DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2008/70

Field relations, petrography and chronology of the component units of the western part of the Palaeoproterozoic Julianehåb batholith, South Greenland

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G E U S

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Abstract

The Julianehåb batholith is a major component of the Palaeoproterozoic Ketilidian orogen in South Greenland. It extends from the south-west coast, where it is 120 km wide, east-north-eastwards under the Inland Ice to the east coast where it is about 80 km wide. Mapping of a 400 km^2 area in the westernmost part of the batholith showed that this part of the batholith consists of six major granitoid units, named for convenience as follows: quartz monzodiorite, the north-western granite, the Qaqqarsuaq granite, the Uiffaat granite, the red granite, and the Saqqarmiut granodiorite. The composition of these granitoid units ranges from quartz monzodiorite to leucocratic granite. Minor components of the batholith are microgranites and relatively small bodies of mafic rocks characterised by having hornblende as the main primary mineral; the latter constitute an appinitic suite and occur particularly within the Saqqamiut granodiorite with which they are closely associated in time. Numerous thin dykes and sheets of intermediate to basic composition occur within all major units in the batholith. The quartz monzodiorite, the north-western granite, the Qaqqarsuaq granite and the red granite have all been sporadically affected by strong shearing that locally gave rise to NE–SW-trending zones of intense solid-state foliation or even mylonitisation.

Age relations between adjacent units in the batholith have been established by contact features such as veining of older units by younger, inclusions of older unit rocks in younger units, and fine-grained margins of younger units where in contact with older units. In addition, the degree to which the units have been affected by shearing when in a solid state can be used as an indication of relative age. By studying all these features it has been established that the quartz monzodiorite is the oldest unit in the western part of the batholith and the Saqqamiut granodiorite the youngest. The Saqqamiut granodiorite almost totally lacks zones of solid-state foliation, and where the Saqqarmiut granodiorite borders strongly sheared quartz monzodiorite, veins of unsheared granodiorite cut across foliation in the quartz monzodiorite. The Saqqarmiut granodiorite also lacks some of the swarms of minor intermediate to basic dykes and sheets seen in the older units, providing yet another indication that the Saqqarmiut granodiorite and its associated microgranites and appinitic rocks stand apart from all the other units in the western part of the batholith.

From field evidence it is clear that the start and close of the evolution of the western part of the Julianehåb batholith are represented by the quartz monzodiorite and Saqqarmiut granodiorite respectively, and that the ages of these units span the period of batholith emplacement in the west. For this reason these units were sampled for U-Pb geochronology and isotopic studies. The ages obtained were as follows: quartz monzodiorite 1868 ± 7 Ma; Saqqarmiut granodiorite 1804 ± 1 Ma. These ages show that this part of the Julianehåb batholith spans more or less the entire age range of the exposed parts of the batholith.

Introduction

The Julianehåb batholith is the dominant component of the Palaeoproterozoic Ketilidian orogen in South Greenland (Fig. 1). According to a new model presented by Chadwick & Garde (1996), the Ketilidian orogen is the result of oblique convergence of a supposed oceanic plate that lay south of the present orogen and an Archaean craton to the north, and the Julianehåb batholith is the root zone of a major Palaeoproterozoic magmatic arc that developed above the northerly subducted oceanic crust.

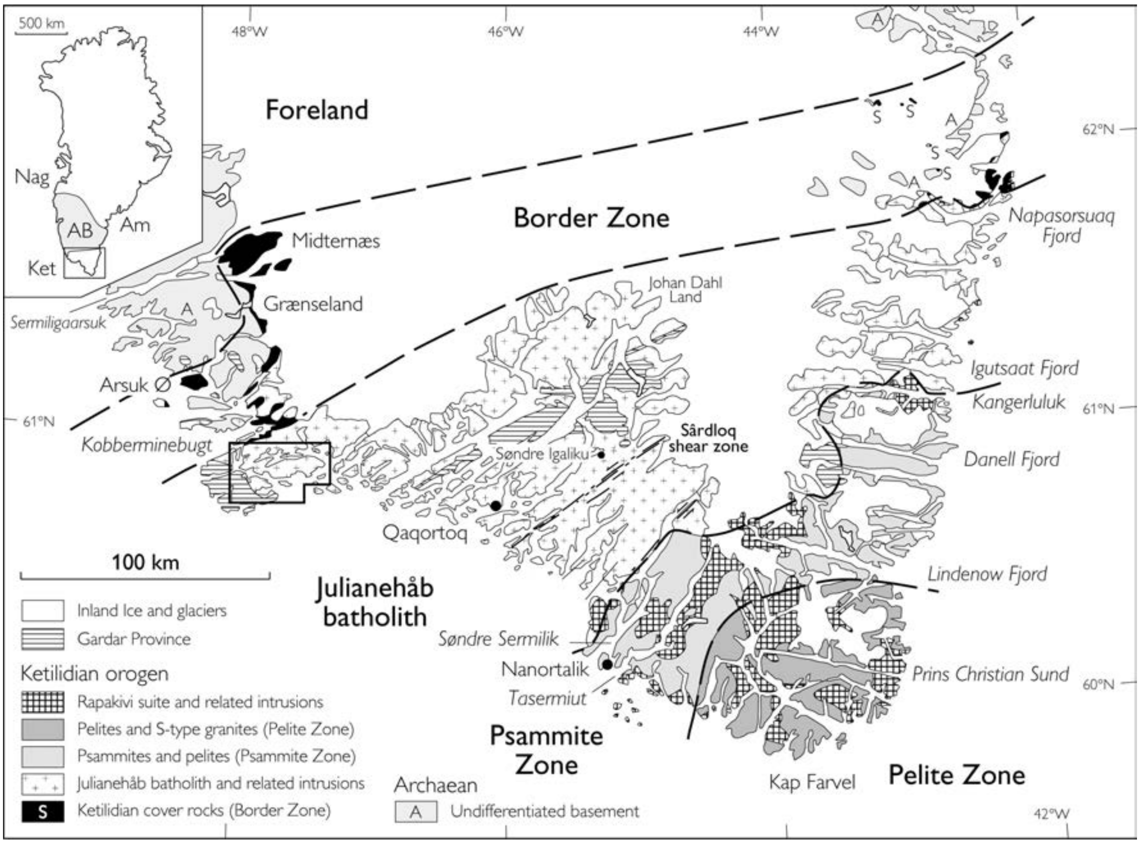


Figure 1. *Index map showing the position of the Ikerasassuaq area in the Ketilidian orogen in South Greenland. Based on Garde et al. (2002b, fig. 1). Inset map shows the positions of the Ketilidian orogen (Ket), the Archaean Block of southern Greenland (AB), and the Ammassalik (Am) and Nagssugtoqidian (Nag) orogenic belts.*

This paper presents a field and petrographic description of the units that make up the Ikerasassuaq area in the western part of the Julianehåb batholith, the only area in this part of the batholith in which distinct units have been systematically mapped out and their age relations established. Six granitoid units have been distinguished, one of which can be further divided into three types; in addition there are smaller bodies of microgranite and microgranodiorite, numerous dioritic and amphibolitic dykes, and small bodies of dioritic to ultramafic rocks characterised by having primary hornblende as the dominant mafic mineral (appinites). By studying the contact relations between juxtaposed granitoid units and the type and degree of deformation within the units, it has been possible to establish the chronological sequence of intrusive events.

In 1997 samples for isotopic dating were collected from several of the granitic bodies in the north-western part of the Ketilidian orogen in South Greenland (Garde *et al.* 1998). Two of the samples collected were from units in the Ikerasassuaq area within the main body of the Julianehåb batholith. The units sampled are known from field relations to be respectively the oldest and youngest in the western part of the batholith, and thus the ages obtained and reported here establish the time span of batholith emplacement.

Regional setting; history of research

The existence of a very large area of granitic rocks in South Greenland extending from Nunakuluut (the large island formerly called Nunarssuit) in the west at least as far east as Julianehåb was first recognised by Ussing (1912), who named this granitic massive the Julianehåb granite. Recently Chadwick & Garde (1996) have renamed this rock complex the Julianehåb batholith, principally because large parts of the complex are formed by rocks that are not strictly speaking granites.

In 1936 C.E. Wegmann carried out an extensive reconnaissance in western South Greenland and established the fundamental division of the rocks in this region into those belonging to an older orogenic complex, the Ketilidian, and those belonging to a younger ‘period’, the Gardar, during which continental sandstones overlain by basalts were deposited and alkaline intrusive complexes and extensive dyke swarms were emplaced (Wegmann 1938). The Julianehåb batholith is a major component of the Ketilidian orogenic complex which also comprises supracrustal rocks of both sedimentary and volcanic origin in all stages of metamorphic alternation from lower greenschist facies to granulite facies.

Systematic mapping of the western part of the Julianehåb batholith was carried out by the former Geological Survey of Greenland (GGU, amalgamated in 1995 with its Danish counterpart to become the Geological Survey of Denmark and Greenland – GEUS) in the late 1950s and early 1960s. The results of this mapping can be seen in a series of 1:100 000 map sheets issued between 1967 and 1973. A later map sheet at scale 1:500 000 (Allaart 1975; Kalsbeek *et al.* 1990) covering all South Greenland south of 62°30′N incorporates results of this mapping with the results of reconnaissance mapping in eastern South Greenland, and Allaart (1976) reviewed the geology of the Ketilidian orogenic complex as then understood. By this time it was clear from isotopic age determinations (e.g. van Breemen *et al.* 1974; Pedersen *et al.* 1974a, b; Gulson & Krogh 1975) that the Ketilidian orogen evolved during Palaeoproterozoic time and was roughly contemporary with the Svecofennian orogen of Scandinavia and the Makkovik Province in north-east Canada.

In 1992 investigations in the Ketilidian rocks of South Greenland were resumed, with particular emphasis on the poorly mapped area on the east coast where supracrustal rocks and shear zones had been shown to have economic mineral potential (project SUPRASYD; Garde & Schønwandt 1995 and references therein; Garde *et al.* 1997; Stendal *et al.* 1997). It was in the course of the SUPRASYD project that the new plate-tectonic model for the entire region evolved (Chadwick & Garde 1996). As already mentioned, in this model the orogen is viewed as the result of oblique convergence between a supposed oceanic plate south of the present orogen and an Archaean craton to the north. According to the model, the Julianehåb batholith is the root zone of a major Palaeoproterozoic magmatic arc that developed above the northerly subducted oceanic crust. To what extent reworked Archaean gneisses underlie the batholith is a matter still under discussion.

In 1997 reinvestigations of the Ketilidian orogenic belt were extended to the north-west side of the Julianehåb batholith and the foreland to the north (Garde *et al.* 1998). The marginal zone of the batholith is exposed in Kobberminebugt where outliers of the batholith are interleaved with Ketilidian supracrustal rocks, mainly basic metavolcanics, into which the granites were emplaced during alternating phases of dextral and sinistral shearing (Garde *et al.* 1998, pp. 115–117). During field work in 1997 samples were collected for isotopic dating, including the samples from the part of Julianehåb batholith described in this paper. However, no new field observations were made in this part of the batholith in 1997, so that the description of rock units and their field relations presented here is based entirely on field work carried out in 1958–60 and 1967 and reported in detail by Pulvertaft (1977).

The Ikerasassuaq area is crossed by a dense swarm of Gardar dykes (age *c.* 1250–1185 Ma; Engel & Pedersen 1974; Patchett *et al.* 1978). These are mainly dolerites with a NE–SW trend. Some of the thickest dykes are composite, with syenitic cores. Only giant dykes (those thicker than 300 m) are shown on the map Fig. 2. Fig. 2 also shows the outline of the Gardar alkaline plutons that occur in the area: the Nunarssuit intrusive complex (Harry & Pulvertaft 1963) and the Puklen intrusion (Pulvertaft 1961; Parsons 1972). Both these plutons are younger than the NE–SW dyke swarm; the Nunarssuit intrusion has been dated at 1171 ± 5 Ma (Finch *et al.* 2001). The youngest rocks in the area are NW–SE-trending dolerite dykes that belong to the Early Cretaceous (138–133 Ma) coast-parallel dyke swarm in South-West Greenland (Larsen *et al.* 1999).

Mapping and compilation of the 1:100 000 Survey map sheet

Mapping of the Ikerasassuaq area was carried out at scale 1:20 000 on maps with 25 m contour intervals prepared photogrammetrically by the Geodetic Institute, Copenhagen (now the National Survey and Cadastre). The results together with those from neighbouring areas were then compiled at scale 1:100 000 and published as Map 60 V.1 Nord Nunarssuit in the Survey's 1:100 000 sheet series. On this map sheet the Julianehåb batholith had to be shown in a single colour because subdivisions had not been consistently mapped out throughout the sheet area. However, the occurrence and relative contents of dark minerals, *in casu* biotite and hornblende, have been shown by superimposed coloured symbols, in this way giving some expression to variations within the batholith, and the contacts between component units where mapped have been shown as lines even though there is no change in colour at the contacts. The principles governing the old GGU standard legend and its application to the Nunarssuit 1:100 000 sheet and a guide as to how this sheet should be read are provided in Pulvertaft (1977).

Place names and naming of geological units

All place names on the 1:100 000 map sheets 60 V Nord Nunarssuit and in the descriptive report by Pulvertaft (1977) were those authorised and approved by the Greenland Place Names Commission in the 1960s, and spellings accord with the rules governing the spelling of the Greenlandic language at that time. However, in 1973 a reform of Greenlandic orthography was decreed with the consequence that place names had to be revised. As a result the names of rock units and formations that were introduced in the 1950s and '60s do not accord with the spelling of the type locality on many newer maps, and in some cases the type locality name has been dropped altogether and can no longer been found on new maps (e.g. the name "Nunarssuit" is no longer approved, even though it was the name used for more than a century for the very large island in the south-west of the sheet area that is now called Nunakuluut).

In this paper old spellings and names will only be used when applied to rock units defined in previously published papers and not merely in internal reports. When the name of a locality or feature has been changed or its spelling revised, the old name or spelling has been given in brackets after the first mention of the locality or feature.

The Julianehåb batholith in the Ikerasassuaq area

General

The area described in this paper is one of low relief by Greenland standards, the highest point in the area being the summit of Qaqqarsuaq (Qáqarssuaq), 481 m a.s.l. Large tracts of the area are less than 200 m a.s.l. The terrain is rough and hummocky, and outcrops are abundant, but in low-lying areas rock surfaces are extensively covered by crustaceous lichen which conceals detail in the rocks. However, the area is ramified by inlets and channels from the sea, and much of the land is in the form of islands, so that there are extensive clean coastal outcrops from which much information can be gleaned. In spite of lichen cover, it was possible to map contacts between lithological units accurately, except where there are transitions between units in the batholith.

The classification and nomenclature used here in the description of the granitoid units in the Julianehåb batholith is that recommended by the International Union of Geological Sciences (IUGS) Subcommission on the Systematics of Igneous Rocks (Le Maitre 1989).

Throughout the Julianehåb batholith there are bodies of ultramafic to intermediate plutonic rocks characterised by containing large primary hornblende crystals. These constitute an appinitic suite. They are regarded as having been emplaced more or less simultaneously with the surrounding grantoids and hence as an integral though volumetrically minor part of the batholith. For this reason a brief description of the appinitic rocks in the Ikerasassuaq (Ikerasagssuaq) area is given here. Another suite of basic–intermediate intrusions associated with the batholith comprises thin dykes and sheets of microdiorite, hornblendite and amphibolite; these are also described briefly in a later section.

Gneisses and supracrustal rocks within the batholith

Gneisses

A narrow screen of leucocratic gneiss separating the red granite and Saqqarmiut granodiorite (units defined on pp. 24 and 26) runs north-east from Tasiusaq (Tasiussaq). The rock is fine grained, pinkish in colour, and rather featureless but for weakly developed dictyonitic structure. It is composed of quartz, microcline and plagioclase, together with a little opaque oxide and rare flakes of muscovite. There are occasional thin rusty zones that are rich in Fe sulphides, magnetite and muscovite. Small balls of epidote, with or without magnetite, also occur in places. Within this leucocratic gneiss screen there are layers and lenses of fine-grained schistose amphibolite up to 20 m thick. There is also hornblendic gneiss, which consists of plagioclase, microcline, quartz, olive-brown biotite, green hornblende and titanite, together with accessory apatite and opaque phases. The dark minerals are concentrated in dark lenses. At the west end of the island to the south, 4.3 km west of Saqqarmiut, there is some streaky biotite-muscovite gneiss of granitic composition.

The origin of the rocks in this leucocratic gneiss screen is not clear. They do not resemble gneisses in the Archaean craton to the north. One possibility is that they were derived from acid volcanic rocks, i.e. are supracrustal.

Supracrustal rocks

Supracrustal rocks occur in a 4 km wide area crossed by the eastern end of the channel Ikerasassuaq. These rocks are completely isolated from the Ketilidian supracrustal rocks in Kobberminebugt (Fig. 1), and their stratigraphical relations are unknown.

There are two main rock types in this area: a fine-grained, pale-coloured type, and fine-grained amphibolite; rocks transitional between these are common. The rocks are believed to be of acid/intermediate and basic volcanic origin respectively

The fine-grained pale type can have a pinkish, grey or brownish hue. Structure is often lacking, but small parallel lenticular aggregates of dark minerals locally impart a weak foliation on the rocks; sometimes the dark lenses reach 5 × 1.5 cm in size. Rarely what are clearly lithic tuffs or agglomerates are seen, with fine-grained fragments of irregular or lenticular shape set in and separated by a pale matrix. These patches of tuff and agglomerate, which are up to a few metres across, have no particular form and extend vaguely in the general NE–SW strike direction.

On one of the islands east of Viiliap Nuua (Vîliap nûa) fine-grained siliceous rocks are characterised by aggregate grains of quartz of rounded form and up to 0.5 cm in size. A platiness due to < 0.5 cm thick layers of pure quartz constitutes the only planar structure on this island. These layers, which are only very local, are spaced 2–6 cm apart and are continuous for up to 40 cm. A few minor folds plunging steeply NE are marked out by the platiness. Joint surfaces in these pale rocks are often coated with muscovite, and muscovite also forms clots up to 1.5 cm in size in the body of the rock.

Another variety of the pale rock is porphyritic, with well-shaped, randomly oriented plagioclase crystals up to 6 mm long set in a very fine-grained matrix. This rock grades in places into uniform amphibolite.

In thin section the pale rocks can be seen to contain quartz, microcline and plagioclase, with very small amounts of any of the following: olive green biotite, green hornblende, epidote, chlorite, ilmenite, titanite and, in the most leucocratic types, muscovite.

Both microcline and plagioclase can form crystals up to 6 mm in size; the plagioclase crystals can be strongly altered.

The amphibolite is for the most part a fine- to medium-grained dark grey-green rock consisting of plagioclase *c.* An_{30}, green hornblende, olive green biotite, epidote, opaque phases, titanite and apatite. Often the rock is spotted with small clusters of hornblende and epidote or larger hornblende crystals; epidote in clots and veins is plentiful in places.

Over much of the outcrop the amphibolite shows little structure. Exceptions occur on the island off north-east Takisut (Takissut) where the rocks are greenish-grey and very evenly layered, and on an island to the north where there is a lens-shaped zone of agglomerate. The fragments in this are up to 30 cm long and consist both of fine-grained rocks resembling those in the immediate surroundings and of granite or granitic gneiss.

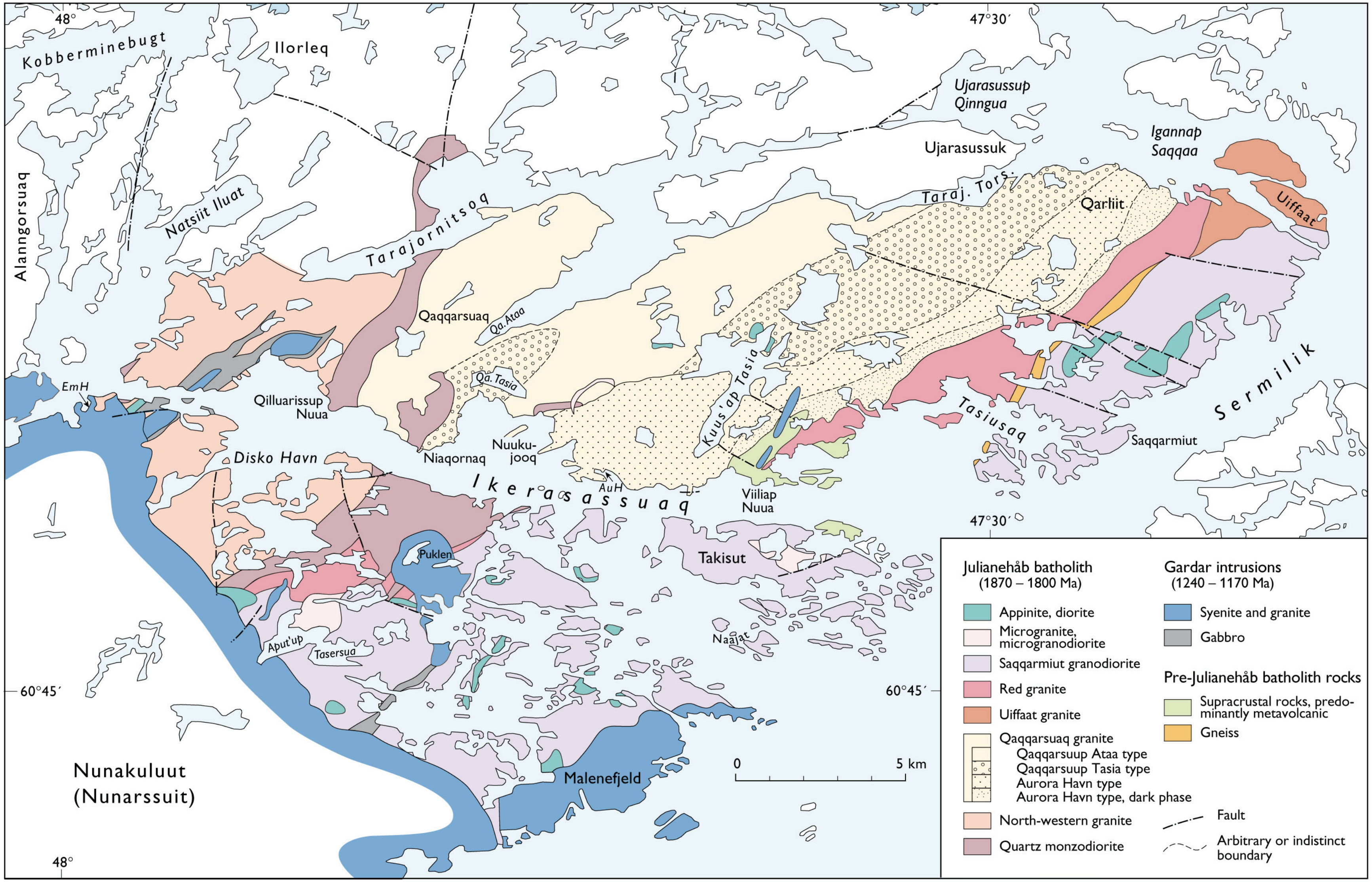
The only definite metasediments found in this area of supracrustal rocks are two layers about a metre thick of rusty-weathering garnet-magnetite schist that occur on the island off north-east Takisut.

Quartz monzodiorite

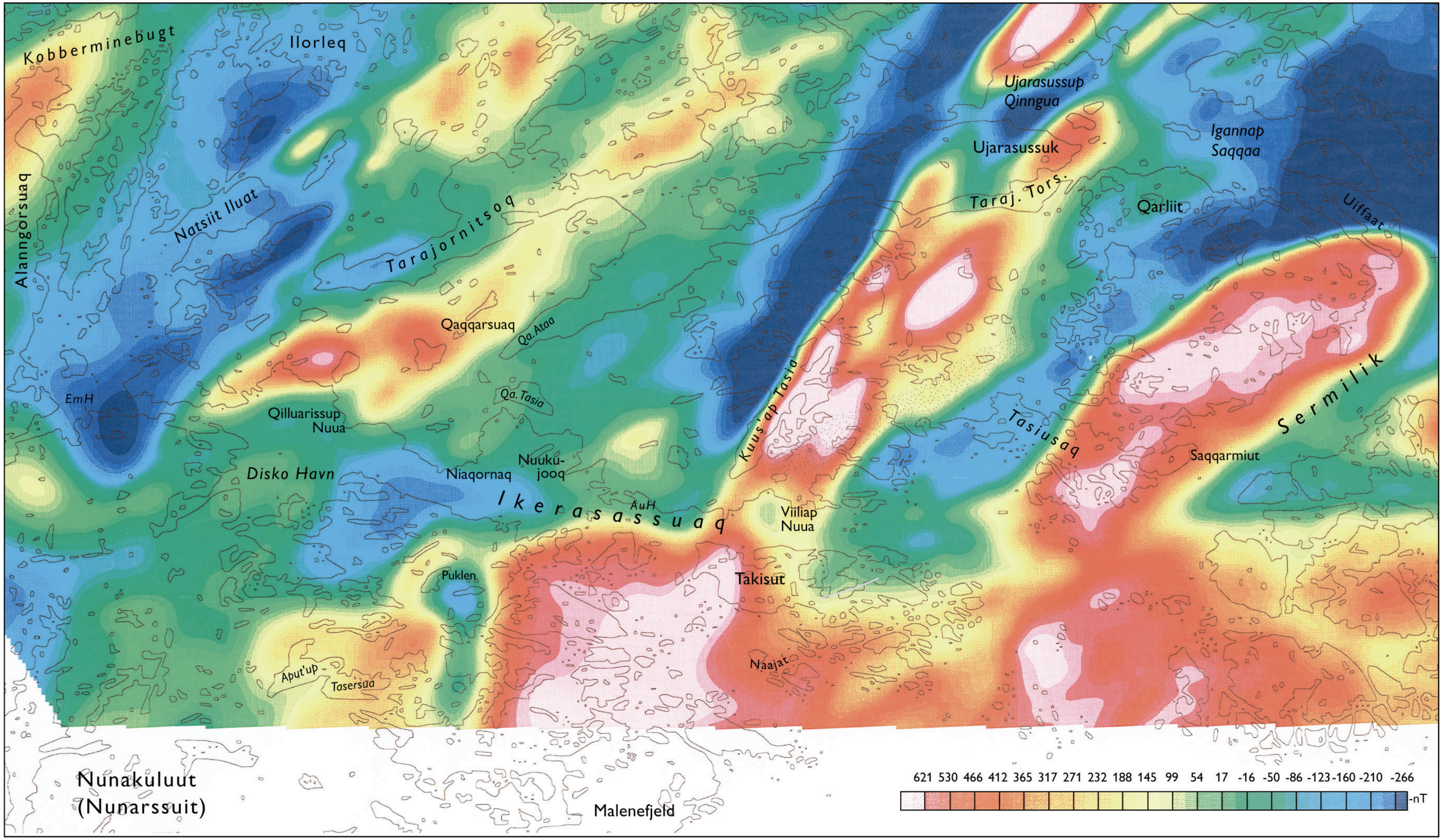
The quartz monzodiorite bodies in the Ikerasassuaq area are easily distinguished from the surrounding units in the Julianehåb batholith on account of their relatively dark colour and low quartz content. The main areas of quartz monzodiorite occur north and south of the sound Ikerasassuaq, in addition to which there are smaller, isolated areas of similar rock, e.g. a kilometre east of Emma Havn, across the sound 1.5 km north-east of Emma Havn, and 2.5 km north-west of Aurora Havn.

Figure 2 (see next page). *Map of the Ketilidian rocks in the Ikerasassuaq area, South Greenland. Place name abbreviations as follows: EmH: Emma Havn; Aput'up Tasersua: Aputaajuitsup Tasersua; Qa. Ataa: Qaqqarsuup Ataa; Qa. Tasia: Qaqqarsuup Tasia; AuH: Aurora Havn; Kuus'ap Tasia: Kuussuatsiaap Tasia; Taraj. Tors.: Tarajornitsup Torsukattaa.*

Figure 3 (see p. 15). *Total magnetic intensity map of the Ikerasassuaq area, South Greenland (from Thorning & Stemp 1997). Compare with Fig. 2.*



GS01.02-017-CP/hz


Kobberminebugt
Ilorleq
Alanngorsuaq
Natsiit Iluat
Tarajornitsoq
Qaqqarsuaq
Qa. Ataa
EmH
Qilluarissup Nuua
Qa. Tasia
Disko Havn
Niaqornaq
Nuuku-jooq
Ikerasassuaq
AuH
Puklen
Aput'up
Tasersua
Nunakuluut (Nunarssuit)
Malenefjeld
Takisut
Naajat
Viiliap Nuua
Kuussuap Tasia
Ujarasussup Qinngua
Ujarasussuk
Taraj. Tors.
Qarliit
Igannap Saqqaa
Uiffaat
Tasiusaq
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Sermilik
621 530 466 412 365 317 271 232 188 145 99 54 17 -16 -50 -86 -123 -160 -210 -266
-nT

The quartz monzodiorites are medium-grained rocks with xenomorphic- or hypidiomorphic-granular texture, consisting of plagioclase, microcline, light green hornblende, greenish-brown biotite and quartz; the plagioclase is usually oligoclase and often shows normal or oscillatory zoning. The accessory minerals most frequently found are opaque phases, titanite, epidote and apatite. Garnet and muscovite were observed in a single sample. The relative amounts of plagioclase, microcline and quartz vary, so that a wide range of rock types from quartz diorite to quartz monzodiorite can occur in the areas denoted quartz monzodiorite in Fig. 2.

Inclusions are common in the quartz monzodiorites. These are usually darker and finer grained than the host rock and can consist of diorite, amphibolite and even hornblendite (Fig. 4). Where inclusions are clustered together the rock is an agmatite. Sometimes the inclusions are lenticular and the surrounding quartz monzodiorite streaky and foliated. Contacts of inclusions can be sharp, sometimes with a dark rim (Fig. 5), or diffuse. Where inclusions are almost entirely digested in the host rock, the hornblende in the inclusions can be clustered into dark knots.

Figure 4. *Quartz monzodiorite rich in inclusions of various sorts, giving rise to a migmatite. Qilluarissup Nuua (Qitdluarigsup nûa).*

Foliation is commonly developed in the quartz monzodiorites and is of two types: 1) foliation marked by a parallel orientation of undeformed hornblende and biotite in an unsheared rock (magmatic flow foliation – Paterson *et al.* 1989); 2) 'shear foliation' or solid-state foliation (Paterson *et al.* 1989), accompanied by partial recrystallisation. Where the solid-state foliation is most intense, for example north-east of Puklen, the monzodiorite has been reduced to a fine-grained schist. The trend of both types of foliation is approximately NE–SW. North-east of Puklen, where the monzodiorite shows very strong shearing, there is also a lineation plunging 40–50° towards 190–225°.

Figure 5. *Inclusions with dark rims in quartz monzodiorite. Qilluarissup Nuua.*

In thin section many samples show cataclastic textures with the development of fine granulated patches and seams. Biotite may be buckled or broken down, and the twinning of plagioclase bent. Shear-foliated samples are fine grained but lack true mortar texture. A pronounced parallelism of biotite gives the rocks their schistosity. Small augen (porphyroclasts) of plagioclase and microcline occur, sometimes with rims that have grown after deformation.

The quartz monzodiorites are cut by veins of pinkish or light grey fine- to medium-grained granite, locally accompanied by pegmatite. These veins are seldom more than a metre thick and, where not deformed, are rather irregular. In areas of intense foliation these veins are locally so sheared that they resemble siliceous gneiss layers.

The north-western granite

As its name implies, this granite unit occupies the north-western part of the Ikerasassuaq area, north-west of the main outcrops of quartz monzodiorite. It appears from the descriptions by Harry & Oen (1964) and Watterson (1965) that the same unit continues into the Alanngorsuaq (Alángorssuaq) and Ilorleq (Ilordleq) areas to the north-west as far as the south-east coast of Kobberminebugt where it shows intrusive relations to the adjoining Ketilidian supracrustal rocks. The contact relations between the north-west granite and the supracrustal rocks and the relationship between granite intrusion and successive phases of deformation in Kobberminebugt have been described by Harry & Oen (1964), Watterson (1965), Garde *et al.* (1998) and Garde *et al.* (2002b), and will not be repeated here.

The north-western granite is typically a medium-grained, light grey, biotite granite with fairly prominent quartz. Locally, as for example around Disko Havn, the granite contains up to 3 cm long, randomly oriented microcline crystals. Weathered surfaces are grey or pinkish, and joint surfaces are often greenish due to the development of epidote. Foliation, both an early foliation and a later solid-state foliation, is unevenly developed in the granite.

In thin section the constituent minerals can be identified as microcline, plagioclase (oligoclase), quartz, and greenish-brown biotite, accompanied by accessory opaque phases, epidote (or clinozoisite), hornblende, titanite, apatite and chlorite. The plagioclase is often zoned; zoning may be normal, reverse or oscillatory. The texture is xenomorphic- or hypidiomorphic-granular, and provides evidence of a complex history of deformation and crystal growth illustrated best by the textural relations of microcline. In samples showing little or no evidence of deformation, microcline often forms large shapeless grains enclosing plagioclase and spreading out between other grains. In some samples showing solid-state foliation, microcline (and also plagioclase) forms porphyroclasts in a fine-grained, recrystallised matrix in which biotite shows a parallel orientation. In yet other samples showing marked shear foliation, microcline occurs as up to 3 cm long, randomly oriented porphyroblasts that may enclose fine-grained plagioclase and quartz. Some large microclines have grown in two stages, an outer rim with small inclusions having grown around an inclusion-free core. All these varieties of microcline may be cut by seams and patches of mortar, showing that a late cataclasis has affected the rocks. Other features indicative of cataclasis include buckled and broken biotite flakes and bent twin lamellae in plagioclase.

Inclusions are not common in the north-western granite outside a few small areas of migmatite. In these the inclusions are mainly of amphibolite recalling rock types seen in the Ketilidian supracrustals in Kobberminebugt. Unfoliated amphibolite usually occurs as agmatite with little reaction between inclusions and host granite, while foliated types show a greater degree of alteration, including transformation of hornblende to biotite. Outside the restricted migmatite areas inclusions are scattered and seldom more than 30 cm is size; they consist of anonymous dark lithologies. Randomly oriented microcline crystals up to 3 cm long are sometimes seen in dark inclusions, just as they also occur in biotite-rich streaks in the granite; these large microclines were originally interpreted as porphyroblasts that grew in their present site. However, an alternative interpretation is that they are phenocrysts that developed in the granite melt at a time when the intermediate–basic material present as inclusions was still mobile and could pick up phenocrysts from the enclosing melt (Barbarin & Didier 1991). These alternative interpretations are discussed by Pitcher (1997, pp. 154–156).

Occasional veins of aplite up to 50 cm thick and also of pegmatite cut the north-western granite. These also cut thin diorite dykes in the granite and therefore must belong to a very late stage in the evolution of the granite.

Contact between the north-western granite and quartz monzodiorite

This contact has been mapped from the boundary of the Nunarssuit intrusion north-eastwards to the shore of Tarajornitsoq. The contact is sharp along its entire length, and as far as could be seen, it is steep. At the contact the north-western granite is finer grained than usual. Blocks of quartz monzodiorite up to 2 m across are enclosed in this marginal facies (Fig. 6); these are usually angular but sometimes they merge into the surrounding granite. Near the contact the monzodiorite is cut by numerous veins of fine-grained granite fed from the marginal facies of the north-western granite. These relations show clearly that *the north-western granite is younger than the quartz monzodiorite*.

Figure 6. *Fine-grained marginal facies of the north-western granite veining and enclosing blocks of quartz monzodiorite. Shore south-east of Disko Havn.*

At Qilluarissup Nuua (Qitdluarigsup nûa) the contact between granite and monzodiorite is discordant to the foliation in these rocks; this foliation continues directly from one rock to the other without being deflected at the contact, although it is less distinct in the granite because of the lower content of biotite in this rock. It is clear that *a solid-state foliation has been imposed on both units after the emplacement of the north-western granite*.

Between 2 and 3 km north-north-east of Qilluarissup Nuua there is a *c.* 200 m wide strip of medium-grained, rather dark, biotite-hornblende granite that separates typical north-western granite from the monzodiorite. A sharp contact between this and typical north-western granite can be traced for about 200 m, and its contact with the monzodiorite is also distinct. This relatively dark granite is shown as part of the north-western granite in Fig. 2 because a) it lacks the inclusions so common in the monzodiorite; b) aplo-granite veins are not common in it as they are in the monzodiorite where it borders the north-western granite; c) hornblende is scanty in this granite while it is plentiful in the monzodiorite.

The Qaqqarsuaq granite

The unit designated the Qaqqarsuaq granite consists of three main types: the Qaqqarsuup Ataa type, the Qaqqarsuup Tasia type, and the Aurora Havn type; the Aurora Havn type is further divided into a pale and a dark phase. Although the Aurora Havn type is a granodiorite–tonalite, not a granite, for convenience the term Qaqqarsuaq granite is used for the unit as a whole. For the most part, boundaries between the types are transitional, indicating that the types are closely related and not independent intrusions requiring status as units.

Common to all types is the relative scarcity of dark inclusions. Where these occur they are usually widely scattered and less than 30 cm in size. However, west and north-west of the summit of Qaqqarsuaq and on the shore of Tarajornitsoq to the north, the granite, here the Qaqqarsuup Ataa type, is locally migmatitic, with inclusions of amphibolite and hornblende ± biotite schist in various stages of being digested in the granite (Fig. 7).

Figure 7. *Inclusions in the Qaqqarsuaq granite, Qaqqarsuup Ataa type, in various stages of assimilation in the granite.*

Another feature in common for all types is the occurrence of zones of solid-state foliation striking approximately NE–SW and dipping steeply NW where not vertical. In places the solid-state foliation is confined to zones less than 60 cm wide within which the shearing is intense, while the intervening rocks are only weakly foliated. Occasionally, as for example 2 km north-west of Aurora Havn, the shearing is so intense that a finely striped mylonite has been produced. In solid-state-foliated quartz-rich granite the quartz is flayed out into lenses, while in darker types biotite and/or chlorite occurs in fine-grained lenticular aggregates and the rock has become a fissile schist. North-west of Qarliit (Qardlît) the foliation is accompanied by a lineation in 238°/55° expressed by the parallel orientation of elongated biotite aggregates.

Veins of aplite, pegmatite and quartz are only a minor feature in the Qaqqarsuaq granite types.

The Qaqqarsuup Ataa type

This type occupies a large area extending north-eastwards from the shore of Ikerasassuaq between Qilluarissup Nuua and Niaqornaq to include the whole of the Qaqqarsuaq peninsula, and another large area extending from the east end of Qaqqarsuup Tasia to Tarajornitsup Torsukattaa (Tarajornitsup torssukátâ).

The Qaqqarsuup Ataa type is typically a medium- to coarse-grained leucocratic granite with feldspars reaching 2 cm in size and prominent quartz, much of it in ovoids up to 8 mm long. Microcline and plagioclase occur in roughly equal proportions. The accessory minerals are brownish-green biotite, chlorite, epidote, titanite and opaque phases. The plagioclase shows both normal and oscillatory zoning, and is often turbid with alteration. Microcline formed later, forming large xenomorphic grains sometimes enclosing plagioclase; it may be perthitic. Quartz is highly strained. Between the large grains in the rock there is much fine intergranular material and even mortar; thin seams of mortar cut all the minerals, including the late microclines.

Contact between the Qaqqarsuup Ataa type and quartz monzodiorite

The contact between the Qaqqarsuup Ataa type and the quartz monzodiorite to the north-west is sharp, except on the shore of Tarajornitsoq where it is obscured by strong shearing which has affected both rocks. The contact with the quartz monzodiorite body at Niaqornaq is transitional over 5–10 cm, and near the contact there are inclusions of monzodiorite up to 30 cm in size in the Qaqqarsuup Ataa granite. Thick veins and sheets of fine- to medium-grained reddish granite in the monzodiorite near the contact are thought to be derived from the Qaqqarsuup Ataa type granite, but this has not been established.

From contact relations it can be confidently stated that *the Qaqqarsuup Ataa type of the Qaqqarsuaq granite is younger that the quartz monzodiorites*.

The Qaqqarsuup Tasia type

This type occurs in a zone extending north-eastwards from the shore of Ikerasassuaq across the west end of Qaqqarsuup Tasia (Qáqarssup tasia) towards the sound to the north, and in another area between the northern end of Kuussuatsiaap Tasia (Kûgssuatsi-aup tasia) and the eastern end of Tarajornitsup Torsukattaa. It is a quartz-rich type but less leucocratic than the Qaqqarsuup Ataa type, and has a plagioclase:microcline ratio >1. The characteristic feature of the Qaqqarsuup Tasia type is the presence of fairly plentiful biotite (or its chlorite pseudomorphs) in blocky pseudo-hexagonal crystals up to 7 mm wide and 5 mm thick, of random orientation. In thin section these crystals can be seen to be frequently strained and buckled, and around their margins broken down to fine aggregates together with epidote. Titanite is a constant and even conspicuous accessory in this type, and a little apatite and opaque material are usually present.

No sharp contacts can be seen between this type and the Qaqqarsuup Ataa type. The biotite/chlorite content increases gradually from the Qaqqarsuup Ataa to the Qaqqarsuup Tasia type; the change in habit of these minerals can take place within as little as 10 m.

Relations between the Qaqqarsuup Tasia type and quartz monzodiorite

This boundary is *transitional*. The transition takes place over about 80 m and is best studied on the shore at Niaqornaq, even though the rocks here are somewhat sheared. Traced eastwards the quartz monzodiorite gradually becomes more leucocratic, and biotite takes over from hornblende as the dominant mafic constituent; an increase in the content of quartz, which is hardly visible in the monzodiorite, accompanies these changes. Eventually the biotite assumes a pseudohexagonal habit and quartz is prominent.

The Aurora Havn Type

The Aurora Havn type forms the south-eastern flank of the Qaqqarsuaq granite. It occupies a ENE–WSW-trending zone extending from the shore of Ikerasassuaq in the south-west to the shore of Igannap Saqqaa (Igánap sarqâ) in the north-east.

Between Nuukujooq (Nûkujoq) and the large lake Kuussuatsiaap Tasia the Aurora Havn type is a medium-grained granodiorite–tonalite with a little hornblende. East of this lake and closer to the south-east margin of the body, the rock becomes darker, hornblende more abundant, and the rock is distinguished on the map Fig. 2 as the Aurora Havn type, dark phase.

The mineral constituents of the Aurora Havn type are plagioclase (dominant), microcline, quartz, biotite and hornblende, together with a little titanite, opaque material and apatite. Plagioclase may form well-shaped, rectangular crystals and is often very much altered but for a clear rim. Microcline, generally in anhedral grains, also forms thin rims around the plagioclase. Hornblende is light green and forms prismatic crystals up to 2 mm long, often clustered with biotite and titanite. There are several instances of biotite clearly replacing hornblende.

The relations between the Aurora Havn type and the other types of Qaqqarsuaq granite vary. West of Kuussuatsiaap Tasia the contact between the Aurora Havn and Qaqqarsuup Ataa types can be placed to within 20 cm and is easily mappable. East of the lake the Aurora Havn type is flanked to the north-west by the Qaqqarsuup Tasia type. The boundary between these types is transitional, the Qaqqarsuup Tasia type gradually passing through a zone of medium-grained biotite granodiorite into the dark phase of the Aurora Havn type. Likewise traversing south-east from a little north-west of Qarliit, the biotite in the Qaqqarssuup Tasia type (or its chlorite pseudomorphs) loses its blocky hexagonal habit as the host rock becomes a coarse biotite granodiorite with prominent quartz. This rock passes in turn into dark grey medium-grained granodiorite–tonalite of the Aurora Havn type. In this transition zone the classification of the transitional rocks as one or other of the Aurora Havn types is arbitrary. About 3 km south-south-west of Qarliit, on either side of a ESE–WNW-trending fault, there is locally a sharp contact between the ‘normal’ and dark phases of the Aurora type granodiorite/tonalite.

Minor granitoid intrusions in the Qaqqarsuaq granite

North and west of Kuussuatsiaap Tasia there are small bodies of plagioclase-porphyritic biotite microgranodiorite that are intrusive into the various types of Qaqqarsuaq granite; these bodies are not shown on the map Fig. 2. North-north-west of Aurora Havn similar rocks occur in ENE-trending intrusions up to 750 m long and 75 m thick, while elsewhere they form gently-dipping sheets with an average thickness of about 10 m. The contacts of these bodies against the surrounding rocks are always sharp, and in some cases they have a very fine-grained, splintery marginal facies. One of the larger bodies carries inclusions of the host granite. Notably, shear foliation has not been observed in these small intrusions.

About 2.5 km north-west of Aurora Havn there is large sheet of non-porphyritic microgranodiorite that cuts both the small quartz monzodiorite body and the Qaqqarsuup Tasia and Aurora Havn types of Qaqqarsuaq granite. This sheet is shown with the same colour as microgranite in the map Fig. 2.

Chronological relationship between the Qaqqarsuaq ‘granite’ types and the north-western granite

In the Ikerasassuaq area the Qaqqarsuaq granite types are separated from the north-western granite by a belt of quartz monzodiorite, so the age relations between the Qaqqarsuaq and north-western granites cannot be directly established. However, comparison of the relations of these granites with the quartz monzodiorite suggests that the north-western granite is younger than the Qaqqarsuaq granite.

Both the north-western granite and the Qaqqarsuup Ataa type of the Qaqqarsuaq granite have sharp contacts against quartz monzodiorite and close to these contacts they contain inclusions of quartz monzodiorite. Thus both units are clearly younger than the quartz monzodiorite. However, the Qaqqarsuup Ataa type grades into the Qaqqarsuup Tasia type, which in turn has a gradational contact with quartz monzodiorite, suggesting that relatively short time intervals separated the emplacement of these three units and hence that the Qaqqarsuup Ataa type cannot be very widely removed in time from the quartz monzodiorite. Since there are no indications at all of transitions between the north-western granite and the quartz monzodiorite, *it is concluded provisionally that the north-western granite is younger that all types in the Qaqqarsuaq granite.*

The Uiffaat granite

The Uiffaat granite is a homogeneous porphyritic granite that occupies the greater part of the island Uiffaat (Uivfait), the island to the north, and a small area on the mainland to the south-west. It resembles the north-western granite, but is situated so far away from this that one cannot judge if these units are related. The Uiffaat granite is bounded to the west by the red granite and to the south-east by the Saqqarmiut granodiorite, both of which are seemingly younger units.

The main constituents of the Uiffaat granite are microcline, plagioclase, quartz and biotite; a little hornblende, titanite, epidote and ?allanite are also present. The porphyritic texture is due to the presence of subhedral phenocrysts up to 4 cm long of slightly micro-perthitic microcline in which there are scattered small inclusions of plagioclase, quartz and biotite.

Small, dark, fine-grained inclusions occur in the Uiffaat granite but are not common. Locally they are elongated and oriented parallel to a weak foliation trending *c.* 50°.

Solid-state-foliation is seldom seen in the Uiffaat granite, in contrast to the red granite described in the next section.

The red granite

This is a leucocratic pinkish-red granite quite unlike any other unit in the Julianehåb batholith in the Ikerasassuaq area. There are two main areas of outcrop of the red granite: one area runs from Tasiusaq north-east to the shore of Igannap Saqqaa, and the other is in central Nunakuluut, west of the Puklen intrusion. Furthermore, xenoliths of granite identical to the red granite in central Nunakuluut are abundant in a ENE–WSW-trending Gardar dolerite dyke that runs from north of Malenefjeld through the Naajat (Naujat) islands and across eastern Takisut; this suggests that the red granite has a wider distribution at depth that at the surface.

The red granite is a medium- to coarse-grained homogeneous leucogranite with prominent quartz. Small local patches are finer grained and have mariolitic cavities. The rock consists almost entirely of microcline and quartz; the remaining, minor, constituents are plagioclase, biotite, chlorite, muscovite, hornblende, pyrite, titanite and fluorite.

A strong, tectonically-imposed solid-state foliation is often evident in the red granite. In foliated rocks the quartz is flayed out into lenses, and occasionally the whole rock has been reduced to a streaky mylonite. The foliation is generally steep and trends roughly NE–SW. In central Nunakuluut a lineation plunging 30–60° toward south-west is locally seen in the sheared granite.

The scattered small dark inclusions so widespread in other units in the Julianehåb batholith are never seen in the red granite. Where the red granite borders supracrustal rocks and gneiss west and north of Tasiusaq there are inclusions of these rocks in its marginal facies.

Aplite veins are very rare in the red granite, and pegmatites even rarer. Quartz veins, however, are numerous in the red granite south-east of Kuussuatsiaap Tasia where they are up 5 m thick and trend between 110° and 167°. Many of these veins contain smears of biotite and/or chlorite, and also pyrite or magnetite which cause the veins to weather rusty-brown.

Contacts between the red granite and surrounding units

The contact of the red granite and the supracrustal rocks south-east of Kuussuatsiaap Tasia is sharp and irregular. The red granite has a fine-grained marginal facies with small phenocrysts of quartz and feldspar and spots of biotite. Blocks of the supracrustal rocks are enclosed in the marginal facies.

On the north shore of Tasiusaq the red granite passes though a 30–40 cm wide transition zone into the bordering gneiss. For the first 1.5 km inland the contact is not clear, but farther north-east it is easily mapped.

The contact between the red granite and the Qaqqarsuaq granite, dark Aurora Havn type, is sharp along its entire length, except where it is obscured by shearing. A medium-grained marginal facies of the red granite is developed in places. The adjacent Aurora Havn granodiorite is sometimes cut by veins of fine-grained granite fed from the red granite, and occasional angular inclusions of granodiorite occur in the marginal red granite.

For the most part the contact between the red granite and the Uiffaat granite is sharp. An inclusion of Uiffaat granite has been observed in the red granite. On the small peninsula on the mainland west of Uiffaat the red granite is in contact with a local fine-grained granite which in turn is in sharp contact with the Uiffaat granite. There is an inclusion of this fine granite in the red granite.

In central Nunakuluut the contact between the red granite and the quartz monzodiorite is not well exposed. Where it can be seen it is sharp, except where the rocks are sheared. Veins of fine-grained pinkish granite in the monzodiorite near the contact are regarded as having been derived from the red granite, but it was not possible to actually trace one of these veins back into the red granite.

In summary, field relations show clearly that *the red granite is younger than the Aurora Havn type of the Qaqqarsuaq granite, in which case it must also be younger than the quartz monzodiorite*, a conclusion supported by the veining of the monzodiorite observed in central Nunakuluut. On the basis of a single inclusion, it is concluded that the red granite is also younger than the Uiffaat granite. This being the case, however, one can wonder why the Uiffaat granite is so little affected by shearing. Part of the explanation may be that the red granite is more susceptible to shearing than the Uiffaat granite because of its much higher quartz content.

The Saqqarmiut granodiorite

The Saqqarmiut granodiorite occupies east central Nunakuluut, all the islands in the archipelago to the east, Takisut and the islands to the south-east, the islands south-west of Saqqarmiut (Sarqamiut) and the eastern part of the mainland peninsula to the north. The north-western contact of the Saqqarmiut granodiorite is very clearly imaged on the total magnetic intensity map (Fig. 3) by a line along which positive anomalies that characterise the Saqqarmiut granodiorite give way to negative anomalies recorded over most of the rocks to the north-west.

The Saqqarmiut granodiorite is usually a massive, medium-coarse-grained, grey rock consisting of plagioclase, microcline, quartz, biotite and hornblende, together with accessory titanite, opaque iron oxides and apatite. Epidote and chlorite are common secondary minerals. In south-east Takisut the granodiorite contains well-developed crystals of diopside up to 4 mm long, but this occurrence is exceptional.

The plagioclase (oligoclase) occurs in anhedral or roughly rectangular grains that are often sericitised or saussuritised, especially in their cores. Where zoned, the zoning can normal, reverse or oscillatory. Both myrmekite and small quartz grains occur around the borders of some crystals. Microcline is of late development and can enclose any of the other minerals; replacement of plagioclase by microcline is sometimes evident. Perthitic textures are common.

Hornblende occurs mainly in small grains, often in aggregates with biotite, but it can also be skeletal or prismatic. In some samples small grains of clinopyroxene are enclosed in the hornblende. Biotite is found in fine aggregates or flakes up to 3 mm in size. Titanite, conventionally treated as an accessory, may be prominent in the Saqqarmiut granodiorite, forming idiomorphic brown crystals up to 3 mm long.

On the shore 5 km north-east of Saqqarmiut, within the granodiorite, there is an area a few tens of metres long of pink syenitic rock consisting of albite and microcline, together with a little pennine chlorite, muscovite, epidote, titanite and Fe oxide. The contact with the surrounding granodiorite is not sharply defined. The surrounding granodiorite is streaky, but this structure is not reflected in the syenite. With its high albite content and lack of quartz, this syenitic rock recalls the albitised, syenitic phases of the north-western granite on Alanngorsuaq described by Harry & Oen (1964).

Occasional veins of aplite and pegmatite occur throughout the Saqqarmiut granodiorite; they are seldom more that a metre thick. Some of the pegmatites contain scattered grains of allanite.

A foliation marked by the parallel orientation of hornblende and biotite is developed in many places in the Saqqarmiut granodiorite, mainly within areas of migmatite (see next section). The trend of this foliation is *c.* NE–SW, following that of the migmatite or inclusion-rich zones (see below). However, solid-state foliation, so common in the other units in the Julianehåb batholith in the Ikerasassuaq area (the Uiffaat granite excepted), is very seldom seen in the Saqqarmiut granodiorite.

Inclusions; migmatite zones

Scattered, small dark inclusions are found throughout the Saqqarmiut granodiorite; these often contain feldspar megacrysts which, as explained on p. 18, could be either porphyroblasts or xenocrysts picked up from the host granodiorite (Fig. 8). In addition there are NE–SW-trending areas in which inclusions are particularly abundant and closely spaced, so that outcrops are best described as migmatite.

A striking migmatite zone extends from the contact of the Nunarssuit intrusion south of Aputaajuitsup Tasersua (Aputaiuitsup taserssua) north-eastwards to the shore of Ikerasassuaq east-north-east of Puklen. Similar migmatite occurs on western Takisut, on the island 4 km west-south-west of Saqqarmiut, and on the mainland to the north-east.

Inclusions in the migmatite zones range from a few centimetres to several metres in size. They are often lenticular in shape, with their long axes parallel to the general NE–SW trend of the zone (Fig. 9). The strike of layering and foliation within the inclusions usually lies in this direction, although locally, as on Takisut, the internal structure of the inclusions shows no clear pattern of orientation, indicating that the inclusions have been rotated haphazardly. The dip of the internal planar structures in the inclusions is steep and more often to the south-east than to the north-west.

Figure 8. *Small dark inclusions in Saqqarmiut granodiorite. Note the feldspar megacrysts in some of the inclusions. 4.5 km north-east of Saqqarmiut.*

The rock type most commonly found as inclusions is fine-grained dark green amphibolite, which can be weakly foliated, layered, or streaky. Diopside, where present, tends to occur as small grains clustered together in lenticular blebs up to centimetre in size. Epidote can form similar aggregates. These clusters may have developed where there were originally amygdales in the basalt precursor.

Leucocratic lithologies are also represented in the inclusions. These rocks are fine grained and very pale grey to light brown in colour. The principal mineral constituents are quartz and microcline, and plagioclase is invariably present. Muscovite is present in some samples, while others contain clinopyroxene, garnet and Mn-epidote. The origin of these pale coloured inclusions is not clear, but some resemble acid metavolcanic rocks.

Other rock types represented in the migmatite zones are biotite schist and calc-silicate. The calc-silicate is a fine-grained, variegated rock consisting of any or all of the following minerals: grossular garnet, diopside, tremolite, epidote, clinozoisite, piemontite, quartz, Fe oxide.

In the migmatite zones the inclusions show every stage of penetration and disruption by the granodiorite (Fig. 9). Some contamination of the granodiorite in and around the migmatite zones can be seen where the granodiorite is darker and finer grained than normal and may also show foliation. Leucocratic veins penetrating the inclusions may have diffuse boundaries with the host rock.

Figure 9. *Inclusions of fine-grained amphibolite in the Saqqarmiut granodiorite. The granodiorite has penetrated the inclusions on every scale. Shore east-north-east of Puklen.*

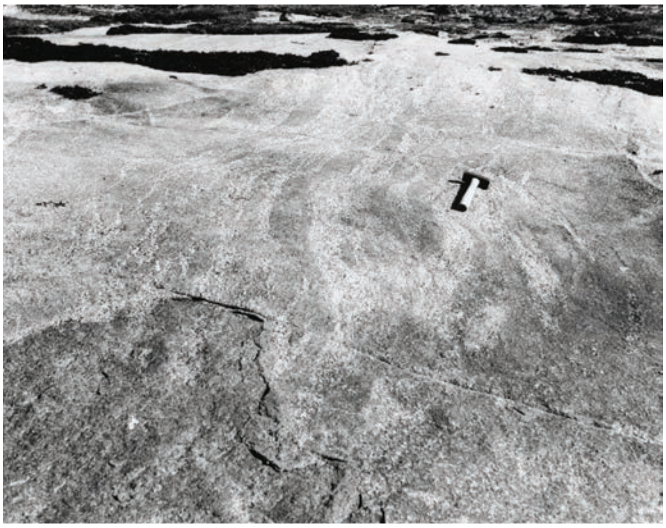


Figure 10. *Streaky nebulitic structure in the Saqqarmiut granodiorite. The dark streaks are richer in biotite and hornblende and generally finer grained than the granodiorite. 3.5 km north-east of Saqqarmiut*.

Nebulitic granite-gneiss is locally developed along the shore of Sermilik a few kilometres north-east of Saqqarmiut. The nebulite consists of vague streaks and wavy bands of fine-grained homogeneous gneiss or hornblende-biotite schist in medium- to typical medium-coarse-grained Saqqarmiut granodiorite (Fig. 10). Contacts between the different rock types are diffuse. Epidote-rich clots and lenses are locally developed. Sometimes there are trains of small amphibolite inclusions in the granodiorite of the nebulite zones. The general strike of the structure in the nebulite is NE–SW to ENE–WSW; dips are steep or vertical. Solid-state foliation is not seen in this nebulite.

Contact relations along the north-west margin of the Saqqarmiut granodiorite

In central Nunakuluut little can be learnt about the contact of the Saqqarmiut granodiorite because of poor exposure. A younger microgranite has been emplaced between the granodiorite and the red granite on the north side of Aputaajuitsup Tasersua.

North-east of Puklen the Saqqarmiut granodiorite is in contact with sheared and locally lineated red granite. The red granite outcrop wedges out about 600 m north-east of the contact of the Puklen intrusion, where the Saqqarmiut granodiorite comes into contact with sheared quartz monzodiorite. The contact between the units is sharp and concordant with the solid-state foliation in the quartz monzodiorite.

a

b

Figure 11. *Veins of undeformed Saqqarmiut granodiorite in sheared migmatitic quartz monzodiorite. Shore north-east of Puklen. a: In this photo the hammer shaft lies across the vein of Saqqarmiut granodiorite. b: Here the vein of Saqqarmiut granodiorite is parallel to the hammer shaft which lies to the upper right of the vein.*

Exposures providing critical evidence regarding age relations of the Saqqarmiut granodiorite occur on the shore of the peninsula about 2.5 km north-east of Puklen. In the south-westernmost of these exposures, about 2 km north-east of Puklen, the quartz monzodiorite in contact with the granodiorite is intensely foliated and also lineated. Near its contact with the monzodiorite the Saqqarmiut granodiorite is migmatitic, as described in the foregoing. At its junction with the monzodiorite, the granodiorite penetrates the monzodiorite along its foliation, and there are both lenses and veins of unfoliated granodiorite in the monzodiorite (Fig. 11a, b). Inclusions of monzodiorite occur in the granodiorite up to a metre or so from the contact. There is never more than a weak trace of foliation in the granodiorite in the contact exposures.

On the point about a kilometre farther to the east-north-east the Saqqarmiut granodiorite-quartz monzodiorite contact is again exposed. Here, however, the monzodiorite is only weakly foliated. The contact between the different rocks is sharp to within a centimetre. The Saqqarmiut granodiorite sends irregular veins up to 5 cm thick into the monzodiorite (Fig. 12). A thin vein of aplite cuts both units.

Figure 12. *Contact of Saqqarmiut granodiorite with quartz monzodiorite. Shore 3 km north-east of Puklen. The Saqqarmiut granodiorite is on the right; the hammer-head rests on quartz monzodiorite.*

From these exposures two conclusions can be drawn:

1) the Saqqarmiut granodiorite is younger than the quartz monzodiorite.

2) The emplacement of the Saqqarmiut granodiorite took place after the strong shearing that affected the quartz monzodiorite, and hence also after shearing in the north-western granite.

North of Ikerasassuaq, on the shore of Tasiusaq, the Saqqarmiut granodiorite is bordered by the strip of gneiss and amphibolitic schist described on pp. 11–12. Against the amphibolite schist the contact is migmatitic, but against leucocratic gneiss it is more sharply defined. Inland, to the north-east, slithers and lenses of leucocratic gneiss and amphibolite are numerous in the Saqqarmiut granodiorite near its contact with the gneiss.

The Saqqarmiut granodiorite-Uiffaat granite contact is easily mapped on account of the relatively dark colour of the granodiorite in this area, but it is well exposed only on the east shore of Uiffaat. This contact is neither sharp nor regular. Within a metre of the contact the granodiorite becomes finer grained and hornblende less plentiful, suggesting that the Saqqarmiut granodiorite is younger than the Uiffaat granite. The contact is gradational over 3–4 cm.

Microgranites within the Saqqarmiut granodiorite

Irregular bodies of microgranite occur in east-central Nunakuluut and on Takisut; in addition to the larger bodies shown on the map Fig. 2, there are widespread smaller veins, sheets and dykes in the vicinity of the larger bodies.

Typically these microgranites are fine-grained, pinkish rocks with < 5 mm long phenocrysts of plagioclase. The matrix consists of microcline (and perthite), plagioclase and quartz, with small amounts of biotite, hornblende, titanite and Fe oxides; apatite, muscovite and epidote can also occur. The microcline forms anhedral grains that can enclose any of the other minerals.

A weak foliation is locally developed in the microgranites, notably in the islands just east of Takisut. In these islands there is a convergence in appearance between the microgranite and the acid–intermediate metavolcanic rocks described earlier, and in places the mapping of these types is uncertain.

The microgranites have sharp contacts with the surrounding rocks and locally carry inclusions of Saqqarmiut granodiorite. They also cut aplites in the Saqqarmiut granodiorites and the appinites and associated basic rocks described in the next section. The microgranites do not however contain small dark inclusions of the type common in the Saqqarmiut granodiorite.

Sequence of emplacement of the units within the Julianehåb batholith

The quartz monzodiorites, the Qaqqarsuaq granite, the north-western granite and the red granite are all crossed by approximately NE–SW-trending zones of shear foliation, a foliation imparted on the rocks by deformation during the solidus stage of development of these units. In contrast, the Saqqarmiut granodiorite has undergone only slight late shearing, and unsheared veins of this granodiorite cut intensely sheared quartz monzodiorite. The Uiffaat granite does not show significant shear foliation either, but contact relations indicate that it is older than the red granite and the Saqqarmiut granodiorite. It has thus been established from field relations alone that *the Saqqarmiut granodiorite is definitely younger than the quartz monzodiorite and furthermore the youngest major unit in the western part of the Julianehåb batholith*. This conclusion is supported by the distribution of pre-Gardar minor intrusions in the six units (see Fig. 15). The microgranite bodies within this granodiorite are younger still.

Both the north-western granite and the Qaqqarsuaq granite, Qaqqarsuup Ataa type, are clearly younger than the quartz monzodiorites. Although the north-western granite and the Qaqqarsuaq granite do not come into contact in the Ikerasassuaq area, there are indirect indications that the north-western granite is the younger of these units (see discussion on pp. 23–24).

The red granite is younger than the Aurora Havn type of the Qaqqarsuaq granite, which is closely related in time to the other types in this unit. The red granite is therefore also younger than the quartz monzodiorites. Contact relations indicate that the red granite is younger than the Uiffaat granite, although the distribution of shear foliation in these units (there is hardly any in the Uiffaat granite) suggests the opposite. There is no way of knowing from field relations how the red granite and north-western granite are related in time. Only if the similarity between the Uiffaat granite and north-western granite is an indication of contemporaneity can one conclude that the red granite is younger than the north-western granite.

The suggested sequence of emplacement of the units is thus: Quartz monzodiorite, Qaqqarsuaq granite, north-western granite, Uiffaat granite, red granite, Saqqarmiut granoidiorite, microgranite.

Isotopic age determinations

In 1997 samples of the quartz monzodiorite and Saqqarmiut granodiorite were collected by K.J.W. McCaffrey and M.L. Curtis specifically for U-Pb geochronology and isotopic studies of these units. As already explained, the ages will establish the time span for batholith emplacement in the western part of its outcrop. The samples were collected on the coast on the peninsula 3 km north-east of Puklen, at a locality where the two units are in contact and their age relations clearly revealed (see pp. 30–31 and Figs 11,12).Conventional U-Pb zircon age determination of the samples was carried out at the Geological Survey of Canada in Ottawa by M.A. Hamilton, using the methods described in Garde *et al.* (2002b) and references therein. The results were as follows (quoted with 2 sigma uncertainties):

Quartz monzonite: 1868 ± 7Ma

Saqqarmiut granodiorite: 1804 ± 1 Ma.

The geochronological data show that this part of the Julianehåb batholith spans more or less the entire age range of the exposed parts of the batholith as currently known, well over 50 Ma (Garde *et al.* 2002).

Appinites, diorites and related rocks

“Appinite” is a term imported to Greenland from Scotland. Appinites were defined by Bailey & Maufe (1916, pp. 167–168) as “dark rocks of medium to coarse texture, and mainly composed of green or brown idiomorphic hornblende (either stumpy or acicular) in a groundmass which contains plagioclase, orthoclase, and quartz in varying proportions; .... olivine (as pseudomorphs), augite and biotite are sometimes present. ....”. Bailey & Maufe realised that the appinites named and described from the type area were associated with rocks such as monzonite, augite diorite and cortlandtite, and as this association became more widely recognised, the term “appinitic” came to used for a suite of hornblendic intermediate to ultramafic rocks commonly associated with granite (Read 1961; Joplin 1964; Walton 1965; Hall 1967; Pitcher & Berger 1972; Palivcová 1981; Ayrton 1991; Pitcher 1997).

Distribution and field characteristics

In other parts of the world appinitic rocks occur mainly in small intrusions in the country rocks periferal to granite plutons (e.g. Pitcher & Berger 1972; Bowes & McArthur 1976), but this is not the case with the appinites associated with the Julianehåb batholith, most of which occur within the batholith (Walton 1965; Allaart 1973).

Appinitic rocks in the Ikerasassuaq area form both irregular masses and elongate dyke-like bodies from a few metres to more than a kilometre wide, that occur mostly in the Saqqarmiut granodiorite. Some areas of appinite are an integral part of this body; these are areas in which the granodiorite becomes gradually more hornblendic and its plagioclase more calcic until one arrives, without having crossed any sharp boundaries, at a hornblende-pyroxene gabbro similar to the characteristic rock type in the discrete appinite bodies. This is the case with the body 2.5 km north-west of Saqqarmiut. Other areas of appinite are agmatites formed of closely spaced inclusions of hornblende-pyroxene gabbro or pyroxene diorite in granodiorite. In order to give a more complete picture of the appinite bodies in the western part of the Julianehåb batholith, observations made on bodies outcropping in the islands south-east of Sermilik (Pulvertaft 1977) are included in the following.

Many of the appinite bodies in the Ikerasassuaq area and south-east of Sermilik consist of more than one rock type, e.g. both ultramafic rocks and quartz diorite can occur in a single body. Contacts between the different components vary from transitional to sharp. However, the distribution of rocks types within a single body is not particularly orderly with respect to the overall form of the body. An unsystematic distribution of several rocks types within a single body is said to be common in appinites elsewhere (Pitcher 1997).

a **b**

Figure 13. *a: Steep layering in the appinitic body north-west of Aputaajuitsup Tasersua. b: Close-up of the same layering as shown in a.*

Although for the most part massive and structureless, the appinitic bodies sometimes show igneous layering. Two types of layering may be mentioned:

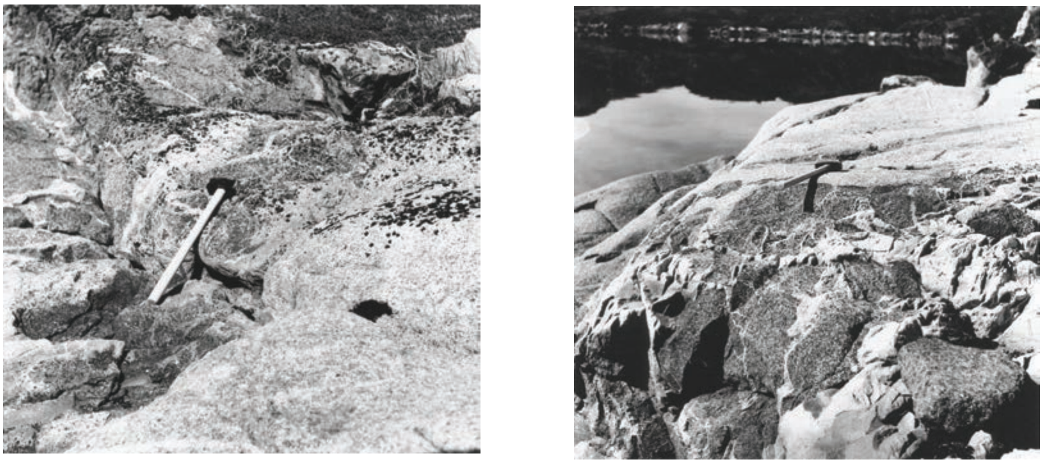
1) mafic layers 3–5 cm thick spaced 20–30 cm apart in structureless appinite; this type of layering usually has a low dip (< 20°);

2) closely spaced (< 10 cm) layering (Fig. 13) with steep dip and generally striking parallel to the margin of the body. Grading is sometimes developed, the gradation from dark to light taking place towards the margin of the body, even when the layering dips steeply away from the contact – that is to say the grading is density-reversed, and the layering cannot be gravity stratification. Very similar layering has been described from the Willow Lake intrusion, Oregon (Taubeneck & Poldervaart 1960).

External contacts and age relations

All the appinitic bodies are engulfed in granodiorite or granite and, with the exception of a few diorite bodies in the Qaqqarsuaq granite, are veined and agmatised by the host granitoids (Fig. 14). Veins in basic appinites are irregular and split the appinite up into angular blocks. The veins become fewer and more leucocratic, the farther one goes into the appinite body. Where there is more than one generation of veins, the early granite veins are cut by pegmatites that are sometimes zoned. In the appinites in the Saqqarmiut granodiorite the latest veins are of microgranite.

The contacts between the host granitic rock or granitic veins and the basic appinite are sometimes sharp, but more often gradational over a few centimetres to a few metres (Fig. 14a). At gradational contacts the host granodiorite (or granite) becomes finer grained and darker approaching the appinite, and may be spotted with single crystals or clusters of hornblende. Fine stringers of quartzo-feldspathic material infiltrate into the appinite and surround individual mafic crystals in the rock.



a **b**

Figure 14. *a: Margin of the appinitic body 2.5 km north of the summit of Malenefjeld, showing veining and alteration of the appinitc rocks by the Saqqarmiut granodiorite. b: Another view of the margin of the same appinitic body as a. Here not only Saqqarmiut granodiorite but also fine-grained, slightly porphyritic microgranite (foreground) takes part in the veining of the appinite.*

From the setting and contact relationships described in the foregoing paragraphs it is concluded that the appinitic rocks are an integral part of the Julianehåb batholith. They could either be fragments of basic precursors of the batholith (cf. Pitcher 1997, pp. 179–180) or they could have been emplaced into their granitic hosts while the latter were still hot and only partially crystallised. In the latter situation the host rocks could easily be reactivated and back-vein the basic bodies.

Petrography

Hornblende-pyroxene gabbro

The hornblende-pyroxene gabbro, which is the characteristic rock of the appinite suite, is composed mainly of hornblende, clinopyroxene, plagioclase and biotite; the proportions of these minerals vary widely. Other minerals that can occur are olivine and orthopyroxene in the more mafic types, and chlorite and epidote of late development. Accessory minerals are very scarce; the commonest are apatite, pyrite, Fe ± Ti oxides and titanite.

Hornblende occurs both as stumpy brownish-green crystals and also in the matrix between these where it is light blue-green or very pale in colour. The large grains contain inclusions of clinopyroxene, biotite, plagioclase and, if they are present, orthopyroxene and olivine. Often the large grains are poikilitic or even skeletal.

Clinopyroxene is colourless or very pale green. It can make up from less than 5% to 40% of the rock. Grains are 0.5–2 mm long; their form varies according to which mineral encloses them. Crystals enclosed in plagioclase are idiomorphic, while grains enclosed in hornblende are usually xenomorphic. Crystals enclosed in plagioclase show slight alteration to hornblende, without the overall idiomorphic shape of the grain being impaired. Grains enclosed in hornblende show replacement by hornblende. Sometimes one sees a grain enclosed in hornblende that has pyroxene shape but is composed of hornblende with a different optic orientation than the enclosing hornblende poikilith. Fresh clinopyroxene crystals often show twinning.

Plagioclase, typically a sodic labradorite, forms anhedral or interstitial areas that are sometimes studded with clinopyroxene inclusions. In several samples the plagioclase was seen to be patchily or completely sericitised. Where the anorthite content of the plagioclase is less than 50%, the rock is a pyroxene diorite.

Biotite is commonly present in the hornblende-pyroxene gabbros, and is a major constituent in some bodies. It is a brown or brownish olive-coloured variety. In some samples the biotite forms small flakes in clusters, while in others the flakes reach 3 mm in width; occasionally these large flakes are bent. Biotite is also seen enclosed in or intergrown with hornblende. Clinopyroxene on the other hand is occasionally enclosed in biotite.

Cortlandtite

In some appinite bodies the hornblende-pyroxene gabbro passes abruptly or gradually into cortlandtite, a rock type particularly well developed in the appinite body about 2.5 km north of Saqqarmiut. The cortlandtite in this body is a coarse-grained rock dominated by large blocky hornblende crystals up to 3 cm in length. These carry inclusions of all the other phases occurring in the rock. The habit of the clinopyroxene (augite) enclosed in the hornblende varies from anhedral to euhedral. Continuity of twin planes and optic orientation in two almost adjacent anhedral augite inclusions suggest that these originally belonged to a single larger crystal that has been partially consumed by the enclosing hornblende megacryst. Where enclosed in plagioclase, the augite is euhedral.

Orthopyroxene (hypersthene) is pale pinkish in colour. It forms subhedral grains that are generally larger than the augite grains.

Olivine is quite abundant and remarkably fresh. It forms roundish grains mostly enclosed in hornblende. These may be in direct contact with the enclosing hornblende, or separated from it by a rim of hypersthene ± biotite.

Biotite (almost colourless to foxy brown) is anhedral, except where enclosed in hornblende where flakes have more regular shapes. Biotite also forms symplectic intergrowths with hornblende. Augite, however, sometimes forms inclusions in biotite.

Plagioclase (calcic labradorite, slightly zoned) is present in small amounts. It is mostly interstitial but a little is enclosed in hornblende.

Very small amounts of apatite and Fe sulphide are the only accessory minerals in the cortlandtite.

The hornblende-pyroxene gabbro of the appinite bodies can grade not only into cortlandtite but also into pyroxenite and norite.

Pyroxenite

Pyroxenite occurs in the appinite body 1.5 km north-west of Aputaajuitsup Tasersua in central Nunakuluut. The rock consists mainly of idiomorphic to subidiomorphic clinopyroxene crystals up to 4 mm in size that are enclosed in, but only very slightly replaced by, poikiliths of pale amphibole accompanied by a little phlogopite and Fe sulphide.

Norite

Norite has been found in the islands south-east of Sermilik. This rock is composed of plagioclase (labradorite zoning to sodic andesine), hypersthene, augite, hornblende, biotite, olivine (largely pseudomorphed) and accessory apatite and Fe sulphide. The texture is ophitic. Hornblende has either the same habit as the ophitic pyroxenes or has been moulded onto augite.

Peridotite

Peridotite forms one small body belonging to the appinite suite. The rock is dominated by large (up to 1.5 cm) hypersthene poikiliths that are studded with numerous idiomorphic to rounded olivine crystals. A little clinopyroxene is found as small grains or patches between hypersthene poikiliths or enclosed in hypersthene. Very small amounts of phlogopite and amphibole occur as flakes or shreds. The peridotite is bordered against the surrounding granodiorite by a 2 m wide zone of pyroxene-mica diorite in which brown hornblende forms both scattered large grains and patchy replacive intergrowths with clinopyroxene.

Hornblende gabbro

Hornblende gabbro is the dominant rock type in some of the appinitic bodies in the islands south-east of Sermilik. The rock is coarse grained and composed largely of plagioclase (labradorite zoning to andesine or oligoclase) and hornblende, together with small amounts of any of the following: pale blue-green amphibole, biotite, clinopyroxene, chlorite, epidote, pyrite, ilmenite, calcite. Even though the clinopyroxene shows slight alteration to hornblende, the minerals and textures in this hornblende gabbro are believed to be in the main primary. Hornblende may enclose plagioclase in a manner recalling ophitic texture.

Troctolitic gabbro

Within one hornblende gabbro body there is a small area of troctolitic gabbro. This rock is exceptional in this setting in that it lacks common hornblende. The constituent minerals are calcic labradorite, olivine, augite, ilmenite, green spinel, and late, shreddy, very pale amphibole and a little chlorite. Olivine, the main mafic mineral, has rims of either augite or amphibole separating it from the surrounding plagioclase.

Diorites

Finally diorites: these are medium- to coarse-grained rocks with hypidiomorphic-granular texture. Plagioclase (andesine) is the dominant mineral; it is often turbid with alteration. Pale brown to bluish grey-green hornblende is the main dark mineral. Apple-green chlorite is often present, but biotite is less common. Any of the following can occur in very small amounts: titanite, epidote, apatite, quartz, pyrite, Fe oxides, calcite. A little microcline has been found in samples from near the margins of some bodies.

Most of the rock types described in the foregoing have also been recognised in appinitic bodies in the Julianehåb batholith farther east (Allaart 1973, 1983).

Discussion

There is general agreement that rocks of the appinitc suite crystallised from basic magmas under high water pressure (Hall 1967; Pitcher & Berger 1972; Pitcher 1997). The mineral parageneses and textures observed in the appinitc bodies in the Ikerasassuaq area are consistent with this interpretation. The order of crystallisation that can be read from the textures is as follows:

Olivine, if present, was the first mineral to crystallise, followed by pyroxene. These were succeeded by hornblende and plagioclase, and finally biotite; there seems to have been considerable overlap in the crystallisation of these three minerals. However, there was little or no overlap in the span of crystallisation of pyroxene and plagioclase; crystallisation of the former was complete before the latter began to fill the interstitial spaces in the rock. This pattern of crystallisation matches that of an olivine tholeiite magma crystallising at around 5 kb water pressure (Yoder & Tilley 1962; Hall 1967) and probably applies over a water pressure range from as low as 2 kb up to at least 10 kb (Cawthorn & O'Hara 1976). Thus as a tentative hypothesis it is proposed that the hornblende-pyroxene gabbros, pyroxene diorites, hornblende pyroxenites and cortlandtite belonging to the appinite suite in the Ikerasassuaq area and islands south-east of Sermilik are the products of crystallisation and differentiation of a hydrous basaltic magma at a depth of at least 2 kilometres.

Pre-Gardar minor intrusions

Minor intrusions of microdiorite, amphibolite and hornblendite are very common throughout the Julianehåb batholith. These intrusions attracted a great deal of attention in the 1960s because, with Sederholm's (1926) interpretations of dykes in the Barösundsfjärd area in southern Finland in mind, it was hoped that they would provide a key to unravelling the history of the batholith (Watterson 1965, 1968; Allaart 1967). Unfortunately, to some extent, to this end they were more of a distraction than a help (e.g. Allaart 1973, pp. 12–13).

The minor microdiorite and amphibolite intrusions in the Ikerasassuaq area are mostly dykes; sheets are locally common, for example around Qaqqarsuaq. The intrusions are thin, so that only a few have been shown on the 1:100 000 map sheet. Of the 447 such intrusions recorded in the area shown on Fig. 2, only 45 are more than 5 m thick. This survey did not include intermediate (quartz latite) dykes of the Ujarasussuk swarm which average 8 m in thickness and may be up to 22 m thick (see pp. 47–48).

In the following the minor intrusions found in the quartz monzodiorites and older granites and those occurring in the Saqqarmiut granodiorite will be described separately.

Minor intrusions in the quartz monzodiorite and older granites

The vast majority of the pre-Gardar minor intrusions in the older units in the Julianehåb batholith are of amphibolite and microdiorite. Some are however ultramafic (hornblenditic) or almost ultramafic in composition; these are referred to as green dykes on account of their characteristic colour. A distinctive swarm of intermediate (quartz latite) dykes occurs in an arcuate zone extending from Ujarasussup Qinngua (Ujarasugssûp qíngua) in the north through the Ujarasussuk (Ujarasugssuk) peninsula to south of Qarliit in the south; these are not known elsewhere and have been distinguished as the Ujasasussuk dykes.

The pre-Gardar minor intrusions in the quartz monzodiorite and older granites are the youngest pre-Gardar rocks within these units. Many examples have been seen of dykes cutting aplite veins in the granites, and a number of dykes have been mapped across the contacts between the granitic units. An exceptional occurrence has however been described by Watterson (1965) from the north-western granite at the inner end of the bay Natsiit Iluat (Natsît iluat). Here an amphibolite dyke that cuts clean through porphyritic north-western granite becomes broken up into a train of closely spaced inclusions when it passes into a small area of pegmatitic granite. This pegmatitic granite must still have been mobile at the time of dyke emplacement.

The orientation of the pre-Gardar minor intrusions in the quartz monzodiorite and older granites in the Ikerasassuaq area (excluding the Ujarasussuk swarm) can best be seen in the histogram in Fig. 15. Only a few dyke intersections have been recorded, largely be

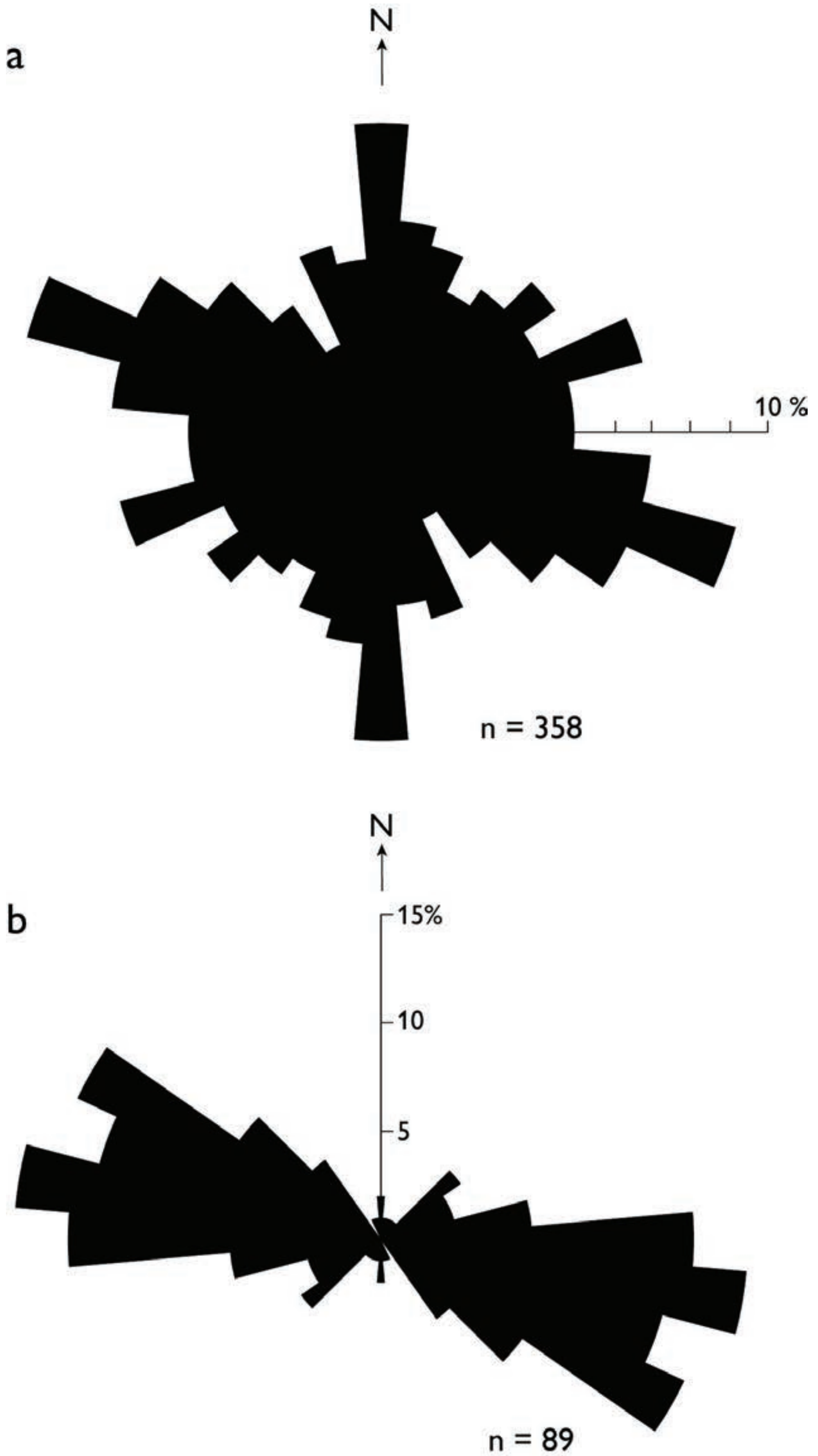


Figure 15. Rose histograms of the directions of amphibolite, microdiorite and 'green' dykes in the Julianehåb batholith in the Ikerasassauq area, South Greenland (Ujarasussuk dykes excluded). a: 358 dykes in the five older units in the batholith. b: 89 dykes in the Saqqar-miut granodiorite.

cause the dykes cannot be traced very far in the lower-lying, less well exposed parts of the area. The observations can be summarised as follows: Dykes in directions between 06° and 15° and between 86° and 105° have been seen cut by ENE–WSW dykes, which in turn are cut by N–S to NNW–SSE dykes. However, two NNW–SSE dykes have been seen cut by dykes in 75°, and an ENE–WSW dyke is cut by a dyke in 10°. These observations are enough to show that there is no simple correlation between direction and relative age of these dykes.

To facilitate description, these minor intrusions have been classified into six groups on the basis of field appearance and petrographic characters. These are a) amphibolites, b) microdiorites, c) metadolerites, d) green dykes, e) composite intrusions, and f) intermediate dykes of Ujarasussuk swarm. The distinction between the amphibolites and microdiorites is based largely on textures: the textures in the amphibolites are interpreted as metamorphic, while textures in the microdiorites are interpreted as primary. However, the textures are seldom so distinctive that one can be confident about these interpretations, and the classification of many of the intrusions is arbitrary. In any case, if dykes crystallise under amphibolite facies conditions, the distinction between primary and metamorphic textures becomes completely blurred.

Amphibolites

These are fine-grained (rarely medium-grained) rocks consisting of hornblende and plagioclase together with small amounts of any of the following: biotite, epidote, chlorite, Fe oxide, titanite and apatite. Textures are metamorphic. The rocks often show a foliation marked by parallel orientation of lenticular aggregates of hornblende or, where hornblende has a prismatic habit, of hornblende crystals. Otherwise hornblende occurs as anhedral grains. Although small blebs of other minerals may be enclosed in the hornblende grains, hornblende in these dykes is generally a clear, pale greenish brown to bluish green variety, only rarely showing the peppering of minute inclusions that characterises hornblende in most of the metadolerite dykes.

The amphibolite dykes often have irregular form and are occasionally folded.

Microdiorites

Minor intrusions in this category are mainly dykes, only rarely sheets. The sheets are regular, but the dykes can be very irregular in shape (Fig. 16). Watterson (1965, 1968) has presented evidence for regarding the irregular shapes of similar dykes as a primary feature, the result of intrusion into active shear fractures. Evidence for this is found in the many microdiorites in the Ikerasassuaq area that are spotted by small lenticular clusters of hornblende. In the central parts of dykes these are oriented obliquely to the margins of the dykes, while towards the margins they swing into near-parallelism with the margins. The resulting fabric is S-shaped if the dykes was emplaced into a dextral shear (Fig. 17), and Z-shaped if the shear was sinistral (cf. Allaart 1967; Berger 1971). Although the number of observations is limited (by no means all microdiorites are spotted, and spots are not always lenticular), it was noted that the fabric defined by lenticular hornblende clusters is Z-shaped in dykes trending roughly N–S, implying sinistral shear in these fractures, while it is S-shaped in dykes with E–W to ESE–WNW trend, implying dextral shear. This suggests that these microdiorite dykes were emplaced into conjugate shear fractures that developed in response to NW–SE-directed compressive stress.

Figure 16. *Irregular dykes of microdiorite/amphibolite in the Qaqqarsuaq granite, Qaqqarsuup Ataa type; hammer-shaft lies in the direction of foliation in the granite. Shore south-east of Qaqqarsuup Tasia.*

Where not spotted, the microdiorites have no special characteristics. The main constituents of the rocks are hornblende and plagioclase (andesine). Other minerals that can be present in small amounts are epidote, biotite, chlorite, opaque Fe oxide and sulphide, apatite and titanite. Quartz and microcline have been observed but are rare.

The texture varies according to the habit of the hornblende. In many samples much of the hornblende occurs as long, narrow prisms with rather irregular outlines, while in other samples the hornblende grains are stumpy; both types can occur in the same rock. The hornblende in clusters has a blunt habit; it is the same brownish to bluish green variety as seen in the matrix to the clusters. A dusting of minute opaque grains may darken the cores of some hornblende grains.

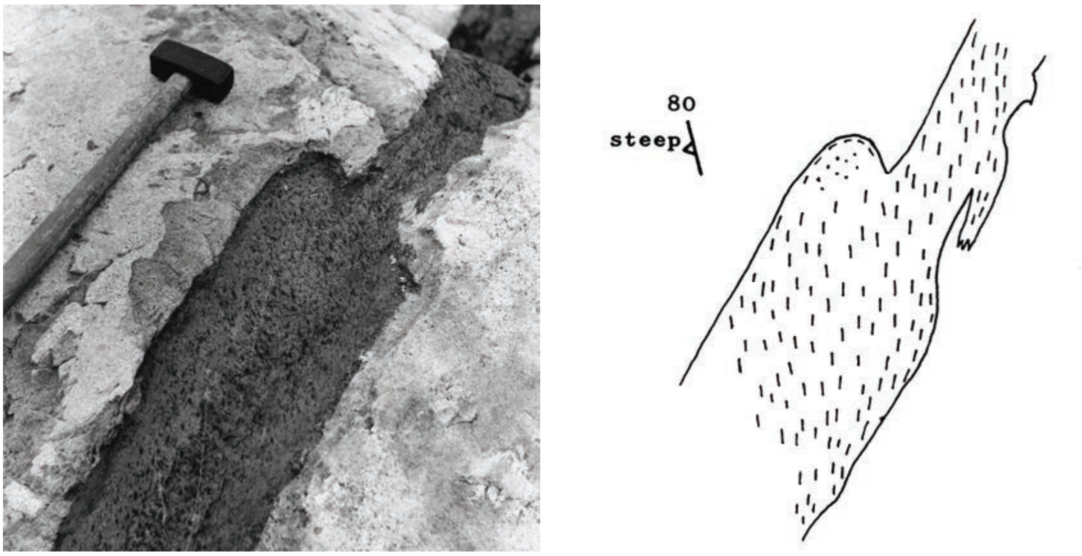


Figure 17. *Microdiorite dyke with small lenticular clusters of hornblende defining an S-shape in the dyke. Shore east of Emma Havn.*

Plagioclase grains are usually equant, but are occasionally seen with rectangular outlines. Rarely plagioclase forms small phenocryts.

Metadolerites

Metadolerite forms both dykes and sheets. The dykes have regular form. Margins are often fine grained, but since shearing has often affected the margins of the dykes, this need not reflect chilling at the contacts.

The metadolerites are characterised by relic ophitic texture; there has been little re-crystallisation of plagioclase, which forms crystals penetrating or even enclosed in single individuals or aggregates of hornblende. Many of the metadolerite dykes are porphyritic, with phenocrysts of plagioclase (labradorite) up to 2 cm long. Hornblende is the same variety as that in the amphibolites, but in the metadolerites the large hornblende grains are peppered with minute inclusions of opaque phases and/or titanite. A little biotite occurs, often in aggregates with fine hornblende.

Metadolerites have been observed both cutting and cut by microdiorites.

Green dykes

These dykes are distinguished by their green colour, which is due to a high content of hornblende. Some green dykes are very regular, others are deformed and foliated.

Hornblende is the dominant mineral, to the extent that some dykes are hornblendites. It is a bluish green variety. The other minerals that can be present are biotite, epidote, plagioclase, clinopyroxene, scapolite, Fe oxide and pyrite. Where clinopyroxene occurs, it forms relatively large grains that are invariably rimmed by hornblende. Occasional hornblende aggregates have the characteristic eight-sided form of sections of pyroxene, suggesting an origin by replacement of pyroxene, but more often than not hornblende occurs in closely packed anhedral or subhedral grains with no suggestive shapes.

The few intersections observed show that green dykes can be cut by metadolerites and that they both cut and are cut by microdiorites.

Composite intrusions

There are three sheets and a single dyke in the Qaqqarsuaq granite, Qaqqarsuup Ataa type, that have a composite structure. These are up to 20 m thick. The outer half-metre on either side of the intrusions consists of microdiorite, while the central parts are formed of pale, very fine-grained, porcelanous microgranodiorite. Contacts between the inner and outer components can be either sharp or gradational through 20 cm.

Intermediate dykes of the Ujarasussuk swarm

The Ujarasussuk dykes make up a distinct swarm that describes an arc of *c.* 80° with radius *c.* 7 km, with a centre in Igannap Saqqaa. The swarm has been displaced about 1.5 km left-laterally by a fault running in *c*. 80° through Ujarasussup Qinngua. The swarm is densest in the western part of the arc, where dykes locally constitute up to 50% of the bedrock (Bridgwater 1959).

The Ujarasussuk dykes are irregular in form and thicker than the other pre-Gardar minor intrusions, more than half the dykes recorded in the Ikerasassuaq area being more than 8 m thick. They are younger than most of the other pre-Gardar dykes, but occasional microdiorites cut the Ujarasussuk swarm. The Ujarasussuk dykes are also younger than shear zones in the Qaqqarsuaq granite, although isolated dykes can be sheared and foliated. The dykes also cut foliated red granite, but none reaches as far south-east as the Saqqarmiut granodiorite.

The Ujarasussuk dykes are for the most part light grey or pale brownish in colour, except where the dyke has a darker marginal facies resembling the spotted microdiorites. Some dykes are multiple, with internal chilled margins. The rocks are fine grained and frequently both plagioclase-porphyritic and spotted by clusters of hornblende and biotite ± chlorite and epidote. In porphyritic dykes the phenocrysts are of plagioclase which, however, is so altered that the sites of phenocrysts are now occupied by a fine aggregates of muscovite (sericite) and epidote and patches of calcite. The plagioclase in phenocrysts is andesine *c.* An_{35}, while matrix plagioclase is more sodic. Rims of very fine perthite have sometimes developed around phenocrysts. Some large phenocrysts (> 1 cm long) consist of two or more individual crystals welded together during growth (synneusis).

Microcline and quartz occur in variable amounts in the matrix. The coloured minerals can be any or all of the following: chlorite (pennine), epidote, biotite (a greenish variety) and hornblende. Apatite and titanite are the only accessory minerals.

A single chemical analysis of a dyke from the Ujarasussuk swarm has been reported by Watterson (1968, p. 59, table 1). This corresponds to a quartz trachyte, although in thin sections the dykes appear to be quartz latites.

Pre-Gardar minor intrusions in the Saqqarmiut granodiorite

Pre-Gardar minor intrusions are more sparsely distributed in the Saqqarmiut granodiorite than in the older units in the Julianehåb batholith in the Ikerasassuaq area. Although some of the rock types represented in the minor intrusions in the Saqqarmiut granodiorite are identical to types described from minor intrusions in the older units, e.g. spotted microdiorites and green mafic–ultramafic types, there are differences between the suite as a whole and the assemblage of minor intrusions seen in the older units. These differences are yet another of the features that mark the Saqqarmiut granodiorite as distinct from all the earlier units in the western part of the Julianehåb batholith (the other features are the magnetic signature seen in the total magnetic intensity map and the almost complete lack of shear foliation in this unit). The characters that distinguish the pre-Gardar minor intrusions in the Saqqarmiut granodiorite from those in the older granites, granodiorites and quartz monzodiorites are:

A) Orientation. The orientation of the 89 dykes recorded in the Saqqarmiut granodiorite is shown in a rose diagram (Fig. 15b). From this it can been seen than the dominant ESE–WNW trend corresponds to one of the maxima in the rose diagram for dykes in the older units, but that N–S and *c.* 70°–250° trends are hardly represented at all in the Saqqarmiut granodiorite. This provides further evidence that the Saqqarmiut granodiorite is distinct from and younger than the other major units in the western part of the Julianehåb batholith (cf. p. 33).

B) Characteristic lithologies. Two of the most characteristic types of minor intrusion in the Saqqarmiut granodiorite are pyroxene diorite (appinite) dykes and composite net-veined intrusions (the latter however only observed south-east of Sermilik; see Windley (1965) for a description of similar sheets in an area south of Julianehåb). Neither of these types has been observed in the older units.

C) Relationships with the host rocks. More than a third of the pre-Gardar dykes recorded in the Saqqarmiut granite in the Ikerasassuaq area are cut by leucocratic veins fed from the host rock (Fig. 18). In this respect, as well as in lithology, these dykes resemble the appinitic bodies. Where intersections between veined and unveined dykes occur, the unveined dykes are always the younger (Fig. 19). Unveined microdiorite dykes also cut the appinitic bodies and the microgranites in the Saqqarmiut granodiorite.

Figure 18. '*Green dyke' cutting Saqqarmiut granodiorite and cut by leucocratic veins fed from the granodiorite. 1 km north-north-east of Saqqarmiut.*

Figure 19. *'Green dyke' cut by leucocratic veins and an unveined S-dipping microdiorite dyke; host rock is Saqqarmiut granodiorite. 3.5 km west-south-west of Saqqarmiut.*

The relationships illustrated in Fig. 18 and 19 are characteristic of pre-Gardar minor intrusions in many parts of the Julianehåb batholith and have been variously interpreted (Watterson 1965, 1968; Allaart 1967). An early interpretation of such relationships between dyke and host rock was that of Sederholm (1926, p. 45), who solved the paradox of dykes appearing to be both younger and older than their host granites by suggesting that this was the result of reactivation of the granitic body during a post-dyke phase of renewed plutonism. However, today dykes that are back-veined by their host granite or even broken up into trains of inclusions in their host are most often termed syn-plutonic dykes (Pitcher 1997). The phenomenon has been recorded in granite terrains all over the world (Pitcher & Bussell (1985) and references therein), and the usual interpretation is that pluton consolidation and dyke intrusion were coeval. The realisation that a still mobile and consolidating granitic melt with up to 30% residual melt can fracture, and thus accept dyke injection, if subjected to rapidly applied stress (Hibbard & Watters 1985) removes the need for renewed heating and partial melting of the host to generate the leucocratic veins cutting the dykes or to allow dykes to break up into blocks that 'float' away from one another. The resulting mafic dyke-granitic host relations depend on at which time during the crystallisation and rheological development of the host granitic melt the mafic material was intruded (Fernandez & Barbarin 1991).

Total magnetic intensity map

An aeromagnetic survey was flown over South Greenland in 1995–96. The survey was flown on a 500 × 5000 m grid with a terrain clearance (drape) of 300 m (Thorning & Stemp 1996, 1997). The survey covered most of the area shown in Fig. 2, and the resulting total magnetic intensity map of this area is shown in Fig. 3 on p. 15.

Some of the geological features and boundaries shown in Fig. 2 and on the 1:100 000 map sheet (Pulvertaft 1967) are clearly reflected in the magnetic anomaly map, while other, equally important, features are not shown at all in the magnetic anomaly pattern. On the other hand, there are striking features in the magnetic anomaly map which have no expression or explanation in the surface geology.

The geological feature most accurately imaged on the total magnetic intensity map is the contact of the Saqqarmiut granodiorite between Puklen and the coast of Ikerasassuaq to the north-east and between Tasiusaq and Uiffaat. At the position of this contact there is a very rapid transition from positive anomalies over the Saqqarmiut granodiorite to negative anomalies over the older rocks to the north-west. South-west of Puklen the contrast in magnetic anomalies is less marked, and there is a tongue of positive anomalies along the west side of the Puklen intrusion that is not reflected in the geological map Fig. 2. This is a low-lying area with lichen-covered outcrop, and it could be that outcrops of Saqqarmiut granodiorite have been erroneously mapped as quartz monzodiorite.

Apart from the north-west contact of the Saqqarmiut granodiorite, none of the other contacts and divisions in the Ketilidian rocks is reflected on the total magnetic intensity map. The other geological features imaged on this map are Gardar intrusions. The Puklen intrusion gives rise to a negative anomaly, most marked in the north where alkali granite forms the central part of the intrusion (Pulvertaft 1961; Parsons 1972). The other Gardar unit imaged on the total magnetic intensity map is the syenite + hornblende granite component of the composite macrodyke north-west of Qilluarissup Nuna; unlike the Puklen intrusion, this is marked by a positive anomaly. However, there is nothing whatever on the total magnetic intensity map that indicates where the syenites and granites of the largest Gardar intrusion in the area, the Nunarssuit intrusive complex, might lie.

A striking feature on the total intensity magnetic map is the positive anomaly that runs north-east from Viiliap Nuua to Tarajornitsup Torsukattaa and passes with a steep gradient into a strong negative anomaly running along the west side of the lake Kuussuatsiaap Tasia. This is parallel to the elongate gabbro-syenite composite intrusions north of Viiliap Nuua which, however, do not show up on the magnetic map, so it is not likely that a deep-seated intrusion of this type at depth is the cause of the conspicuous negative anomaly. At the moment no explanation can be offered for this negative anomaly.

References

Allaart, J.A. 1967: Basic and intermediate igneous activity and its relationships to the evolution of the Julianehåb granite, South Greenland. Bulletin Grønlands Geologiske Undersøgelse 69, 136 pp. (also Meddelelser om Grønland 175(1)).

Allaart, J.H. 1973: Geological Map of Greenland, 1:100 000, Julianehåb 60 V.2 Nord. Descriptive text, 41 pp. Copenhagen: Geological Survey of Greenland.

Allaart, J.A. 1975: Geologisk kort over Grønland, 1:500 000, Sheet 1 Sydgrønland. København: Grønlands Geologiske Undersøgelse.

Allaart, J.A. 1976: Ketilidian mobile belt in South Greenland. In: Escher, A. & Watt, W.S. (eds): Geology of Greenland, 120–151. Copenhagen: Geological Survey of Greenland.

Allaart, J.H. 1983: Geological Map of Greenland, 1:100 000, Narssarssuaq 61 V.3 Syd. Descriptive text, 20 pp. Copenhagen: Geological Survey of Greenland.

Ayrton, S.N. 1991: Appinites, lamprophyres and mafic microgranular inclusions: three related products of interaction between acid and basic magmas. In: Didier, J. & Barbarin, B. (eds): Enclaves and granite petrology, 465–476. Amsterdam: Elsevier.

Bailey, E.B. & Maufe, M.B. 1916: The geology of Ben Nevis and Glen Coe. Memoir of the Geological Survey of Scotland, 247 pp.

Barbarin, B. & Didier, J. 1991: Macroscopic features of mafic microgranular enclaves. In: Didier, J. & Barbarin, B. (eds): Enclaves and granite petrology, 253–262. Amsterdam: Elsevier.

Berger, A.R. 1971: Dynamic analysis using dikes with oblique internal foliations. Geological Society of America Bulletin 82, 781–786.

Berrangé, J.P. 1966: The bedrock geology of Vatnahverfi, Julianehåb district, South Greenland. Rapport Grønlands Geologiske Undersøgelse 3, 48 pp.

Blake, D.M., Elwell, R.W.D., Gibson, I.L., Skelhorn, R.R. & Walker, G.P.L. 1965: Some relationships resulting from the intimate association of acid and basic magmas. Quarterly Journal of the Geological Society of London 121, 31–49.

Bowes, D.R. & McArthur, A.C. 1976: Nature and genesis of the appinite suite. Krystalinikum 12, 31–46.

Bridgwater, D. 1959: Report [of field work] 1959. Unpublished report, Geological Survey of Greenland, Copenhagen.

Cawthorn, R.G. & O'Hara, M.J. 1976: Amphibole fractionation in calc-alkaline magma genesis. American Journal of Science 276, 309–329.

Chadwick, B. & Garde, A.A. 1996: Palaeoproterozoic oblique plate convergence in South Greenland: a reappraisal of the Ketilidian orogen. In: Brewer, T.S. (ed.): Precambrian crustal evolution in the North Atlantic region. Geological Society (London) Special Publication 112, 179–196.

Engell, J. & Pedersen, S. 1974: Rhubidium-strontium whole rock isochron age determination from the Bangs Havn intrusion, South Greenland. Bulletin of the Geological Society of Denmark 23, 130–133.

Fernandez, A.N. & Barbarin, B. 1991: Relative rheology of coeval mafic and felsic magmas: nature of resulting interaction processes and shape and mineral fabrics of mafic microgranular enclaves. In: Didier, J. & Barbarin, B. (eds): Enclaves and granite petrology, 263–275. Amsterdam: Elsevier.

Finch, A.A., Mansfeld, J. & Andersen, T. 2001: U-Pb radiometric age of the Nunarsuit pegmatite, Greenland: constraints on the timing of Gardar magmatism. Bulletin of the Geological Society of Denmark 48, 1–7.

Garde, A.A. & Schønwandt, H.C. 1995: Project SUPRASYD 1994 – Ketilidian supracrustal rocks in South-East Greenland and gold-bearing shear zones in the Julianehåb batholith. Rapport Grønlands Geologiske Undersøgelse 165, 59–63.

Garde, A.A., Chadwick, B., Grocott, J. & Swager, C. 1997: Metasedimentary rocks, intrusions and deformation history in the south-east part of the *c.* 1800 Ma Ketilidian orogen, South Greenland: Project SUPRASYD 1996. Geology of Greenland, Survey Bulletin 176, 60–65.

Garde, A.A., Chadwick, B., McCaffrey, K. & Curtis, M. 1998: Reassessment of the north-western margin of the Palaeoproterozoic Ketilidian orogen, South Greenland. Geology of Greenland Survey Bulletin 180, 111–118.

Garde, A.A., Chadwick, B., Grocott, J., Hamilton, M.A., McCaffrey, K.J.W. & Swager, C.P. 2002a: Mid-crustal partitioning and attachment during oblique convergence in an arc system, Palaeoproterozoic Ketilidian orogen, southern Greenland. Journal of the Geological Society (London) 159, 247–261.

Garde, A.A., Hamilton, M.A., Chadwick, B., Grocott, J. & McCaffrey, K.J.W. 2002b: The Ketilidian orogen of South Greenland: geochronolgy, tectonics, magmatism, and fore-arc accretion during palaeoproterozoic oblique convergence. Canadian Journal of Earth Science 39, 765–793.

Gulson, B.L. & Krogh, T.E. 1975: Evidence of multiple intrusion, possible resetting of U-Pb ages, and new crystallization of zircons in post-tectonic intrusions ('Rapakivi granites') and gneisses from South Greenland. Geochimica et Cosmochimica Acta 39, 65–82.

Hall, A. 1967: The chemistry of appinitic rocks associated with the Ardara pluton, Donegal, Ireland. Contributions to Mineralogy and Petrology 16, 156–171.

Harry, W.T. & Oen Ing Soen 1964: The Pre-Cambrian basement of Alángorssuaq South Greenland and its copper mineralization at Josvaminen. Bulletin Grønlands Geologiske Undersøgelse 47, 72 pp. (also Meddelelser om Grønland 179, 1)).

Harry, W.T. & Pulvertaft, T.C.R. 1963: The Nunarssuit intrusive complex, South Greenland. I. General description. Bulletin Grønlands Geologiske Undersøgelse 36, 136 pp. (also Meddelelser om Grønland 169(1)).

Hibbard, M.J. & Watters, R.J. 1985: Fracturing and diking in incompletely crystallized plutons. Lithos 18, 1–12.

International Union of Geological Sciences 1973: Plutonic rocks. Classification and nomenclature recommended by the IUGS Subcommission on the Systematics of Igneous Rocks. Geotimes 18, 26–30.

Joplin, G.A. 1964: A petrography of Australian igneous rocks, 210 pp. Sydney: Angus & Robertson.

Kalsbeek, F., Larsen, L.M. & Bondam, J. 1990: Geological map of Greenland, 1:500 000, Sydgrønland Sheet 1. Descriptive text, 36 pp. Copenhagen: Geological Survey of Greenland.

Larsen, L.M., Rex, D.C., Watt, W.S. & Guise, P.G. 1999: ^{40}Ar–^{39}Ar dating of alkali basaltic dykes along the south-west coast of Greenland: Cretaceous and Tertiary igneous activity along the eastern margin of the Labrador Sea. Geology of Greenland, Survey Bulletin 184, 19–29.

Le Maitre, R.W. (ed.) 1989:A classification of igneous rocks and glossary of terms. Recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks, 193 pp. Oxford: Blackwell Scientific Publications.

Palivcová, M. 1981: Microtextures of gabbroic and dioritic rocks associated with intrusive granitoid complexes. Geologický Zborník – Geologica Carpathica 32, 559–589.

Parsons, I. 1972: Petrology of the Puklen syenite–alkali granite complex, Nunarssuit, South Greenland. Meddelelser om Grønland 195(3), 73 pp.

Patchett, P.J., Bylund, G. & Upton, B.G.J. 1978: Palaeomagnetism and the Grenville orogeny: new Rb-Sr ages from dolerites in Canada and Greenland. Earth and Planetary Science Letters 40, 349–364.

Paterson, S.R., Vernon, R.H. & Tobisch, O.T. 1989: A review of criteria for the identification of magmatic and tectonic foliations in granitoids. Journal of Structural Geology 11, 349–363.

Pedersen, S., Larsen, O., Bridgwater, D. & Watterson, J. 1974: Rb/Sr whole rock isochron age determinations on metamorphosed acid volcanic rocks and granitic gneisses from the Ketilidian mobile belt, South-East Greenland. Rapport Grønlands Geologiske Undersøgelse 66, 12–20.

Pitcher, W.S. 1997: The nature and origin of granite, 387 pp. London: Chapman & Hall.

Pitcher, W.S. & Berger, A.R. 1972: The geology of Donegal: a study of granite emplacement and unroofing, 435 pp. New York: Wiley-Interscience.

Pitcher, W.S. & Bussell, M.A. 1985: Andean dyke swarms: andesite in synplutonic relationship with tonalite. In: Pitcher, W.S., Atherton, M.P., Cobbing, E.J. & Beckinsale, R.D. (eds): Magmatism at a plate edge. The Peruvian Andes, 102–107. Glasgow: Blackie.

Pulvertaft, T.C.R. 1961: The Puklen intrusion, SW Greenland. Bulletin Grønlands Geologiske Undersøgelse 29, 33–50 (also Meddelelser om Grønland 123(6), 33–50).

Pulvertaft, T.C.R. 1977: The Archaean and Lower Proterozoic (Ketilidian) rocks of the Nunarssuit 1:100 000 sheet area (60 V.1 Nord), South Greenland, 135 pp. Unpublished report, Geological Survey of Greenland, Copenhagen.

Read, H.H. 1961: Aspects of Caledonian magmatism in Britain. Liverpool and Manchester Geological Journal 2, 653–683.

Sederholm, J.J. 1926: On migmatites and associated Pre-Cambrian rocks of southwestern Finland. Part II. The region around the Barösundsfjärd W. of Helsingfors and neighbouring areas. Bulletin de la Commission Géologique de Finlande 77, 143 pp.

Stendal, H., Mueller, W., Birkedal, N., Hansen, E.I. & Østergaard, C. 1997: Mafic igneous rocks and mineralisation in the Palaeoproterozoic Ketilidian orogen, South-East Greenland: project SUPRASYD 1996. Geology of Greenland, Survey Bulletin 176, 66–74.

Taubeneck, W.H. & Poldervaart, A. 1960: Geology of the Elkhorn Mountains. Part II: Willow Lake intrusion. Geological Society of America Bulletin 71, 1295–1322.

Thorning, L. & Steemp, R.W. 1996: Airborne geophysical surveys in 1995. Bulletin Grønlands Geologiske Undersøgelse 172, 71–73.

Thorning, L. & Stemp, R.W. 1997: Projects Aeromag 1995 and Aeromag 1996. Results from aeromagnetic surveys over South Greenland (1995) and South-West Greenland and southern West Greenland (1996). Danmarks og Grønlands Geologiske Undersøgelse Rapport 1997/11, 44 pp.

Ussing, N.V. 1912: Geology of the country around Julianehaab Greenland. Meddelelser om Grønland 38, 1–376.

van Breemen, O., Aftalion, M. & Allaart, J.H. 1974: Isotopic and geochronologic studies on granites from the Ketilidian mobile belt of South Greenland. Geological Society of America Bulletin 85, 403–412.

Wager, L.R. & Bailey, E.B. 1953: Basic magma chilled against acid magma. Nature 172, 68–70.

Walton, B.J. 1965: Sanerutian appinitic rocks and Gardar dykes and diatremes, north of Narssarssuaq, South Greenland. Bulletin Grønlands Geologiske Undersøgelse 57, 66 pp. (also Meddelelser om Grønland 179(9)).

Watterson, J. 1965: Plutonic development of the Ilordeq area, South Greenland. Part I: chronology, and the occurrence and recognition of metamorphosed basic dykes. Bulletin Grønlands Geologiske Undersøgelse 51, 147 pp. (also Meddelelser om Grønland 172(7)).

Watterson, J. 1968: Plutonic development of the Ilordleq area, South Greenland. Part II: late kinematic basic dykes. Bulletin Grønlands Geologiske Undersøgelse 70, 104 pp. (also Meddelelser om Grønland 185(3)).

Wegmann, C.E. 1938: Geological investigations in southern Greenland Part I. On the structural divisions of southern Greenland. Meddelelser om Grønland 113(2), 148 pp.

Windley, B.F. 1965: The composite net-veined diorite intrusives of the Julianehåb district, South Greenland. Bulletin Grønlands Geologiske Undersøgelse 58, 60 pp. (also Meddelelser om Grønland 172(8)).

Yoder, H.S. & Tilley, C.E. 1962: Origin of basalt magmas: an experimental study of natural and synthetic rock systems. Journal of Petrology 3, 342–532.

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