Descriptive text to the Geological map of Greenland, 1:100 000, Kangaatsiaq 68 V.1 Syd and Ikamiut 68 V.1 Nord

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Keywords
Geological mapping, Archaean, Nagssugtoqidian orogen, Palaeoproterozoic ocean floor, crustal reworking, zircon geochronology

Cover
Extract of the western part of the Kangaatsiaq map sheet showing Archaean rocks reworked during the Palaeoproterozoic Nagssugtoqidian orogeny. The main components are arc-related metasedimentary and metavolcanic rocks embedded within younger orthogneiss and Kangaatsiaq granite. The prominent NE–SW-trending structural grain is due to Nagssugtoqidian tectonic reworking.

Frontispiece: facing page
Mesoarchaean synkinematic granite displaying ptygmatic folding, emplaced into polyphase orthogneiss in the southern part of the Aasiaat domain that is unaffected by Palaeoproterozoic Nagssugtoqidian tectonic reworking. Island at the head of Saqqarput 34.3 km south-east of Kangaatsiaq.

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Abstract


The two adjacent Kangaatsiaq and Ikamiut map sheets cover a coastal area of central West Greenland in the northern part of the Palaeoproterozoic Nagssugtoqidian orogen. The map area is part of the Aasiaat domain, which almost entirely consists of Neoarchaean orthogneisses with intercalated meta-morphosed volcano-sedimentary belts. The Aasiaat domain was partially reworked during the Nagssugtoqidian orogeny, but Palaeoproterozoic components are restricted to mafic dykes, the ≤1904 ± 8 Ma (2σ) Naternaq supracrustal belt east of Kangaatsiaq, and remnants of a c. 1850 Ma Palaeoproterozoic ocean-floor – arc-trench association on small islands north-east of Aasiaat. Undated, lithologically similar rocks occur on Hunde Ejlande north of Aasiaat.

The Archaean volcano-sedimentary belts are up to 2 km thick and comprise fine-grained mafic and minor, intermediate amphibolite of ex- and intrusive origin, gabbro, leucogabbro-anorthosite, and biotite-garnet schist with common sillimanite pseudomorphs after andalusite. The c. 2.8 Ga Archaean orthogneiss is largely tonalitic besides minor dioritic and granodioritic components, and preserves intrusive relationships with some of the supracrustal belts. Sheet-like bodies of late-kinematic crustal melt granites are up to about 10 km in length and 2 km thick. One of these has yielded a zircon Pb-Pb age of 2748 ± 19 Ma (2σ). Up to kilometre-thick units of quartz-feldspathic and locally garnet-bearing paragneisses also occur, some of which are younger than the orthogneisses.

The Aasiaat domain has undergone two Archaean orogenic episodes, separated by injection of mafic dykes and sedimentation at its margins. Archaean deformation resulted in kilometre-scale, tight to isoclinal folds refolded by upright to overturned folds, and its southern part reached granulite facies P–T conditions with widespread partial melting. The Aasiaat domain also underwent heating during the Nagssugtoqidian orogeny, but only its northern part was tectonically reworked, resulting in an intense E-W- to NNE–SSW-trending structural grain associated with subhorizontal extension lineation.

The Palaeoproterozoic Naternaq supracrustal belt in the eastern part of the Kangaatsiaq map area has a complex synformal structure and displays a prominent structural discordance against the underlying Archaean rocks; the belt also contains a second phase of SE-plunging, overturned folds. The Palaeoproterozoic ocean-floor – arc trench association on islands north-east of Aasiaat comprises pillow lava, manganiferous chlorite schist, chert, banded iron formation, graded aluminous schist, and siliceous sandstone, and points to the existence of a palaeosuture in this area.

A Palaeogene picritic sill complex and a small exposure of sandstone form the c. 15 km long island group of Kitssuannuguit / Grønne Ejland in the north-eastern Ikamiut map area. Two contemporaneous, N–S-trending mafic dykes were emplaced into the basement rocks south-west of the islands. One of these was hydraulically chilled and fractured during its emplacement, presumably due to contact with meteoric or sea water. Widespread hydrothermal alteration occurs along faults and joints in the basement rocks in the northern archipelago. The alteration may have been caused by circulation of magmatically heated meteoric or sea water during the development of the Cretaceous–Paleocene basalt province in West Greenland.

No deposits of economic interest have been found in the Archaean rocks within the map area. A massive sulphide deposit in the Naternaq supracrustal belt was discovered and explored in the 1960s by Kryolitselskabet Øresund A/S, and a VHMS-style copper-gold-zinc mineralisation was reported in 2004 from Kitsissuarsuit / Hunde Ejlande by a local inhabitant. The potential for ornamental rocks is largely unexplored.

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Fig. 1. Geological map of the Nagssugtoqidian orogen in West Greenland with tectonic divisions and the locations of published 1:100 000 geological maps (modified from van Gool & Marker 2007). The northern boundary of the Aasiaat domain with its associated Palaeoproterozoic ocean-floor rocks is drawn so that it follows the change of the magnetic signatures in Fig. 4, and is tentatively correlated with the palaeosuture north of Ilulissat proposed by Connelly et al. (2006). The southern boundary of the Aasiaat domain is located along the previously identified Nordre Strømfjord shear zone (see van Gool et al. 2002), where NNW-directed Palaeoproterozoic thrusting occurs e.g. at the head of Ataneq (see Fig. 19); the rocks along the westernmost part of the Nordre Strømfjord shear zone are near-vertical or dip steeply towards SSE.
Introduction

The Kangaatsiaq–Ikamiut map area is located in central West Greenland (Fig. 1) and encompasses the town of Aasiaat, the large settlement of Kangaatsiaq, as well as several small settlements including Ikamiut in the north-east. The map area covers a large part of the Archaean Aasiaat domain of amphibolite to granulite facies orthogneiss with intercalated supracrustal belts that constitutes the northern part of the Palaeoproterozoic Nagssugtoqidian orogen from the Nordre Strømfjord shear zone to Ilulissat (Fig. 1). The map area also includes sporadic Palaeoproterozoic dykes as well as Palaeoproterozoic metavolcanic and -sedimentary rocks on

Fig. 2. Simplified geological map of the Kangaatsiaq and Ikamiut map areas with place names used in the text. The positions of field photographs shown in subsequent figures are shown with blue lettering.
islands north-east of Aasiaat and at Natemaq/Lersletten. A few Palaeogene olivine-phyric basaltic dykes occur in the northern and eastern parts of the map area; the contemporaneous island group of Kitsissunnguit / Grønne Ejland in the north-east exposes picritic basalt and a small outcrop of sandstone.

Adjacent map sheets

Three 1:100 000 scale map sheets in the vicinity of the Kangaatsiaq and Ikamiut sheets have previously been published. The Agto map sheet 67 V.1 N (Olesen 1984) directly south of the Kangaatsiaq map sheet that straddles the boundary between the Aasiaat domain and the central Nagssugtoqidian orogen and was mapped in the 1960s and 1970s. The map units were mainly defined and mapped according to their mineral parageneses, mostly without distinction between igneous and sedimentary protoliths. This approach displayed the distribution of metamorphic facies very clearly, but impeded correlation with the subsequently published Kangaatsiaq and Ussuit map sheets, where the map units are largely based on recognition of protoliths (van Gool & Marker 2007).

The Ussuit map sheet 67 V.2 N itself (van Gool & Marker 2004) south-east of the Kangaatsiaq map area was based on work by the Danish Lithosphere Centre (1994–1999) and a final field season with two teams in 2000. There is no direct geological overlap with the present work. The Ussuit map sheet is located south of the Aasiaat domain, in the eastern part of the central Nagssugtoqidian orogen and comprises Palaeoproterozoic supra-arc plutonic rocks, the contemporaneous Aferjuk intrusive complex, and in its southern part intensely reworked Archaean rocks belonging to the North Atlantic craton.

The Kangersuneq map sheet 68 V.2 S (van Gool 2005) east of the Ikamiut map sheet was produced almost concurrently with the latter sheet, hence there are no breaks in the map units in the contact area south-east of Ikamiut (Fig. 1). This map sheet in the north-eastern part of the Aasiaat domain almost exclusively consists of variably reworked Archaean rocks; no Palaeoproterozoic supracrustal rocks have been discovered. The Archaean orthogneisses and supracrustal belts in the boundary area between the two map sheets are cut by sporadic, deformed Palaeoproterozoic mafic dykes, which document Palaeoproterozoic tectonic overprinting in this area.

Field work

The first geological study in the northern Nagssugtoqidian orogen by the Geological Survey of Greenland (GGU) took place already in 1948, when Ellingsgaard-Rasmussen (1954) mapped and described the well-preserved metavolcanic and metasedimentary rocks occurring on some small islands north-east of Aasiaat (see later sections). Later, Noe-Nygaard & Ramberg (1961) and Henderson (1969) carried out coastal reconnaissance investigations for GGU, which included the northern Nagssugtoqidian orogen. The latter investigation was undertaken for the 1:500 000 scale geological map sheet Søndre Strømfjord – Nûgssuaq (Escher 1971). The region was visited again in the 1990s by the Danish Lithosphere Centre, when Kalsbeek & Nutman (1996) and Whitehouse et al. (1998) carried out reconnaissance geochronological studies.

Henderson’s (1969) work and his unpublished coastal maps in the Survey archives served as a convenient starting point for the subsequent systematic mapping of the Kangaatsiaq, Ikamiut and Kangersuneq map areas undertaken in 2001–2003 by the Geological Survey of Denmark and Greenland (GEUS) and an international group of geologists. Based on this work three geological maps on a scale of 1:100 000 were published by Garde (2004, 2006) and van Gool (2005). Most of the field work for the Kangaatsiaq and Ikamiut map sheets described here was performed using rubber dinghies along the coasts and supplemented by a few foot traverses and limited helicopter-supported work in inland areas. Index maps on the two map sheets display the positions of all 2001–2003 ground observation points as recorded by satellite positioning along with the names of the mapping geologists. The field work was supplemented by interpretation of black and white aerial photographs on a scale of 1:150 000 by the first author, but apart from accurate
Aeromagnetic and geochronological data

Most of the map area is covered by high-quality aeromagnetic maps (Thorning 1993; Rasmussen & van Gool 2000). Nielsen & Rasmussen (2004) produced interpretative aeromagnetic maps from the northern Nagssugtoqidian orogen from this data set. Maps of the total magnetic intensity (Fig. 4A) and the vertical gradient of the latter (Fig. 4B) clearly delineate several important features, labelled 1–6 and with an arrow. The southern part of inland areas are commonly overgrown by lichens or thick blankets of moss. The map area also comprises the protected Naternaq/Lersletten wetland area, a periglacial outwash plain of raised shallow marine deposits which is an important area for breeding and moulting of greater white-fronted geese (Fig. 3). The sediment was derived from the glacier Akuliarutsip Sermersuaq / Nordenskiöld Gletscher east of the Kangartsiaq map area. The scattered rounded hills of exposed bedrock within the Naternaq area are somewhat difficult to access except by helicopter.

**Physiography**

Much of the Kangartsiaq–Ikamiut map area forms an archipelago that is easily accessible by boat (Fig. 2). The mainland is relatively flat with elevations up to 450 m, dissected by several ENE- and ESE-trending fjords. Exposure is excellent in the intertidal zone and reasonable on south-facing slopes, whereas north-facing slopes in inland areas are commonly overgrown by lichens or thick blankets of moss. The map area also comprises the protected Naternaq/Lersletten wetland area, a periglacial outwash plain of raised shallow marine deposits which is an important area for breeding and moulting of greater white-fronted geese (Fig. 3). The sediment was derived from the glacier Akuliarutsip Sermersuaq / Nordenskiöld Gletscher east of the Kangartsiaq map area. The scattered rounded hills of exposed bedrock within the Naternaq area are somewhat difficult to access except by helicopter.

**Aeromagnetic and geochronological data**

Fig. 4A. Aeromagnetic map of the northern Nagssugtoqidian orogen showing total magnetic intensity. (1) tectonically unworked southern Aasiaat domain with open, curved magnetic signatures. (2) central and northern Aasiaat domain with strong ENE-trending linear pattern due to intense Nagssugtoqidian reworking. Arrow at Naternaq supracrustal belt with low total intensity and angular discordance between its N–S-trending western flank and ENE-trending basement structures. (3) ENE-trending belt of narrow high and low magnetic intensity zones at the northern plate boundary of the Aasiaat domain outlining a simple fold pair. (4) smooth signature of high magnetic intensity, likely underlain by homogeneous granitic rocks of Archaean age. (5, 6) Palaeogene dolerite dykes, trending almost N–S. See main text for references and discussion.
of the map area (1) displays open, curved magnetic signatures and corresponds to the tectonically unreworked part of the Archaean Aasiaat domain (described later). The central part of the map area (2) displays a strong ENE-trending linear pattern due to intense Nagssugtoqidian reworking. Arrow at Naternaq supracrustal belt with low total intensity and angular discordance between its N–S-trending western flank and ENE-trending basement structures. (3) ENE-trending belt of narrow high and low magnetic intensity zones at the northern plate boundary of the Aasiaat domain outlining a simple fold pair. (4) smooth signature of high magnetic intensity, likely underlain by homogeneous granitic rocks of Archaean age. (5, 6) Palaeogene dolerite dykes, trending almost N–S.

Fig. 4B. Aeromagnetic map of the northern Nagssugtoqidian orogen: vertical gradient of the total magnetic intensity. (1) tectonically unreworked southern Aasiaat domain with open, curved magnetic signatures. (2) central and northern Aasiaat domain with strong ENE-trending linear pattern due to intense Nagssugtoqidian reworking. Arrow at Naternaq supracrustal belt with low total intensity and angular discordance between its N–S-trending western flank and ENE-trending basement structures. (3) ENE-trending belt of narrow high and low magnetic intensity zones at the northern plate boundary of the Aasiaat domain outlining a simple fold pair. (4) smooth signature of high magnetic intensity, likely underlain by homogeneous granitic rocks of Archaean age. (5, 6) Palaeogene dolerite dykes, trending almost N–S.

**Geochronological data**

This work contains a couple of new ion microprobe U–Pb zircon age determinations of Archaean rocks that are addressed where appropriate in the main text and described in detail in the Appendix. All age data quoted in this publication are given with 2σ errors.
Lithological components

As mentioned above the Kangaaatsiaq–Ikamiut map area is underlain by the Aasiaat domain, most of which consists of Neoarchaean orthogneiss with interspersed supracrustal belts of generally undated Archaean amphibolite, mica schist (± sillimanite, garnet), and garnet-bearing quartzo-feldspathic paragneiss (Hollis et al. 2006; Moyen & Warr 2006; Garde et al. 2007a; St-Onge et al. 2009; Garde & Hollis 2010). Palaeoproterozoic metavolcanic and metasedimentary rocks are restricted to the Naternaq supracrustal belt in the eastern part of the Kangaaatsiaq map area, the islands of Isuamiut–Qaqarsuatsiaq and Equutiit Killiat about 10 km north-east of Aasiaat, and presumably also the island group of Hunde Eilande (Garde & Hollis 2010). Metamorphosed mafic dykes of presumed Palaeoproterozoic age have been observed in the archipelago west and north-east of Aasiaat, where they are intensely deformed, and in the southern part of the Aasiaat domain close to 68°N, where they are undeformed. Small bodies of heterogeneous S-type granite occur in the hinge zones of Palaeoproterozoic folds within the Naternaq supracrustal belt, and straight, late-orogenic Palaeoproterozoic pegmatites up to a few metres wide can be found throughout the Aasiaat domain. Rare Palaeogene olivine-phenocrystic mafic dykes occur e.g. in the north-western part of the Ikamiut map area, and a N–S-trending, hydraulically chilled and fractured Palaeogene dyke occurs in its eastern part.

Previous interpretations

Ramberg (1949) identified the southern boundary of the Nagssugtoqidian orogen by means of the deformation front that affects the Kangâmiut mafic dyke swarm in the Kangâmiut mafic dyke swarm (2040 Ma) area between 66 and 67°N. However, the northern limit of the orogen was never firmly established, and the part north of 68°N has not been studied in detail prior to the mapping project in 2001–2003. In the days prior to the recognition of plate tectonics and when also geochronological data were not easily available, the Nagssugtoqidian orogeny was described in terms of in situ reworking of Archaean crust, “most likely at the beginning of the Proterozoic or end of the Archaean” (i.e. at around 2.5 Ga, Escher et al. 1976; Kortsgaard 1979). However, Kalsbeek et al. (1978) showed that the Kangâmiut dyke swarm and hence the Nagssugtoqidian orogeny is much younger. Kalsbeek et al. (1984) subsequently demonstrated that the central Nagssugtoqidian orogen also comprises at least one juvenile magmatic arc of Palaeoproterozoic age as well as Palaeoproterozoic supracrustal rocks. Kalsbeek et al. (1987) furthermore suggested that a cryptic Palaeoproterozoic suture occurs in the central part of the orogen.

Studies in 1994–1999 by the Danish Lithosphere Central
tre (DLC) concentrated in the Ussuit area (Fig. 1) led to a collisional plate-tectonic model for the Nausuqtoqidian orogen with a tentative interpretation of southward subduction of a northern collisional plate under the North Atlantic craton, which forms the southern foreland of the orogen (Connelly et al. 2000; van Gool et al. 2002; van Gool & Marker 2007). The northern plate was not investigated in much detail by the DLC and was thought to be contiguous with the Archaean basement of the Rinkian fold belt farther north. Figure 5 shows a slightly simplified version of this plate-tectonic model; for a general description of the Rinkian fold belt see Henderson & Pulvertaft (1987). The most recent mapping project in the northern Nausuqtoqidian orogen firmly established that the Archaean rocks south and south-east of Kangiaq escaped Palaeoproterozoic deformation (Piazolo et al. 2004; Mazur et al. 2006; van Gool & Piazolo 2006), and the model of Fig. 5 is now considered outdated (see below, later sections and Garde & Hollis 2010 for further discussion).

Studies in 2001–2003 within the Rinkian fold belt also verified that the Rinkian fold belt is collisional in nature and that the Nausuqtoqidian orogen and the Rinkian fold belt are contemporaneous (Garde et al. 2003; Thrane et al. 2003; Sidgren et al. 2006). Connelly et al. (2006) proposed a second south-dipping suture at Paakitsoq (Fig. 1), where a major system of flat-lying, ultramylonitic shear zones is exposed. Garde & Hollis (2010) have subsequently shown that the outcrops of volcanic and sedimentary rocks on the Isuamiut–Qaqqarsuatsiaq and Equutiit Killiat islands north-east of Aasiaat represent Palaeoproterozoic ocean floor and a buried spreading ridge (see below). According to Garde & Hollis (2010) these rocks have been preserved in a south-dipping palaeosuture at the boundary between the Aasiaat domain and the Archaean Rae craton which underlies the Rinkian fold belt. This model is discussed in a later section.

Archaean and Palaeoproterozoic map units and their division

The Kangiaq and Ilulissat map sheets mostly comprise similar rock units that are contiguous with each other. They are treated together in the following descriptions. The current division between Archaean and Palaeoproterozoic supracrustal rocks is based on a combination of field relationships and age determinations. However, the limited available geochronological data and their uneven geographical distribution imply that some supracrustal rock units mapped as Archaean may in fact be Palaeoproterozoic in age. This is especially the case in areas of intense deformation where primary contact relationships have been completely destroyed, and in the area immediately south of Naternaq where the few existing field observations were made before it was realised that the supracrustal belts comprise both Archaean and Palaeoproterozoic rocks. The supracrustal rocks on Hunde Ejlande north of Aasiaat are shown as Palaeoproterozoic because they are lithologically similar to Palaeoproterozoic rocks north-east of Aasiaat, but geochronological work on Hunde Ejlande is needed to confirm this.
Archaean orthogneiss complex and remobilised granitic rocks

The Archaean orthogneiss complex comprises two main rock associations. The first and most voluminous one comprises polyphase tonalitic–trondhjemitic–granodioritic (TTG) orthogneisses (including minor dioritic rocks). These are commonly migmatised and generally at least moderately deformed, also where Nagssugtoqidian tectonic overprinting is absent. The second association comprises variably porphyritic granites and pegmatites. These are younger and usually less deformed than the TTG orthogneisses and preserve field and compositional evidence of having been derived from orthogneiss precursors by partial melting.

Orthogneiss, mainly tonalitic (gn)

Medium-grained, biotite- and locally hornblende-bearing, tonalitic to granodioritic orthogneiss is by far the most voluminous rock association in the map area. Such rocks from Ikamiut have been described in some detail by Hollis et al. (2006), who also published age data (see below). The metamorphic grade is upper amphibolite facies throughout the central and northern Aasiaat domain: the biotite in the orthogneiss mostly occurs as evenly distributed flakes 2–3 mm long, suggesting that the rocks have not been through granulite facies metamorphism and subsequent retrogression. In the northern archipelago the orthogneiss is commonly homogeneous and porphyritic, with subhedral plagioclase crystals up to 1.5 cm long. Elsewhere the orthogneiss is commonly migmatised with indistinct veinlets of local partial melt origin (Fig. 6A). At the latitudes between Aasiaat and Kangiaasiq the orthogneiss has obtained an intense, steep, NNE–SSW-trending schistosity and a subhorizontal extensional linear fabric (Fig. 6B–C). The overprinting diminishes southwards and is absent in the southern half of the Kangiaasiq map area. It is interpreted as a result of the Nagssugtoqidian orogeny (Mazur et al. 2006; Thrane & Connelly 2006; Garde & Hollis 2010). The different resulting tectonic styles in the unworked and reworked parts of the Aasiaat domain are clearly visible on the aeromagnetic maps of Fig. 4.

Disrupted relics of mafic dykes, commonly only a few centimetres thick and in many places folded, have been observed e.g. at Arfersiorfik and Saqqarput in the southeast of the map area (Fig. 7), where Nagssugtoqidian tectonic overprinting is absent. The folded dyke fragments

Fig. 6. Orthogneiss in the central and northern Aasiaat domain. A. Deformed polyphase tonalitic orthogneiss with migmatic partial melt seams just west of the Naternaq supracrustal belt. Coin for scale (d = 2.8 cm). B, C. Archaean orthogneiss with intense Nagssugtoqidian tectonic overprinting, producing intense schistosity on the island of Naajat (B, person for scale) and ENE-trending extension lineation and refolding at embayment east of Naajat (C, compass for scale). Locations shown in Fig. 2.
are presumed to denote an Archaean episode of crustal extension that must have occurred between the emplacement of the orthogneisses at around 2.85–2.80 Ga (see below) and the latest (Archaean) episode of deformation at 2748 ± 19 Ma as determined by Thrane & Connelly (2006).

In the south-eastern part of the Kanguaatsiaq map area the orthogneisses display an overall prograde transition into brown-weathering, granulite facies, medium-grained, foliated to equigranular rocks with common migmatisation and up to centimetre-sized hypersthene porphyroblasts besides biotite and locally hornblende. This rock type is difficult to distinguish in the field from weakly compositionally layered, likewise migmatised, quartzo-feldspathic paragneiss (q) e.g. around the narrow Amitsoq fjord, especially where the latter rocks are not garnetiferous.

Hollis et al. (2006) carried out zircon U-Pb ion microprobe and laser ablation ICP-MS age determinations of two samples of amphibolite facies orthogneiss from Ikerassuassuq/Langesund about 20 km east of Aasiaat and obtained ages of 2831 ± 23 Ma and 2741 ± 53 Ma, respectively. The former age was interpreted as the emplacement age of the magmatic precursor. Additional zircon U-Pb age data were obtained from a sample of orthogneiss collected on a small island just east of Maniitsoq. This orthogneiss has intrusive contacts into supracrustal amphibolite (Garde et al. 2004; see Appendix for age data). An emplacement age of at least c. 2810 Ma is indicated by the oldest grains, but many grains appear to have been affected by early lead loss (see Appendix).

Chemical analyses of orthogneiss obtained by Moyen & Watt (2006) and from sample 467558 (Table 1) indicate that the compositions are predominantly tonalitic and locally granodioritic. The analysed samples have strongly fractionated rare-earth element (REE) patterns relative to chondrite, with strong enrichment in light REE and chondrite-normalised La/Lu ratios commonly >100.

K- and Si-metasomatised orthogneiss (gm)
The orthogneiss exposed around Aasiaat and in the coastal area north-west of Nivaap Paa locally displays evidence of intense hydrothermal alteration related to brittle faults and fractures. The most intensely hydrothermally altered rocks are brick-red and largely consist of unoriented intergrowths of medium-grained quartz and red K-feldspar; superficially these rocks may look like granite.

Around Aasiaat the hydrothermal alteration is concentrated in centimetre- to decimetre-wide zones along
N–S- and NNW–SSE-trending brittle faults and joints. The hydrothermal alteration at Nivaap Paa is much more widespread. The alteration occurs in elongate zones up to hundreds of metres wide, but due to the intensity of the alteration its spatial relationship to faults and joints is not nearly as obvious as at Aasiaat. A brief investigation at the tip of the peninsula Nuuk north-west of Nivaap Paa (68°24.5´N, 51°05.7´W) shows a complete transition from minor hydrothermal alteration of migmatised orthogneiss along healed hairline fractures (Fig. 8A) to rocks which have undergone thorough hydrothermal alteration and complete recrystallisation into massive, equigranular, medium-grained quartz-K-feldspar rock with complex grain boundaries (Fig. 8D). The compositional change from the essentially unaltered to thoroughly altered rock is illustrated by four chemical analyses shown in Table 2. K, Rb, U and Th are strongly enriched in the most intensely altered rocks, whereas most other elements including REE are strongly depleted and Sr almost completely lost; an apparent gain in REE elements in samples 440935 and 440936 (Table 2) may be due to original compositional differences between the sampled rocks.

The hydrothermal alteration was most probably caused by circulation of magmatically heated meteoric water or sea water along fractures and joints in the uppermost crust. The hydrothermal episode has not been dated, but it is considered most likely that it was related to the development of the Cretaceous–Paleocene basalt province in West Greenland. In the map area the volcanic province is represented by basaltic sills of Grønne Ejland north of Nivaap Paa and dolerite dykes in the Aasiaat and Nivaap Paa areas (see below).

Dioritic orthogneiss (di)
Medium-grained, hornblende- and/or biotite-bearing gneissic rocks of quartz-dioritic to dioritic composition occur as deformed sheets up to c. 200 m wide within the orthogneiss complex north-east of Kangaaqtaq. Due to strong deformation their contact relationships are ambiguous; there is no evidence, however, that any of the dioritic sheets found within the orthogneiss complex were emplaced as dykes. A deformed body of quartz diorite near Qasigiannguit in the adjacent Kangersuneq map area, which has intrusive contacts against metasedimentary and metavolcanic rocks, yielded a U-Pb zircon age of 2801 ± 34 Ma interpreted as its emplacement age (Thrane & Connelly 2006).

Granodioritic orthogneiss (gr)
Pale pink weathering, medium-grained orthogneiss of granodioritic composition is prominent in three places within the map area. Such granodioritic orthogneiss is exposed in the island group of Kigiguit / Kronprinsens Eiland about 40 km north-west of Aasiaat, on the c. 5 km

| Table 1. Chemical analyses of orthogneiss and granodiorite, Maniitsoq and adjacent islands |
|-----------------------------------------|-----------------------------------------|-----------------------------------------|
| **Tonalite** | **Granodiorite** | **Granodiorite** |
| SiO₂       | 68.654 | 68.4576 | 68.4575 |
| TiO₂       | 0.410  | 0.449  | 0.288  |
| Al₂O₃      | 15.331 | 14.958 | 14.957 |
| Fe₂O₃      | 2.719  | 2.534  | 1.658  |
| MnO        | 0.014  | 0.021  | 0.022  |
| MgO        | 1.034  | 0.785  | 0.421  |
| CaO        | 2.709  | 2.253  | 1.856  |
| Na₂O       | 5.180  | 4.760  | 4.900  |
| K₂O        | 2.119  | 2.694  | 2.805  |
| P₂O₅       | 0.148  | 0.128  | 0.062  |
| Volatiles  | 0.450  | 0.160  | 0.150  |
| Total REE  | 59.768 | 58.771 | 58.967 |

Major elements (wt%) by XRF and trace elements (ppm) by ICP-MS at GEUS. See Kystol & Larsen (1999) for analytical procedures. Fe₂O₃ = total Fe calculated as Fe₂O₃. Volatiles = loss on ignition corrected for oxygen uptake due to oxidation of iron.
Fig. 8. Hydrothermal alteration of Archaean orthogneiss at Nuuk north of Nitaaq Paa, associated with near-surface brittle faults and fractures. The alteration is interpreted as related to the Palaeogene magmatic activity at Disko Bugg (see main text). Coin is 2.8 cm in diameter.

A: Migmatised tonalitic orthogneiss with hydrothermal alteration along hairline fractures. Migmatisation texture still visible, and biotite present.

B: Partially hydrothermally altered orthogneiss. Extensively hydrothermally altered rock, in which some parts have been completely altered to quartz – K-feldspar aggregates. Extensively hydrothermally altered rock with irregular syn-alteration quartz veins. The location is shown in Fig. 2.
long island of Maniitsoq and adjacent islands c. 5 km north-west of Aasiaat. It forms an elongate, c. 10 km long body underlying the Naternaq supracrustal belt in the Naternaq area. The granodiorite is commonly K-feldspar-porphyric, and on Kronprinsens Eiland and Maniitsoq it is only weakly deformed. The granodiorite on the latter island hosts common, flat-lying pegmatites up to a few tens of centimetres thick that are increasingly deformed towards the south. None of the three main occurrences of granodiorite display well-exposed contacts with the regional orthogneiss.

Major and trace element analysis (Table 1) and zircon U-Pb ion microprobe geochronology have been carried out on two samples from the K-feldspar-megacrystic granodiorite body which crops out on Maniitsoq and adjacent islands (Fig. 2). Sample 467565, collected on the triangular island south-west of Maniitsoq, has yielded an age of 2771 ± 3 Ma (Mean Square Weighted Deviation (MSWD) = 3.3) based on the ten oldest of 18 analysed grains (see Appendix). The data obtained from sample 467575 collected on the south coast of Maniitsoq island are also of good analytical quality (see Appendix). In this sample the ages of individual zircon crystals display a wide range between c. 2600 and 2800 Ma. The oldest grains, which have low U and Th contents, point to a minimum age of emplacement of about 2750 Ma, consistent with the age data from sample 467565. The younger grains are U- and Th-rich (typically with U and Th contents around 1000 and 500 ppm, respectively) and are considered likely to have undergone substantial early lead loss (see Appendix).

Granite (g)

Several large bodies of white, pink and pale red, medium- to coarse-grained, K-feldspar-porphyritic biotite granite up to a few kilometres across occur within the map region. Similar granite also occurs as smaller sheets and metre- to centimetre-scale veins. The granite bodies are generally less deformed than their orthogneiss hosts. Field observations of gradational transitions between migmatitic veins in tonalitic orthogneiss and massive granite suggest that the granite has been derived from adjacent tonalitic–granodioritic orthogneiss (Fig. 9). The three largest occurrences are the Kangaatsiaq granite east of Kangaatsiaq (Moyen & Watt 2006) and two bodies south of Nivaap Sullua c. 20 km west of Ikamiut and south-east of Alanngorsuup Imaa (Fig. 2). The Kangaatsiaq granite is pink, coarse-grained and K-feldspar-porphyritic, and displays a strong rodding lineation and schistosity (L to L>S tectonic fabric). It was emplaced into a series of basic to intermediate metavolcanic and pelitic rocks and subsequently folded into a complex synform a few kilometres wide (Moyen & Watt 2006, fig. 2). The granite west of Ikamiut, which is located within the hinge zone of a large antiform, was described by Hollis et al. (2006). It is porphyritic and holds a weak tectonic fabric, much weaker than found in the surrounding supracrustal rocks and orthogneisses.

Table 2. Chemical analyses of hydrothermally altered orthogneiss, Nuuk peninsula, Nivaap Paa

<table>
<thead>
<tr>
<th></th>
<th>Almost unaltered</th>
<th>Intensely altered</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>70.797</td>
<td>74.577</td>
</tr>
<tr>
<td>TiO₂</td>
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<td>0.185</td>
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<tr>
<td>Al₂O₃</td>
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<tr>
<td>Fe₂O₃*</td>
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<tr>
<td>MnO</td>
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</tr>
<tr>
<td>Na₂O</td>
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<td>3.460</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.564</td>
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</tr>
<tr>
<td>P₂O₅</td>
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<td>0.031</td>
</tr>
<tr>
<td>Volatiles</td>
<td>0.210</td>
<td>0.310</td>
</tr>
<tr>
<td>Sum</td>
<td>99.242</td>
<td>99.297</td>
</tr>
</tbody>
</table>

Cu 4.0 Sc 4.0 Ba 215.1
Sn 20.4 Sr 389.1
Ti 0.098 Sn 20.4
V 0.22 Tl 0.81
Cr 4.4 Ta 1.8
Co 35.0 Th 215.8
Ni 5.3 Ti 5.0
Cu 3.5 Sr 389.1
Zn 42.4 Ba 215.1
Ga 21.3 Sr 389.1
Ge 7.1 Fe2O3 = total Fe calculated as Fe₂O₃. Volatiles = loss on ignition corrected for oxygen uptake due to oxidation of iron.

Major elements (wt%) by XRF and trace elements (ppm) by ICP-MS at GEUS. See Kystøl & Larsen (1999) for analytical procedures.
The position of the granite west of Ikamiut in an antiformal hinge zone and its relatively undeformed nature suggest it was emplaced late in the Archaean deformation history after the main fabric-forming events. The field observations suggesting that the granite bodies have been derived by partial melting of orthogneisses are supported by the chemical composition of the Kangaatsiaq granite, which is slightly metaluminous with low Ni and Cr contents and low Mg/Fe ratios and moderate Rb, Sr and Ba contents. The REE concentrations are slightly higher than in the regional orthogneiss. The REE patterns in chondrite-normalised diagrams are similar to those of the regional orthogneiss except for variable negative Eu anomalies which point to retention of plagioclase in the granite source (Moyen & Watt 2006).

**Granitic and pegmatic veins (p)**

The pegmatite symbols shown in full red colour on the maps denote areas with decimetre- to metre-sized and occasionally thicker sheets of variably deformed pegmatite of presumed Archaean age, as well as areas with abundant migmatisation and local, partial melt veins centimetres to decimetres thick, which have been visibly separated from their source. The pegmatites are of the simple type with about equal proportions of quartz, K-feldspar and sodic plagioclase, as well as minor biotite. Centimetre- to metre-thick veins of late-kinematic granite occur e.g. at Saqqarput, where they commonly form small discordant bodies in hinge zones of folds (Fig. 9A) and thin sheets and veins subparallel to the deformed flanks of the same generation of folds (Fig. 9B). A zircon \(^{207}Pb/^{206}Pb\) age of 2748 ± 19 Ma age was obtained from a late-kinematic granite on the flank of one of these folds (Thrane & Connelly 2006), proving the Archaean age of the regional deformation in the southern part of the Aasiaat domain.

The extensive biotite-garnet-sillimanite schist southwest of Nivaap Paa in the Ikamiut map area has been subject to widespread partial melting resulting in centimetre- to metre-sized schlieren and veins of white, heterogeneous, coarse-grained, garnet-bearing granite grading into pegmatite. The partial melting event in this area has not been dated. However, age determination of metamorphic rims on zircon grains from an adjacent metasedimentary rock collected on the south coast of Nivaap Paa suggests that the area underwent high-grade metamorphism at c. 2740–2700 Ma (Hollis et al. 2006). It is therefore considered most likely that the partial melting of the biotite-garnet-sillimanite schist was Archaean and broadly contemporaneous with partial melting in the southern part of the Aasiaat domain (and thus unrelated to Nagsugtoqidian thermal reworking, see later).

**Archaean supracrustal and related intrusive rocks: main components and relationships with orthogneiss**

Like in other Archaean regions within the Nagsugtoqidian orogen, and in the North Atlantic craton farther south (Windley & Garde 2009), the orthogneisses in the map area are intercalated with supracrustal associations of (meta) volcanic, intrusive and sedimentary rocks. In low-strain areas such as hinge zones of Archaean folds the orthogneiss precursors can be seen to have intruded into the supracrustal rocks, and a majority of the supracrustal belts are thus likely to be older than the orthogneisses.
Heterogeneous, fine-grained mafic amphibolite of presumed volcanic origin (locally associated with layered metagabbro) and biotite schist (± muscovite, garnet and/or sillimanite) are the two most widespread rock types and commonly occur together. Kalsbeek & Taylor (1999) obtained a Palaeoproterozoic Rb-Sr whole-rock age from metasedimentary rocks at Ikamiut, whereas their extrapolation backward in the Sr evolution diagram points to a depositional age at around 2.8 Ga.

The occurrences of quartz-feldspathic paragneiss in the south-east of the Kangaatsiaq map area are not associated with amphibolite except in a synform on the south coast of Arfersiorfik at 68°07’N. The structurally lowest supracrustal rocks in this synform are quartzite and marble a few metres thick, overlain by quartz-feldspathic paragneiss and fine-grained amphibolite in the core of the synform. During the field work for the Kangaatsiaq map sheet no depositional unconformity between the quartzite and the underlying orthogneiss was recognised. The contact appears to be tectonic but was not scrutinised along its entire length.

Amphibolite (a)
The largest, more or less coherent outcrops of amphibolite occur in southern Naternaq and around Arfersiorfik in the Kangaatsiaq map area and outline a broad, more or less continuous arc, which is more than 40 km long and comprises refolded, right to isoclinal overturned folds. Fine-grained, heterogeneous amphibolite with a strong planar and linear tectonic fabric and an irregular deformed, centimetre- to decimetre-scale network of veinlets with diopside, calcic plagioclase and locally garnet and/or calcite is most common. Other outcrops display centimetre-scale compositional layering but are devoid of calc-silicate minerals (Fig. 10), and may be of tuffaceous origin. Horizons of homogeneous amphibolite up to several metres thick are also common. Moyen & Watt (2006) presented geochemical data for seven samples of fine-grained, mafic amphibolite collected north-east of Kangaatsiaq and concluded that the amphibolite is tholeiitic and MORB-like, with completely flat chondrite-normalised REE patterns at about 10× chondrite.

The fine-grained, heterogeneous, calc-silicate-bearing amphibolite is interpreted as volcanic in origin, most likely pillow lava or pillow breccia. The homogeneous varieties of fine-grained amphibolite may represent former hypabyssal sills and/or flows.

Successions up to 10–20 m thick of fine-grained, grey hornblende-plagioclase-biotite rocks displaying well-defined, planar compositional, centimetre-thick layering are common and frequently associated with ordinary mafic amphibolite. They have typically been given field labels such as ‘intermediate amphibolite’ or ‘grey amphibolite’, and have andesitic compositions. Locally volcanioclastic rocks with centimetre-scale angular, felsic clasts in a fine-grained, darker matrix have also been found, e.g. on the western side of the small island between the islands of Qeqertarsuatsiaq and Niaqat (Fig. 11C). These rocks are interpreted as intermediate volcanic breccia, ruff and/or tuffite. Some of these successions also comprise zones rich in garnet and biotite but with low feldspar contents (Fig. 11A–B). Similar Archaean garnet-rich parageneses devoid of feldspar are known e.g. from metamorphosed intermediate tuffs or tuffites in the Godthabfjord region that have been affected by intense synvolcanic hydrothermal alteration (e.g. Garde et al. 2007b; Garde 2008).

Metagabbro (ai)
Medium-grained hornblende-plagioclase metagabbro, locally with centimetre-sized, euhedral hornblende and/or plagioclase megacrysts, is sometimes intercalated within the fine-grained amphibolite or crops out within the orthogneiss as discrete bodies with tectonic or tec-
tonised margins. A medium- to coarse-grained metagabbro body c. 2 km in diameter at Ataneq also comprises coarse-grained leucogabbro locally grading into anorthosite. The (meta) gabbroic and associated rocks are considered to be an integral part of the supracrustal association(s.l.) which predates the orthogneisses.

On the island west of the abandoned settlement Ikerasak in the south-western corner of the Kangaatsiaq map area, within the granulite facies part of the Aasiaat domain, occurs a tightly folded body of metagabbro with a stratigraphic thickness of several hundred metres. The metagabbro is part of a supracrustal association that also comprises fine-grained, heterogeneous amphibolite and biotite schist. It has not been mapped in detail, but according to a few observations along the coasts of the island it consists of medium-grained rocks with variable proportions of hornblende, orthopyroxene, iron oxide and plagioclase, which commonly display centimetre- to decimetre-scale magmatic layering. Another much smaller sheet of metagabbro occurs 3 km east of Ikerasak. It is more than 50 m thick and displays well-exposed, rhythmic, magmatic, centimetre-thick layering (Fig. 12). Its contact relations with the orthogneises are not known; it may be a raft of the former body.
Anorthosite and leucogabbro (an)

Coarse-grained anorthosite with calcic plagioclase of the ‘Fiskenæsset type’ (Myers 1985) has been observed on the islands of Saattut and Upernivik at Nivaap Paa associated with coarse-grained hornblende leucogabbro. On Saattut itself the anorthosite–leucogabbro displays a tectonic or tectonised magmatic contact against biotite schist, whereas no other rock types (and thus no contacts) have been observed on Upernivik or its adjacent skerries. South of Saattut a train of intensely deformed anorthosite inclusions is sandwiched between orthogneiss and metasedimentary rocks. Intensely deformed anorthosite–leucogabbro is also found in a c. 2 km large body of metagabbro at Tulukaat Tasersuat north of Ataneq (Fig. 13).

Ultrabasic rocks (ub)

Ultrabasic rocks only form a tiny proportion of the map area, mainly as intensely deformed, variably serpentinated, metre-sized layers and lenses of medium-grained, olivine- and pyroxene-rich rocks. The ultrabasic rocks occur within or adjacent to amphibolite e.g. on an elongate island 7 km north-east of Aasiaat, and form trains of tectonic lenses in orthogneiss e.g. north of inner Saqqarput and south of Arfersiorfik. None of them have been studied in detail.

Biotite schist and paragneiss ± garnet and/or sillimanite (s)

The second most widespread Archaean supracrustal lithology after the fine-grained amphibolite is 2–3 mm-grained, compositionally layered biotite schist ± garnet-, muscovite and/or sillimanite. The biotite schist is commonly interlayered with the amphibolite varying from tens to hundreds of metres. The biotite schist may grade into quartz-feldspathic paragneiss ± garnet, and e.g. in the Ikamiut area grades into pale, siliceous paragneiss (q). Biotite schist also commonly forms elongate xenoliths in adjacent orthogneiss, indicating that at least some schist occurrences are older than the latter. As mentioned under the heading ‘Granitic and pegmatitic veins’, partial melting of biotite schist is widespread in some areas and particularly prominent south-west of Nivaap Paa.

Sillimanite is relatively common in some areas and almost invariably occurs within distinct layers a few centimetres apart as evenly scattered, blocky, centimetre-sized aggregates. The sillimanite aggregates are roughly lozenge-shaped where deformation is not intense, and are interpreted as pseudomorphs after andalusite. The repetitive distribution of these aggregates within regularly spaced layers may suggest that these rocks were originally deposited from density currents.
Medium-grained quartz-feldspathic paragneiss, commonly garnet-bearing and commonly grading into biotite schist, forms large outcrops in the south-eastern part of the map area especially around Amitsoq. Due to deformation and granulite facies metamorphism, the exact boundaries of these rocks are difficult to determine, and their contact relationship with the orthogneisses has not been established.

Hollis et al. (2006) performed a zircon U-Pb ion microprobe and Pb-Pb laser ablation ICP-MS age determination of a gneissic quartz-feldspathic rock from the Ikamiut area. They obtained a tight cluster of ICP-MS ages close to 2800 Ma from cores of individual zircon grains with igneous-type oscillatory zonation, which thus represent the maximum age of deposition. This overlaps with the age of an orthogneiss from the same area mentioned above (see the section ‘Archaean crustal evolution’).

Moyen & Watt (2006) described aluminous metapelites and layered biotite gneisses north-east of Kangaatsiaq and used major and trace element geochemical data to discuss their origin; as these particular rocks are not sufficiently voluminous to be shown separately on the map, they are both comprised in the unit of quartzofeldspathic paragneiss (q). Moyen & Watt (2006) concluded that the composition of the aluminous metapelites consistently points to a depositional setting in a continental or oceanic arc with a volcanic component in the source. Relatively high Ni, Cr and heavy REE contents preclude an origin solely from continental rocks such as TTG gneisses. This conclusion is in agreement with the field characteristics of the biotite schists and their contact relationships with adjacent rocks. The layered biotite gneiss yielded an ambiguous major and trace element geochemical signature. According to Moyen & Watt (2006) the layered biotite gneiss may either be interpreted as a felsic volcanic rock (their preferred interpretation) or as a clastic sedimentary rock.

Marble and calcareous rocks (m)
Two very small occurrences of marble and calc-silicate rocks have been found just east of Maniitsoq island (north of Aasiaat) and on the south coast of Arfersiorfik near the south-eastern map boundary. Medium-grained, equigranular calcite marble locally forms layers up to c. 20 cm thick interspersed with more voluminous diopside-rich calc-silicate rocks. The marble and calcareous horizons are in turn interstratified with quartzofeldspathic metasedimentary rocks.
Naternaq supracrustal belt at Naternaq/Lersletten: main components and structure

The c. 20 km long and up to 4 km wide, intensely deformed Naternaq supracrustal belt is the only large occurrence of metavolcanic and metasedimentary rocks of known Palaeoproterozoic age (Fig. 14; Østergaard et al. 2002; Garde & Hollis 2010). Most of the belt occurs in the north-eastern part of the Kangaatsiaq map area; its northernmost part within the Ikamiut map area appears under the heading ‘West of Kuussuup Qinngua’ on the latter map. The Naternaq supracrustal belt shows up on the aeromagnetic map as an area with low total magnetic intensity (Fig. 4, right side of arrow). It mainly consists of fine-grained amphibolite and siliceous to aluminous mica schist, besides volumetrically minor calcareous and volcanogenic-exhalative rocks. Only some parts of the belt have been mapped in detail, and accordingly it may not yet be fully understood (see below). The belt was previously considered to be of Archaean age, but detrital zircon age data from a fine-grained muscovite-sillimanite schist in its southern part have yielded a maximum depositional age of 1904 ± 8 Ma (Thrane & Connelly 2006, including data by the present authors). This depositional age is compatible with derivation from a hypothetical volcanic arc associated with the 1921–1885 Ma Arferrortfik intrusive suite in the central Nagssugtoqidian orogen. The southern part of the Naternaq supracrustal belt hosts a massive sulphide deposit, which was investigated by the company Kryolitselskabet Øresund A/S in the 1960s (see section on economic geology).

With its Palaeoproterozoic age the Naternaq supracrustal belt is an important structural marker, resting on the Archaean basement above a presumed tectonic contact. It comprises an overturned, asymmetrical syncline (F1) with an intense planar fabric (S1), which has been refolded into a large V-shaped body. Its NNE–SSW-trending western limb delineates a major, map-scale structural discordance against the underlying Archaean orthogneiss with its narrow, WNW-trending metavolcanic amphibolite belts and flat-lying lineations and fold axes. The discordance is conspicuous on both aeromagnetic and geological maps (Figs 4, 14). The contact itself is only exposed in the southern hinge zone of the Naternaq belt and along part of the southern limb of its main

Palaeoproterozoic map units

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Palaeoproterozoic map units

Naternaq supracrustal belt at Naternaq/Lersletten: main components and structure

The c. 20 km long and up to 4 km wide, intensely deformed Naternaq supracrustal belt is the only large occurrence of metavolcanic and metasedimentary rocks of known Palaeoproterozoic age (Fig. 14; Østergaard et al. 2002; Garde & Hollis 2010). Most of the belt occurs in the north-eastern part of the Kangaatsiaq map area; its northernmost part within the Ikamiut map area appears under the heading ‘West of Kuussuup Qinngua’ on the latter map. The Naternaq supracrustal belt shows up on the aeromagnetic map as an area with low total magnetic intensity (Fig. 4, right side of arrow). It mainly consists of fine-grained amphibolite and siliceous to aluminous mica schist, besides volumetrically minor calcareous and volcanogenic-exhalative rocks. Only some parts of the belt have been mapped in detail, and accordingly it may not yet be fully understood (see below). The belt was previously considered to be of Archaean age, but detrital zircon age data from a fine-grained muscovite-sillimanite schist in its southern part have yielded a maximum depositional age of 1904 ± 8 Ma (Thrane & Connelly 2006, including data by the present authors). This depositional age is compatible with derivation from a hypothetical volcanic arc associated with the 1921–1885 Ma Arferrortfik intrusive suite in the central Nagssugtoqidian orogen. The southern part of the Naternaq supracrustal belt hosts a massive sulphide deposit, which was investigated by the company Kryolitselskabet Øresund A/S in the 1960s (see section on economic geology).

With its Palaeoproterozoic age the Naternaq supracrustal belt is an important structural marker, resting on the Archaean basement above a presumed tectonic contact. It comprises an overturned, asymmetrical syncline (F1) with an intense planar fabric (S1), which has been refolded into a large V-shaped body. Its NNE–SSW-trending western limb delineates a major, map-scale structural discordance against the underlying Archaean orthogneiss with its narrow, WNW-trending metavolcanic amphibolite belts and flat-lying lineations and fold axes. The discordance is conspicuous on both aeromagnetic and geological maps (Figs 4, 14). The contact itself is only exposed in the southern hinge zone of the Naternaq belt and along part of the southern limb of its main
The fine-grained amphibolite with calc-silicates is interpreted as former pillow lava and/or pillow breccia. Medium-grained, grey, homogeneous, plagioclase-rich, biotite-bearing amphibolite of andesitic composition locally occurs, as well as hornblende-quartz rocks of presumed hydrothermal origin. Small bodies of medium-grained, variably foliated hornblende- or plagioclase-porphyroblastic amphibolite are interpreted as intrusive in origin.

**Biotite ± muscovite schist, commonly with garnet, staurolite and/or sillimanite (ns)**

The largest part of the Naternaq supracrustal belt is comprised of fine-grained, pelitic to siliceous biotite ± muscovite schist. The most siliceous varieties are generally light grey to light brown and commonly appear massive without much apparent lithological variation. No primary structures have been observed within them. In some places these rocks contain up to centimetre-sized, blocky aggregates of sillimanite afterandalusite. Garnet-rich horizons are common adjacent to amphibolite contacts. Layers of fine- to medium-grained garnet-mica schist ranging from centimetres to many metres in thickness, commonly sillimanite- and locally staurolite-bearing (Fig. 15A), are intercalated with both siliceous schist and amphibolite; these rocks mostly display a strong penetrative S or LS fabric. In some areas they contain local, quartz-feldspathic, centimetre-thick melt veins. The biotite ± muscovite schist may in part be of volcanic origin, most likely derived from acid ruff or tuffite.

**Amphibolite (na, na₂)**

Amphibolite mainly occurs as a c. 200–400 m thick belt along the outer periphery of the Naternaq supracrustal belt, which is intercalated with thinner strata of mica schist (Østergaard et al. 2002). Only small pockets of amphibolite have been preserved on the northern flank of the southern, E–W-trending part of the main syncline, along the tectonic contact with the orthogneisses. The amphibolite is mostly a very fine-grained hornblende-plagioclase rock which is commonly very schistose and/or intensely lineated, especially along the outer margin of the belt. Minor quartz and biotite are common, and locally garnet is present. Some localities display 1–5 cm long plagioclase aggregates. The amphibolite very commonly contains irregular, interconnected calc-silicate layers and lenses up to a few centimetres thick, which are more or less conformable with the main foliation. Calc-silicate layers up to c. 20 cm thick and tens of metres long have locally also been observed.

**Marble and calc-silicate rocks (c), and volcanogenic-exhalative horizons with chert and sulphidic rocks (v)**

In the southern and north-western parts of the Naternaq supracrustal belt the peripheral amphibolite is succeeded inwards/upwards by an irregular, generally intensely deformed sequence of marble, minor carbonate- and oxide-facies banded iron formation and cherty exhalites, and local semi-massive to massive sulphides. Detailed mapping by Østergaard et al. (2002) showed that a single original sequence has been repeated by folding so that it crops out as three geographically separate belts in some areas.

The up to c. 100 m thick occurrences within the Naternaq belt shown as marble on the Kangiaatiaq and Ikamiut map sheets mainly consist of impure, greysish to brownish weathering, fine-grained dolomitic marble, commonly with centimetre- to decimetre-thick intercalations of calcite marble and calc-silicate rocks dominated
by tremolite/actinolite + diopside ± dolomite and late talc. The lack of forsterite and the presence of sillimanite in adjacent pelitic rocks suggest P-T conditions of approximately 650 ± 50°C at 4.5 ± 0.5 kbar; tremolite/actinolite may have grown during decreasing temperature. Carbonate-facies banded iron formation forms sporadic, 0.5–1 m thick layers on the south-eastern fold flank along strike of the dolomite marble, and consists of alternating centimetre-thick layers of dolomite, magnetite, siderite, quartz, and calc-silicate minerals (Fig. 15B; Østergaard et al. 2002).

A range of conformable horizons of very fine-grained siliceous and sulphidic rocks associated with amphibolite and/or marble were interpreted by Østergaard et al. (2002) as volcanogenic-exhalitic rocks. Light grey, finely laminated cherty rocks predominate and usually contain up to c. 20% dark, very fine-grained sulphidic seams. A fine lamination of presumed chemical sedimentary origin has been destroyed in most places by intense hydrothermal alteration and impregnation with iron sulphides. Seams of fine-grained dolomite and micaceous sediment are commonly intercalated with the mineralised cherty layers, resulting in heterogeneous, rusty weathering outcrops. The largest semi-massive to massive, pyrrhotite-rich sulphide mineralised zones are located just east of the map boundary (see Østergaard et al. 2002). Disseminated sulphides are common in the host rocks adjacent to the semi-massive and massive sulphide occurrences.

Metavolcanic and metasedimentary rocks on Isuamiut–Qaqqarsuatsiaq and Equuittit Killiat islands and Hunde Ejlande north-east and north of Aasiaat

A large variety of spectacular Palaeoproterozoic metavolcanic and metasedimentary rocks crop out on the Isuamiut–Qaqqarsuatsiaq and Equuittit Killiat islands north-east of Aasiaat. These islands were first studied by Ellitsgaard-Rasmussen (1954), who published a map and a detailed description of metamorphic parageneses and the main structures. A short account by Garde et al. (2004) presented previously unrecognised primary volcanic and sedimentary features such as pillow structures and graded bedding.

The latter authors presumed that the rocks on these islands were Archaean, based on correlation along strike with fine-grained amphibolite and pelitic metasedimentary rocks on other small islands farther west, where Archaean orthogneiss has intruded the amphibolite (Garde et al. 2004). However, Garde & Hollis (2010) have demonstrated that the Isuamiut–Qaqqarsuatsiaq and Equuittit Killiat islands are of Palaeoproterozoic age, as detrital zircon from a metasedimentary rock have yielded a maximum deposition age of c. 1850 Ma.

Mafic pillow lava and sills, black manganiferous chlorite schist, chert, banded iron formation, graded aluminous schist and siliceous sandstone are the main components. The rocks are mostly excellently preserved at low to intermediate amphibolite facies grade, mainly...
attributed to contact metamorphism (Garde & Hollis 2010). The rocks generally possess a single weak to moderate cleavage, which is axial planar to upright to overturned. S-plunging folds ranging from metres to hundreds of metres in wavelength and amplitude. Garde & Hollis (2010) interpreted these rocks as representing an ocean-floor assemblage on Isuamiut–Qaqqarsuatsiaq (Fig. 16A–E) and a buried spreading ridge adjacent to an arc trench on Equutiit Killiat (Fig. 16F–K). Similar undated rocks on Hunde Ejlande are tentatively assigned to the same Palaeoproterozoic association.

**Greenstone: pillow lava (a) and sill complex (na1, na2); garnet-bearing greenstone (ng)**

Fine-grained mafic pillow lava and sills (Figs 16A, 16H, 16K), typically comprising massive actinolite, albite and epidote ± garnet, are the most widespread rocks on the Isuamiut–Qaqqarsuatsiaq islands, alternating with layers of chloritic schist. At the contacts the sills preserve chilled margins, which grade into more massive and slightly coarser-grained actinolite-albite rocks that dominate the outcrops of mafic rocks. Fine-grained mafic sills with chilled intrusive contacts into aluminium metatur-

**Chlorite schist (cs) with intercalations of sandstone (mm), chert (cq), banded iron formation and calcareous rocks**

Dark, fine-grained, relatively siliceous chlorite-garnet-biotite ± muscovite schist with very fine-grained disseminated graphite (Fig. 16B) is widespread on the Isuamiut–Qaqqarsuatsiaq islands, intercalated with greenstone of in- and extrusive origin. The chloritic schist is manganiferous (Garde & Hollis 2010). Local beds of quartz-rich sandstone occur within the dark chloritic schist and typically range from a few centimetres to a few decimetres in thickness (Fig. 16B); a sandstone unit up to 10 m thick was observed at the western end of the island northwest of Qaqqarsuatsiaq. LARGER exposures of quartz-rich sandstone and arkose occur in northern Hunde Ejlande. The chloritic schist locally preserves centimetre-thick, graded bedding and ripple marks (Fig. 16C). In some places the schist is interlayered with finely laminated, fine- to medium-grained actinolite-albite ± garnet-bearing siliceous rocks less than 1 m thick, which are interpreted as metamorphosed tuffs.

On the Isuamiut–Qaqqarsuatsiaq islands there are also horizons and elongate lenses up to a few metres thick of chert, jasper (Fig. 16D), manganese-rich banded iron formation (Fig. 16E) and iron-rich carbonate rocks with actinolite and locally diopside. These rocks are interstratified with the chlorite schist and greenstones.

**Staurolite-andalusite-muscovite-biotite-garnet schist (ss1, ss2)**

Aluminous andalusite-staurolite ± garnet schist forms most of the Equutiit Killiat islands, along with mafic sills. The schist displays more or less ubiquitous and well-preserved graded bedding (Fig. 16G), locally with finely laminated beds and local climbing ripple marks (Figs 16F, 16J). Where observed, the sedimentary younging is structurally upward. Mafic sills are abundant (Figs 16H, 16K, see above). The sandy bases of graded beds are quartz-feldspathic and biotite-bearing; centimetre-sized staurolite and biotite porphyroblasts occur in the middle parts, and the aluminous tops host subhedral andalusite crystals up to c. 5 cm in size (Fig. 16G). At the contacts to the sills the schists display ubiquitous recrystallised and apparently metamorphosed reaction rims up to about 10 cm wide (Figs 16H, 16K).
Metadolerite (m)

Relict dolerite dykes of inferred Palaeoproterozoic age and presumably emplaced during pre-Nagssugtoqidian rifting are known from two parts of the map area.

Groups of E–W-trending, vertical, undeformed dolerite dykes with medium-grained amphibolite to granulite facies metamorphic textures occur in the southern part of the Aasiaat domain. Some of the dykes straddle the southern boundary of the map area at 68° latitude and have been described by Glassley & Sørensen (1980) and Arting (2004). The former authors studied the metamorphic evolution of the dykes. Arting (2004) observed planar and linear tectonic fabrics at the dyke margins and relict subophitic textures in their cores.

Being undeformed (unlike other relict dykes in the southern part of the map area) these dykes are of great interest as tectonic markers, because they show that the southern part of the Aasiaat domain acted as a stable block during the Nagssugtoqidian collision.

Intensely deformed and disrupted mafic dykes up to a couple of metres thick have been observed by boat in the archipelago north-east of Aasiaat (Fig. 17) and in Sydostbugten east of the map area. These dykes have been recrystallised into fine-grained amphibolite and commonly possess a strong schistosity and E–W-trending extension lineation of hornblende. They are flat-lying to moderately inclined, broadly conformable with their hosts of Archaean orthogneiss, and commonly display tectonic pinch-and-swell structure and boudinage, or are completely disrupted. A close inspection usually reveals a tight angular discordance between the dykes and their hosts. The dykes are in turn cut by undeformed Palaeoproterozoic pegmatites (Fig. 17). Such small pseudocordant dykes may also be common in inland areas but would be difficult to identify there, due to moss and lichen overgrowth.

Granite and pegmatite (gp, P)

As mentioned in the general description of the Natemaq belt, irregular bodies of white, tourmaline-bearing pegmatite grading into coarse-grained, leucocratic, white to pink granite (gp) are commonly associated with the hinge zones of late folds in the belt. There are also isolated tourmaline-bearing pegmatites up to a few metres wide in areas where there are no folds (Fig. 15C).
Basalt, picritic (b)
Kitsissunnguit / Grønne Ejland in south-eastern Disko Bugt is a group of small islands which almost entirely consist of olivine basalt constituting a large dolerite sill. The sill at Grønne Ejland was emplaced into sediments close to the regional unconformity with the Precambrian basement. It has been dated at 60.45 ± 0.88 Ma (40Ar/39Ar analysis on plagioclase, Larsen 2006) and was thus related to continental breakup and extrusion of the voluminous flood basalts in the Disko–Nuussuaq–Svartenhuk Halvø region. Another major sill complex in the Disko Bugt area, which includes exposures e.g. in Saqqaqdalen on Nuussuaq (Henderson et al. 1976), is of Early Eocene age (Storey et al. 1998).

Sandstone (st)
A 4–6 m thick, non-marine section of cherty shale, chert, siltstone with plant remains and friable strongly convoluted sandstone, intercalated with tuffaceous material, forms a small occurrence on the south side of the southeastmost island of Grønne Ejland in south-eastern Disko Bugt (Henderson et al. 1976). The presence of tuffaceous material indicates that the age of the sediments is Palaeogene. A sediment sample from Grønne Ejland was included in a survey of the detrital zircon age distribution in Cretaceous and Paleocene sandstones in West Greenland (Scherstén & Sønderholm 2007). The survey showed a Palaeoproterozoic peak and a larger composite Meso–Neoarchaean peak all of which are probably locally sourced, as well as a few grains with Grenvillian ages which were interpreted as having a Canadian source.

Cretaceous–Paleocene rocks

Dolerite dykes (δ)
Three major dykes are known to occur in the Aasiaat region, one of which has been dated as Paleocene in age (see below). The dykes are plagioclase-clinopyroxene-olivine-phyric to aphyric and tholeiitic and have strongly chilled margins against their basement hosts (Larsen 2006). The dykes are clearly visible on the aeromagnetic maps of Fig. 4. The most studied dyke is the c. 60 km long, N–S-trending ‘globule dyke’ that occurs in the eastern part of the map area (Ellitsgaard-Rasmussen 1951; Arting 2004), and which has been dated at 55.77 ± 0.24 Ma (40Ar/39Ar analysis on plagioclase, Larsen 2006). This dyke consists of globules or ellipsoids up to c. 20 cm in size with aphanitic mantles that are commonly surrounded by black volcanic glass. The globules are arranged in several adjacent ‘brick walls’ each about 1 m in thickness (Ellitsgaard-Rasmussen 1951). The peculiar structure of the dyke was most likely caused by contact with water during near-surface intrusion.

The two other dykes have homogeneous, medium-grained interiors. A 6–8 m thick, NNE-trending, side-stepping dyke occurs at Manermiut and can be followed as a strong linear feature with reversed magnetic polarity from 15 km south of Kangiaatiaq to well within Disko Bugt (Fig. 4). A second, 6–15 m thick, WNW-trending dyke occurs at Sydostbugten. This may be contiguous with an isolated dyke exposure near Aasiaat.
Quaternary deposits

The Quaternary deposits in the Kangaatsiaq and Ikamiut areas mainly consist of shallow marine silt that formed an outwash plain in front of the Akuliarutsup Sermersua / Nordenskiöld Glacier east of the Kangaatsiaq map area and were subsequently raised above sea level during isostatic rebound. Weidick & Bennike (2007) recently published an account of the Quaternary evolution in the adjacent Disko Bugt area, which also contains some general information about the Kangaatsiaq and Ikamiut areas.

Archaean crustal evolution

The Aasiaat domain:
a distinct Archaean crustal segment

Most of the Aasiaat domain escaped intense reworking during the Nagssugtoqidian orogeny and therefore presents a window to study Archaean crustal evolution in central West Greenland. The idea that the northern part of the Nagssugtoqidian orogen is generally less intensely reworked than its central and southern parts is not new. For instance, Whitehouse et al. (1998) noted that two samples of Archaean biotite gneiss from the northern Nagssugtoqidian orogen did not show evidence of Palaeoproterozoic disturbance of their Rb-Sr isotopic systems, contrary to most samples of orthogneiss from the central part of the orogen. The same two samples have negative $\varepsilon_{\text{Nd}}(t)$ values of c. –2 and $T_{DM}$ model ages 300–450 Ma in excess of their estimated emplacement ages, suggesting that these rocks contain evolved Nd from older crust.

The systematic new work for the two present map sheets produced much new evidence. Piazolo et al. (2004), Mazur et al. (2006) and van Gool & Piazolo (2006) demonstrated on structural grounds that a large part of the Aasiaat domain in the area between Kangaatsiaq and Nordre Strømfjord acted as a stable tectonic block during the Nagssugtoqidian orogeny, and the geotectonic significance of the metamorphosed but essentially undeformed, E-W-trending dykes near 68°N (which were originally described by Glassley & Sørensen 1980) was established. In addition, Connelly & Thrane (2005) showed that the Aasiaat domain has a different Pb-isotopic signature than the central and southern parts of the Nagssugtoqidian orogen although zircon ages obtained from orthogneisses in all these regions are similar, and suggested that the Archaean of the northern part of the Nagssugtoqidian orogen (viz. the Aasiaat domain) might represent a different segment of Archaean crust than the North Atlantic craton in the south (Fig. 1). The Archaean age of the main phases of deformation, metamorphism and partial melting in the southern part of the Aasiaat domain was proven with the $2748 \pm 19$ Ma age of a late-kinematic granite at Saqqurput obtained by Thrane & Connelly (2006).

Archaean crustal accretion in arc environments, and evidence of Archaean rifting and sedimentation at the margins of the proto-Aasiaat domain

The main lithological components in the Aasiaat domain and their mutual relationships are broadly similar to those recently identified in six representative, upper to lower crustal blocks in the North Atlantic craton by Windley & Garde (2009) and interpreted as representing oceanic and continental arcs which eventually amalgamated into a continent.

As is evident from the map sheets and described by Hollis et al. (2006) and Moyen & Watt (2006) the supracrustal and associated rocks comprise tholeiites of volcanic and intrusive origin, smaller volumes of andesitic–dacitic and felsic volcaniclastic rocks of intermediate composition, gabbro–leucogabbro–anorthosite, as well as pelitic and not least quartzofeldspathic sediment; the latter is relatively voluminous compared to most blocks in the North Atlantic craton. As shown by Hollis et al. (2006) and Moyen & Watt (2006), the Archaean orthogneisses within the map area are of TTG-type and were probably largely produced by slab melting. Minor dioritic components are also present, in which a mantle component has been identified (Steenfelt et al. 2005). Also late-kinematic crustal melt granites are present, like in most parts of the North Atlantic craton farther south.
The detrital rocks at Kangaatsiaq have chemical compositions corresponding to greywackes and shales and may have been sourced from both a mafic–intermediate arc and a gneissic basement (Moyen & Watt 2006). The Ikamiut belt contains detrital material that was at least in part sourced from, and deposited adjacent to, the igneous precursors of Neoarchean granodioritic to tonalitic orthogneisses (Hollis et al. 2006). However, no depositional unconformity has so far been identified to underlie any of these sequences. Little detailed information exists about the quartzo-feldspathic rocks in the southern and south-eastern parts of the Kangaatsiaq map area. Where the nature of the original contacts has not been destroyed by deformation and metamorphism the TTG rocks generally have intrusive relationships with the supracrustal rocks. However, the contact relationships between the quartzo-feldspathic sedimentary units and adjacent orthogneiss are uncertain. Such uncertainty also remains at the previously mentioned locality on the south coast of Arfersiorfik close to the south-eastern corner of the Kangaatsiaq map area, where siliceous metasediment and marble occur at the base of a supracrustal sequence dominated by amphibolite. It may be significant that the c. 2850 Ma detrital zircon peak in quartz-rich metasediment at the head of Ataneq reported by Thrane & Connelly (2006) is compatible with derivation from the adjacent orthogneiss.

The Archaean tectono-metamorphic evolution in two small parts of the map area has been addressed by Hollis et al. (2006) and Moyen & Watt (2006), respectively. In both areas, early isoclinal folds have been refolded by one, two or three sets of overturned to upright folds. The deformation was accompanied by amphibolite facies and granulite facies metamorphism in the south. The ubiquitous presence of biotite and hornblende also in the granulite facies areas shows that the granulite facies metamorphism was not accompanied by complete dehydration and was most likely of the thermal type described by Wells (1980), which is characteristic of large parts of the North Atlantic craton.

Detailed analysis of the Archaean geotectonic evolution is not attempted here. However, it may be noted that the rhodolithic and intermediate metavolcanic rocks are largely concentrated in a few moderately to steeply inclined belts up to c. 2 km thick with an overall NE–SW trend. In contrast the quartzo-feldspathic paragneisses are largely concentrated in the Kangaatsiaq, Amitsq and Ikamiut areas in the vicinity of the present northern and southern margins of the Assiats domain. This distribution might suggest that the magmatic and tectonic accretion of the Assiats domain took place in two main stages separated by rifting and sedimentation. In the first stage, several arc systems, which are now represented by TTG plutons enveloped by large amphibolite belts, were amalgamated into a proto-Assiats domain. Then followed rifting and injection of mafic dykes, which can still be identified as widespread, deformed dyke fragments within the southern part of the Assiats domain that was not reworked in the Palaeoproterozoic (see Fig. 7). No age data are available from the paragneiss at Kangaatsiaq, but intrusive orthogneiss contacts have not been documented. It has previously been shown that the quartzo-feldspathic paragneisses in Ikamiut area are younger than the adjacent TTG-type orthogneisses (Hollis et al. 2006), and the same may well be the case for the paragneisses at Amitsq in view of the 2850 Ma detrital zircon peak reported by Thrane & Connelly (2006). Also the latter metasedimentary rocks may well represent younger continental margin sediment that was deposited on the outboard sides of the proto-Assiats domain, and which were in turn deformed and metamorphosed during a second Archaean orogenic phase.

**Palaeoproterozoic tectonic evolution and plate-tectonic model**

The Palaeoproterozoic evolution of West Greenland in a plate-tectonic context has been addressed in several publications over the last decade as summarised in the introduction. Garde & Hollis (2010) recently presented a different plate-tectonic interpretation of the Nagssugtoqidian orogen, which is briefly outlined in the following. Their model is based on the recognition of the stable Assiats domain, and of a Palaeoproterozoic ocean floor – arc trench assemblage and a buried spreading ridge on islands north-east of Assiats. These observations require a suture to be present between the islands and the reworked Archaean rocks of the Assiats domain to the south of the islands, and thus necessitate a revision of the previous plate-tectonic model for the Nagssugtoqidian orogen (van Gool et al. 2002; van Gool & Marker 2007). The insight that the Nagssugtoqidian orogen and Rink-
ian fold belt represent the southern and northern parts of one major collisional orogenic system between the Rae and North Atlantic cratons in western Greenland and eastern Canada, and the proposal of a suture zone at Paakitsoq in the southern Rinkian fold belt by Connelly et al. (2006) were major first steps in this revision.

The new plate-tectonic model for the Nagssugtoqidian orogen and the southern part of the Rinkian fold belt is shown in Fig. 18. It was initially presented as a rough idea by Garde et al. (2007a) and was subsequently incorporated into the correlation between the Palaeoproterozoic in eastern Canada and western Greenland by St-Onge et al. (2009), where the Aasiaat domain and new Disko Bugt suture were first labelled. In the new model there are two S- to SE-dipping subduction zones in the central and northern Nagssugtoqidian orogen, respectively, which are separated by the Aasiaat domain. The new suture on the north side of the Aasiaat domain can be linked with the proposed suture at Paakitsoq by Connelly et al. (2006) that appears to form a tectonic splay system in the Ilulissat area separating the Rae craton and the Aasiaat domain (Figs 1, 18). A continuation of this splay system is proposed to exist north of Aasiaat as indicated on Fig. 1 (see also Garde & Hollis 2010).

In the new model the 1895 Ma Arfersiorfik intrusive suite (Fig. 18) is interpreted to have been fed by the northernmost of the two subduction zones. The Arfersiorfik intrusive suite itself presumably represents the
Economic geology

An overview of all known mineral occurrences in central West Greenland from 66° N to 70°15’ N can be found in Survey reports by Schjøth & Steenfelt (2004) and Stenadal et al. (2004). The Archaean base metal occurrences that have been identified to date are insignificant both in terms of their frequency and size and will not be discussed further here. There are no known occurrences of gold or platinum group elements in the map sheet area, but there may be a gold potential in Archaean amphibolites, especially since some of them e.g. east of Kangatsiaq have been shown to be arc-related. The potential for dimension stone has not been evaluated but is not considered very promising due to strong Palaeoproterozoic tectonic reworking in part of the map area, and the heterogeneous nature of the basement rocks in the southern Aasiaat domain. However, the granodiorites and granites on Maniitsoq and Kronprinsens Ejland in the north might possess a potential.

From an economic point of view the most important occurrences in the map area are probably volcanic-hosted massive sulphide (VHMS-type) deposits of Palaeoproterozoic age. Semi-massive to massive, pyrrhotite-rich sulphide mineralised zones are located in the Naternaq supracrustal belt. The largest mineralised zones just east of the Kangartsiaq map boundary were discovered and investigated by Kryolitselskabet Øresund A/S in the 1960s, and were described by Østergaard et al. (2002). Massive VHMS-type rocks typically form up to c. 2 m wide and 4 m long lenses (maximum size 2 × 10 m); the mineralised rocks are iron-rich and dominated by pyrrhotite, with minor chalcopyrite and sphalerite (up to c. 3%) and subordinate pyrite, arsenopyrite, magnetite and graphite. Thinner, conformable horizons containing disseminated to semi-massive sulphides may be followed for up to a few hundred metres. Information about the host rocks can be found in the descriptions of marble and calc-silicate rocks (c) and volcanogenic-exhalative horizons with chert and sulphidic rocks (v), and in Østergaard et al. (2002).

Another sulphide occurrence was reported by an inhabitant of Hunde Ejlande c. 15 km north-northwest of Aasiaat in the 2004 ’Ujarassiorit’ campaign organised by the Greenland Home Rule Government. As stated in a previous section this island group consists of amphibolite facies, low-strain, very fine-grained volcanic and hypabyssal mafic rocks as well as aluminous and siliceous clastic rocks which resemble the ocean floor – arc trench rock associations found on the Isua–Qaapsuarsiaq
Equitit Killiat islands. Accordingly, the rocks on Hunde Ejlande are likely to be of Palaeoproterozoic age. Several sulphidic, iron-rich quartz vein samples with VHMS-style Cu-Zn-Au-Ag-Hg-Se mineralisation occur, and a chemical analysis of one of them is reproduced in Garde & Hollis (2010); such VHMS-type mineralisation may be found today in ‘black smokers’ on the ocean floor. More work on Hunde Ejlande is required to substantiate the age, setting and significance of its host rocks and mineralisation. Palaeoproterozoic banded iron formation occurs both on the islands of Isuamiut and Qaqarsuatsiaq where it is in oxide facies and contains around 3 wt% MnO, and in the Naternaq supracrustal belt where it is in carbonate facies (Fig. 15B; Østergaard et al. 2002). The occurrence described in the latter publication is located just east of the map boundary, but there may be others inside it. None of these deposits are sufficiently large to be considered of economic interest.

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References


Sample preparation and analytical methods

The three samples described in the following were crushed, sieved and their zircons separated at the Geological Survey of Denmark and Greenland as described by van Gool & Marker (2007). The grains were mounted together with reference zircon 91500 (Ontario, Canada, weighted average 207Pb/206Pb age of 1065 Ma, Wiedenbeck et al. 1995). Zircon morphologies were identified using backscattered electron imaging using a Philips XL 40 scanning electron microscope at GEUS, operating at 20kV and a working distance of 10 mm. U-Pb zircon data were collected using a Cameca IMS 1270 secondary ion mass spectrometer at the NORDSIM laboratory, Swedish Museum of Natural History, Stockholm. Analytical procedures and common lead corrections are similar to those described by Whitehouse et al. (1997, 1999). U-Pb concordia ages were calculated using IsoPlot (Ludwig 2000).

Orthogneiss 467558, island east of Maniitsoq

A weakly deformed, medium-grained, grey orthogneiss with intrusive contacts into supracrustal amphibolite was sampled on the west coast of a small elongate island just east of Maniitsoq (Fig. 2). A photograph of the sample-locality was published by Garde et al. (2004), who thought that the supracrustal rocks intruded by the orthogneiss precursor represented a lateral continuation of the lower-grade greenstones on the Isumait–Qaaqarsuaq islands (now known to be of Palaeoproterozoic age; Garde & Hollis 2010). The location and major and trace element compositions of this sample are given in Table 1, and the geochronological data in Fig. 20 and Table 3.

The zircon grains are elongate, typically about 200 µm long, and display oscillatory zoning typically found in igneous zircon, and no distinct metamorphic rims were observed. No isochron or valid Pb-Pb age could be calculated, as a whole range of ages between c. 2815 and 2750 Ma were obtained from individual grains (see Fig. 20 and Appendix: zircon U-Pb geochronological data).

Fig. 20. U-Pb concordia diagram for sample 467558, a > 2810 Ma Archaean orthogneiss with intrusive contact to supracrustal rocks on island east of Maniitsoq. Only an approximate age of 2810 Ma (or older) could be obtained due to scatter of the datapoints beyond the analytical precision, which may be due to early lead loss. Sample location given in Table 1.

Fig. 21. U-Pb concordia diagrams for two samples of Neoarchaean granodiorite at Maniitsoq and adjacent islands north of Aasiaat. The grains with the oldest ages in sample 467565 (Fig. 21A) yield an isochron with an age of 2771 ± 3.3 Ma, which is geologically meaningful. The large scatter of datapoints, especially in sample 467575, is interpreted as due to early lead loss in the relatively U- and Th-rich zircon crystals.
Table 3). The oldest grains indicate an emplacement age of at least c. 2810 Ma. The lower Pb-Pb ages of many grains suggest they have been variably and commonly significantly affected by early lead loss.

**K-feldspar porphyritic granodiorite 467565, Maniitsoq and 467575, adjacent island**

Geochronological data were obtained from two samples of the homogeneous, weakly deformed, medium-grained, K-feldspar megacrystic granodiorite that crops out on Maniitsoq and adjacent islands (Fig. 2), and which in several places contains magmatic enclaves of various sillimanite-grade metasedimentary rocks and supracrustal amphibolite. Major and trace element analysis and sample coordinates are given in Table 1, and zircon U-Pb ion microprobe geochronology in Table 3 and Fig. 21. Sample 467565, collected on the triangular island south-west of Maniitsoq (Fig. 2), yielded an age of 2771 ± 3 Ma (MSWD = 3.3) based on the ten oldest of 18 analysed grains (Table 3, Fig. 21A). The zircon crystals in these samples are stubby to elongate prisms that are typically around 200–300 µm long. On scanning electron microscope backscatter images the zircon crystals display very conspicuous oscillatory zoning and occasional homogeneous rims of likely metamorphic origin that are too narrow to be analysed (Fig. 22).

The second sample of granodiorite (467575) was collected on the south coast of Maniitsoq island. The zircon morphology is the same as already described for sample 467565, and the geochronological data are likewise of good analytical quality. Twenty-one analytical spots in 18 grains were analysed. The ages of individual zircon crystals fall in a wide range between c. 2600 and 2800 Ma (Fig. 21B), and the oldest, low-U and low-Th grains point to a minimum age of emplacement of about 2750 Ma. Within error this age is consistent with the age of 2771 ± 3 Ma obtained from sample 467565. Numerous other grains yield younger apparent ages. These grains are U- and Th-rich (typically with around 1000 ppm U and 500 ppm Th; Table 3), and are considered likely to have undergone substantial early lead loss, like in the nearby sample of tonalitic gneiss 467558 addressed above.
<table>
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<tr>
<th>Sample</th>
<th>Location</th>
<th>U Th Pb</th>
<th>Th/U f</th>
<th>206 Pb %</th>
<th>207 Pb %</th>
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<td>24</td>
<td>15</td>
<td>22</td>
<td>10</td>
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<td>Granodiorite, island south-west of Maniitsoq</td>
<td>27</td>
<td>16</td>
<td>24</td>
<td>13</td>
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<td>(68°45.047´N, 52°59.460´W)</td>
<td>28</td>
<td>17</td>
<td>25</td>
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</table>
The national map sheet coverage

Greenland
1:100 000

Inland Ice