of the formation as a whole, invite a superficial comparison with the gneisses of Kap Greg as described by Krank (1935, p. 49), and Coe & Cheeney (1972, p. 11).

Veined garnetiferous hornblende-biotite gneiss formation

This formation crops out over an area of 300 km^2 in southernmost Liverpool Land where the rocks appear to be disposed in very broad, twin domes so that a dumb-bell shaped outcrop arises. To the north and west the formation is found to have a sheath of mylonitised rocks; to the south and east the outcrop is bounded by the coast. The degree of exposure is modest: the ground is of low relief and is extensively covered with rock-debris, much of which may well be of local derivation. Many of the characters of the formation appear to be gradational from west to east but this is across the poorly exposed ground of lower Jættedal so that the transitions may be illusory. Kranck (1935, pp. 18–47) commented extensively on this formation.

Rock types and internal relations

This is a very variable formation of gneisses. In very general terms, the principal ferromagnesian phases in the western part of the outcrop are garnet and hornblende, and, in the eastern part of the outcrop, hornblende and biotite. A schistose augen gneiss variant is developed in the north-east where the formation grades into the hornblende granodiorite formation and a hornblende schist envelope or sheath is persistently found along the exposed parts of the northern and western margins of the formation.

Inclusions of various sizes and of various ultramafic rock types are characteristic of the formation and their mineral composition seems to be connected with that of the host gneisses. Thus, the inclusions in the western part of the outcrop are garnet, pyroxene and olivine-bearing, those of the eastern part of the outcrop are hornblende-bearing. Similarly, the ferromagnesian mineral content of some cross-cutting veins seems to reflect the composition of the host gneisses. Pegmatites are common and occur in two modes: pre- and post-tectonic.

The gneisses: general remarks

So variable is this formation, that it is hazardous to generalise. However, it may be said that the proportion of ferromagnesian minerals, although varying between wide limits, is commonly near about one half of the rock. Again, relations between the more leucocratic and the more mafic components of exposures are sometimes exceedingly intricate, as shown in fig. 7.

However, the organisation of field work resulted in these rocks receiving particular attention in three areas, namely upper Rendeelv (70°31′N, 22°20′W), Amdrup Havn (70°28′N, 21°52′W) and north of Hvidefjeld (fig. 2). Thus, the rocks are conveniently described in relation to these three areas, but then unfortunately, taken in isolation, the descriptions that emerge from each of these three areas may appear to be of distinctly different groups of

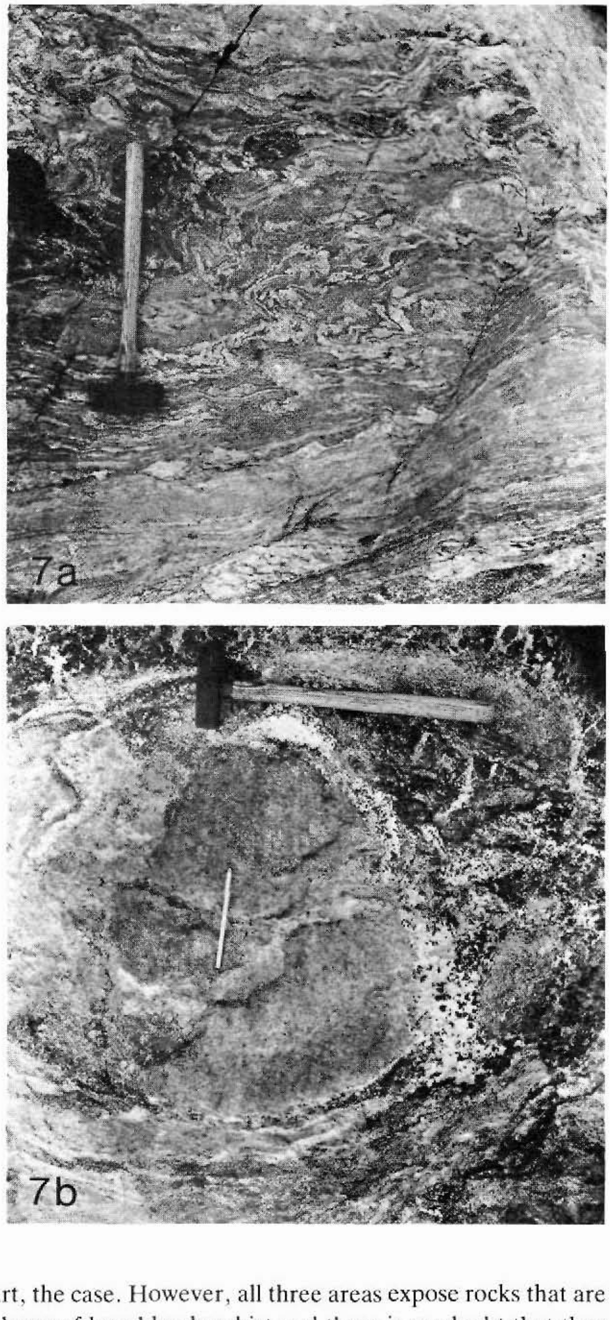


Fig. 7. Rock types in the veined garnetiferous hornblende-biotite gneiss formation. (a) Dominantly quartzo-feldspathic part of the formation. Upper Rendeelv. (b) Discordant block of garnet pyroxenite/eclogite with foliation parallel to the pencil, enclosed within host gneiss whose foliation in the exposure as a whole is parallel to the hammer handle. Large dark crystals are of hornblende. Upper Rendeelv.

rocks and this is undeniably, in part, the case. However, all three areas expose rocks that are structurally beneath a distinctive layer of hornblende schist and there is no doubt that they occupy equivalent positions in the structural succession. Gradations of texture and composition are readily traced between the three areas although this is somewhat masked by the poor exposure of lower Jættedal.

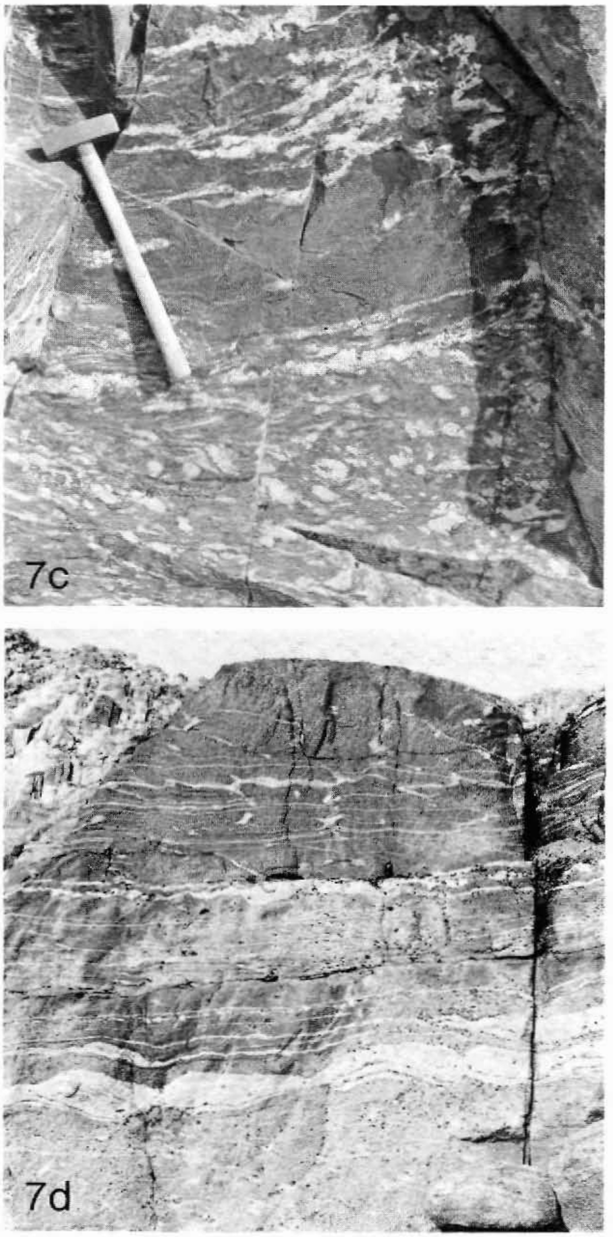


Fig. 7. *cont.* (c) Contact of hornblende gneiss and augen gneiss. Lower Hulelv. (d) Hornblende- and biotite-bearing gneisses with coarse-grained quartzo-feldspathic layers interpreted as boudinaged pegmatites. Rock face about 3 m high. Amdrup Havn.

The gneisses of Rendeelv and Tværdal

The leucocratic gneisses of the Rendeelv area are invariably foliated, fig. 7a providing a typical example, with alternating layers from ½ to 5 cm thick and composed of buff-coloured quartzo-feldspathic gneiss or grey hornblendic gneiss with quite sharp surfaces of separation. Whiter quartzo-feldspathic rock occurs in a few veinlets and irregular patches.

Where ferromagnesian minerals become more dominant, a division can readily be made into hornblende-bearing and garnet-bearing types and an association of the hornblende-bearing types with the leucocratic gneisses appears particularly common, fig. 7c showing an example of these compositionally more variable rocks. Typically, the foliated gneiss might consist of alternations of pink quartzo-feldspathic layers with dark-green hornblendic layers, the layers of the two rock types being 1 to 10 cm thick. The two rock types each contain partings of the other and there are lenses 3 cm thick to 10 cm long of the hornblendic rock in the quartzo-feldspathic rock. Fig. 7c shows a dominantly hornblendic host rock containing irregularly shaped, para-concordant veins, about 1 cm thick, of quartzo-feldspathic material and, and, in certain zones, concentrations of 'blobs' of buff-coloured quartzo-feldspathic rock, all with sharp margins. A more complete segregation of the hornblendic and quartzo-feldspathic components of the gneiss occurs, for example, where there is a sharp surface of separation of dark-green hornblendic rock, with only a few 1 cm thick quartzo-feldspathic layers, from a buff-coloured quartzo-feldspathic rock comprising an aggregate of 1 cm thick lenses with very thin hornblendic partings.

The garnet-bearing rocks are most arresting and an example is illustrated in fig. 8; they may be with or without foliation. Characteristically, a non-foliated example consists of dark, pinkish-brown rock with irregular dark-green hornblende-rich patches and is cut by sparse, irregular quartzo-feldspathic veins, 2 to 4 cm thick, with both sharp and diffuse margins and containing both hornblende and garnet. Nearby, alternations of dark pinkish-brown and light-brown, richly garnetiferous layers 2 to 10 cm thick are developed, associated with which are thinner (less than 1 cm) concordant and discordant layers of white quartzo-feldspathic rock containing hornblende.

A more distinctly foliated variant of the garnet-rich rocks is seen in fig. 8. Some of these layers, which are up to 5 cm thick, are almost pure, pinkish-brown garnet rock and they al-

Fig. 8. Layers of garnet and clinopyroxene constituting part of the veined garnetiferous hornblende-biotite gneiss formation. Dark crystals are of hornblende, otherwise, garnet or clinopyroxene dominates. Upper Hulelv.

ternate with quartzo-feldspathic layers in which the garnet is a minor constituent. Some of these quartzo-feldspathic layers contain large, 1 cm, hornblende crystals instead of garnet.

Garnet and hornblende-bearing rocks, broadly of the types described above, also crop out in the cliff faces of upper Tværdal (70°34′N, 22°11′W) and further to the north-east in Nissedal (70°36′N, 22°05′W). In these big cliffs, the irregular, large-scale layering of the formation is much more clearly displayed than among the small, scattered exposures to the southwest.

Modally, hornblende and biotite are the dominant ferromagnesian phases amongst the mafic gneisses with garnet and clinopyroxene in minor amounts. Medium to coarse grain size makes hand specimen identification of these minerals quite easy since the clinopyroxene is a pale-coloured variety. Nearly all contain at least a small proportion of quartz and one or both of the feldspars, while accessories include apatite, sphene, biotite and opaque minerals. Textures are interesting and very variable. Thus, specimen 141912 shows hornblende which occurs in two modes: as large discrete crystals with clinopyroxene cores and as small crystals in coronae surrounding garnets, which is a texture characteristic of the inclusions within the veined garnetiferous hornblende-biotite gneiss formation and is described more fully below. The larger hornblende crystals are frequently poikiloblastic, and the alkali feldspar is invariably perthitic. Nearer the upper contact of the formation, where there is a schistose envelope, textures reflect the transition: grain size is diminished, quartz extinction becomes undulose and biotite helps define a schistosity.

The leucocratic gneisses are dominated by a quartz-two feldspar mixture in widely varying proportions, but feldspar determination is frustrated by sub-microscopic inclusions. Quartz crystals are commonly large and free of undulose extinction except, again, nearer the upper contact of the formation. Ferromagnesian minerals include clinopyroxene and garnet as well as hornblende and biotite, the latter frequently with parallel intergrowths of chlorite. Specimen 104407 is interesting, but unusual, in having scattered, large crystals of orthite.

The gneisses near Amdrup Havn

The gneisses of the veined garnetiferous hornblende-biotite gneiss formation are relatively uniform in composition and structure in the Scoresbysund – Amdrup Havn – Kap Tobin – Kap Swainson area of south-east Liverpool Land as compared with the outcrops of the same formation in the Rendeelv area as described above. Two notable features of distinction are that the Amdrup Havn outcrops appear to be free of garnet and that a quite distinct, regular foliation is developed on all scales.

The composition of the gneisses in this area is quite simple. They are hornblende-biotite gneisses in which the dominant variable seems to be the relative abundances of the major mineral phases: hornblende, biotite, feldspar and quartz. A distinct anisotropy of distribution of these minerals has been introduced tectonically such that foliation surfaces are strongly lineated. This lineation takes the form of parallel bands or ribbons of quartzo-feldspathic material from less than one to about 5 cm wide. In exposure surfaces through the gneiss, parallel to this lineation but perpendicular to the foliation, there is a deceptive parallelism of all the structures including the surfaces of separation between the mineral layers. Discordances of structures, giving clues to pre-tectonic history of the gneisses, are only seen in those exposure surfaces that are perpendicular to both the foliation and the lineation, revealing, for example, boudinaged quartz-feldspar pegmatites.

Evidence of some hydrothermal alteration of the rocks is confined to fairly large but isolated patches. Thus, a large exposure north of Kap Tobin is traversed by a number of vertical, north-north-east trending zones of altered rock in which quartz and epidote are abundantly developed.

Thin-section studies reveal that in Jættedal there remain some of the assemblages common further to the west, namely clinopyroxene-garnet bearing, but they are rare. Most rocks consist of some combination of the two feldspars, quartz, hornblende and biotite with accessory amounts of apatite, sphene and opaque minerals. In a few cases only are more exotic minerals present, e.g. sillimanite in specimen 141904, rutile in specimen 141905. Both feldspars and biotite bear indications of having been altered: clouding with inclusions in the case of the former, parallel growths of chlorite in the latter. Textures are highly variable and range from granoblastic polygonal (e.g. specimen 141905) through rocks with well developed linear schistosity (e.g. specimens 142616 and 104428) to strongly cataclastic (e.g. specimens 142648 and 141901).

The gneisses north of Hvidefjeld

This well exposed area is of special interest because of the display of the vertical transition between the veined garnetiferous hornblende-biotite gneiss formation and the hornblende granodiorite formation that it affords. The cliff face situated at 70°33′N, 21°46′W exposes rocks near the transition: those that may be assigned to the veined garnetiferous hornblende-biotite gneiss formation are layered feldspar-hornblende-quartz rocks with a few 1 to 2 cm feldspar augen. Individual layers in the gneisses here fall into the range of 2 to 5 cm thickness.

At a locality situated at 70°33′N, 21°43′W, a rock type with a much more distinctive cataclastic appearance is exposed. It is medium to coarse-grained quartzo-feldspathic hornblende gneiss and has a wavy layering as well as a lineation of the type seen in the gneisses near Amdrup Havn, but differs from the latter in containing an abundance of flat feldspar augen. Some slightly discordant dark layers are present.

The mineralogy of the gneiss here seems unusually simple: hornblende, feldspar, quartz with some biotite and sphene and, in specimen 142647, a small amount of clinopyroxene. Feldspars are invariably impossible to identify on account of sub-microscopic inclusions and quartz always shows strongly undulose extinction.

The inclusions in the veined garnetiferous hornblende-biotite gneiss formation

Inclusions, that is, angular, sub-angular, sub-rounded and rounded bodies of distinctive composition, with sharp contacts against the host gneisses, are common throughout the veined garnetiferous hornblende-biotite gneiss formation and are found to range in size from a few centimetres to several hundred metres in maximum dimension. Over the eastern parts of the outcrop of the formation, east of Jættedal, the composition of the inclusion-minerals is not markedly different from that of the host gneisses so that they tend to consist of mafic gneisses, hornblende and hornblende-biotite bearing, with and without small proportions of a quartzo-feldspathic component. In the western outcrops, more exotic rock types are found as inclusions and it is these that attracted the attentions of Kranck (1935, pp. 30–33) and Sahlstein (1935). These earlier workers used the term eclogite to describe the more exotic

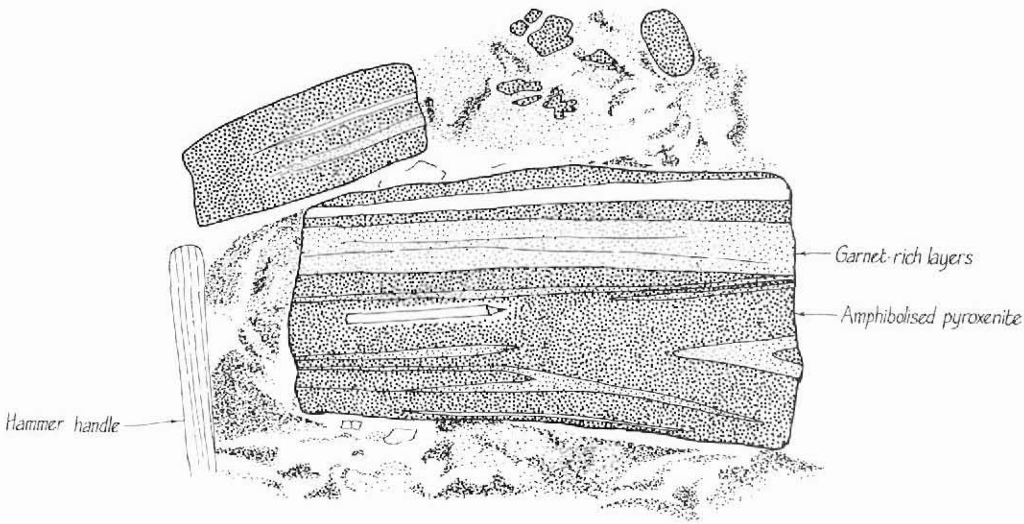


Fig. 9. Inclusions of eclogitic aspect within host rocks of the veined garnetiferous hornblende-biotite gneiss formation. Length of pencil approximately 15 cm. (Drawn from a transparency). Upper Rendeelv.

rock types but usage and interpretation have evolved to a considerable degree, such that the reader is referred to Smith *et al.* (1982) for a discussion of eclogites and their problems. The principal objective here is to outline their occurrence and relationships.

Fig. 7b shows some of the characteristic features of these more exotic inclusions. Here, we have a rounded block approximately 50 cm in outcrop diameter composed of grey-green finer-grained ultramafic gneiss enclosed by coarser-grained hornblendic gneiss, the latter containing hornblende-bearing quartzo-feldspathic veins with rather diffuse margins. The foliation in the host gneisses, not clearly shown in the photograph, is parallel to the hammer-handle, whereas the foliation of the inclusion is parallel to the pencil so that the strikes of the two foliations on the exposure surface are perpendicular. This distinctive relationship of the foliation of the inclusions with the foliation of the host gneisses is widely developed but the difference in composition between the inclusion and the host gneiss may be less distinct, both rock types being richly garnetiferous.

Completely isolated angular inclusions are clearly visible in upper Rendeelv and some are illustrated in fig. 9. The inclusions consist of layers less than 1 cm thick of various shades of dark greenish-grey, and are composed of amphibolised pyroxenite with and without garnet. The host rocks are hornblende quartzo-feldspathic gneisses with a rather irregular, patchy distribution of the minerals. The smaller of the two inclusions in fig. 9 is about 20 by 10 cm and represents about the lower limit of size amongst all of the inclusions. Larger inclusions seem to measure up to 200 to 300 m in maximum dimensions at least and, given time for precise survey, could be represented on maps of the scale 1:50 000.

Just to the west of Jættedal, at a locality 70°32′N, 22°11′W, abundant boulders up to about 50 cm in diameter in poorly exposed country consist of further exotic rock types amongst which are yellow-weathering peridotites. Glacial transport does not seem to have been very important in determining present superficial deposits in south-west Liverpool Land and it may be suggested that these peridotites may have much the same mode of occurrence as the exotic rock types of the inclusions. The peridotitic rocks tend to be heavily serpentinised but the primary phases are still recognisable and as well as the dominant olivine, they include clinopyroxene, garnet and an orthorhombic amphibole. The garnets are surrounded by coronae of radiating crystals, generally too fine-grained for optical identification. One of these specimens has been subjected to more detailed studies (Smith & Cheeney, 1981).

On the whole the mineral composition of the majority of the inclusions greatly resembles that of many of the host gneisses, especially in the exposures of Rendeelv and Tværdal and, given hand specimens or thin sections alone, it is impossible to draw a strict line of demarcation: only the greater content of ferromagnesian minerals in the inclusion rocks aids in setting them apart. Thus, in the western exposures of the veined garnetiferous gneiss formation, inclusions dominated by clinopyroxene and garnet are characteristic. In these rocks, the minerals are of medium to coarse grain size and exhibit a number of interesting textures. The clinopyroxene is colourless or very pale green, slightly pleochroic and the crystals are nearly always poikiloblastic. The inclusions in the crystals fall into two groups: amoeboid and acicular, the latter sharing a common orientation. Some of the amoeboid inclusions yield to optical identification: they are of plagioclase or alkali feldspar, or sometimes both. Microprobe analysis of the needles demonstrates them to be quartz (Smith & Cheeney, 1980, Smith *et al.*, 1982). The garnets are large, free of inclusions, on the whole, but insulated from all other coarse-grained phases by coronae consisting of radiating aggregates of crystals. Crystals in some of these aggregates are determinable as plagioclase/hornblende mixtures with a dusting of opaque phases. Quartz is another coarse-grained phase and, together with less common alkali feldspar of similar grain size, is commonly surrounded by a thin, fine-grained selvage of orthopyroxene. In some rocks (e.g. specimen 104406), the orthopyroxene also occurs as a rim to the clinopyroxene. Hornblende, biotite and plagioclase also occur in these rocks in a mode of occurrence very similar to that in the gneissic host rocks.

Schistose envelope to the veined garnetiferous hornblende-biotite gneiss formation

The western and northern boundaries of the veined garnetiferous hornblende-biotite gneiss formation are marked by a distinctive development of dark-coloured, fine-grained, strongly laminated, strongly lineated and schistose rock forming a structural unit 100 to 200 m thick on the top of the gneiss formation.

The best exposures are found in the cliffs on the south side of Skåldal (70°37′N, 22°10′W) where the unit exceeds 200 m thickness. Scattered exposures occur further to the south-west, in the less well exposed, small valleys that drain westwards into Hurry Inlet, where the finely laminated rocks of schistose or mylonitic aspects are dark-coloured, with individual laminae one centimetre or less in thickness. Fine grain size prevents mineral determination in the field.

There are no exposures between the Skåldal cliffs and upper Jættedal (70°34′N, 22°01′W), further to the east, but the unit is assumed to be structurally continuous as is the case with its thicker, flanking formation. It is thinner in upper Jættedal, certainly under 100 m, and comprises a biotite garnet schist, with prominent lineation, in contact with coarse-grained, foliated feldspathic amphibolite belonging to the underlying gneiss formation.

Continuity of exposure is again lost to the east until excellent exposures in a deep corrie situated at 70°35′N, 21°52′W. Here, the unit is about 100 m thick and is readily identified as a strongly lineated hornblende-biotite schist with flaser structure developed in quartzo-feldspathic layers. There is a clear contact of the schist with the gneisses below.

These are the easternmost exposures of this unit. The equivalent position in the structural succession across the deep valley between here and Spærrebugt is taken by hornblende pyroxenites (diorites) exposed in crags at 70°34′N, 21°45′W, and described above, but further highly schistose rocks are seen at 70°33′N, 21°43′W. It is thus only a small step to infer that the dark-coloured, strongly lineated rocks of schistose and mylonitic aspects are deformational derivatives of the hornblende pyroxenite and its associates.

The wide compositional variation in these rocks reflects that of the less schistose rocks in their immediate vicinity. The schistosity that characterises these rocks is, paradoxically, somewhat variable, depending on bulk mineralogical composition. In hornblende-rich types, a linear fabric prevails, in biotite-rich rocks, a planar schistosity. Quartz is always undulose and with highly sutured grain boundaries.

Contact relations

Because of the structural scheme of south Liverpool Land, outlined in the introduction, two types of gradational contact need to be described, *transverse* contacts and *lateral* transitions. The first deals with contacts across strike against compositionally completely different rocks, the second relates to transitions along strike into the hornblende granodiorite formation, of much the same composition but with somewhat different internal structures.

There are two sets of exposures where the transverse contacts of the veined garnetiferous hornblende-biotite gneiss formation have been found to be well displayed. The first is in upper Jættedal (70°34′N, 22°00′W) and the second is in the north-east facing valley side near 70°34′N, 21°52′W. At both localities, the veined garnetiferous hornblende-biotite gneiss formation grades structurally upwards into the schistose envelope (described above) over a distance of a few tens of metres perpendicular to the foliation. At the second locality, this transition occurs at the left of the panorama shown in fig. 10.

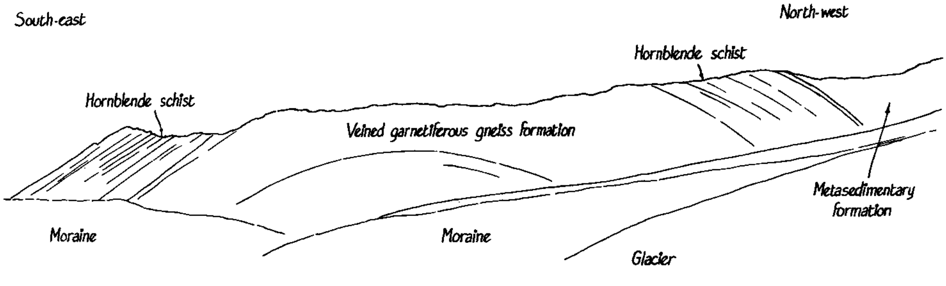


Fig. 10. Contact relations of formations exposed in an open antiform north-west of Hvidefjeld. Width of profile about 3 km. (Drawn from a photographic panorama).

Fieldwork restrictions prevented the veined garnetiferous hornblende-biotite gneiss formation being seen in contact with the underlying metasedimentary hornblende-biotite gneiss formation except by air during helicopter reconnaissance. It is surmised that this contact is of the same general type as the upper contact, i.e. gradational over a few tens of metres perpendicular to the foliation.

Detailed mapping of the large crags and nunataks that lie to the north-east, north and north-west of the snowfield Hvidefjeld demonstrates that the veined garnetiferous hornblende-biotite gneiss formation is gradational into the hornblende granodiorite formation over a distance of four to five kilometres as measured along the strike of their joint foliation. There is similarity in composition of the two formations but internal structures are quite different.

Metasedimentary formation with schists, quartzites, amphibolites and marbles

The dominant rock types of this formation are marble, quartzite, amphibolite and schist and they are found in a narrow, sinuous but continuous outcrop from Skåldal to Spærrebugt. In the east, the outcrop is split into two branches which flank a part of the outcrop of the hornblende granodiorite formation (see above, and fig. 2).

The formation belongs to a structural succession, such that it is overlain by the granodioritic gneiss formation and underlain by the veined garnetiferous hornblende-biotite gneiss formation; it has a thickness of 300 to 400 m.

The principal exposures are to be found on the south side of middle Gubbedal (70°38′N, 22°10′W) in lower Skåldal (70°36′N, 22°14′W), in Nissedal (70°36′N, 22°04′W), in middle Jættedal (70°33′N, 22°08′W and 70°34′N, 22°02′W), in a large rock basin (70°36′N, 21°52′W) and in Spærrebugt. The westernmost exposures show the effects of the later intrusion of the Hurry Inlet granite and will be described in the appropriate section below.

Internal structure and rock types

The dominant features of the internal structure of the formation are well displayed in the large rock basin at 70°36′N, 21°52′W and in Nissedal (70°36′N, 22°04′W). These localities show the formation to consist of interlayered rocks of widely different colours with individual layers of the order of 1 to 5 m thick. The lateral continuity of individual layers and of groups of layers is highly variable and layers are broken and folded on a small scale.

In detail, the formation is found to contain a wide variety of rock types. At a locality in Nissedal (70°36′N, 22°04′W), a quartzo-feldspathic biotite schist, with and without garnets, marble and quartzite are found in close association. In middle Jættedal (70°33′N, 22°08′W), a large crag contains closely associated coarse-grained pyroxene-olivine marble and quartzite, while further to the north-east in the same valley (70°34′N, 22°03′W) a low crag near a small lake exposes an even wider variety of rock types. These latter include quartzo-feldspathic gneisses with garnet, biotite and/or hornblende, layers of marble, generally coarse-grained, and lenticles of hornblende-garnet gneiss (garnetiferous amphibolite). Some of the more pelitic layers, forming a minor component of the formation, contain clearly visible kyanite crystals. A few veins, up to 5 cm thick, contain ore minerals. About 200 m eastwards along this same crag, quartzo-feldspathic gneisses are found in juxtaposition to a marble containing olivine and graphite.

Near the structural top of the formation at 70°35′N, 21°48′W, both coarse-grained white marble and less common fine-grained grey marble are found, with calc-silicate assemblages developed in some of the former. A pale-green amphibole is abundantly developed and occurs as lenticles in the marble.

On the peninsula west of Spærrebugt, the metasedimentary formation is very well displayed and its disposition is clear on vertical aerial photographs. At 70°35′N, 21°44′W, near the structural top of the formation, interlayered grey and white marbles with abundant calc-silicate minerals and amphibolite lenticles are interleaved with biotite-hornblende-feldspar gneisses, while lower down the succession, quartzite layers and quartzo-feldspathic layers with abundant amphibolite lenticles are seen.

All of the carbonate rocks sectioned show a granoblastic polygonal texture, including those that appear fine-grained in hand specimen. Grain size is variable but generally medium to coarse. Most of the carbonate appears to be calcite and is commonly accompanied by clinopyroxene, either diopside or hedenbergite. Olivine is less common and is frequently altered to serpophite/antigorite pseudomorphs. Accessory sheet silicates are common and in some cases may be confidently identified as talc by combination of optical and X-ray diffraction methods. However, other sheet-silicates are more difficult to determine and await further study. An interesting assemblage is found in specimen 142670, near the contact with the hornblende granodiorite formation, which contains parallel intergrowths of hornblende and clinopyroxene that seem to characterise that formation. Amongst accessories in the same rock is monticellite.

The amphibolites are less striking. Textures are again granoblastic polygonal and medium to coarse-grained. The schistose rocks appear to come from that part of the formation closest to the schistose envelope that surrounds the veined garnetiferous hornblende-biotite gneiss formation. Much of the quartz and feldspars of these rocks possesses strong undulose extinction and highly sutured grain boundaries. Further from the schistose envelope, rocks still schistose but with quartz and feldspar lattices less mechanically disordered, contain kyanite.

Contact relations

The compositional layering, or foliation, in the veined garnetiferous hornblende-biotite formation is para-concordant with that in the flanking formations and there is interleaving of rock types at both upper and lower contacts.

Exposures of the lower contact are few. One of the better is at 70°34′N, 22°01′W, in Jættedal, where the metasedimentary formation is in transitional contact with the schistose sheath to the veined garnetiferous hornblende-biotite gneiss formation. The transition takes place over a distance of a few metres as measured perpendicular to the foliation. The same contact is less clearly exposed further to the east at 70°34′N, 21°50′W (panorama, fig. 10) and at 70°35′N, 21°54′W where it is substantially similar.

The upper contact is moderately well exposed in upper Nissedal (70°36′N, 22°06′W), in crags at 70°34′N, 21°59′W and near the summit of Trefoden at 70°36′N, 21°53′W. In all three places, it is clear that the upper contact is transitional over a much greater interval of the structural succession than the lower contact and that layers of marble, in particular, may be found deep inside the area that has been mapped as the granodioritic gneiss formation.

In the east, where the metasedimentary formation has branched to enclose a part of the hornblende granodiorite formation that itself grades laterally into granodioritic gneiss formation, the contacts of the metasedimentary formation are very similar to that described in the last paragraph. One is excellently exposed on the north-west shore of Spærrebugt.

Granodioritic gneiss formation with amphibolite layers

This formation, the highest in the structural succession, crops out in the rugged mountain country in the north of the present area, extending from the northern boundary of the metasedimentary formation described above, northwards, into the area described by Coe (1975). Exposures are magnificent and consequently difficult of access, forming cliffs, arêtes and horns in the upper parts of the Hans Gletscher and Grete Gletscher. More accessible but smaller exposures, which show rocks near the contacts with the structurally underlying metasedimentary formation, are found in upper Skåldal (70°37'N, 22°03'W), upper Nissedal (70°36'N, 22°06'W) near the summit of Trefoden (70°37'N, 21°55'W) and in the valley draining southwards from there (70°34'N, 21°59'W).

The formation is predominantly of pink, layered gneiss with amphibolite layers, some discordant, some agmatised, becoming heterogeneous towards its base where it is conformably interlayered with the underlying metasedimentary formation.

Rock types and internal relations

Distant views of cliffs eroded in this formation give the impression of a distinct colour-layering developed in rocks which have only subtle variations in composition and texture. The most distinct colour-layering is seen in the northernmost exposures, the structurally

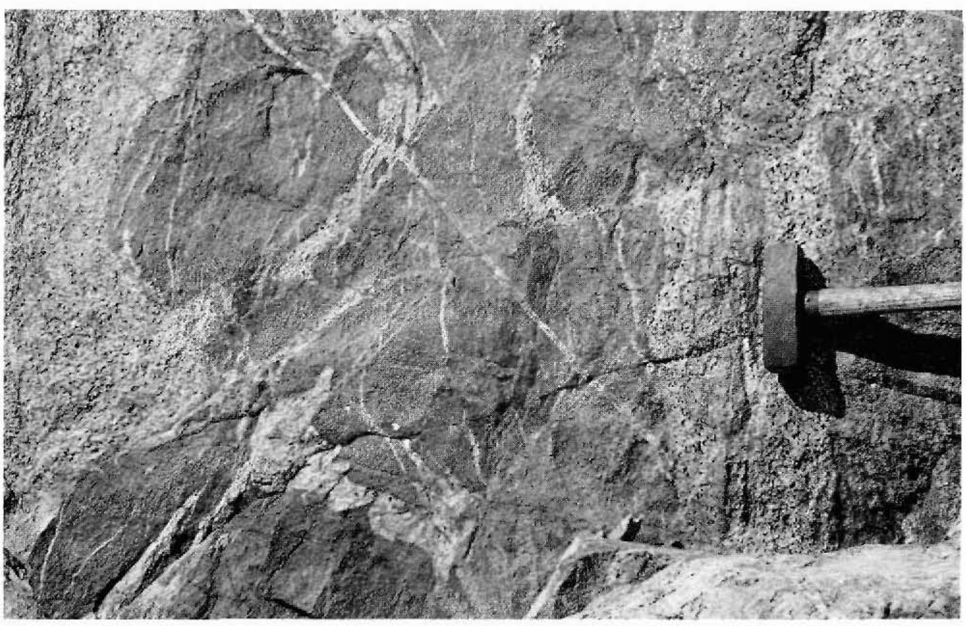


Fig. 11. Rocks of the granodioritic gneiss formation. Agmatised hornblende gneiss in a quartzo-feldspathic host, cross-cut by pegmatitic sheets. Un-named locality 70°36'N, 21°58'W.

highest found in this area. Near the base of the formation, layering is much less distinct although subtle compositional variation is still present, giving the rocks a heterogeneous aspect.

The dominant rock type is a medium to coarse-grained quartzo-feldspathic gneiss with colour index largely determined by variation in content of accessory hornblende and/or biotite. A few very distinctive layers are characterised by 1 to 2 cm porphyroblasts of Carslbad-twinned feldspar. A minor, but not insignificant, component of the formation is amphibolite which occurs in continuous sheets, in agmatised sheets and in isolated lenticles (fig. 11) being typical of an agmatised sheet. A very small number of these sheets are slightly discordant.

In the upper parts of the formation, markedly discordant sheets of aplite, granite and pegmatite are abundantly developed and reach thicknesses of up to about 50 m. Nearer the base, such sheets are not found, but these lower levels are more distinctive in containing epidote, often coating joint surfaces, chlorite and other alteration indicators such as clouded feldspars.

Fieldwork did not indicate any wide variation in composition of this formation nor any rocks of particularly diagnostic mineralogy so only two specimens were sectioned. Both are of uniform, medium grain size with quartz showing undulose extinction. Feldspars are clouded and chlorite seems a secondary development after biotite.

Contact relations

Only the lower contact of this formation is known in the area. It is concordant and rock types of this formation are interleaved with rock types of the underlying metasedimentary formation over a range of about 100 m perpendicular to the foliation. However, higher up, isolated layers of marble, 1 to 2 m thick, are sometimes encountered against which the gneiss often consists of a coarse quartz-feldspar-hornblende rock. The best exposure of the contact is in the valley side at 70°34′N, 21°59′W and a similar relationship is indifferently exposed in upper Nissedal (70°36′N, 22°06′W). A large enclave of hornblende granodiorite in this formation has already been mentioned above.

Biotite ('Hurry Inlet') granite

In the north-west of the area being described, there occurs the extreme southern end of the outcrop of a large granite mass (fig. 2), reported by Kranck (1935, pp. 84–89) and named by him the 'Hurry Inlet granite'. This granite is the largest of the granite masses in Liverpool Land, cropping out over an area of about 400 km^2. The main lithological and chemical variations of the granite have been described by Coe (1975).

Within the area described here, the outcrop is confined to the lowest few kilometres of the valleys of Nøkkedal and Gubbedal, extending no further south than Castor Elv. Exposure is severely limited, the outcrop being largely obscured either by ground and lateral moraines or by extensive areas of loose boulders and patterned ground. The principal exposures consist of a few granite tors on higher ground and valley-side cliffs in Nøkkedal and Gubbedal. The contacts of the granite with neighbouring formations are exposed in an overflow channel west of Skåldal and in a gorge section along Castor Elv.

Rock types and internal relations

As far as the limited exposure permits, the formation appears to consist of a homogeneous, medium-grained biotite granite with feldspars extensively clouded and epidote-covered joint surfaces widely developed. Some variation in the immediate vicinity of the contact is described in detail below. Apparently well away from the contact but perhaps near the roof of the intrusion there are a number of large xenoliths of marble to be seen in a valley-side exposure in lower Gubbedal (70°38′N, 22°24′W). This exposure would appear to be the only one in which xenoliths may be seen in this southern area.

Contact relations

Good exposures showing the very sharp contact of the granite with a marble of the metasedimentary formation are seen in a glacial overflow channel at 70°36′N, 22°15′W. There is little apparent alteration in either formation.

Better exposures of the contact occur in the banks of Castor Elv (70°35′N, 22°20′W) where the granite has intruded the hornblende schist sheath to the veined garnetiferous hornblende-biotite gneiss formation described above. Fig. 12a shows detail of the heterogeneous marginal facies of the granite body. The more typical homogeneous, pink medium-grained granite is seen on the left, a slightly coarser-grained, heterogeneous grey-green hornblendic rock in the centre, and a distinctly more mafic rock of similar grain size at the actual contact on the right. Light-coloured rocks are later aplite sheets.

Fig. 12b shows an augen-like development of quartzo-feldspathic lenses in a xenolith of the country rock close to the margin.

Similar deformed country rock is only developed very near to the granite contact, not

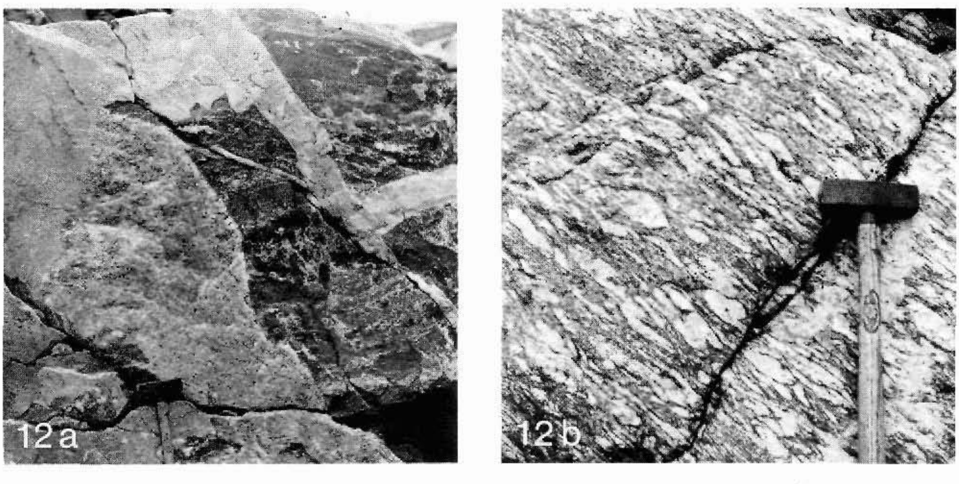


Fig. 12. Contact relations of the Hurry Inlet granite. (a) Hornblende-bearing gneisses (centre and right) cut by earlier and later phases of the granite. Castor Elv. (b) Xenolith of hornblende schist in the marginal part of the granite in which augen have developed. Similar augen occur in the country rocks but never more than 1 m from the granite. Castor Elv.

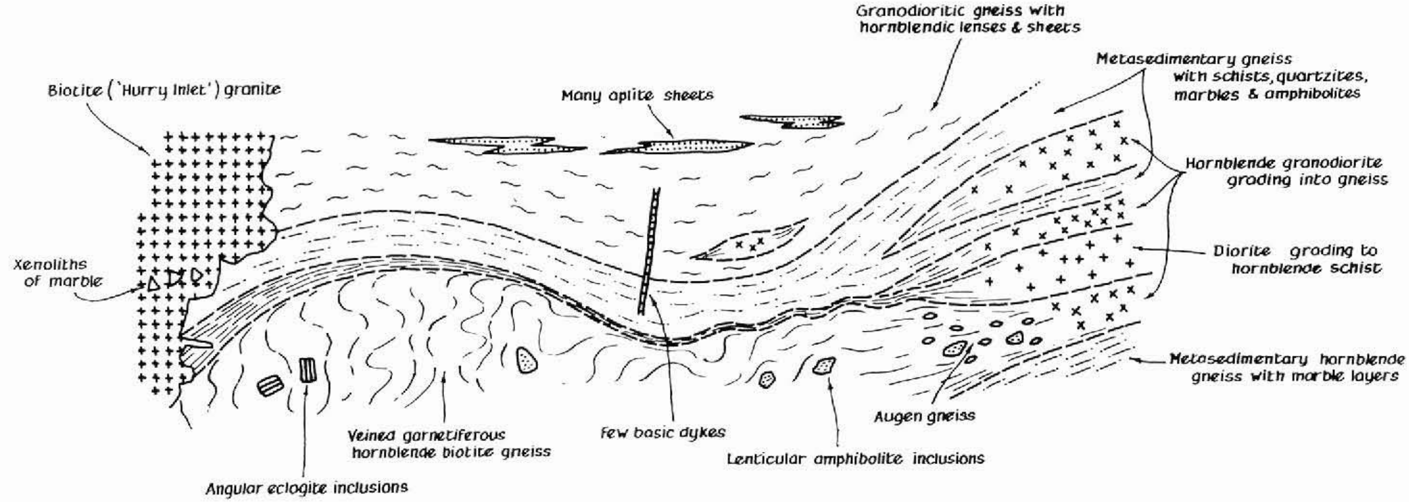


Fig. 13. Rock-relation diagram illustrating the supposed relationships between the principal formations. Note there is no scale and no orientation: this is not a cross section.

more distant than 1 m. This observation supports the conclusion of Coe (1975, p. 13) that the granite was emplaced by a process of high-level stoping.

In the structurally highest part of the granodioritic gneiss formation, markedly discordant, sub-horizontal sheets of aplite, granite and pegmatite attain abundant development and reach thicknesses up to 50 m. Their relations to the Hurry Inlet granite remain unknown, but their lack of foliation, together with their discordant relation to the host metamorphic formation make them almost certainly post-metamorphic.

Minor intrusive sheets, post-metamorphic

At several widely scattered localities, steep, north–south trending sheets of doleritic aspect are seen. None is more than a few metres thick. An irregularly disposed, but generally flat-lying sheet of similar dimension and composition is found in the extreme south-west of southern Liverpool Land. All of these doleritic sheets are discordant to formations described above. A Tertiary age was assumed by Kranck (1935) and Coe & Cheeney (1972) for these, and other minor basic intrusions.

The localities are: (1) On the ridge separating Skåldal and Gubbedal (70°37′N, 22°11′W); a steeply inclined sheet with north–south trend traceable intermittently northwards on the vertical aerial photographs and with a short extension southwards into middle Skåldal. (2) In middle Skåldal (70°36′N, 22°09′W); a steeply inclined sheet with north–south trend traceable over a short distance. (3) In middle Jættedal (70°33′N, 22°00′W); a steeply inclined sheet with north–south trend traceable over a short distance, deeply altered. (4) In upper Grøfteelv (70°30′N, 22°20′W); an irregular sub-horizontal sheet traceable over 100 to 200 m. (5) In the outskirts of Scoresbysund (70°29′N, 21°57′W); a steeply inclined sheet with north–south trend traceable over a short distance. (6) In middle Jættedal (70°34′N, 22°03′W); a concentration of loose doleritic boulders.

SYNTHESIS: PRINCIPALLY METAMORPHIC

This section is a linked interpretation of the field and laboratory investigations based almost entirely on the descriptive content of the earlier sections and gives a brief statement on the geological evolution and present state of the crystalline complex of southern Liverpool Land.

Fig. 13 is *not* a cross-section but attempts a simplified presentation of the broad relationships between the principal formations: metamorphic rocks of both igneous and sedimentary origin are cut by post-tectonic, post-metamorphic intrusions.

Briefly, the metamorphic formations appear to have consisted of a high-grade, veined garnetiferous hornblende-biotite gneiss in the west and high-grade meta-plutonic hornblende granodiorite and associated mafic rocks of dioritic aspect in the north-east. Even before subsequent cataclasis, it is probable that these formations, together with high-grade meta-sedimentary types, formed a complex that was prominently layered, at least in part.

Cataclasis is localised. The dioritic rocks grade laterally into hornblende schist, the hornblende granodiorite into augen and granodioritic gneisses, all of which contain localised zones of cataclastic rocks. Nevertheless, no thrusts have been detected, so large-scale lateral transport of the formations relative to each other is not thought likely.

The earlier, high-grade formations

Pertinent field relations and petrographic features will be mentioned and an interpretation of the state of metamorphism offered.

The hornblende granodiorite formation

The predominating leucocratic members of this formation are rocks of granodioritic and monzonitic composition but up to one third of outcrop area is occupied by melanocratic types: largely hornblende clinopyroxenite. The rock types comprising the formation are prominently interleaved on local and regional scales with each other and with adjacent formations. Locally and regionally, strong deformation resulting in production of schistosities paraconcordant to formation boundaries has been operative but the effect has by no means been uniform. Evidence that much of the deformation leading to paraconcordance of formation boundaries was pre-metamorphic lies in the granoblastic textures of the affected rocks: true cataclasis is extremely localised.

However, because of the inhomogeneity of this deformation, discordances typical of plutonism have been preserved in less deformed parts of the formation. A hint that the hornblende granodiorite formation invaded pre-existing sedimentary rocks is provided by an isolated example of a granodioritic sheet discordant to layering in metasedimentary rocks close to the boundary between the two formations.

The plutonic igneous origin of the formation thus seems well founded and is supported by the preservation of Carlsbad-twinned feldspar phenocrysts in some of the less deformed leucocratic rocks. Nevertheless, the abundance of pink-red garnets in the leucocratic rocks and the abundance of sphene suggests that reconstitutive metamorphism was effective and this is confirmed by the metabasites. However, clear-cut allocation to a specific metamorphic facies, based on the mineralogy of this formation alone, seems difficult, but the following observations seem pertinent to the position of these rocks relative to uppermost amphibolite/granulite facies.

Turner (1968, p. 325), in describing the amphibolite to granulite facies transition in the north-west Adirondacks, notes that with increasing grade, sphene and muscovite disappear, diopside becomes abundant and ultimately hypersthene appears. Further (p. 327), he mentions that at Broken Hill, basic assemblages ascribed to the granulite facies include hornblende, one or two pyroxenes (possibly diopside alone) and plagioclase and (p. 334) that anorthite is the only Ca-Al silicate in granulites. Sphene (p. 330) never occurs in granulites, rutile and/or ilmenite being the Ti-bearing phases.

Myashiro (1973), surveying the same problem notes (p. 210) the formation of calcic plagioclase at the expense of calcite and epidote and also of aluminous minerals (e.g. muscovite) because of the higher alumina to lime ratio of plagioclase with respect to epidote. Discussing garnet (p. 214), he says garnets rich in pyrope are not stable in conditions of regional metamorphism except in granulite and eclogite facies. Regarding hornblende (pp. 243, 254), he notes increasing tendency towards uptake of Ti with increasing grade as shown by changes in pleochroic schemes (Z goes from blue/green to green to brown).

Lastly, Winkler (1974, p. 81) defines the breakdown of muscovite in the presence of quartz and plagioclase as marking the change from medium to high grade metamorphism and states (p. 161) that diopside-rich pyroxene may form in amphibolites at high temperatures. Discussing granulite formation (p. 261), he argues that suitable conditions may arise when magmatic rocks are metamorphosed without introduction of additional water, i.e. temperature and pressure of high-grade regional metamorphism but with water pressure considerably less than prevailing hydrostatic pressure.

Taking these points approximately in turn with respect to the hornblende granodiorite formation of southern Liverpool Land, we may note:

(a) Sphene, although abundant, is by no means ubiquitous: suggesting equilibration in amphibolite facies for many specimens but allowing granulite facies for some.

(b) there is no muscovite in leucocratic rocks: suggesting high-grade conditions of metamorphism.

(c) there is abundant diopsidic pyroxene but no hypersthene: suggesting high temperature amphibolite facies or lowest granulite facies.

(d) hornblende-diopside-plagioclase assemblages are common: reported from both amphibolite and granulite facies terrains.

(e) plagioclase is common, epidote is not: allowing allocation to upper amphibolite or granulite facies.

(f) garnets are prominent pink-red and thus perhaps pyrope-rich: if so, then suggesting stabilisation under granulite facies conditions.

(g) hornblende in some rocks has Z = brown (e.g. specimen 142646, which is also sphene-free) although Z = dark-green or olive-green is more common: Ti-content thus appears high in some hornblendes, indicative of uppermost amphibolite or granulite conditions.

(h) scapolite, now pseudomorphed, has been abundant in specimen 142657 and is an occasional constituent of other meta-basites (the same mineral is abundant in adjacent meta-sedimentary formations): CO_2 pressure was thus probably high and water pressure correspondingly low, allowing crystallisation of granulite facies assemblages under pressure–temperature conditions more generally attributed to upper amphibolite facies with higher water pressure.

The conclusion is that the rocks of the hornblende granodiorite formation were intruded into sedimentary or meta-sedimentary rocks; subsequently they were deformed to produce the prominent striping of the formation, then metamorphosed under upper amphibolite and/or granulite facies conditions (with variable fluid composition) and lastly, subjected to localised but sometimes extreme cataclasis and hydrothermal alteration.

The veined garnetiferous hornblende-biotite gneiss formation

As well as occurring as principal constituents of the inclusions, distinctive garnet and clinopyroxene crystals, with their coronae and amoeboid inclusions respectively, are found scattered widely through the mesocratic and leucocratic host gneisses. Consequently, it may be that the conclusion arising from fieldwork that the formation consists of *host gneisses* and *inclusions* is misleading and the division, in fact, illusory: the petrographical studies suggesting a continuum.

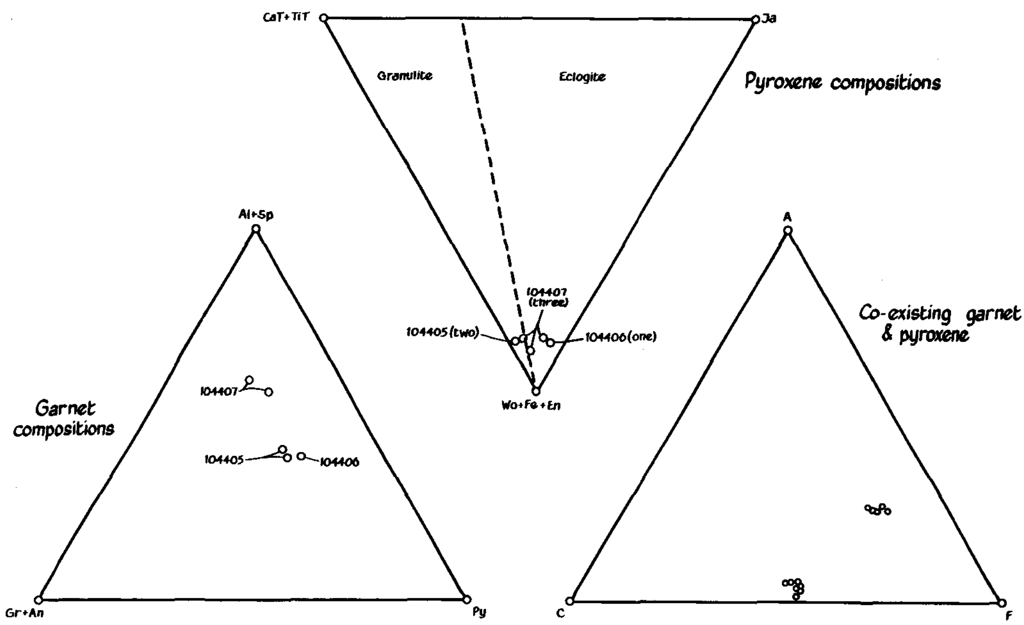


Fig. 14. Analyses of garnets and pyroxenes of the eclogitic inclusions within the veined garnetiferous hornblende-biotite gneiss formation. Left and centre: apices labelled according to end-member compositions; number within the triangles are those of GGU specimens. Right: ACF diagram representing co-existing phases in the same specimens as figured left and centre.

In the melanocratic rocks, the assemblage of primary minerals is clearly:

garnet + clinopyroxene + quartz ± (alkali feldspar)
or:
garnet + clinopyroxene + olivine + (orthoamphibole)

Amongst the melanocratic and mesocratic rocks, minerals of the secondary assemblages clearly include orthopyroxene, plagioclase, hornblende and biotite, all in some abundance.

Discussing granulite-facies rocks, Winkler (1974, p. 256) provides assemblages presented here as fig. 15. On these diagrams, many of the melanocratic rocks of the veined garnetiferous gneiss formation would appear to plot near the crossing of the almandine-clinopyroxene and plagioclase-orthopyroxene tie lines. The common occurrence of orthopyroxene selvages and plagioclase/hornblende coronae indicate the rocks have passed from one to the other of these sub-zones of the granulite facies, i.e. the primary phases crystallised under conditions of pressure in excess of 8 to 10 kb.

However, Myashiro (1973, p. 310 *et seq.*) in describing relations between granulite and eclogite facies rocks, notes that with increasing pressure, the anorthite content of plagioclase is incorporated into pyroxenes (which are thus highly aluminous) while the albite content also contributes to the clinopyroxene in the form of the jadeite molecule. Indeed (p. 313), the absence of plagioclase (as in the primary assemblages here) is taken to indicate eclogite-

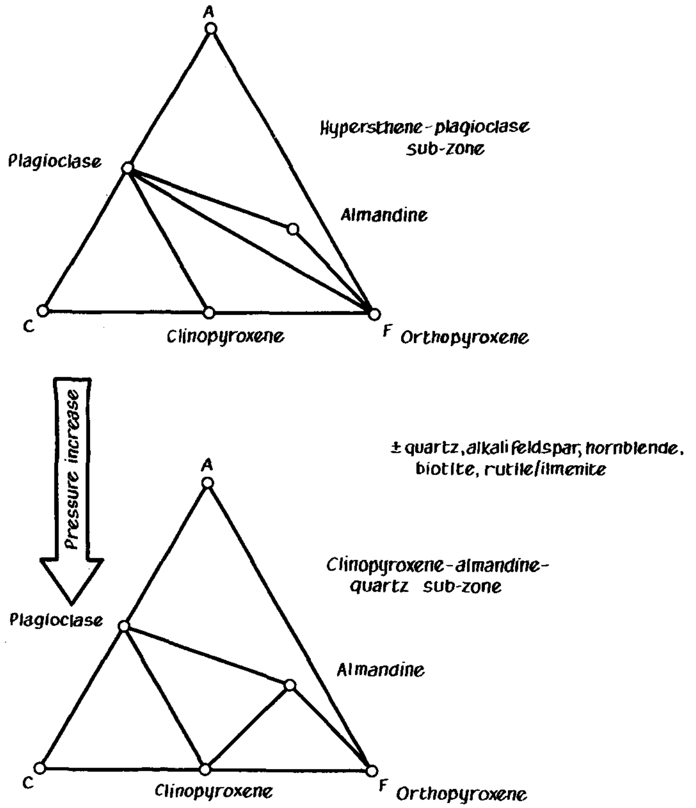


Fig. 15. Assemblages in granulite-facies rocks (after Winkler, 1974, p. 256), presented on ACF diagrams.

facies conditions. In summarising the work of White (1964) and Lovering & White (1969), Myashiro (1973, p. 317) describes how the ratio of jadeite to Tschermaks molecules in the clinopyroxene may be used to characterise granulite/eclogite assemblages: the data from Liverpool Land appear in fig. 14. Further, Myashiro (p. 318) notes that the work of Banno & Matsui (1965) and Lovering & White (1969) seems to demonstrate that the range of values of the Fe/Mg distribution coefficient, such as is found in the co-existing garnet and clinopyroxene in Liverpool Land, indicate kimberlitic affinities for these eclogitic rocks.

That the primary assemblage of garnet and clinopyroxene falls well within the eclogite facies is argued by Smith & Cheeney (1980) based on the occurrence of acicular quartz crystals included in clinopyroxenes, thought to be the consequence of an exsolution process from a supersilicic clinopyroxene.

Thus, although primary assemblages indicate that at least some of the rocks crystallised under eclogite-facies conditions, there is evidence for subsequent retrogression to granulite facies (incoming of orthopyroxene and plagioclase) and then further retrogression (or hydration) to upper amphibolite facies conditions (incoming of hornblende and biotite), analogous to those of the hornblende granodiorite formation.

Lastly, some evidence for later alteration of the gneisses is provided by the widespread occurrence of chlorites and altered feldspars. Specimen 104414, collected very close to the contact with the post-metamorphic, post-tectonic Hurry Inlet granite contains muscovite and a cataclastic rock, specimen 141904, collected in the vicinity of the schistose sheath, contains fibrolitic sillimanite. Kranck (1935, pp. 35, 38), however, reports the seeming widespread occurrence of andalusite. Localities are not given and I have not seen this mineral. Its contribution to the parageneses thus remains obscure.

The concluding statement is thus that perhaps the bulk of the rocks of the veined garnetiferous hornblende-biotite gneiss formation owe some of their present character to metamorphism at very high temperature and pressure, appropriate to the eclogite facies, and that they have subsequently been downgraded to granulite or upper amphibolite facies. The field-based descriptions in terms of 'inclusion' and 'host gneiss' may be misleading in that these field relations may arise as a consequence of relatively mild deformation under these high grade conditions: i.e. the 'inclusions' really belong to the gneisses in which they are found.

The metasedimentary formations

Formations including pelitic schists and marbles occupy two horizons in the structural succession (fig. 13). At the base is a metasedimentary hornblende gneiss formation with marble layers while higher is a metasedimentary formation with schists, quartzites, amphibolites and marbles. The outcrop of the latter is split towards the north-east, the two branches enclosing part of the outcrop of the hornblende granodiorite formation. The mineralogy of these rocks allows their division into three types: siliceous carbonates, metapelites and metabasites.

All of the siliceous carbonates are carbonate-bearing, calcite being present to the exclusion of dolomite. Calcite and quartz occur together and scapolite rather than plagioclase is the common Ca-Al phase, the meionite content being invariably over 0.75. Diopside is very common and may be accompanied by one or more of a number of silicates drawn from forsterite, antigorite, talc, phlogopite and hornblende. The last two are rare, nearly all assemblages being of anhydrous phases.

The rarity of hydrous phases, the co-existence of calcite + quartz and the occurrence of scapolite rather than plagioclase all seem to indicate high carbon dioxide pressures in the fluid phases. Winkler (1974, p. 114) notes the possibility that dolomite, if initially present, may be consumed with increasing metamorphic grade, in, for example, reactions with K-feldspar to give phlogopite (p. 125). That carbon dioxide concentrations in fluids may be subject to steep gradients is suggested here by the close proximity of scapolite and plagioclase-bearing parageneses as well as elsewhere by the observations of others. Ekström (1972, p. 179) suggests scapolite with meionite content over 0.75 probably has no chlorine and that the presence of calcite (ubiqitous here) may buffer the scapolite composition. Both Myashiro (1973, p. 267) and Kerrick (1970) propose uneven distribution of carbon dioxide, the latter suggesting control by original rock composition.

With respect to pressure– temperature regimes, Winkler (1974, pp. 121–122) says that the assemblage calcite+diopside+forsterite is stable at 5 kb and 780°C, while Myashiro (1973, p. 271) allots this assemblage to the high amphibolite facies. Further, Myashiro (pp. 268, 270) deduces that scapolite, although stable only at the highest temperatures in low pressure terrains (alongside wollastonite) is found from the tremolite zone upwards in high pressure areas.

Similarly, in reviewing metamorphic zonation in carbonate and calcsilicate terrains, Thompson (1973) noted a sharp decrease in biotite content with incoming microcline and sphene with increase of grade. Pegmatites indicative of partial melting, are restricted to this 'diopside-microcline' zone: all reminiscent of southern Liverpool Land.

Metapelitic rocks with diagnostic mineralogies seem less common. Plagioclase, microcline, quartz and biotite in these rocks form a base for the occurrence of garnet, often accompanied by kyanite. Except in rocks subsequently subject to cataclasis, sillimanite is not seen.

Amphibole-bearing assemblages are common in the rocks of the metasedimentary formation and characteristically contain also one or more of diopside, biotite, plagioclase, microcline and quartz. The amphibole is either hornblende or actinolite and the bulk compositions of the rocks may be appropriate to metabasites, metavolcanics or to ferriferous marls.

Kyanite being the characteristic Al-Si polymorph labels the assemblages as being of high pressure types. Occurrence of diopside with microcline + sphene rather than biotite indicates higher temperatures, as noted above.

Acknowledgements

Office and laboratory facilities at the Grant Institute of Geology, University of Edinburgh were made available by permission of the Regius Professor of Geology and B. Jeffries, G. R. Angell and P. G. Hill of the Institute assisted with various analyses. Electron microprobe facilities are supported by the Natural Environment Research Council.

K. Coe, J. D. Friderichsen, N. Henriksen and A. K. Higgins provided valuable support and discussion both in the field and subsequently but the interpretations expressed here are entirely the responsibility of the author. As field assistants, R. G. Cawthorne and T. V. Hansen expended considerable physical efforts. Mrs F. Verth typed the first version of the manuscript and A. K. Higgins and F. Kalsbeek provided most valued advice and support from GGU, Copenhagen, in the preparation of the final version.

REFERENCES

Banno, S. & Matsui, Y. 1965: Eclogite types and partition of Mg, Fe and Mn between clinopyroxene and garnet. *Proc. Japan Acad.* **41**, 716–721.

Coe, K. 1975: The Hurry Inlet granite and related rocks of Liverpool Land, East Greenland. *Bull. Grønlands geol. Unders.* **115**, 34 pp.

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

Ekström, T. K. 1972: Co-existing scapolite and plagioclase from two iron formations in northern Sweden. *Lithos* **5**, 175–185.

Funder, S. 1972: Remarks on the Quaternary geology of Jameson Land and adjacent areas, Scoresby Sund, East Greenland. *Rapp. Grønlands geol. Unders.* **48**, 93–98.

Funder, S. 1978: Holocene stratigraphy and vegetation history in the Scoresby Sund area, East Greenland. *Bull. Grønlands geol. Unders.* **129**, 66 pp.

GGU 1969: Report on the 1968 geological expedition to Scoresby Sund, East Greenland. *Rapp. Grønlands geol. Unders.* **21**, 53 pp.

GGU 1970: Report on the 1969 geological expedition to Scoresby Sund, East Greenland. *Rapp. Grønlands geol. Unders.* **30**, 44 pp.

GGU 1971: Report on the 1970 geological expedition to Scoresby Sund, East Greenland. *Rapp. Grønlands geol. Unders.* **37**, 59 pp.

GGU 1972: Report on the 1971 geological expedition to Scoresby Sund, East Greenland. *Rapp. Grønlands geol. Unders.* **48**, 117 pp.

GGU 1973: Report on the 1972 geological expedition to Scoresby Sund, East Greenland. *Rapp. Grønlands geol. Unders.* **58**, 76 pp.

GGU 1980: Geological map sheet 1:100 000. 71 Ø.1 S, Carlsberg Fjord. Copenhagen: Geol. Surv. Greenland.

GGU 1981: Geological map sheet 1:100 000. 70 Ø.1 N, Hurry Inlet. Copenhagen: Geol. Surv. Greenland.

Haller, J. 1971: *Geology of the East Greenland Caledonides.* 413 pp. New York: Interscience Publishers.

Hansen, B. T., Frick, W. & 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.

Henriksen, N. & Higgins, A. K. 1976: East Greenland Caledonian fold belt. *In* Escher, A. & Watt, W. S. (edit.) *Geology of Greenland,* 182–246. Copenhagen: Geol. Surv. Greenland.

Higgins, A. K. & Phillips, W. E. A. 1979: East Greenland Caledonides – a continuation of the British Caledonides. *In* Harris, A. L., Holland, C. H. & Leake, B. E. (edit) The Caledonides of the British Isles – reviewed. *Geol. Soc. London. Spec. Publ.* **8**, 19–32.

Higgins, A. K., Friderichsen, J. D. & Thyrsted, T. 1981: Precambrian metamorphic complexes in the East Greenland Caledonides (72°–74°N) – their relationships to the Eleonore Bay Group, and Caledonian orogenesis. *Rapp. Grønlands geol. Unders.* **104**, 5–46.

Kerrick, D. M. 1970: Contact metamorphism in some areas of the Sierra Nevada, California. *Bull. geol. Soc. Amer.* **81**, 2913–2938.

Koch, L. 1929: The geology of East Greenland. *Meddr Grønland* **73**(2), 1, 204 pp.

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

Lovering, J. F. & White, A. J. R. 1969: Granulite and eclogitic inclusions from basic pipes at Delegate, Australia. *Contr. Miner. Petrol.* **21**, 9–52.

Myashiro, A. 1973: Metamorphism and metamorphic belts. 492 pp. London: Allen & Unwin.

Rex, D. C. & Gledhill, A. R. 1981: Isotopic studies in the East Greenland Caledonides (72°–74°N) – Precambrian and Caledonian ages. *Rapp. Grønlands geol. Unders.* **104**, 47–72.

Rosenkrantz, A. 1942: The Lower Jurassic rocks of East Greenland. Part II. The Mesozoic sediments of the Kap Hope area, southern Liverpool Land. *Meddr Grønland* **110**(2), 56 pp.

Sahlstein, T. G. 1935: Petrographie der Eklogiteinschlüsse in den Gneissen des südwestlichen Liverpool Landes in Ostgrönland. *Meddr Grønland* **95**(5), 43 pp.

Scoresby, W. 1823: Journal of a voyage to the Northern Whale-fishery. 472+xlii pp. Edinburgh: Archibald Constable & Co.

Smith, D. & Cheeney, R. F. 1980: Orientated needles of quartz: evidence for exsolution of SiO_2 from a non-stoichiometric supersilicic "clinopyroxene". Abstracts, 26th International Geol. Congr., 7–17 July, 1980, Paris, France, p 145.

Smith, D. C. & Cheeney, R. F. 1981: A new occurrence of garnet-ultrabasite in the Caledonides: a Crrich chromite-garnet-lherzolite from Tværdalen, Liverpool Land, East Greenland. *Terra cognita* **1**, 3 only.

Smith, D. C., Kienast, J.-R., Kornprobst, J. & Lasnier, B. 1982: Eclogites and their problems. *Terra cognita* **2**, 283–296.

Steiger, R. H., Hansen, B. T., Schuler, C., Bär, M. T. & Henriksen, N. 1979: Polyorogenic nature of the southern Caledonian fold belt in East Greenland. *J. Geol.* **87**, 475–495.

Thompson, P. H. 1973: Mineral zones and isograds in 'impure' calcareous rocks, an alternative means of evaluating metamorphic grade. *Contr. Miner. Petrol.* **42**, 63–80.

Turner, F. J. 1968: Metamorphic petrology: mineralogical and field aspects. 403 pp. New York: McGraw-Hill.

White, A. J. R. 1964: Clinopyroxenes from eclogites and basic granulites. *Amer. Miner.* **49**, 883–888.

Winkler, H. G. F. 1974: Petrogenesis of metamorphic rocks. 320 pp. 3ed. Berlin: Springer-Verlag.

ISSN 0418-6559
AiO Tryk as, Odense