

**Explanatory notes to the Geological  
map of Greenland, 1:100 000,  
Ussuit 67 V.2 Nord**

Jeroen A.M. van Gool and Mogens Marker

## Geological Survey of Denmark and Greenland Map Series 3

### Keywords

Geological mapping, Nagssugtoqidian orogen, Palaeoproterozoic, Archaean, metamorphism, deformation, collisional tectonics, zircon geochronology, economic potential.

### Cover

Extract of the eastern part of the Ussuit map sheet showing the eastern part of the Nordre Isortoq steep belt which disappears underneath the Inland Ice. The rocks in this belt are dominated by Palaeoproterozoic garnet-biotite schists and gneisses with minor quartzite, quartz-dioritic gneiss, amphibolite and lenses of ultrabasic rock. This is the thickest continuous occurrence of metasedimentary rocks in the map area. The Nordre Isortoq steep belt is bound to the north and west by Archaean orthogneisses, including thin sheets of both Palaeoproterozoic and Archaean supracrustal rocks.

### Frontispiece: facing page

Layered amphibolite at the western end of the lake Ikorfiit Tasiat, in the south-western corner of the map area. The hills in the background form an elevated region north of Nassuttooq (Nordre Strømfjord). View towards the north.

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# Abstract

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The Ussuit map area is situated around the inner Nassuttoq (Nordre Strømfjord) in central West Greenland, in the core of the Palaeoproterozoic Nagssugtoqidian orogen. The orogen largely consists of reworked Archaean gneisses, as well as Palaeoproterozoic ortho- and paragneisses in its central part. Easy access through the branched fjord system and good exposures along its coastlines, combined with less intense reworking compared to neighbouring areas to the west and south, have made the Ussuit map area the most intensely studied and best known part of the orogen. The most recent research and mapping projects were organised by the Danish Lithosphere Centre (1994–1999) and the Geological Survey of Denmark and Greenland (2000–2001).

The predominant rocks are late Archaean tonalitic and granodioritic orthogneisses, intruded by postkinematic granites. Archaean supracrustal rocks are predominantly of mafic composition, but only few have been recognised. Palaeoproterozoic rocks occur as tectonic sheets (the Ussuit unit) which are always in tectonic contact with the Archaean orthogneisses. The most abundant Palaeoproterozoic rock types are biotite schist and biotite-bearing paragneiss, besides orthogneiss of the Arfersiorfik intrusive suite. The latter rocks are mainly deformed quartz diorites intrusive into the metasedimentary rocks and interpreted as remnants of a magmatic arc above a subduction zone. The Ussuit unit also includes amphibolite, marble and calc-silicate rocks, and lenses of ultrabasic rocks. Small bodies of younger syn- and post-tectonic granites occur throughout the map area. The interleaved Palaeoproterozoic and Archaean rocks form a major anticlinal fold structure between two crustal-scale shear zones, the Nordre Strømfjord shear zone in the north and the Nordre Isortoq steep belt in the south. These shear zones formed during the latest ductile deformation event (D4), following ductile thrusting (D1) and kilometre-scale folding (D2 and D3). The deformation and high grade metamorphism are the result of collision of two Archaean blocks at *c.* 1850 Ma, with a presumed strongly deformed suture rooted in the southern Ussuit area.

No economically feasible mineral occurrences have been discovered to date within the Ussuit map area. Minor sulphide mineralisation related to hydrothermal activity occurs in faults and shear zones, and minor stratabound iron formations have been observed. The most promising industrial mineral deposits are minor diopside occurrences and potential dimension stone in migmatized orthogneiss.

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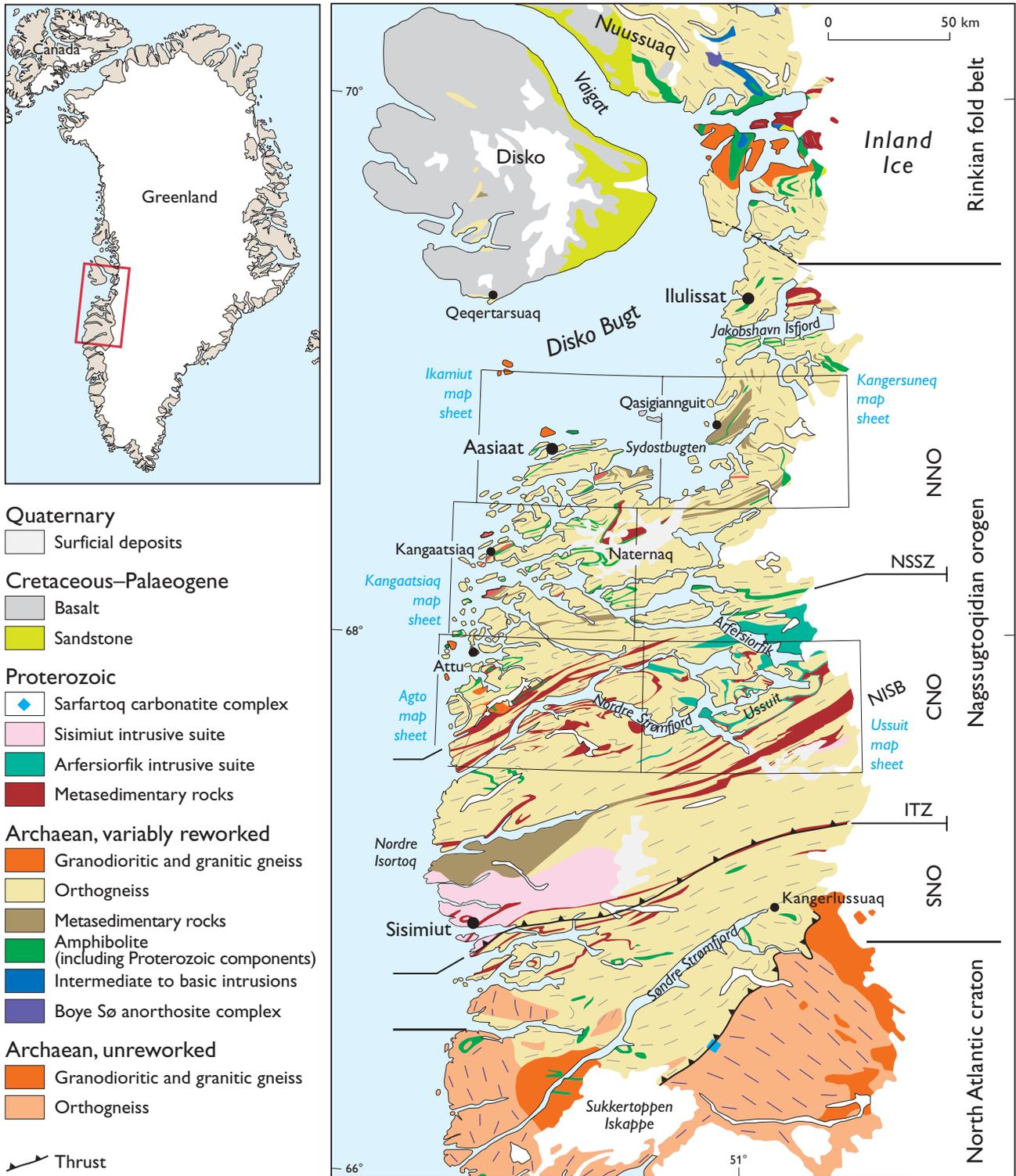


Fig. 1. Geological map of the Nagsugtoqidian orogen in West Greenland (modified from van Gool *et al.* 2002). The locations of the Ussuit and adjoining 1:100 000 scale map sheets are indicated. ITZ, Ikertôq thrust zone; NISB, Nordre Isortoq steep belt; NSSZ, Nordre Strømfjord shear zone; SNO, CNO and NNO are the southern, central and northern Nagsugtoqidian orogen, as defined by Marker (1995).

# Introduction

The Ussuit map area is located in central West Greenland and covers part of the Nagssugtoqidian orogen (Fig. 1). Recent research has shown that the geology of the Ussuit area plays a key role in the understanding of the tectonic evolution of the whole orogen (Kalsbeek *et al.* 1987; Connelly *et al.* 2000; van Gool *et al.* 2002). The relatively low metamorphic grade and moderate strain have made it possible to recognise lithological and structural elements that can be directly related to collisional tectonics. Much of the research in the Nagssugtoqidian orogen in recent years has been focused on the Ussuit area. Publication of the map sheet was part of the 2000–2003 Geological Survey of Denmark and Greenland (GEUS) performance contract, and it is the first of four 1:100 000 scale maps that have been published in this project.

## Background of DLC and GEUS projects

Publication of the Ussuit map sheet (van Gool & Marker 2004) marked the ten-year anniversary of the start of the Nagssugtoqidian project of the Danish Lithosphere Centre (DLC) in Copenhagen. This project, financed through grants from the Danish National Research Foundation, was mainly initiated to investigate the plate tectonic setting of the Nagssugtoqidian orogen in West Greenland. Investigations covered a large area from Sukkertoppen Iskappe in the south to Jakobshavn Isfjord in the north (Fig. 1; Marker *et al.* 1995; van Gool *et al.* 1996; Mengel *et al.* 1998). An important part of the work was concentrated in the Nordre Strømfjord region because of the favourable geological setting, and because of the relatively easy accessibility to large areas by boat. Much of this work was carried out along the coastlines in the central part of the map area. A considerable amount of new ideas and publications resulted from this project, many of which covered aspects of the Ussuit region (see reference list and van Gool *et al.* 2002). Although the DLC project was not specifically established to produce geological maps, mapping was used as an analytical tool in some key areas, in order to construct cross sections and block diagrams, which aided in the understanding of the structural evolution of the area. However, the mapping was not carried out systematically or consistently, and some of the map data produced during this project have proved difficult to interpret and incorporate into the final, published map. However, at the onset of the later GEUS project to study

the evolution of Palaeoproterozoic and Archaean crust in the northern Nagssugtoqidian orogen in 2000–2003, it was deemed that one summer of field work would be sufficient for the compilation of the Ussuit map sheet to be completed.

The bedrock was mapped predominantly in the field, with minor additions from analysis of aerial photographs. Boundaries to the Quaternary deposits were mainly based on interpretation of 1:40 000 and 1:150 000 scale black and white aerial photographs, and are rather subjective, especially in areas only covered by reconnaissance field work.

## Previous work

Investigations in the Ussuit map area prior to the start of the DLC Nagssugtoqidian project in 1994 are limited. The earliest coastline reconnaissance mapping was by H. Ramberg and A. Noe-Nygaard in 1948 (field maps in GEUS archives; Noe-Nygaard & Ramberg 1961), while A. Escher carried out reconnaissance in the Nordre Strømfjord area in 1965 for the compilation of the 1:500 000 scale geological map (Escher 1971). Henderson (1969) published a preliminary 1:250 000 scale map of the northern Nagssugtoqidian orogen between 68°N and 69°N (i.e. north of the Ussuit map sheet), and his field maps (GEUS archives 1966) include the south-eastern part of Arfersiorfik fjord which extends into the Ussuit map sheet. Isotope geochemistry and geochronology by Kalsbeek *et al.* (1987) on several orthogneiss samples from the map area were crucial to the understanding of the tectonic evolution of the whole orogen. These authors showed that the Arfersiorfik quartz diorite in the north-western corner of the map area has a Palaeoproterozoic age and a chemical signature similar to that of modern day magmatic arcs. Unpublished, isolated bedrock observations by A. Steenfelt (personal communications 1997–2003) during a sampling programme for stream sediment geochemistry (Steenfelt & Dam 1991), were also used in the compilation of the present map sheet. The latter were the only inland observations available prior to the start of the DLC project, as all other work had been carried out along, or close to the fjord shorelines.

The area surrounding the eastern arm of Ussuit fjord was described by Manatschal *et al.* (1998). A detailed map of a small area in the eastern Arfersiorfik region was published in a paper by van Gool *et al.* (1999),

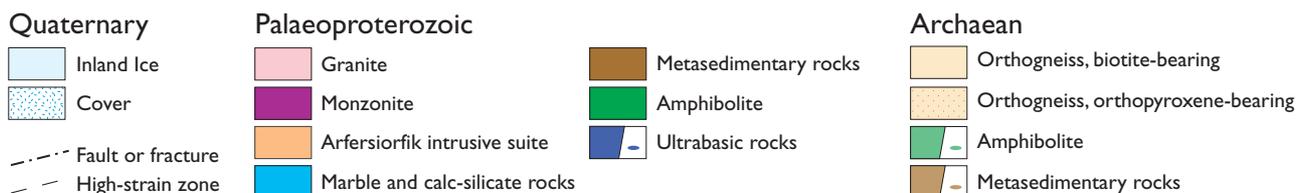
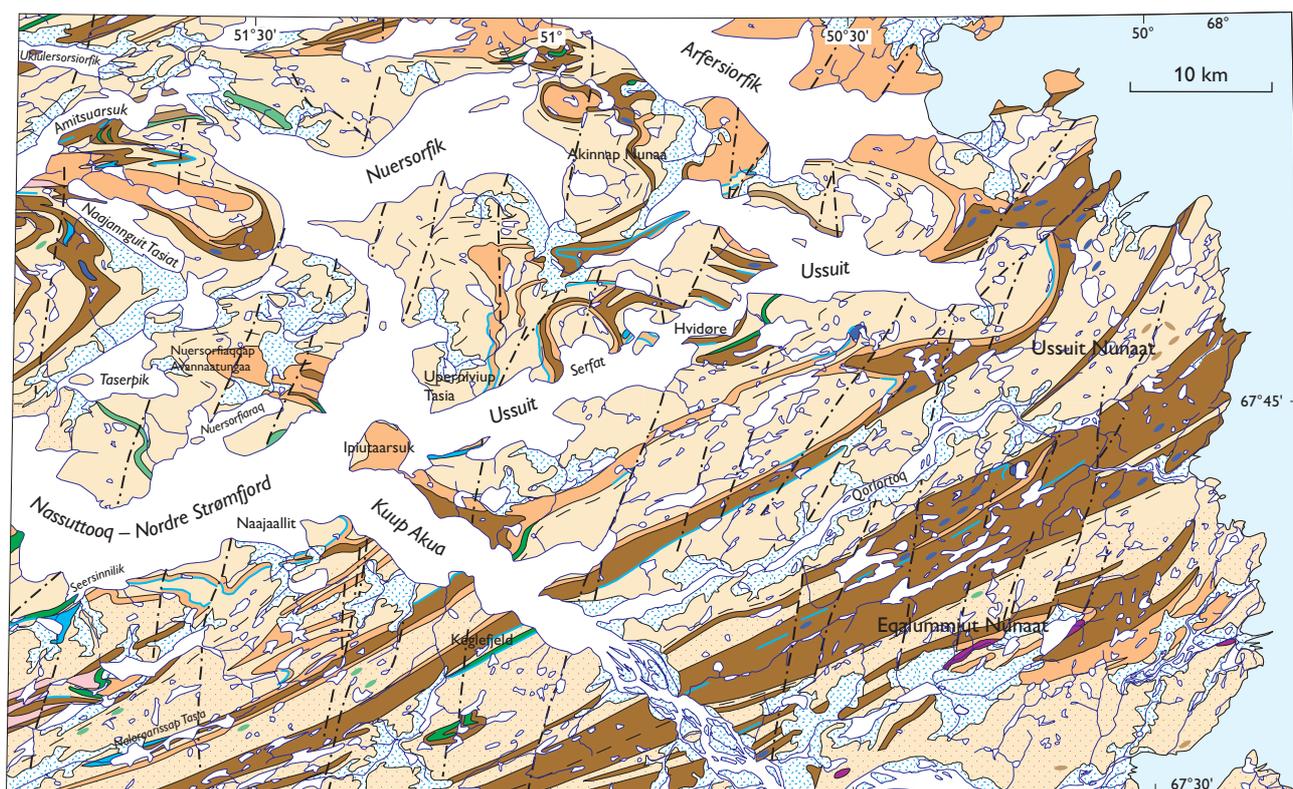


Fig. 2. Simplified geological map of the Ussuit map area.

documenting the thrust nature of the early deformation in the area. The results of investigations in the eastern part of the Nordre Strømfjord shear zone and of the Arfersiorfik intrusive suite in 2002 are presented by Sørensen *et al.* (2006).

### Adjoining map sheets

The only previously published 1:100 000 scale geological map from within the Nagssugtoqidian orogen was the Agto map sheet (67 V.1 N; Olesen 1984) to the west of the Ussuit sheet (Fig. 1). It was the result of an intense mapping campaign in the 1960s and 1970s, by a group of geologists and students from the University of Aarhus. Rock units in this area were mapped predominantly on the basis of mineralogy, and the majority of the rocks were mapped as either orthopyroxene- or amphibole-bearing gneisses. Protoliths were rarely distinguished, so for example granitic, tonalitic and quartz-dioritic gneisses would often be mapped as the same

unit. Since the mapping of the Ussuit map sheet is to a much larger extent based on lithotectonic units and protolith types, the fit between the Agto and Ussuit map sheets is in general not good.

Within the framework of GEUS' 2000–2003 mapping and resource evaluation project in West Greenland, field mapping for three other map sheets was undertaken in the northern Nagssugtoqidian orogen between 68°N and Jakobshavn Isfjord (Fig. 1). The Kangaatsiaq map sheet (68 V.1 S) to the north-west (Fig. 1) was published by Garde in 2004. It is located north of the Nordre Strømfjord shear zone, and shows a significantly different geology, dominated by Archaean lithologies and tectonism. Two further 1:100 000 scale geological maps have subsequently been published, Kangarsuneq (68 V.2 N; van Gool 2005) and Ikamiut (68 V.1 N; Garde 2006), south-east and south of Disko Bugt (Fig. 1).

## Field work

Field work in the DLC project was carried out in the summers of 1994, 1995 and 1997, with participation of approximately 25 geologists, of which 16 contributed to the mapping in the Ussuit area. In the summer of 2000, four geologists worked in the area: one two-person team for four weeks, and another team for six weeks. The areas surrounding Ussuit and Kuup Akua fjords are the most intensely investigated parts. Small helicopter camps were established in the inland areas, from which mapping was carried out along traverses. These camps were set up to establish sections through the most important parts of the map area, and concentrated on the occurrences of the Palaeoproterozoic metasedimentary and intrusive rocks. As a result, there is no total ground coverage, as is clearly shown on the inset map on the map sheet. Limited helicopter-based reconnaissance mapping was carried out in areas not covered on foot. Extremely poor weather in the summer of 2000 hampered the field work, affecting especially the reconnaissance by helicopter.

## Physiography

The inner part of Nordre Strømfjord forms a branched network of fjords (Figs 1, 2), providing easy access by boat to an extensive area as well as providing excellent outcrop along the wave-washed shores. Ussuit is the main fjord arm in the eastern extension of Nordre Strømfjord, consisting of two parts that are connected by a narrow passage with strong tidal currents. In the north-east of the map is the head of Arfersiorfik fjord, which forms a similar branched fjord network. South of Ussuit, slopes rise up to a plateau at 500–600 m altitude, which is cut by several deep, rather straight valleys with melt-water rivers. The remainder of the area has a less pronounced relief with smaller hills reaching more moderate altitudes, and is easily accessible by foot from the fjords. Exposure is best at the shorelines and near the Inland Ice, but deteriorates westward from the ice cap due to increasing vegetation and lichen cover. In general there is a marked difference in exposure between north- and south-facing slopes, as the former are commonly much more overgrown.

# Geological background

## The Nagssugtoqidian orogen

Over the past ten years the understanding of Nagssugtoqidian geology has improved significantly due to the projects carried out by the DLC and GEUS. The presently accepted model indicates that the region was the site of a full Wilson cycle with opening and closing of an ocean basin followed by continental collision (van Gool *et al.* 2002). The orogen is dominated by Archaean gneisses that were reworked at elevated metamorphic grade during the Palaeoproterozoic. It was divided into three segments by Marker *et al.* (1995; Fig. 1): the southern Nagssugtoqidian orogen (SNO) forming a parautochthonous southern foreland, the central Nagssugtoqidian orogen (CNO), which is the central collisional core comprising interleaved Palaeoproterozoic allochthonous units and Archaean gneisses, and which attained the highest metamorphic grade, and finally, the northern Nagssugtoqidian orogen (NNO), which is less intensely reworked and transitional to the Rinkian fold belt to the north. These three lithotectonic segments are separated by high-strain shear zones, the Ikertôq thrust belt between the SNO and CNO, and

the Nordre Strømfjord shear zone between the CNO and NNO. The metamorphic grade in the SNO and NNO is largely amphibolite facies, while most of the CNO is in granulite facies.

The CNO, in which the Ussuit map sheet is located, can be divided into a northern and southern part, previously referred to as the northern and southern flat belts (e.g. van Gool *et al.* 1996), which are separated by the Nordre Isortoq steep belt. The southern part is dominated by uniform Archaean orthogneisses with minor supracrustal rocks occurring predominantly as 50–200 m thick sheets, intruded in the west and north by a complex of Palaeoproterozoic intrusive rocks of the Sismiut intrusive suite (Bridgwater *et al.* 1996). The latter consists of calc-alkaline igneous rocks that form a continental arc in the southern CNO. The gneisses in the southern CNO are variably folded and overall shallowly to moderately dipping. The Nordre Isortoq steep belt, a WSW–ENE-trending zone of steeply dipping gneisses dominated by supracrustal rocks of both Archaean and Palaeoproterozoic age, extends from the coast at Nordre

Isortoq fjord to the Inland Ice (Fig. 1). The zone is characterised by a steep and consistent orientation of the gneisses, high strain, and a fairly consistent sinistral sense of shear, forming a structure similar to the Nordre Strømfjord shear zone. The northern part of the CNO contains the Arfersiorfik intrusive suite (AIS, Figs 1, 2), which like the Sisimiut intrusive suite is a magmatic complex of calc-alkaline rocks. In contrast to the Sisimiut arc, the AIS is intrusive into supracrustal rocks that are allochthonous with respect to the Archaean gneisses (see below). The northern CNO contains relatively large proportions of Palaeoproterozoic rocks, including both the arc rocks of the AIS, and a suite of metasedimentary and metavolcanic rocks. The map pattern of the northern CNO is dominated by interleaved Archaean and Palaeoproterozoic gneisses deformed in kilometre-scale fold structures. The Nordre Strømfjord shear zone at the northern boundary of the CNO is a many kilometres wide linear belt of steeply dipping gneisses with variable strain that is generally higher than in the rocks to the north and south (Bak *et al.* 1975; Sørensen 1983; Hanmer *et al.* 1997; Sørensen *et al.* 2006). The shear sense is consistently sinistral, and the zone is considered a crustal scale strike-slip structure, that post-dates all other ductile deformation in the region.

### The Ussuit area

The Ussuit area (Fig. 2) comprises the eastern half of the northern CNO flat belt. Palaeoproterozoic supracrustal and intrusive rocks together form an allochthonous lithotectonic unit, the Ussuit unit. It is interleaved with Archaean gneisses and forms a marker for Nagssugtoqidian deformation and metamorphism, which permits the distinction between Archaean and Proterozoic structures. The lower maximum metamorphic grade, compared to the areas to the south and west, and the relatively low strain, make this area uniquely suited for a study of the early tectonic development of the Nagssugtoqidian orogen.

The map area shows a large-scale fold interference pattern which is bounded by the two linear belts to the north and south. The enveloping surface of the structures in the flat belt forms a shallowly east-plunging antiform, while the steep belts were formed by reactivation of the fold limbs. Archaean and Palaeoproterozoic gneisses are interleaved in several thrust sheets that are folded by the major antiform. The rocks in the area are predominantly at amphibolite facies, with garnet, biotite and sillimanite stable in pelitic rocks, and local anatexis is commonly observed. Mafic rocks contain hornblende and plagioclase, less commonly garnet, and rarely ortho- or clinopyroxene. The western and south-western parts of the map area are at granulite facies, which is characterised by the appearance of orthopyroxene besides amphibole in the orthogneisses.

Kalsbeek *et al.* (1987) proposed that the Palaeoproterozoic, calc-alkaline Arfersiorfik intrusive suite in the northern CNO, was part of an oceanic island arc and could represent a cryptic suture to the Nagssugtoqidian orogen. The juxtaposition of these arc rocks and the Archaean gneisses took place by large-scale thrusting of an allochthonous terrane onto an Archaean continental margin, often with intervening thin slices of supracrustal rocks (Kalsbeek & Nutman 1996; van Gool *et al.* 1999, 2002).

Mapping in the adjoining Agto map sheet led to a series of publications (e.g. references in Korstgård 1979) concentrating on the timing of deformation, high grade metamorphism, and the crustal scale Nordre Strømfjord shear zone. Structural analysis of the flat belt or 'pre-Nagssugtoqidian islands' in the Agto map area (Olesen 1984) revealed that these areas were affected by several phases of deformation, resulting in complex fold interference patterns that pre-date the ENE-trending, steep structures (e.g. Sørensen 1970; Skjærnaa 1973). The higher metamorphic grade in the western part of the flat belt hindered the recognition of the protoliths to the gneisses, and a different mapping concept was employed, as mentioned above. This prevents an easy correlation of lithologies in the Agto and Ussuit map sheets.

## Description of the lithological units

On the Ussuit map sheet 15 different rock types or assemblages of rocks are distinguished. Where the ages of the rocks are known or can be inferred by correlation, the rocks are attributed to either the Archaean or the Palaeoproterozoic, otherwise they are attributed to a category of undifferentiated Archaean and Palaeoproterozoic rocks. The tectono-stratigraphic sequence in the Palaeoproterozoic rocks of the Ussuit unit is fairly consistent locally, but in general no consistent stratigraphy was recognised.

### Archaean

Archaean gneisses include both ortho- and paragneisses. The different purposes of the DLC and GEUS field projects, and the difficulty in distinguishing between felsic orthogneisses and psammitic paragneisses resulted in a heterogeneous approach to the definition of lithologies within the Archaean gneiss complex. As a result, in most of the map area, no effort was made to map out different lithological units within the Archaean gneisses. Generally, whenever in doubt during compilation, rocks were entered on the map as orthogneiss.

### Archaean orthogneiss (gn)

The complex of Archaean orthogneisses (gn) forms the most voluminous lithotectonic unit and is exposed throughout the area. There are three main lithological components that are not individually distinguished on the map:

1. The oldest rocks are heterogeneous gneisses with compositions ranging from dioritic to granodioritic. They have intermediate grain sizes, are commonly banded (Fig. 3) and may contain minor volumes of predominantly mafic (hbl-cpx-bearing) layered supracrustal rocks, as inclusions and rarely as more continuous layers. The heterogeneous gneisses contain hornblende, plagioclase, quartz and biotite, with or without clinopyroxene. These gneisses are highly migmatitic and contain abundant narrow melt veins and vein networks. Locally they occur with agmatitic texture. This group of gneisses may contain both gneisses of original intermediate compositions, and felsic gneisses that have become more mafic by assimilation of the mafic material they intruded into.

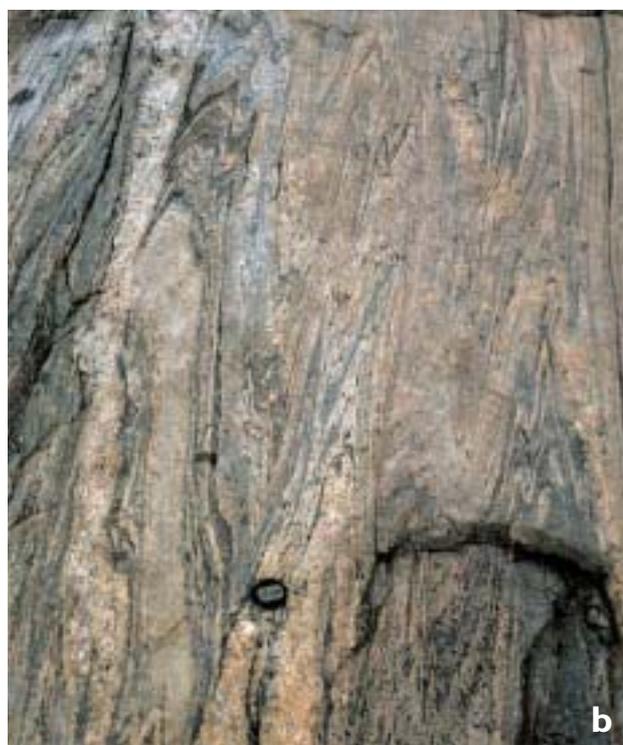


Fig. 3. Heterogeneous, banded Archaean gneisses. a: Archaean gneiss with three components. Layered dioritic gneiss is included in tonalitic migmatitic gneiss. The rocks are intruded by less deformed pink pegmatite veins. Hammer shaft is 40 cm long. b: Banded Archaean biotite-bearing orthogneiss, intensely deformed by F2 folds. Western shore of central Kuup Akua. Lens cap is 5 cm in diameter.



Fig. 4. Homogeneous Archaean gneiss with pegmatitic veins in western Ussuit, north of Serfat. Lens cap is 5 cm in diameter.

2. The dominant lithology on the map is a homogeneous grey tonalitic gneiss (Fig. 4), which locally truncates the gneissic layering of the older dioritic phases. The gneisses are fine- to medium-grained, contain biotite as the main mafic component, and minor hornblende. In the south of the map area, where the rocks are at granulite facies, orthopyroxene replaces hornblende, but remnant hornblende is also common. The granulite facies rocks are distinguished on the map with a red dot pattern, but boundaries between the two are not indicated. This main group of gneisses is also migmatized and characterised by abundant thin melt vein networks. A finely-spaced differentiated layering is common. At a few localities these rocks are porphyritic and form augen gneisses with deformed phenocrysts up to 2 cm in

diameter. Large extents of these porphyritic gneisses occur at Amitsuarsuk fjord and both west and south of Nuersorfiaq, as shown on the map with a pattern of open rectangles, while several smaller occurrences are not indicated on the map. Contacts with non-porphyritic phases are usually progressive and also formed locally by strain gradients. North of the map area intrusive relationships were observed, where porphyritic phases were intruded by a finer-grained homogeneous phase. The deformation state of the orthogneisses varies from mildly foliated to a well developed gneissic layering.

3. The youngest component of the orthogneiss complex comprises homogeneous granites and granodiorites, which are medium to coarse-grained, biotite-bearing, and usually pink in colour. They have intrusive contacts with the other lithological components. The granites are variably deformed and locally form migmatitic vein networks within the older phases. Larger stocks of these granites are indicated on the map with a pattern of red crosses, but contacts are not drawn, since they tend to be transitional, or not consistently mapped out. The central-western part of the map area contains the largest volumes of these late granites, and is also invaded by abundant granitic pegmatites.

Locally, grey biotite-bearing quartzofeldspathic gneisses contain garnet, indicated on the map with small red circles. These gneisses tend to be homogeneous and fine- to medium-grained, with garnets up to 3 mm in diameter, and evenly distributed through the rocks. The quartz content in these rocks is higher than in the remainder of the Archaean biotite gneisses, which may



Fig. 5. Rock face with large F3 fold on the southern slopes of Qorlortoq valley. Several dykes of variable thickness are conspicuous on the central cliff and the rock face to the left, and form part of the dyke swarm in this part of the map area. Rock face is *c.* 100 m high. Photograph taken from a helicopter looking east.

suggest that these are metasedimentary rocks, or contaminated orthogneisses (S-type intrusions). The occurrences of the garnetiferous gneisses are isolated, and they have not been mapped systematically.

There are few age data from the Archaean orthogneisses in the map area, and all are ion probe U-Pb zircon reconnaissance data (Kalsbeek & Nutman 1996). However, by correlation with rocks in the remainder of the Nagssugtoqidian orogen, the ages of the Archaean orthogneisses are fairly well known, except for the older layered and dioritic gneisses. The younger tonalitic to granodioritic gneisses are part of a late Archaean intrusive complex with protolith ages ranging from 2870–2810 Ma and with metamorphic ages from 2810–2720 Ma (Kalsbeek & Nutman 1996; Connelly & Mengel 2000). Three late Archaean post-tectonic (with respect to Archaean deformation) megacrystic granites from outside the Ussuit map sheet have yielded ages between 2720 Ma and 2700 Ma (Connelly & Mengel 2000) and may tentatively be correlated with some of the younger Archaean granites in the Ussuit map sheet.

Manatschal *et al.* (1998) defined a distinct Archaean lithotectonic unit (the Qorlortoq unit) within the orthogneiss complex south of Ussuit fjord, mainly on the northern slopes of the Qorlortoq valley between two large tracts of metasedimentary rocks. The majority of the gneisses here are very leucocratic, medium-grained, and have distinct flamed textures, presumably resulting from heterogeneous deformation in the presence of a high proportion of melt. One ion probe U-Pb analysis of zircons from such a gneiss yielded a middle Archaean age ( $3123 \pm 9$  Ma, A.P. Nutman and F. Kalsbeek, unpublished data 1996), quite distinct from all other gneiss ages from the Nagssugtoqidian orogen. However, this age could not be repeated in other samples from the same lithotectonic unit, and an isotope study of gneisses in a transect along Kuup Akua showed no isotopic differences between the orthogneisses on either side of the northern metasediment sequence (Roth 2000). Therefore the term Qorlortoq was abandoned again. The leucocratic orthogneisses in the Qorlortoq valley have not been mapped consistently, and are therefore not indicated as such on the map. However, the extent of these gneisses coincides broadly with a swarm of mafic dykes in the Qorlortoq valley (Fig. 5) and along strike to the north-east and south-west. The dolerite dykes in this swarm are foliated and metamorphosed, and are heterogeneous, locally with rather felsic cores. In the densest part of the swarm, the dykes occupy up to 20% of the rock volume. Most are 1–3 m wide, while the largest dykes are up to *c.* 30 m wide. The dykes contain variable proportions of plagioclase, hornblende, clinopyroxene and garnet, with minor titanite, biotite and magnetite. Attempts to date zircons from the more



Fig. 6. Layered supracrustal amphibolite which forms an integral part of the Archaean orthogneiss complex at western Ussuit. The amphibolite outcrop is too small to be shown on the map.

felsic cores of these dykes gave no meaningful results, but the swarm has some resemblance to the Kangâmiut dyke swarm in the SNO and southern foreland. The Qorlortoq dyke swarm is confined to this central part of the map area, but isolated meta-dolerite dykes occur elsewhere.

### Archaean supracrustal rocks ( $bs_A$ and $a_A$ )

Archaean rocks of supracrustal origin have been recognised in several locations, by the fact that they are intruded by the regional Archaean gneisses. Age determinations to prove their Archaean age are generally lacking, but one pelitic gneiss at the head of Amitsuarsuk (on the map erroneously included with metasedimentary rocks of undifferentiated age) contained  $2731 \pm 5$  Ma metamorphic monazite and must be of Archaean age (Connelly & Mengel 2000). Archaean paragneisses occur generally in small volumes as inclusions, rarely as larger continuous sequences (e.g. west of Naajannguit Tasiat and south of Taserpik near the western boundary of the map area). Some of the sequences of undifferentiated age might also be of Archaean age.

Most of the Archaean supracrustal rocks form remnants of greenstones, and occur as amphibolites ( $a_A$ ). The amphibolites are commonly well-layered on centimetre-scale, fine- to medium-grained and are extensively migmatized (Fig. 6). Layering is formed by variations in composition as well as grain size. Most of these rocks are presumably of volcanic origin. They contain hornblende, plagioclase, biotite, quartz, titanite and opaque minerals. Small panels and lenses of layered biotite paragneisses and metapelite ( $bs_A$ ) occur either isolated, or associated with the amphibolites. They are medium-grained and generally have a compositional layering on

a centimetre- to decimetre-scale. They are commonly biotite-rich, and locally they contain garnet, and rarely also sillimanite. These rocks stand out from the surrounding orthogneisses by their brown weathering colour.

### Palaeoproterozoic rocks: the Ussuit unit

Palaeoproterozoic rocks include both ortho- and paragneisses and occur throughout the map area. They commonly form tectonic sheets that are intricately interleaved with Archaean gneisses, and which have been referred to as the Ussuit unit in the literature (Manatschal *et al.* 1998; van Gool *et al.* 1999, 2002). Although it is not used on the map sheet as a mapped unit, this name is used here for descriptive purpose, and in order to conform to published material. The lithotectonic Ussuit unit consists of a sequence of supracrustal rocks, lenses of ultramafic rocks, and sills and stocks of the Arfersiorfik intrusive suite of quartz-dioritic to tonalitic composition (Fig. 7). The supracrustal rocks are

dominated by pelitic and psammitic gneisses and include marble, calc-silicate rocks, banded amphibolite and fine-grained and finely layered felsic to intermediate rocks, interpreted as extrusive and volcanoclastic rocks. The provenance age of the supracrustal rocks of the Ussuit unit has been determined at four locations, as described below. Other occurrences of supracrustal rocks were interpreted to be of Palaeoproterozoic age on the basis of correlation and the tectonic setting of the rocks, separated from Archaean gneisses by a zone of high strain.

As a result of the intense deformation, no consistent stratigraphy or tectono-stratigraphy could be determined for the whole map area. However, in the centre of the area, where the layering generally has shallower dips and isoclinal folds appear to be absent, a fairly consistent lithological sequence commonly occurs. The tectonic base of the sequence is often marked by marble and ultramafic lenses, and locally by thin slices of clastic metasedimentary rocks (Fig. 8). These are commonly overlain by quartz-dioritic gneiss, which again is overlain by thicker sequences of metasedimentary rocks. Amphibolite and metavolcanic rocks can occur anywhere in this sequence.

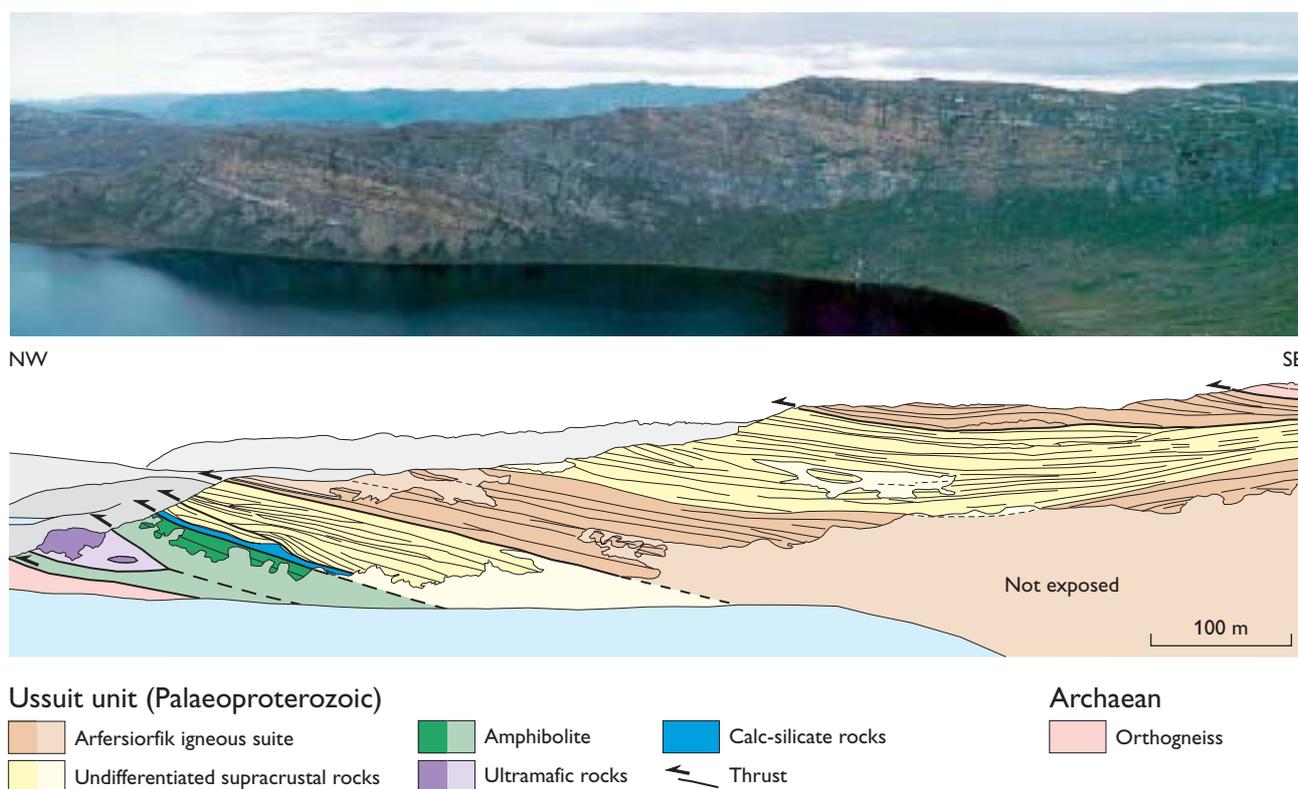
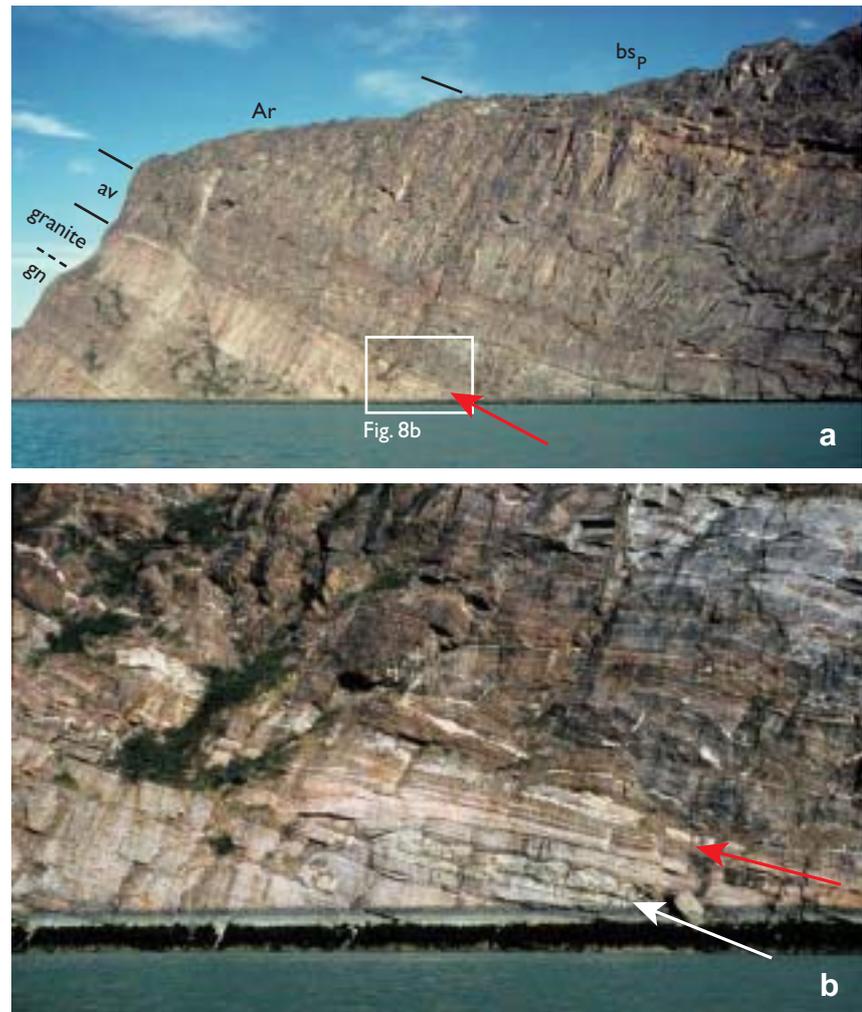


Fig. 7. Photograph and geological interpretation of a cliff face at Akinap Nunaa in the north of the map area showing the Ussuit unit sandwiched between Archaean gneisses. Grey sheets of quartz diorite of the Arfersiorfik intrusive suite intrude yellowish metasedimentary rocks consisting mainly of biotite schist. These two rock units are repeated by internal thrust structures. The basal thrust of the unit overriding Archaean orthogneisses is marked by a lens of ultramafic rock, enveloped by amphibolite. Top of the cliff is about 100 m above the lake. From van Gool *et al.* (1999).

Fig. 8. Tectonic contact between the Ussuit unit thrust over Archaean gneisses in Kuup Akua. **a**: The Archaean gneisses (**gn**) are heterogeneous, consisting of a pink granite layer (**granite**) immediately underneath the tectonic contact, and grey biotite-orthogneiss in the lower part of the section. The tectonic contact (**red arrow**) is marked by a layer of Palaeoproterozoic calc-silicate rocks up to three metres thick. Above the contact occurs a *c.* 50 m thick layered amphibolite (**av**), overlain by homogeneous quartz-diorite gneiss (**Ar**). At the top are layered metasedimentary rocks (**bs<sub>p</sub>**). Height of cliff 250–350 m. **b**: A detail of the contact outlined in Fig. 8a, marked by 1–2 m of calc-silicate rocks (**red arrow**); a second level of calc-silicate and marble lenses occurs *c.* 10 m below the tectonic contact (at **white arrow**). Visible part of cliff *c.* 50 m high.



### Marble and calc-silicate rocks (**m**)

Marble and calc-silicate rocks are very common at the tectonic base of the Ussuit unit. They also occur within the supracrustal sequence and rarely, as isolated tectonic lenses and thin layers within the Archaean orthogneisses, decorating shear zones (Figs 7, 8). Commonly, these rocks form thin layers, less than 5 m wide, and many occurrences shown on the map are exaggerated in size. Thicker layers are rare and occur only in a few locations, mainly in the west of the map area. Calc-silicate rocks are also common within Archaean orthogneisses in thin discontinuous but persistent layers between 10 and 100 m below the lower contact of the Ussuit unit. Here they are believed to form décollement horizons, for example on splays of the main thrust between the tectonic units (Fig. 8b).

Pure marbles are rare, and the rocks are commonly well layered on a centimetre to metre scale (Fig. 9). They are white to light grey in colour, and commonly contain calcite, dolomite and diopside, with minor phlogopite, humite, graphite, titanite and wollastonite. Fluorite and

garnet are uncommon. Thin quartzitic or pelitic layers may occur, as well as very fine-grained evaporitic layers. Flow textures, e.g. of marble intruding into fractures in the wall rocks, have been observed and testify to the low viscosity of the calc-silicate rocks during metamorphism.

### Biotite schist (**bs<sub>p</sub>**)

Most of the clastic metasedimentary rocks were mapped as one lithological unit, but they vary widely from mica-rich pelitic schists and gneisses to semipelitic quartzofeldspathic gneisses. These rocks are widespread throughout the map area, commonly as 5–100 m thick layered sequences (e.g. Fig. 7). Thicker sequences occur in the two main panels of the Ussuit unit south and east of Ussuit fjord, where their structural thickness is up to *c.* 7 km, resulting from repetition by folding and thrusting of an originally thinner sequence.

Fine- to medium-grained biotite gneisses are the most common lithology. These have a yellowish brown weathering colour, and may contain subordinate garnet. With



Fig. 9. Narrow island with layered calc-silicate rocks in Serfat, central Ussuit. **a**: Sequence of layered calc-silicate rocks and marble, which is folded in an isoclinal, reclined F2 fold. Width of the island in the centre of the photograph is *c.* 50 m. Photograph taken from a helicopter, looking north-north-east. **b**: Close-up of the outcrop in the bottom left of Fig. 9a, looking along strike to the east. On the left is the top of a poorly exposed zone, *c.* 10 m wide, of rather homogeneous diopside.



increasing mica content also garnet becomes more common, and sillimanite may occur. The most aluminous compositions are often rusty weathering, but grey in fresh exposures and may contain minor graphite. Biotite, sillimanite and garnet are common, together with quartz and minor plagioclase, and at higher metamorphic grade melt veins are abundant (Fig. 10). The biotite gneisses are commonly compositionally banded, which is believed to be a combined effect of an original layering and metamorphic segregation during deformation.

The biotite schist unit on the map includes some massive, fine-grained dark-grey, homogeneous to coarsely layered amphibole-biotite bearing felsic to intermediate gneisses. These occur as part of sequences with pelitic rocks as well as associated with amphibolites. Their significance is uncertain, although they have tentatively been interpreted as meta-andesite.

Age determinations of detrital zircons from several of the biotite schist sequences showed common age populations between 2000 and 2100 Ma, with the youngest zircons around 1950 Ma, and only minor Archaean zircons (Marker *et al.* 1999; Nutman *et al.* 1999). Together with the age of the intruding Arfersiorfik intrusive suite (see below), the depositional age is constrained between 1950 and *c.* 1920 Ma.

### Quartzite and quartzofeldspathic gneisses ( $q_p$ )

Occurrences of quartz-rich rocks, ranging from psammitic gneisses to orthoquartzites, are most common in the metasedimentary sequence of the Nordre Isortoq steep belt and in the Ussuit unit crossing Keglefeld,

south-west of Kuup Akua. In the latter area a 1 km wide quartzite sequence is prominent. It comprises locally up to 80% quartz, as well as small proportions of garnet, biotite, plagioclase and rarely sillimanite and/or cordierite, and is dark grey in colour with lighter streaks. The rocks are rather heterogeneous on a small scale, but fairly uniform in appearance on a larger scale.

Felsic paragneisses are common, with predominantly grey to light brown weathering colours and they may contain abundant but small garnets, up to 5 mm in diameter. These felsic paragneisses are more heterogeneous than most of the grey orthogneisses and contain more quartz, but in the field they can easily be confused with the Archaean grey biotite orthogneisses.

Thin layers of quartzite, up to 2 m thick, occur locally on top of the Archaean gneisses, below the base of the Ussuit unit, and may be overlain by thin layers of calc-silicate rocks that are a few centimetres to a few metres thick. Since there appears to be no sign of localised high strain at the contact with the Archaean orthogneisses, these occurrences are viewed as possible remnants of an original unconformable sedimentary sequence, e.g. comparable to the Karrat Group in the Rinkian fold belt.

One occurrence of compositionally layered quartzofeldspathic paragneiss on the north shore of Kuup Akua is atypical for this unit, in that it contains ubiquitous, thin layers of amphibolite, commonly up to 20 cm wide. Palaeoproterozoic detrital zircons from this unit define its Palaeoproterozoic age (Nutman *et al.* 1999).

### Amphibolite (a<sub>p</sub>)

This lithological map unit comprises a variety of mafic lithologies that were not distinguished consistently during mapping. It includes both intrusive and extrusive rocks, such as homogeneous and layered amphibolite, metagabbro, and also dioritic and quartz-dioritic gneisses. Primary igneous textures are generally not preserved because of intense deformation and recrystallisation, although relict pillow structures were positively identified in relatively low-strain amphibolites within metasedimentary rocks north-east of Ussuit fjord. Less well-preserved pillow structures occur in several locations in more strongly deformed heterogeneous amphibolites, e.g. at the northern flank of the synform east of Nuersorfik, where the rocks also contain a veined network of calcite. There is a progressive transition from the amphibolites into the unit of metavolcanic rocks on the map sheet (av, described below) and the two are not everywhere distinguished. Some of the homogeneous amphibolite lenses in the orthogneisses may well represent disrupted mafic dykes, but no discordant contacts are preserved.



Fig. 10. Garnet-sillimanite pelitic gneiss with small melt veins. Asymmetric pressure shadows around garnets and shear bands indicate a sinistral sense of shear. Eastern part of Nordre Isortoq steep belt.

Amphibolite (*s.l.*) occurs throughout the map area mainly as narrow layers up to several tens of metres wide, and as metre- to decametre-scale tectonic lenses within other lithologies. Although they form thin layers, they are laterally consistent, but locally boudinaged on a scale of tens of metres. Only one larger occurrence was mapped in the core of the doubly plunging synform west of Kuup Akua. At many locations the amphibolites are associated with calc-silicate rocks, with rocks of the Arfersiorfik intrusive suite, and with ultrabasic rocks. Chemical analyses of a few amphibolite samples were published by Kalsbeek & Manatschal (1999) who suggested that the protoliths included both gabbroic and basaltic rocks.

The majority of the amphibolites are homogeneous to slightly layered, medium-grained mafic gneisses that weather dark green to black. They are commonly migmatized and predominantly consist of hornblende and plagioclase, with variable amounts of quartz, titanite, biotite, garnet and rarely clinopyroxene. In the granulite facies region, orthopyroxene may occur in melt segregations in the amphibolites.

### Metavolcanic rocks (av)

At a few localities, sequences of finely layered mafic, intermediate and felsic rocks were interpreted as metavolcanic rocks (Fig. 11). Some thicker sequences occur on the south shore of Nordre Strømfjord at the western margin of the map area, and in the central Ussuit fjord. These sequences grade into amphibolites or clastic metasedimentary rocks, without sharp boundaries. Other sequences that are up to a few metres wide, are too small to be presented on the map sheets, and are included



Fig. 11. Layered amphibolite interpreted as a metavolcanic rock, with calc-silicate layers to the right. The amphibolite is quite rusty at this locality, which is not common. Central Ussuit, east of Serfat. Lens cap is 5 cm in diameter.

within associated amphibolite units, where this was applicable.

The metavolcanic rocks are fine-grained, heterogeneous, and contain variable proportions of plagioclase, hornblende and biotite  $\pm$  quartz  $\pm$  clinopyroxene  $\pm$  K-feldspar. Variations in composition form a layering at a scale of millimetres to centimetres.

### Ultrabasic rocks ( $ub_p$ )

Lenses of serpentinised and metamorphosed ultrabasic rocks form bodies varying from several metres up to  $c.$  100 m in length, with few occurrences that are several hundreds of metres long. These rocks commonly occur together with mafic meta-igneous sequences (amphibolites). Kalsbeek & Manatschal (1999) recognised two types of ultramafic rocks, of which one type is mainly of dunitic to harzburgitic composition ( $ub_p$ ), and is often found above marbles at the lower tectonic contact of the Ussuit unit. A second type occurs mainly as hornblendites ( $ub_{pk}$ ), which are more aluminous and pyroxenitic in composition and form lenses within amphibolites. Hornblendites are common and well exposed within the metasedimentary rocks in the north-eastern part of the map area, between the lake Iterfiluup Tasia and the Inland Ice. Here they occur together with amphibolite that has preserved pillow structures. Kalsbeek & Manatschal (1999) demonstrated that the composition of the dunitic to harzburgitic ultramafic rocks is consistent with an interpretation as mantle peridotites, while the chemical composition of the hornblenditic type is reminiscent of komatiitic or picritic high-magnesium basalts.

### Arfersiorfik intrusive suite ( $Ar$ and $d_p$ )

A complex of orthogneisses, predominantly of quartz-dioritic composition, occurs throughout the map area. It was originally described by Henderson (1969) and later by Kalsbeek *et al.* (1987), who published chemical and isotopic analyses. The main occurrence in the north-

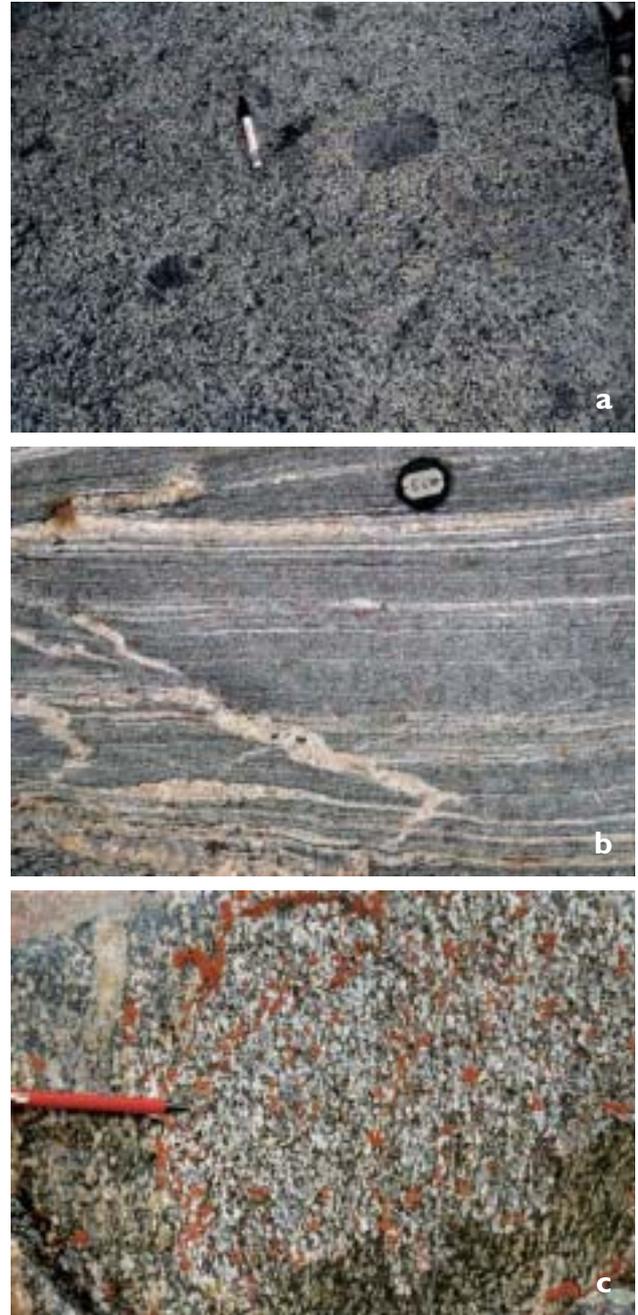


Fig. 12. Three examples of quartz diorite of the Arfersiorfik intrusive suite. a: Undeformed quartz diorite containing dioritic inclusions, in the north-east part of the map area at Nunatarujuk. b: Common homogeneous appearance of the reworked quartz diorite as hornblende-bearing grey orthogneiss, typically with thin white leucosome veins. c: Porphyritic quartz diorite in the south of the map area at Eqalumiut Nunaat.

east of the map, distinguished as the Arfersiorfik quartz diorite (Fig. 12a), overlies the Archaean orthogneisses with a tectonic contact. The two are separated by *c.* 10 m of sheared biotite schist. The quartz diorite is estimated to be at least 2 km thick and continues northwards to the Nordre Strømfjord shear zone in Arfersiorfik fjord. Strongly deformed sheets of Arfersiorfik orthogneiss 50–200 m wide occur throughout the map area at different tectonic levels (Figs 7, 8), and have locally preserved intrusive contacts with the Palaeoproterozoic metasedimentary rocks (Fig. 12b). These orthogneisses are mainly of quartz-dioritic to tonalitic composition, and locally dioritic or even granitic. They are all correlated with the main Arfersiorfik quartz diorite, and are together named the Arfersiorfik intrusive suite (Ar). Kalsbeek (2001) proposed that the more felsic varieties that occur in the thinner sheets were probably formed by fractionation from the original, more mafic magma body. At several locations, rocks of the Arfersiorfik intrusive suite grade into layered metavolcanic rocks, without an obvious sharp contact. The rocks of the Arfersiorfik intrusive suite may strongly resemble the homogeneous parts of the Archaean orthogneisses, both in composition and appearance. However, the former tend to have more mafic compositions and have darker weathering colours, compared to the Archaean gneisses that are generally of tonalitic composition. Kalsbeek (2001) suggested that the Palaeoproterozoic orthogneisses may have formed by crystallisation of mantle-derived magmas, in contrast to the Archaean orthogneisses which may have formed by melting of rocks of basaltic composition.

Although strongly deformed near the tectonic contact, the centre of the main body of the Arfersiorfik quartz diorite is relatively undeformed and has locally preserved its original igneous texture (Fig. 12a). These low-strain rocks are medium-grained, homogeneous, light grey and rarely porphyritic. They contain plagioclase, orthopyroxene, hornblende, quartz and biotite. Small inclusions of rocks of more mafic dioritic composition are interpreted to be less evolved phases of the same intrusive suite. The deformed sheets of the Arfersiorfik intrusive suite that occur away from the main body lack primary orthopyroxene and appear in outcrop as orthogneisses (Fig. 12b). These rocks are medium-grained, homogeneous to subtly layered, and commonly have a rather dark grey colour; white melt veins commonly form a migmatitic texture. Depending on the metamorphic grade, they contain metamorphic hornblende or orthopyroxene as the main mafic mineral, with plagioclase, quartz, and minor biotite and K-feldspar. Small inclusions of supracrustal rocks are common along the intrusive contacts, both in the main body and the thinner sheets. The quartz diorite and associ-

ated rocks may be garnet-bearing near the contacts with metasedimentary rocks. It is not clear whether this is an effect of assimilation of metasedimentary rocks during intrusion, or an effect of later metasomatism. Porphyritic varieties of the Arfersiorfik intrusive suite (Fig. 12c) contain plagioclase porphyroclasts and have been mapped in the thinner sheets at several locations. These porphyritic rocks occur commonly in the upper contact areas, and might represent cumulates in the original melt.

South of the river Qorlortoq several persistent diorite sheets ( $d_p$ ) *c.* 50 m wide were mapped. Although not investigated in detail, they are interpreted to be part of the Arfersiorfik intrusive suite based on their similar intrusive relationships with the surrounding metasedimentary rocks.

The first published geochronological data for the main body of the Arfersiorfik quartz diorite indicated an intrusive age of *c.* 1920 Ma (Kalsbeek *et al.* 1987). A multitude of subsequent age determinations during the DLC project indicated that these rocks have an age range of 1921–1885 Ma (Kalsbeek & Nutman 1996; Connelly *et al.* 2000). The most southerly, confirmed occurrence of the Arfersiorfik intrusive suite is at Equalumiut Nunaat, at the southern margin of the Isortoq steep belt. A zircon  $^{207}\text{Pb}/^{206}\text{Pb}$  age of  $1897 \pm 8$  Ma was recently obtained by secondary ion mass spectrometer (SIMS or ion probe) analysis for a sheet intrusive into the metasedimentary rocks on the north slope of the large, unnamed valley containing a series of lakes. The analytical results are presented in the Appendix (sample 480605). Furthermore, the large body of quartz diorite south of the Nordre Isortoq steep belt in the southeastern corner of the map, shown on the map as orthogneiss of undifferentiated age, has been dated since the publication of the map. It has yielded a Palaeoproterozoic age that falls within the same range of ages as the Arfersiorfik intrusive suite. This quartz diorite body is described below together with the orthogneisses of undifferentiated age, and the results of the geochronological analysis are likewise presented in the Appendix.

### Leucogranite and pegmatite (p)

Coarse-grained, white leucogranite occurs as homogeneous bodies up to 300 m wide mainly in the central part of the map area. They are most common at the tectonic contacts of the Ussuit unit, but also occur elsewhere. The leucogranites are transitional to white pegmatites, which occur throughout the map area. These rocks are virtually undeformed and consist predominantly of plagioclase and quartz, with minor K-feldspar; mafic minerals are rare. Some of the larger bodies

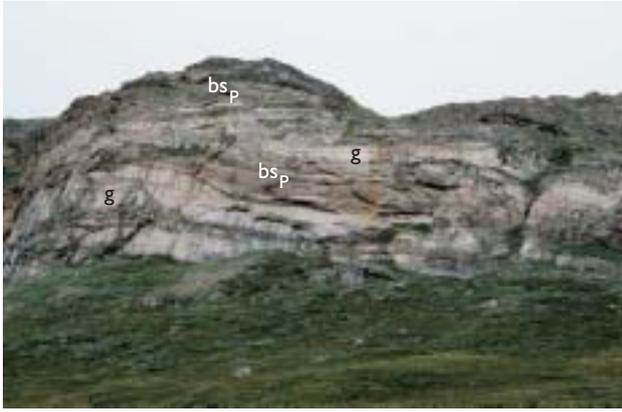


Fig. 13. Sheets of slightly deformed pink granite (g) intruded into brown Palaeoproterozoic biotite paragneiss (bs<sub>p</sub>). Height of the exposed part of the rock face is about 40 m. South-western corner of the map area.

in the central part of the map area are associated with upright F3 folds (see below). The largest bodies in Illut Nunaat and Akinap Nunaa, as well as several smaller ones, not shown on the map, occur as concordant sheets in the antiformal hinges of F3 folds, similar to one described by Noe-Nygaard & Berthelsen (1952) from the western Nordre Strømfjord region. One of these yielded an age of  $1825 \pm 1$  Ma (U-Pb zircon data; Connelly *et al.* 2000), and thus dates the F3 folding.

### Monzonite and monzodiorite (mz)

Monzonitic rocks form sheet-like bodies in an ENE-trending zone in the south-eastern part of the map area. Within this zone, granitic and monzonitic sheets or veins up to 50 m wide have intruded the orthogneiss. This zone continues to the west-south-west beyond the boundary of the map sheet. Few kilometres south of the map area, it forms a prominent zone more than 1 km wide of sheeted intrusions, alternating with ortho- and paragneisses. The veins and sheets truncate the regional fabric, they are slightly discordant and are normally undeformed, but locally they contain narrow shear zones. The monzonite is a grey, fine- to medium-grained rock, commonly with porphyritic feldspar. Pink, coarser-grained patches and stringers of reddish, pegmatitic appearance occur in places. The monzonite comprises K-feldspar, plagioclase, hornblende, biotite, apatite and magnetite as the main constituents.

Chemically, the monzonitic rocks contain around 55 wt% SiO<sub>2</sub> for mesocratic varieties and *c.* 65% for leucocratic varieties. K<sub>2</sub>O/Na<sub>2</sub>O is > 1, concentrations of P, Ba, Sr and light rare-earth elements (REE) are anomalously high, and chondrite-normalised REE spectra are steep. The monzonitic rocks have high magnetic suscep-

tibility, owing to the high concentrations of magnetite. Porphyritic granites just south of the Ussuit map sheet that have yielded 1820–1850 Ma ages (Kalsbeek & Nutman 1996, data repository, sample numbers 414982 and 415072) are likely to be part of this suite of monzonitic rocks, which therefore is considered of Nagsugtoqidian origin.

### Granite (g)

Medium- to coarse-grained, homogeneous, pink granite occurs in the west and north of the map as stocks, sheets (Fig. 13) and pegmatitic dykes and veins (Fig. 14a).

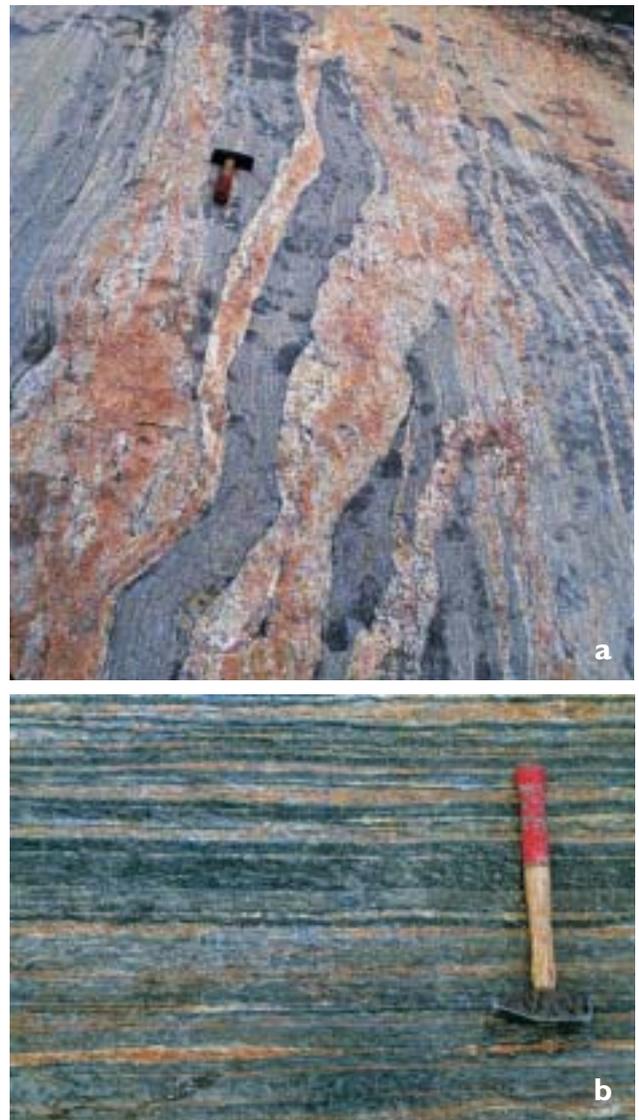


Fig. 14. Archaean biotite-bearing orthogneiss with pink melt veins near the thrust contact with the overlying Ussuit unit. **a:** About 50 m below contact, with irregularly shaped and discordant melt veins; **b:** 2 m below the contact, all melt veins are totally transposed and stretched. Central Ussuit, north of Hvidøre. Hammer shafts are 40 cm long.

These rocks intrude metasedimentary rocks and the Arfersiorfik quartz diorite, as well as the Archaean gneisses. All these lithologies occur as inclusions within – or contain thin sheets of – the granite near the intrusive contacts of the larger bodies. Biotite is common in small proportions, but most abundant in the granite sheets in the south-western part of the map area. Sillimanite occurs in centimetre-sized blebs together with garnet and quartz in the granite along Arfersiorfik fjord. The granites are rarely porphyritic, and lack themigmatitic character of the older granitoid rocks. They are commonly slightly deformed, with a weak foliation. One granite body that occurs in the core of an F3 synform in the south-western part of the map area, has a well-developed foliation that is axial planar to the F3 synform, although it is not itself folded.

These granites also grade into pegmatites, and the latter cannot always be distinguished from pegmatites associated with the leucogranites (P). Furthermore, very similar late Archaean pink granites occur. On the basis of field observations alone, these cannot always be distinguished from the younger Palaeoproterozoic granites, where they occur in zones of low Palaeoproterozoic strain. For this reason, no age connotation is given to the pegmatite symbols on the map sheet. The area south and west of Uperniviuq Tasia at the western end of Ussuit is particularly intensely invaded by pegmatites. Many of these pegmatites truncate the main foliation in the area, and therefore post-date this early deformation phase.

Kalsbeek & Nutman (1996) and Whitehouse *et al.* (1998) reported ages of late granite sheets in the Ussuit area that range from 1840–1770 Ma; all these sheets are interpreted as local melts. Ages of pegmatites in the larger Nordre Strømfjord region range from 1821–1761 Ma (Kalsbeek & Nutman 1996; Connelly *et al.* 2000) and indicate that they have intruded during an extended period during and in the late stages of the Nagsugtoqidian orogenic activity. Where no age data are available, the presence of inclusions of Arfersiorfik quartz diorite and Palaeoproterozoic metasedimentary rocks demonstrates the Palaeoproterozoic age of the granites. The lack of widespread penetrative deformation, and the field relationship of the granite that intrudes into the F3 synform, are consistent with a late Nagsugtoqidian age (post *c.* 1825 Ma). The  $\epsilon_{Nd}$  values of the pegmatites indicate that they represent melts derived from Archaean orthogneisses (Whitehouse *et al.* 1998).

### **Undifferentiated Archaean or Palaeoproterozoic rocks**

Where correlation with rocks of known age was not possible, and relationships with adjoining rocks were

uncertain, no age connotation (Archaean or Palaeoproterozoic) could be assigned to the rocks. Lithologically, most of these resemble rocks of either age. However, some have a strong resemblance to the Palaeoproterozoic supracrustal rocks, although their occurrence as isolated lenses or layers within Archaean orthogneiss makes this correlation questionable. Doleritic and pegmatitic dykes in the Archaean gneisses are younger than the gneisses they intrude. However, since none of the dykes in the map area have been dated, only this maximum age constraint is known with certainty for the majority of the dykes.

### **Ultrabasic rocks (ub)**

Within the Archaean orthogneisses, ultrabasic rocks occur as rare, isolated lenses, up to 50 m long. Most of these are found in the north-east of the map area, south of the main body of metasedimentary rocks, where they were observed from helicopter during reconnaissance. Other occurrences, observed on the ground, consist of metamorphosed dunite, similar to those near the tectonic contacts of the Ussuit Unit. The ages of these lenses are unknown. They may be either deformed xenolithic inclusions in the orthogneisses, in which case they are Archaean, or tectonic lenses within Palaeoproterozoic shear zones, in which case their age remains uncertain.

### **Amphibolite (a)**

Amphibolite of unknown age occurs as isolated bodies within Archaean orthogneisses, but with unclear contact relationships. These are not accompanied by other rock types that might be correlated with rocks of known age. These amphibolites form lenses or layers that may be several kilometres long and up to 200 m wide, most commonly in the north-western part of the map area. They are commonly heterogeneous and banded, and the majority resembles the Palaeoproterozoic layered metavolcanic rocks, but more homogeneous varieties also occur. The two large amphibolite layers at the north-western end of Nuersorvik fjord are homogeneous and of dioritic composition.

### **Quartzite and quartzofeldspathic paragneiss (q)**

Quartz-rich paragneisses of unknown age that resemble the Palaeoproterozoic quartz-rich rocks, occur as lenses, some together with biotite schist, in two locations within Archaean orthogneiss. They occur on ei-

ther side of the Nordre Isortoq steep belt, at Ussuit Nunaat and Eqalummiut Nunaat. Most of these rocks are garnet- and biotite-bearing, quartz-rich paragneiss, and less commonly true quartzite.

### **Biotite schist and biotite-rich paragneiss (bs)**

Biotite-rich paragneisses occur within the Archaean orthogneiss as small lenses up to 50 m wide, and as larger sheets that are up to several hundred metres wide. These rocks cannot be distinguished lithologically from either confirmed Archaean or Palaeoproterozoic paragneisses. They are most commonly heterogeneous biotite-rich gneisses or schists, commonly containing garnet, and rarely also sillimanite. Thin layers of pelitic mica schist are common.

### **Orthogneiss, quartz-dioritic to dioritic (d)**

This lithological unit mainly comprises sheets of quartz-dioritic gneiss up to several hundred metres wide that can be traced for many kilometres along strike. These sheets appear to form integral parts of the Archaean orthogneisses, but have compositions (judged from field appearance) that are similar to the Arfersiorfik quartz diorite. Neither distinct tectonic contacts with the surrounding rocks, nor an association with Palaeoproterozoic supracrustal rocks was observed. Therefore, in the absence of age data, no definite correlation with the rocks of the Arfersiorfik intrusive suite could be made.

The largest body of this lithological unit, shown in the south-east part of the map sheet, is actually of Palaeoproterozoic age. It is a multi-phase, poorly foliated body up to 3 km wide consisting of tonalitic to dioritic gneiss, and occurs together with presumed Palaeoproterozoic metasedimentary rocks. It is medium- to coarse-grained, commonly plagioclase-porphyritic in a matrix of quartz, hypersthene and biotite, with minor hornblende and opaque minerals. Geochronological data from this body that became available after the publication of the map sheet, yielded a U-Pb zircon age of  $1907 \pm 3$  Ma (Appendix, sample 480616).

This body of quartz diorite includes lenses of metasedimentary rocks (presumed to be Palaeoproterozoic in age) but in the south it appears to be intrusive into Archaean gneisses, although the nature of this contact has not been studied carefully. Its location south of the Nordre Isortoq steep belt, and the inferred intrusive contact with Archaean gneisses may suggest that a tentative correlation can be made with the Sisimiut intrusive suite. The latter is a suite of Palaeoproterozoic calc-alkaline intrusions, similar in age and composition to

the Arfersiorfik intrusive suite, that occurs in the southwestern CNO (Fig. 1; Marker *et al.* 1995; Kalsbeek & Nutman 1996; Whitehouse *et al.* 1998). The rocks of the Sisimiut intrusive suite intrude into, and are contaminated by, Archaean orthogneisses (Bridgwater *et al.* 1996; Whitehouse *et al.* 1998), whereas no intrusive contacts of the Arfersiorfik intrusive suite into Archaean gneisses have ever been reported.

### **Metadolerite ( $\delta$ )**

Metadolerite dykes occur most abundantly as a swarm in the orthogneisses of the Qorlortoq valley and the area along strike west of Kuup Akua (Fig. 5). The dykes of this swarm have been described above (together with the Archaean orthogneisses, **gn**, in which they occur) and are indicated on the map with a separate signature (dark green dashes). They do not differ significantly from the individual dykes seen in the remainder of the Ussuit area. The latter are commonly 30–70 cm wide, black and quite homogeneous, and were only recognised within Archaean orthogneisses. Few of these dykes are clearly discordant with respect to the oldest gneissic fabric in the rocks, but even those that appear concordant are probably younger than the oldest gneissic fabric in the host rocks. All dykes are foliated and some are folded, and all have metamorphic mineral assemblages similar to the dykes in the swarm at Qorlortoq. However, no felsic cores or garnet were observed in these smaller dykes. Their discordant nature with respect to the Archaean gneissic fabric, and their deformed nature suggest a late Archaean or early Palaeoproterozoic age.

### **Pegmatite**

Coarse-grained pegmatite dykes are abundant throughout the map area. They occur both in swarms as dykes up to several metres wide, and as isolated dykes. They are most common in the vicinity of the larger granite bodies and some are obviously transitional to these granites. They range from undeformed and discordant, to highly stretched, boudinaged and transposed to the dominant fabric (Fig. 14). Most are pink in colour, fewer are white, and all contain plagioclase, quartz and K-feldspar, with variable amounts of biotite, and locally minor magnetite, hornblende or orthopyroxene.

Archaean and Palaeoproterozoic pegmatites can locally be distinguished, where they either are associated with Archaean or Palaeoproterozoic granites, or where they intrude Palaeoproterozoic rocks. However, the majority is of uncertain age, and therefore no age connotation is shown on the map for any of the pegmatites.

## Quaternary

The main emphasis of the 1:100 000 map series is the bedrock geology, and the Quaternary deposits are only shown schematically on the map. The distribution and boundaries of the majority of the deposits were drawn by interpretation of black and white 1:40 000 and 1:150 000 scale aerial photographs. In areas dominated by Quaternary deposits, small but important outcrops of bedrock are often depicted for clarity at greater than actual size. About ninety percent of the deposits are overgrown. The landscape is to a large extent shaped by Quaternary glaciations, although a recent geomorphological study shows that older, preglacial landscape forms have survived at regional scale (Bonow *et al.* 2006). The

Ussuit area is covered by the 1:500 000 scale Quaternary map of central West Greenland (Weidick 1974).

Of the Quaternary deposits, only obvious glaciofluvial and fluvial deposits and moraine ridges were distinguished. The latter include both recent moraine along the present ice margin and historic end- and side moraines. Glaciofluvial and fluvial deposits have only been marked in the larger meltwater river systems. Redeposition of the finer fraction by wind occurred in the larger plains along the meltwater rivers, where the deposits are not overgrown. The third map unit of undifferentiated surficial deposits contains predominantly till, talus slopes, marine terraces along the fjords, and bogs, as well as undifferentiated (glacio-) fluvial and moraine deposits.

## Palaeoproterozoic tectonic and metamorphic evolution

The rocks of the Ussuit area have been affected by both late Archaean and Palaeoproterozoic orogenesis. Although Palaeoproterozoic rocks make up only a small proportion of the bedrock in the Nagssugtoqidian orogen, this Palaeoproterozoic orogenic phase has left the strongest imprint on the rocks and determined the map patterns. Based on the occurrence of the Arfersiorfik quartz diorite with its geochemical arc signature, Kalsbeek *et al.* (1987) suspected the presence of a suture in the core of the orogen. Van Gool *et al.* (2002) proposed that the CNO was the locus of continental collision and that it contains several tectonic elements that record this collisional event. The rocks in the Nagssugtoqidian orogen record intrusion of mafic dykes in the SNO during extension, arc magmatism in the CNO during subduction, thrusting and high grade metamorphism in the CNO during collision, and folding during continued, post-collisional contraction. Furthermore, the time intervals between these events are similar to those in modern collisional belts. Therefore all these features support the interpretation of the collisional setting for the Nagssugtoqidian orogen.

### Metamorphism

The core region of the Nagssugtoqidian orogen has undergone high temperature, granulite-grade metamorphism, but most of the Ussuit map area is underlain by

amphibolite facies rocks. The metamorphic grade was mainly determined from the presence of orthopyroxene  $\pm$  biotite versus amphibole  $\pm$  biotite in the orthogneisses, and from their appearance in outcrop and hand specimens. The greasy lustre and greenish grey colour of fresh surfaces were taken to indicate granulite grade metamorphism, although these characteristics were also common in orthogneisses without visible orthopyroxene. The transition from granulite to amphibolite facies in the field occurs over a wide zone in which orthopyroxene is generally partly retrogressed to hornblende and biotite. This retrogression is particularly obvious along zones of high strain. Since the metamorphic boundaries are transitional and difficult to map precisely, no such boundaries were indicated on the map. No indications have been found that the area north of Ussuit fjord has ever reached granulite grade.

In pelitic gneisses, sillimanite is the stable aluminosilicate, and appears in assemblages with garnet and biotite. Partial melt veins are common throughout the map area, but melting was most extensive in the south, in the area of granulite facies. Cordierite occurs together with sillimanite in quartz-rich rocks, but was only observed in the rocks of the Ussuit unit in the south and south-east of the map area. No thermo-barometric estimates have been published from the map area itself, but data published from the Nordre Strømfjord area farther west (Hansen 1979; Mengel 1983) and from the Sisimiut area in the south-western CNO (David-

son 1979) indicate maximum temperatures above 800°C at pressures of 7–9 kbar.

Metamorphic textures are commonly well equilibrated at high temperatures, and retrograde metamorphic reactions below upper–middle amphibolite facies conditions are rare. This agrees with observations based on thermochronology that cooling after peak metamorphism was slow, and that temperatures were still high during the last deformational stages (Willigers *et al.* 2001).

The peak metamorphism is estimated to have occurred at *c.* 1850 Ma, on the basis of Pb isotope analysis of marbles (Taylor & Kalsbeek 1990) and lower intercepts of U–Pb zircon discordia as well as ages of less common metamorphic zircons (Kalsbeek & Nutman 1996; Connelly *et al.* 2000). This metamorphism is interpreted to be the result of crustal thickening by thrusting during continental collision.

## Deformation

The presence of Palaeoproterozoic rocks within the Ussuit unit provides the opportunity to distinguish between Archaean and Palaeoproterozoic structures. The Archaean structures are generally overprinted by intense Palaeoproterozoic deformation and thus can only be recognised in areas of low Nagssugtoqidian strain. Therefore, it has not been possible to establish a consistent

Archaean structural history, but it is evident that both a gneissic fabric and isoclinal folds predate the earliest Palaeoproterozoic deformation. The youngest Archaean granites lack this gneissic fabric, and they tend to possess a simple foliation of unknown age.

Four Palaeoproterozoic deformational events have been distinguished in the rocks of the Ussuit unit. They can all be traced into the Archaean gneisses and are therefore synchronous with, or post-date the juxtaposition of Archaean and Palaeoproterozoic rocks. These four phases include: ductile thrusting (D1), at least one phase of folding, preserved in tight and isoclinal folds (D2), a phase of kilometre-scale upright folding (D3), and sinistral shearing (D4) along the Nordre Strømfjord shear zone and the Nordre Isortoq steep belt. The overall structure that constrains the present map pattern, is an anticlinorium between these two high-strain zones. Figure 15 schematically presents this situation in a block diagram.

### D1 ductile thrusts

The oldest penetrative Palaeoproterozoic structure is a regionally penetrative foliation (S1), which can be correlated with a phase of ductile thrusting, whereby the allochthonous Ussuit unit and Archaean gneisses were tectonically interleaved (Figs 7, 8). Internal thrust structures in the Ussuit unit have been described from Akin-

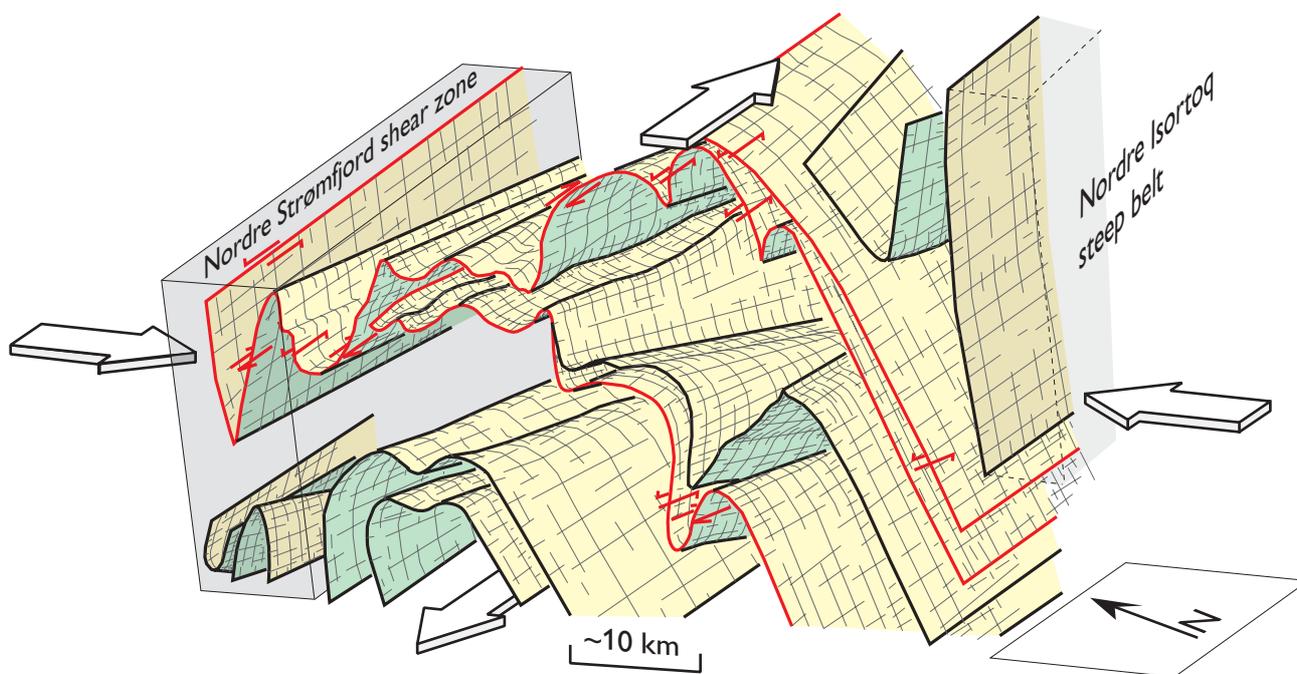


Fig. 15. Schematic block diagram of the eastern Ussuit area, showing the shallowly ENE-plunging D3 anticlinorium between two steep belts/shear zones of D4 age. Drawn surfaces represent the D1 lower thrust contacts of the Ussuit unit. Where marked in red, these were reactivated during D3 by top-to-E shearing. For simplicity, the sketched folds lack the non-cylindrical nature of the real folds.

nap Nunaa west of Arfersiorfik fjord by van Gool *et al.* (1999; Fig. 7). High-strain shear zones, interpreted as ductile thrusts juxtaposing Archaean and Palaeoproterozoic rocks, occur throughout the map area. They are predominantly developed as straight gneisses with a strong foliation (Fig. 14b), but poor grain-shape fabrics. Strain gradients towards these shear zones are best expressed by the progressive deformation and transposition of commonly occurring synkinematic melt veins. These melt veins are slightly deformed and discordant outside the shear zones (Fig. 14a), but become progressively more deformed and transposed into the regional foliation towards the shear zones. At the highest strains remnants of these veins are seen as pink streaks (Fig. 14b), locally with remains of K-feldspar porphyroclasts. Overprinting of shear-zone fabrics on the regional fabric was not observed and suggests that the two developed simultaneously. A poorly developed mineral lineation occurs locally in these shear zones, and is commonly strongly overprinted by a younger extension lineation (Ls on the map, see below). Kinematic indicators are rare in these rocks, but where seen indicate a top-to-NW movement direction.

These shear zones commonly occur on the contacts between Archaean gneisses and rocks of the Ussuit unit. However, locally the rocks of the Ussuit unit are excised at thrust ramps, and the thrusts continue as high-strain zones into the Archaean gneisses, locally decorated by thin slivers of metasedimentary rocks, marble and quartz-diorite, and locally also ultrabasic rocks. An example of this is seen in the folded sequences in the north-western part of the map, south-east of Amitsuarsuk.

## F2 folds

At least two generations of tight to isoclinal folds post-date the thrusting. These folds deform the regional foliation, axial planar cleavages are poorly developed or absent, and orientations of fold axes are highly variable. Although there are more than one generation of tight to isoclinal folds, they are jointly referred to as F2. Interference patterns of two generations of isoclinal folds are rare on outcrop scale; however, one exists at map scale just to the west of the map area in the Agto map sheet (Olsen 1984). No kilometre-scale isoclinal folds were recognised within the map area, but their existence cannot be ruled out, since the tectono-stratigraphic sequence is locally inverted. On an outcrop scale, F2 folds are common (Figs 3, 6, 9). At few locations F2 folds refold an older lineation associated with the regional S1 foliation (e.g. on the elongate island at Serfat, in the centre of the map area, Fig. 9).

## F3 folds

On the map no distinction was made between the different generations of folds, but the large majority is F3 folds dominating the map pattern together with the linear belts. The F3 folds are consistently upright to slightly overturned, open to moderately tight folds. Fold axes plunge fairly consistently to the ENE at a low angle, approximately along the strike of the axial planes. Figure 5 shows an example of a set of dykes in the Qorlortoq valley, folded by an F3 syncline. Small F3 folds are uncommon. Decimetre-scale F3 folds at the western end of Nuersorfik and at a few other locations have melt veins along their axial planes. Furthermore, some of the larger F3 antiforms contain phacolithic pegmatite sheets in their hinge zones, suggesting that sufficient melt was present in the rocks at the time of folding, to collect in the hinge zones of these folds.

Shallow, ENE-plunging extension lineations, occur commonly parallel to the F3 fold axes, suggesting extension along this orientation during folding. Rare top-to-ENE kinematic indicators are associated with this lineation. Manatschal *et al.* (1998) proposed that F3 folding in the Ussuit area occurred contemporaneously with extensional, top-to-ENE shearing on overall east-dipping corrugated shear planes.

## Crustal scale shear zones – D4

Two main ENE-trending linear belts occur in the northern CNO: the Nordre Strømfjord shear zone that forms the northern boundary of the CNO, and the Nordre Isortoq steep belt that divides the CNO into two distinct northern and southern segments, as described above (Fig. 1). The sinistral shearing in these two belts is the last penetrative ductile deformation event in the region and resulted in the dominant ENE–WSW trend of the Nagssugtoqidian orogen.

### Nordre Strømfjord shear zone

The Nordre Strømfjord shear zone was originally described from the Agto map area to the west as a crustal-scale, sinistral shear zone with 120 km lateral offset (Bak *et al.* 1975; Sørensen 1983). More recently, also its eastern extension has been studied in the Arfersiorfik region to the north (Passchier *et al.* 1997; van Gool *et al.* 2002; Sørensen *et al.* 2006). Hanmer *et al.* (1997) questioned its significance as a shear zone and proposed that it is a monoclinical structure comprising isolated minor shear zones. The Nordre Strømfjord shear zone trends ENE from the mouth of Nordre Strømfjord at the coast to

the head of Arfersiorfik fjord and continues to the Inland Ice (Fig. 1). It cuts across the extreme north-western corner of the Ussuit map area, where it runs through the lake Ukiulersorsiorfik. It consists of an up to 20 km wide zone of steeply dipping straight gneisses and isolated anastomosing mylonitic zones, in which ortho- and paragneisses are interleaved. Kinematic indicators are rare, but consistent, and in combination with a sub-horizontal extension lineation indicate sinistral shear. This is also consistent with map patterns; specifically the aeromagnetic anomaly maps clearly show a sinistral drag on the regional fabric into the shear zone (Sørensen *et al.* 2006).

The deformation in the shear zone post-dates F3 folding, and has been dated at *c.* 1775 Ma (metamorphic zircon U-Pb ages, Connelly *et al.* 2000). Locally, steep sinistral shear zones related to the Nordre Strømfjord shear zone developed on steep flanks of F3 folds; other examples occur where F3 folds are tightened and deflected into the shear zone, e.g. in the kilometre-scale F3 synform in the north-west of the map area, north of the lake Naajannnguit Tasiat.

### Nordre Isortoq steep belt

The regional significance of the Nordre Isortoq steep belt has recently been recognised, and it is now considered to be a crustal-scale, strike-slip shear zone similar to the Nordre Strømfjord shear zone (van Gool *et al.* 1996, 2002). The Nordre Isortoq steep belt is well defined between the Inland Ice and the head of Nordre Isortoq fjord, but its extension farther west is uncertain. It is less accessible and not as well exposed as the Nordre Strømfjord shear zone, and therefore not as well known. It consists of a zone of steeply NNW-dipping, straight gneisses 10–15 km wide, of which the central 7 km are predominantly occupied by metasedimentary rocks, interleaved with thin sheets of Archaean orthogneisses. Isolated, mylonitic, strike-slip shear zones occur. Kinematic indicators are rare; in combination with a shallowly ENE-plunging extension lineation most of them indicate a sinistral sense of movement (Fig. 10). The lateral extent of the Nordre Isortoq steep belt is poorly defined, and there is a gradual strain gradient on both sides of it.

### Brittle faults – D5

The map area is cut by several sets of brittle faults, which were mainly mapped by interpretation of 1:150 000 and 1:40 000 scale aerial photographs, but not studied in detail. The faults form linear depressions in the terrain, and fault rocks are rarely exposed. Offset or sense of displacement was rarely observed in the field, and was only mapped out in a few locations. Locally, red staining of K-feldspar, epidote growth and/or silicification are associated with the faults, while only minor mineralisation was observed (see section on economic geology below). A chlorite-rich fault gouge was observed in the fault north of Hvidøre in Ussuit fjord.

A set of NNE–SSW-trending faults with a general strike of *c.* 20° is dominant; individual faults have strikes varying between *c.* 0° and 40°. These faults are subvertical, with dip angles that are steeper than 70°. For most of these faults no offset could be determined, but those with a visible offset are sinistral. The largest strike separations measured on the major faults are slightly greater than 1 km. Where the faults offset large-scale folds, the N-dipping limbs show larger offsets than the south-dipping limbs, indicating that the movement pattern is oblique-slip, sinistral and west side down. A slight dextral block rotation occurs between NE–SW-trending faults, which is most visible in the metasedimentary rocks of the Nordre Isortoq steep belt.

Minor populations of brittle faults in other orientations also occur. NW–SE-trending faults are assumed to be conjugates to the NNE–SSW-trending faults, but are uncommon. NE- to ENE-striking faults are assumed to form a separate population; one of these, east of Ussuit, has a kilometre-scale dextral offset. Foliation-parallel faults were documented in a few places, mostly within the steeply dipping linear belts; they may well be common, but difficult to detect.

A study of onshore fault systems was carried out along the coast, from just north of Nordre Strømfjord, to Nordre Isortoq (Wilson *et al.* 2006). The main fault systems along the shore can be correlated with those in the Ussuit area, although the density of faults is much lower so far inland. Wilson *et al.* (2006) correlated the onshore fault systems with those in the Labrador Sea, Davis Strait, and Baffin Bay that formed during the opening of the seaways between Canada and Greenland in the Mesozoic to Cenozoic, under SW–NE extension.

# Aeromagnetic data

by Bo Møller Stensgaard

The regional high-resolution aeromagnetic survey of central West Greenland includes the Ussuit map sheet (Fig. 16a). The aeromagnetic data were obtained during the Aeromag 1999 project (Rasmussen & van Gool

2000). The vertical gradient of the total magnetic field intensity (Fig. 16b) was calculated from the measured data. The vertical gradient enhances shallow features and sharpens the boundaries/flanks of the anomalies,

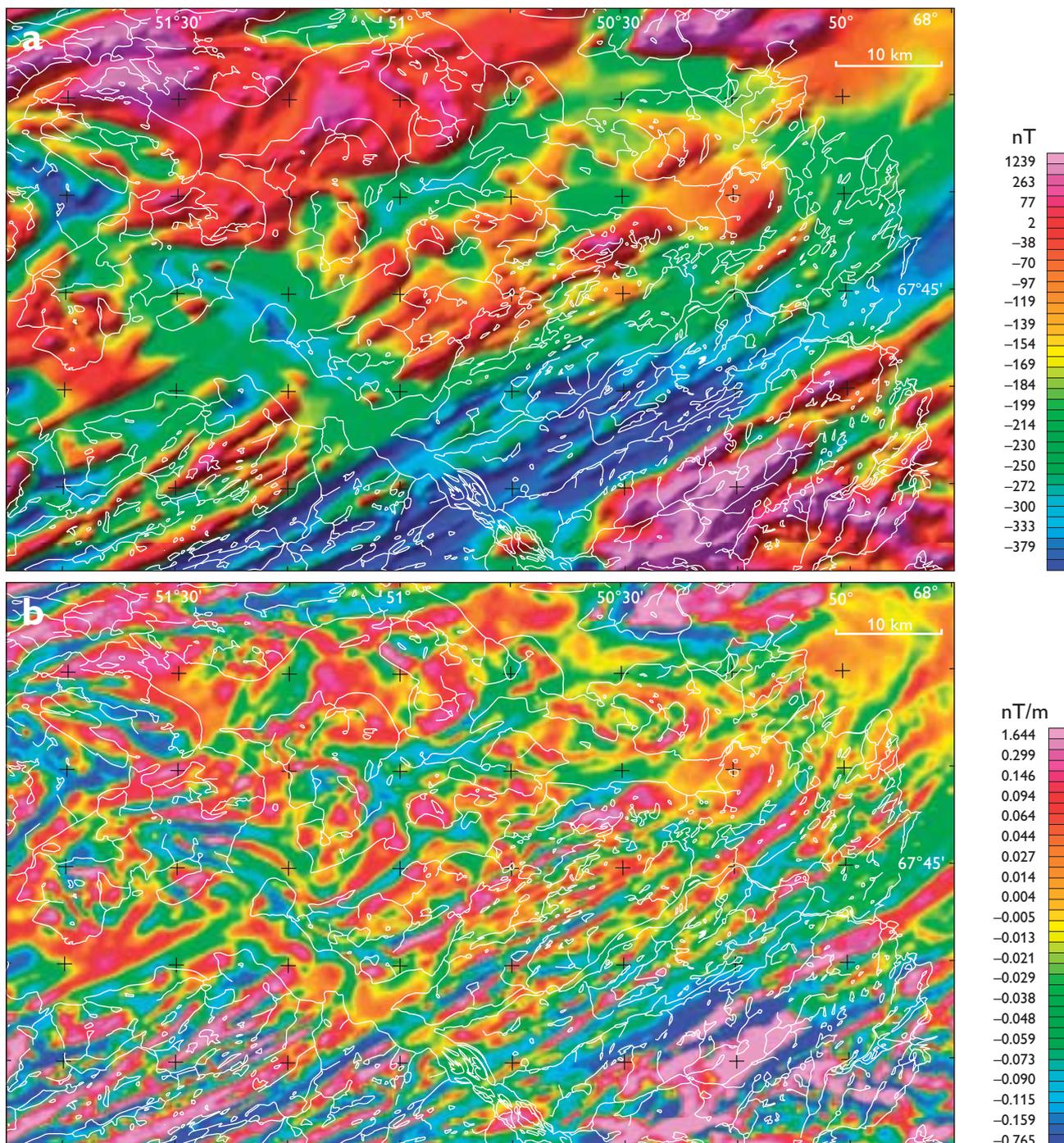


Fig. 16. Aeromagnetic maps of the Ussuit map area. a: Magnetic total field intensity map with shaded relief. b: Vertical gradient of the total magnetic field intensity. The data were collected along N-S flight lines with a spacing of 500 m, and orthogonal tie-lines with a spacing of 5000 m. The survey terrain clearance was 300 m (gently draped). The total magnetic field intensity was recorded at approximately every 7 m along the lines.

and is very useful in the interpretation of geological structures and patterns at the surface. Aeromagnetic data and interpretations that include the Ussuit map area are also presented in Rasmussen & van Gool (2000), Nielsen & Rasmussen (2002, 2004), Nielsen (2004), and Sørensen *et al.* (2006).

In general, a very close correlation can be observed between the mapped surface geology and the aeromagnetic anomaly patterns (Fig. 16a, b). The Nordre Isortoq steep belt is outlined as a distinct broad linear ENE–WSW-trending low magnetic domain. The large-scale upright fold structures in the centre and north-west of the map area are also clearly shown by the aeromagnetic anomaly patterns. The granulite facies orthogneisses in the south-eastern corner of the area are generally characterised by more complex and higher-amplitude anomaly patterns, compared to the areas of amphibolite facies rocks in the remainder of the map area.

Areas of orthogneisses can be correlated mostly with patterns of moderate and high magnetic anomalies, whereas low magnetic anomalies are often associated with supracrustal rocks. Supracrustal rocks within the Nordre Isortoq steep belt are reflected by an aeromagnetic low (*c.* –300 to –500 nT), while short-wave elongate anomalies with higher amplitude within the steep belt may reflect sheets of orthogneiss or more magnetite-rich supracrustal rocks. This is in agreement with data from more detailed magnetic surface profiles and measured magnetic susceptibilities in the area (Nielsen & Rasmussen 2002). Small, isolated highly magnetic anomalies (*c.* –100 to 50 nT) within the lows of the

steep belt are thought to relate to bodies of granitic or mafic to ultramafic rocks which are not necessarily all exposed. Also in other parts of the map area, the areas with lower aeromagnetic responses are occupied by supracrustal rocks. The south-eastern corner of the map area, south of the steep belt, is characterised by elongate high-amplitude magnetic anomalies (50 to 950 nT) that are considered to be associated with the magnetite-bearing monzonite–monzodiorite bodies (Fig. 16a).

The Arfersiorfik intrusive suite has a rather complex and variable response. Many of the small thin units interleaved with the supracrustal rocks are not visible in the magnetic data, whereas wider, larger units often have a low magnetic response. For example, in the western part of the area the WNW-trending synform occupied by quartz diorite, which can be traced from Nuersorfiqqap Avannaatungaa across the fjord to Ipiutaarsuk, forms a distinct aeromagnetic low. The core of the main intrusive body of Arfersiorfik quartz diorite in the north-eastern corner of the map area has a pronounced magnetic high (300 to 490 nT); significant amounts of magnetite occur here as millimetre-scale needles and as magnetite grains 1–3 cm large. A small part of the southern Nordre Strømfjord shear zone, located in the north-western corner of the map area, is just visible as a distinct low magnetic lineament, reflecting both the presence of supracrustal rocks and destruction of magnetite within the shear zone. Several NNW- to NW-striking faults are visible in the magnetic patterns (Fig. 16b), including some that are not shown in the geological map.

# Surface geochemical data

by Agnete Steenfelt

Geochemical element distribution maps have been produced for most of West Greenland (Steenfelt 2001; Schjøth & Steenfelt 2004). These maps are based on chemical data from the < 0.1 mm grain-size fraction of stream sediment samples collected systematically at a density of one sample per 25–30 km<sup>2</sup>. A pronounced E–W-trending geochemical boundary runs through the Nagssugtoqidian orogen and transects the southern part of the Ussuit map sheet. The boundary is exemplified here in the map of CaO (Fig. 17a). North of the boundary, the element distribution is rather homogeneous,

with elevated concentrations of SiO<sub>2</sub> and K<sub>2</sub>O, reflecting a predominance of granodioritic gneisses. The region south of the boundary is enriched in elements associated with dioritic orthogneisses and mafic metavolcanic rocks (e.g. Ca, Mg, Sr, Ti, and V). Palaeoproterozoic monzonitic magmatism is outlined by high Ba and Sr. The map of K<sub>2</sub>O (Fig. 17b) illustrates potassium depletion in the southern part of the Ussuit map area, as well as the location of stream sediment samples with high values of Ba relative to K<sub>2</sub>O ( $Ba \times 10\,000 / K_2O > 380$ ).

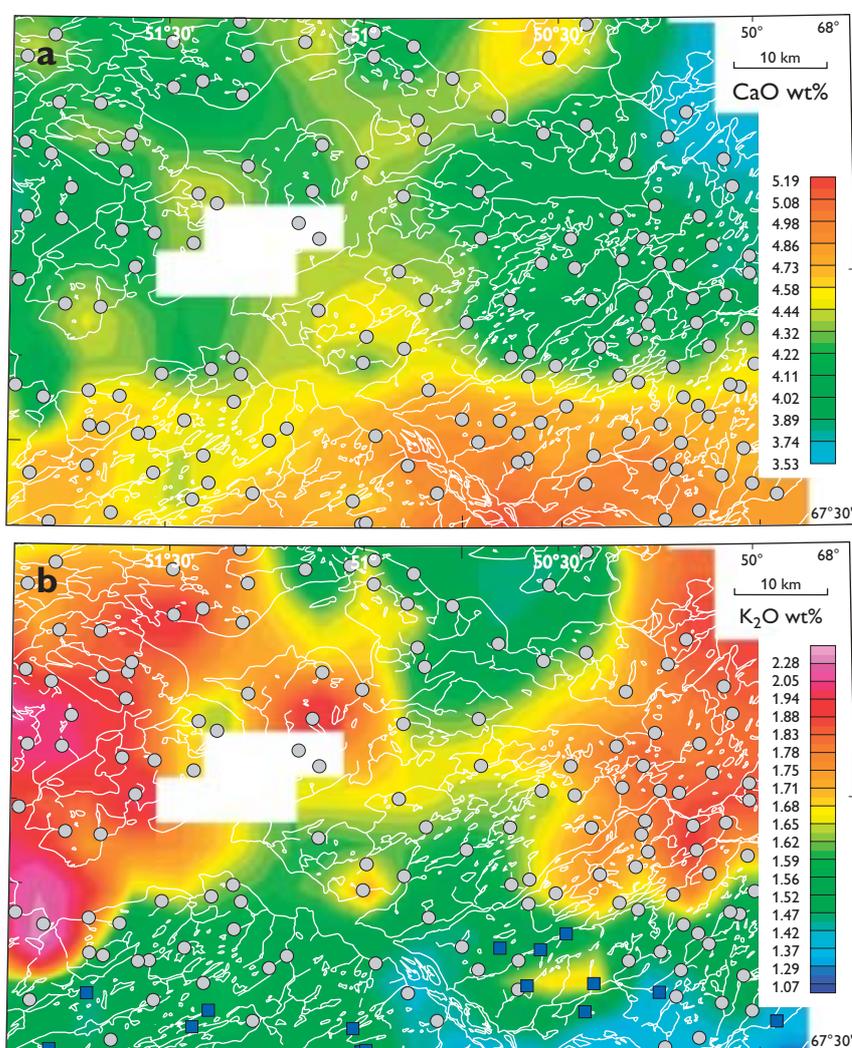


Fig. 17. Examples of element distribution patterns over the Ussuit map area (a: CaO% and b: K<sub>2</sub>O%). The maps show contoured grids based on chemical data from the < 0.1 mm grain-size fraction of stream sediment samples. The white areas indicate grid cells with insufficient data. Grey dots indicate sample sites. Blue squares in b mark samples with  $Ba \times 10\,000 / K_2O > 380$ .

# Tectonic model

by Jeroen A.M. van Gool and Mogens Marker

The currently accepted tectonic model for the whole Nagssugtoqidian orogen assumes that the orogen has gone through a complete Wilson cycle (Connelly *et al.* 2000; van Gool *et al.* 2002). The geology of the Ussuit area plays an important role in the tectonic model for the orogen, because it includes the calc-alkaline Arfersiorfik intrusive suite, interpreted as subduction-related (Kalsbeek *et al.* 1987), Palaeoproterozoic metasedimentary rocks interpreted as allochthonous (Nutman *et al.* 1999; van Gool *et al.* 2002), and early thrust structures (van Gool *et al.* 1999). The tectonic model presents the Nagssugtoqidian orogen as the site of continental collision between the North Atlantic Craton and a less well-known Archaean Craton underlying the Rinkian fold belt, after opening and closing of an oceanic basin.

The subsequent orogenic phases are shown schematically in Fig. 18, and are documented in more detail by van Gool *et al.* (2002).

Crustal extension and opening of an oceanic basin are linked to the intrusion of the dolerites of the Kangâmiut dyke swarm in the SNO and southern foreland at around 2045 Ma (Nutman *et al.* 1999; Mayborn & Leshner 2006). Metasedimentary rocks in the SNO and CNO containing Palaeoproterozoic detrital zircons indicate the presence of sedimentary basins between 1950 Ma (youngest detrital zircon) and 1920 Ma (oldest age on Arfersiorfik intrusive suite). A phase of convergence and consumption of oceanic crust is indicated by the subduction-related Arfersiorfik intrusive suite, with ages between *c.* 1920 and 1885 Ma (Kalsbeek *et al.* 1987; Kalsbeek & Nutman 1996;

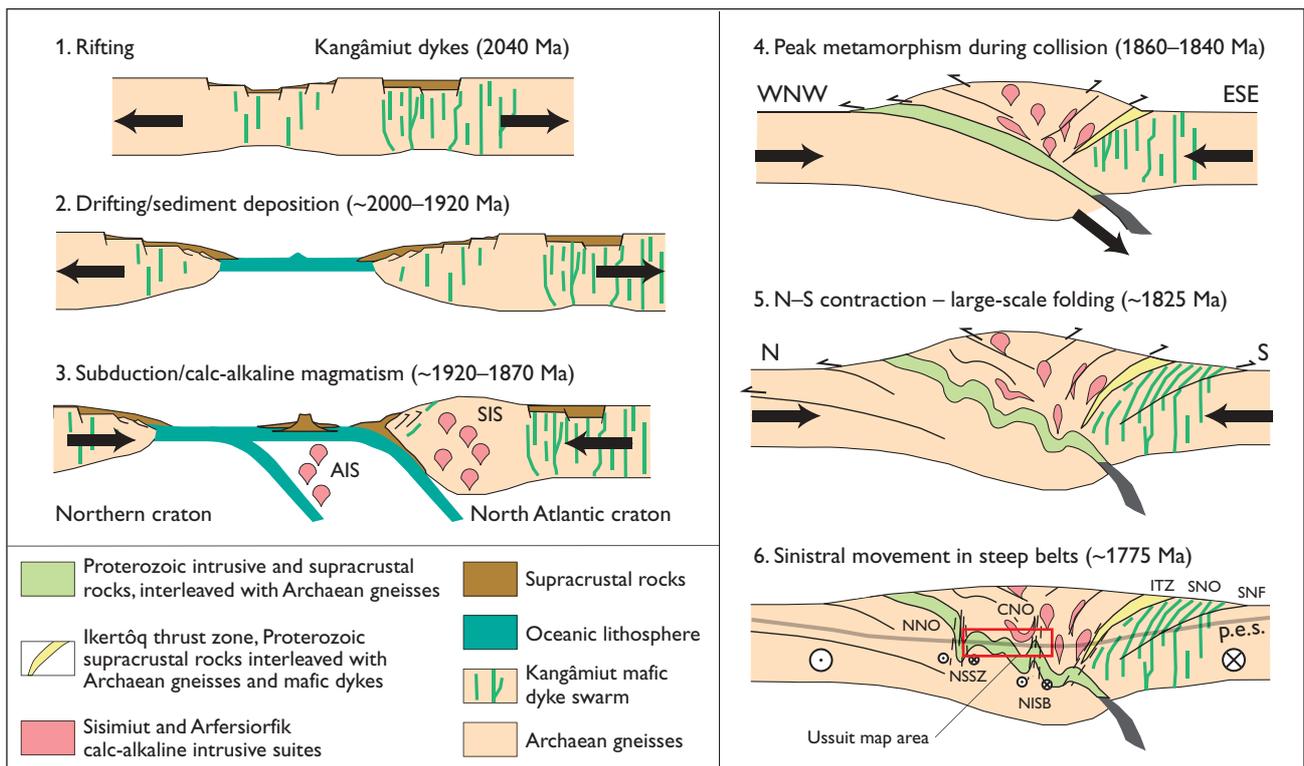
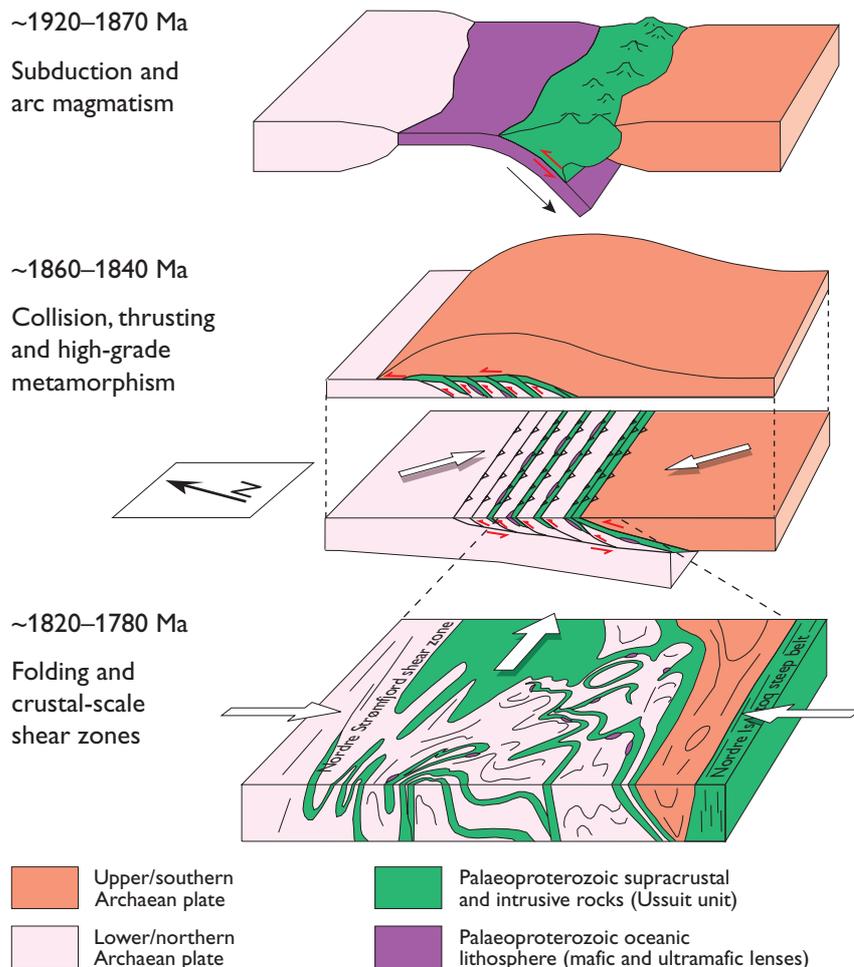


Fig. 18. Schematic model for the tectonic evolution of the Nagssugtoqidian orogen. The orientation of the section is schematic for the first three stages, due to the uncertainty of the geometric configuration of the two plates. The change in orientation of the section between stages 4 and 5 indicates the rotation of the kinematic framework at that time. The Sisimiut intrusive suite and the Arfersiorfik intrusive suite are depicted as separate arcs to emphasise the different nature of the two, but as discussed in the text they are presumed to be along-strike equivalents of a single arc. SNO, CNO, and NNO are the southern, central and northern Nagssugtoqidian orogens as defined by Marker *et al.* (1995). AIS, Arfersiorfik intrusive suite; ITZ, Ikertôq thrust zone; NISB, Nordre Isortoq steep belt; NISSZ, Nordre Strømfjord shear zone; SIS, Sisimiut intrusive suite; SNF, Southern Nagssugtoqidian front; p.e.s., present erosion surface. From van Gool *et al.* (2002).

Fig. 19. Schematic tectonic model showing the main elements of the Palaeoproterozoic development in the Ussuit area in three stages.



Whitehouse *et al.* 1998; Connelly *et al.* 2000). Continental collision is marked by NW-directed thrusting, crustal thickening and high-temperature metamorphism. Metamorphism and synchronous ductile thrusting occurred at *c.* 1860–1840 Ma (Taylor & Kalsbeek 1990; Kalsbeek & Nutman 1996; Connelly *et al.* 2000). N–S convergence continued at least until 1825 Ma, the age of one ENE-trending F3 fold, and was synchronous with E–W extension (Manatschal *et al.* 1998). The youngest crustal-scale movements are strike-slip shearing in the Nordre Strømfjord and Nordre Isortoq shear zones at *c.* 1775 Ma (Connelly *et al.* 2000).

The model presented above implies the presence of a suture within the CNO, and van Gool *et al.* (2002)

suggested that it is located along the tectonic contact of the Ussuit unit, and that it was intensely deformed by folding and thrust repetition (Fig. 19). This zone then roots in the Nordre Isortoq steep belt, coinciding with the northernmost known occurrence of the Sisimiut intrusive suite. However, the similarity of geochronological data from Archaean gneisses on either side of the proposed suture does not support this interpretation (Kalsbeek & Nutman 1996; Connelly *et al.* 2000). New isotope work in the Disko region may suggest that there are grounds for locating a suture farther north at the Nagssugtoqidian–Rinkian boundary, across which a distinct difference in the Archaean evolution occurs (Connelly *et al.* 2006).

# Economic geology

by Bo Møller Stensgaard and Henrik Stendal

## Exploration activities

Little mineral exploration has been carried out in the inland areas of the Ussuit map area, largely because of its remoteness from the outer coast. Only a limited number of mineral occurrences are known and none of these are currently classified as having a potential for being economically feasible. Most of the known occurrences have been located or visited during the GEUS resource evaluation programme of central West Greenland in 2000–2003 (e.g. Stendal *et al.* 2002; Jensen *et al.* 2004; Nielsen & Rasmussen 2004; Schjøth & Steinfelt 2004; Stendal *et al.* 2004). All information on known mineral occurrences from this assessment has been compiled in Stendal *et al.* (2004), upon which this contribution is partly based. The mineral occurrences in the map area can be subdivided into metalliferous minerals and industrial minerals.

The Ussuit area was also included in more extensive regional exploration campaigns, such as reconnaissance exploration after base metal occurrences or radiogenic minerals (Gothenborg & Keto 1980; Secher 1980; Geyti 1990). Recently, commercial exploration focused on nickel-copper occurrences in ultrabasic rocks and Voisey's Bay analogies has been undertaken in the area (Car 1997; Diamond Fields International Ltd. 2004).

## Metalliferous minerals

In the map area, metalliferous minerals include occurrences such as (1) iron sulphides with minor copper related to hydrothermal activity in fault and shear zones, and (2) stratabound iron formation related to supracrustal rocks.

Several distinct NNE-trending fault zones occur in the area between Kuup Akua and Ussuit (Stendal *et al.* 2002). Sinistral displacement of several kilometres can be deduced for many of the faults from mapping and aeromagnetic data (Nielsen 2004; Nielsen & Rasmussen 2004). Some of these fault zones contain pyrite, pyrrhotite and minor chalcopyrite mineralisations related to hydrothermal activity, which are the dominating type of metalliferous occurrences. Two types of alteration are associated with the fault zones. One type is characterised by an unusually high content of red to pink K-feldspar and green epidote, which is very common for fault zones throughout central West Greenland. The extent of this alteration into the wall rock of

the fault is variable. Another type of alteration is silicification and locally chloritisation. In many cases there seems to be a correlation between the latter type of alteration and the content of iron-copper sulphide minerals. North of the map area, in the inner part of Arfersiorfik fjord, a late-stage postkinematic, hydrothermal mineral assemblage at prehnite pumpellyite and lower greenschist facies is associated with brittle fracturing and veining in a fault zone with silicification and chloritisation. Although the faults in the Ussuit area have not been investigated in detail, it is likely that similar late-stage hydrothermal mineral assemblages also occur here. Most mineralised fault zones also contain magnetite and hematite, e.g. at Ulitsiivik. Weathering commonly results in malachite staining within the fault zones, and locally this can be very intense, e.g. in the fault at the mouth of Qorlortoq (Fig. 20). The iron and iron-copper sulphides in the fault zones are found as semi-massive iron-sulphide lenses 5–10 cm thick, as disseminated iron-sulphide grains, and as iron-sulphide stringer systems with stringers less than 1 cm thick. No commercial exploration has been carried out on the fault zones in the map area. The most notable analytical results from the GEUS assessment are elevated copper contents of up to several thousands ppm Cu. The highest gold values, 50 ppb Au, were obtained from silicified and chloritised rock samples collected in fault zones at the inner part of Ussuit fjord. The iron sulphide mineralisation is thought to be related to hydrothermal activity in structurally defined low-pressure zones, either during orogenic metamorphism and deformation, or



Fig. 20. Malachite staining in heavily fractured biotite schist in the main NNE-trending fault zone in Kuup Akua (from Stendal *et al.* 2004).

during later-stage deformation and hydrothermal activity in connection with e.g. regional uplift.

Another structurally controlled mineral occurrence is located at the small bay Seersinnilik in the south-western part of the map area, where disseminated pyrrhotite and minor pyrite occur in a 50 cm thick rusty horizon within a local shear zone in garnet-bearing quartzite; this yielded an elevated copper content of 3747 ppm, but no other interesting element values.

An isolated occurrence 2.5–3 m thick of stratabound, banded quartz and magnetite with disseminated pyrite grains is located in a small supracrustal unit south of the lake Naloraarissap Tasia. No significant element concentrations have been obtained from this occurrence.

## Industrial minerals

Monomineralic monazite, diopside and magnesite constitute the known occurrences of industrial minerals, besides a potential for dimension stone.

During an airborne radiometric survey in 1975 (Secher 1976) and ground follow-up in the following years (Secher 1980), a large number of monazite-bearing pegmatites were located, six of which are situated within the map area. Monazite is found as 0.5–5 mm orange coloured euhedral crystals in white plagioclase-biotite pegmatites. The monazite occurs in elongate aggregates accompanied by biotite, set in a matrix of primarily plagioclase. The white pegmatites are generally concordant (but locally discordant) to the foliation of the surrounding granulite facies gneiss. The individual pegmatite bodies are typically 5–10 m wide and 50–200 m long, often with gradual contacts to the host rock. The rare-earth element contents of monazite-bearing pegmatite samples are: 1–2% La, 2.5–4% Ce and 5–7% Nd. Other interesting element contents are 1–1.5% Zr, 500 ppm Y and 5–10% Th.

In general, pale green diopside is the most abundant calc-silicate mineral in the marble and calc-silicate units in the inner parts of Nassuttooq and Ussuit fjords. It occurs as skarns in most of the marble and calc-silicate occurrences in the map area, which can be very coarse-grained. The largest reported accumulation of diopside is located on an elongate island at Serfat in the western part of Ussuit fjord. Here the diopside forms a nearly monomineralic layer c. 10 m wide within layered calc-silicate rocks that are part of a thin sequence of isoclinally folded supracrustal rocks (Fig. 9). The sequence also includes silicified mafic metavolcanic rocks, a quartz vein 1.5 m wide, minor biotite schist, ultrabasic rocks and a thin sheet of quartz diorite.

Magnesite has been found south of Naajaallit within a 300–400 m thick supracrustal sequence with garne-

tiferous quartzofeldspathic gneisses, marble, calc-silicate rocks and sheets of quartz diorite. The magnesite is concentrated in massive to schistose layers 2–3 m thick, which can be followed along strike for at least 200 m. To the south, the horizon is bounded by garnet-bearing gneiss, succeeded by thin quartz diorite, and 150 m farther south the supracrustal sequence is bounded by a 10 m wide marble–calc-silicate zone. Rock samples from the magnesite layer yield 24% Mg, 0.25% Ni and 0.2% Cr. No detailed investigations have been carried out on the occurrence, but the high nickel and chromium contents suggest that the layer represents a metamorphosed and metasomatically altered ultramafic rock.

Biotite-bearing migmatitic orthogneisses have been sampled to test their quality as a natural dimension stone resource at a number of localities in the south-western part of the map area (Rasmussen 2002, 2003). Several of these localities (not shown on the map) may be regarded as candidates for good dimension stone resources. Homogeneous grey biotite gneiss with red melt veins in a flamed pattern is the most promising lithology.

## Economic potential

Within the Ussuit map area, no economically feasible mineral occurrences have been discovered to date. However, in this respect the area is still a frontier region with a very low degree of exploration. Considering the geological environment and history of the area, a potential may exist for syn- or epigenetic gold mineralisation in the supracrustal rocks or the orthogneisses, as well as platinum group elements or nickel in the ultrabasic rocks. The monomineralic occurrences of industrial minerals and possible resources of dimension stone also provide potential targets for exploration.

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## Appendix

### Zircon U-Pb geochronological data

In order to test the southern extent of the Palaeoproterozoic intrusive rocks, the ages of two samples of quartz-dioritic gneiss were determined by zircon U-Pb geochronology. Both ICPMS and ion probe methods were used (see analytical details below).

#### Sample description

Sample 480605 is a porphyritic quartz-dioritic gneiss collected at the southern margin of the Nordre Isortoq steep belt on the northern shoulder of the large valley at Eقالummiut Nunaat (coordinates: 67°35.869'N, 50°19.352'W). The quartz diorite forms a *c.* 150 m wide zone at the southern margin of a *c.* 700 m wide metapelitic gneiss of the Ussuit unit. The sampled rock is medium-grained and contains plagioclase porphyroclasts up to 1 cm in diameter, in a dark grey matrix of hornblende, biotite, plagioclase and quartz. Thin sheets of the quartz-dioritic gneiss have intruded the adjoining metasedimentary rocks. The contact of the quartz-dioritic gneiss with the Archaean gneisses to the south is not exposed.

Sample 480616 is from a plagioclase-porphyritic dioritic gneiss that occurs on the plateau east of the large valley at Eقالummiut Nunaathomogeneous (coordinates: 67°37.549'N, 49°53.068'W). It was sampled at the easternmost exposures of an ENE-trending complex of tonalitic to dioritic gneisses, *c.* 3 × 15 km in outcrop size, most of which are porphyritic. The sampled dioritic gneiss is a homogeneous, medium- to coarse-grained granulite facies rock that contains plagioclase porphyroclasts up to 5 mm long and slightly smaller anhedral grains of orthopyroxene. The matrix consists of biotite, hornblende, plagioclase and quartz. The gneiss complex is intruded by numerous decimetre- to metre-sized sheets of pink granite. This rock is interpreted to be part of the Sisimiut intrusive suite, as explained in the main text.

#### Sample preparation

The two samples in this report were jaw-crushed, crushed again to a coarse powder in a ring mill, sieved to < 400 µm, and separated using a shaking wash table to obtain pre-concentration of the heavy fraction and

removal of very fine-grained material. Magnetic minerals were then removed using a Frantz magnetic separator. The remaining non-magnetic fraction was further separated using heavy liquids to obtain a concentrate containing zircon, titanite, rutile, and sulphide minerals. Individual zircon grains were then hand-picked and mounted on double-sided sticky tape with a few grains of the ion probe zircon standard 91500 (1065 Ma, Wiedenbeck *et al.* 1995). The mounted samples were cast in epoxy, ground to reveal the mid-sections of the zircons, and polished. All zircons were then imaged using back-scattered electrons on a scanning electron microscope at GEUS. The data reported in Table 1 and Fig. 21 were obtained using two different methods (see below); the age calculations were performed with IsoPlot/Ex 3.0 (Ludwig 2003).

## Methodology

### Secondary ion mass spectrometry (SIMS, or ion probe)

Sample 480605 was analysed using the CAMECA IMS 1270 secondary ion mass spectrometer at the Nordsim laboratory at Naturhistoriska Riksmuseet in Stockholm. Analytical procedures and common Pb corrections were used as in Whitehouse *et al.* (1997). A primary  $O^{2-}$  ion beam is focused into a 20  $\mu m$  spot that sputters material off the sample and leaves a flat-bottomed crater. Sputtered positive ions (including composite species) are extracted and separated in a mass spectrometer into the peaks of interest:  $^{90}Zr^{16}O$ ,  $^{204}Pb$ ,  $^{206}Pb$ ,  $^{207}Pb$ ,  $^{208}Pb$ ,  $^{238}U$ ,  $^{232}Th^{16}O$ , and  $^{238}U^{16}O$ . The raw analytical data were corrected by matrix-matched external standardisation using the 1065 Ma 91500 zircon standard (Whitehouse *et al.* 1997).

### Laser ablation-sector field-inductively coupled plasma mass spectrometry (LA-SF-ICPMS)

Sample 480616 was analysed at GEUS using a NewWave Research/Merchantek UP213 laser instrument with an Nd-YAG 213 nm laser and an Element2 (Thermo-Finnigan, Bremen) single-collector, double focusing, magnetic sector ICPMS (see Hollis 2005 for a complete description of the analytical procedure). The laser beam can be focused to 30  $\mu m$ , roughly the same size as in SIMS analysis, but it erodes a considerably deeper hole in the target crystal. The eroded material is transferred from the laser to a plasma and mass spectrometer for isotopic quantification. The data acquisition time for each analysis was 90 s. The instrument was tuned to

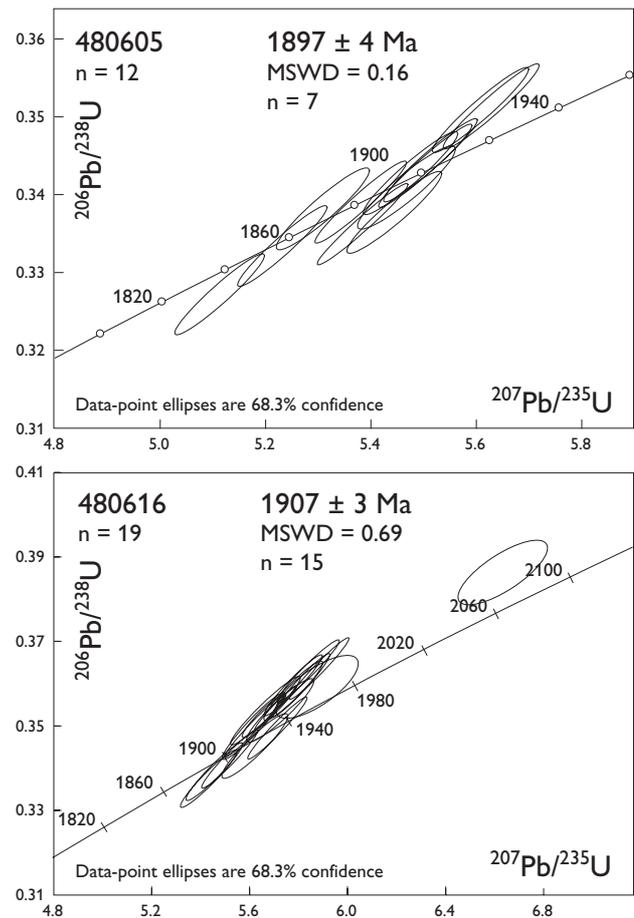


Fig. 21. Concordia diagrams of samples 480605 (Arfersiorfik intrusive suite) and 480616 (Sisimiut intrusive suite). n, number of analysed spots.

give large, stable signals for the  $^{206}Pb$  and  $^{238}U$  peaks, low background count rates (typically around 300 counts/s for  $^{207}Pb$ ) and low rates of oxides ( $^{238}U^{16}O/^{238}U$  generally below 2.5%). The following masses were measured:  $^{202}Hg$ ,  $^{204}(Pb + Hg)$ ,  $^{206}Pb$ ,  $^{207}Pb$ ,  $^{208}Pb$ ,  $^{232}Th$ ,  $^{235}U$ , and  $^{238}U$ .  $^{202}Hg$  was measured to monitor the  $^{204}Hg$  interference on  $^{204}Pb$ , using a  $^{202}Hg/^{204}Hg$ -ratio of 4.36. In sample 480616 the net intensity of  $^{204}Pb$ , corrected for  $^{204}Hg$ , was never significantly above the limit of detection, and thus no correction for common Pb was performed. The laser-induced element fractionation and the instrumental bias on measured isotopic ratios were corrected by matrix-matched external standardisation using the GJ-1 zircon standard (Jackson *et al.* 2004).

## Results

**480605:** The zircons are typically 200–400  $\mu m$  long with aspect ratios of 1:2–1:3 and subhedral to rounded terminations. They commonly show moderately developed oscillatory zonation. There are no signs of over-

Table 1. U-Pb age data

Spot #	[U] ppm	[Th] ppm	Th/U measured	f <sub>206</sub> %	<sup>207</sup> Pb/ <sup>206</sup> Pb	± 1σ %	<sup>207</sup> Pb/ <sup>235</sup> U	± 1σ %	<sup>206</sup> Pb/ <sup>238</sup> U	± 1σ %	<sup>207</sup> Pb/ <sup>206</sup> Pb age Ma	± 1σ Ma	Discordance % conventional
480605 1897 ± 4 Ma (2σ), MSWD = 0.16, n = 7 of 12 (ion probe data)													
<b>1</b>	447	249	0.558	0.01	0.11385	0.39	5.3088	1.10	0.33818	1.03	1861.8	7.0	1.0
<b>4</b>	450	319	0.708	0.01	0.11612	0.27	5.5030	1.06	0.34372	1.03	1897.3	4.8	0.4
<b>6</b>	644	407	0.632	0.01	0.11609	0.29	5.5130	1.07	0.34443	1.03	1896.8	5.2	0.7
<b>13</b>	295	185	0.626	0.07	0.11591	0.32	5.6079	1.08	0.35089	1.03	1894.1	5.7	2.7
<b>14</b>	501	354	0.706	0.30	0.11584	0.34	5.4750	1.08	0.34277	1.03	1893.1	6.1	0.4
<b>17</b>	402	127	0.316	0.08	0.11618	0.30	5.6281	1.07	0.35135	1.03	1898.2	5.3	2.6
<b>18</b>	305	147	0.483	0.02	0.11631	0.43	5.4675	1.12	0.34092	1.03	1900.3	7.8	-0.6
21	274	145	0.531	0.02	0.11691	0.37	5.4442	1.09	0.33772	1.03	1909.6	6.6	-2.0
25	365	158	0.432	0.06	0.11510	0.29	5.3805	1.06	0.33905	1.03	1881.4	5.1	0.0
28	365	195	0.536	0.04	0.11381	0.31	5.2318	1.07	0.33341	1.03	1861.1	5.6	-0.4
32	334	201	0.601	0.03	0.11333	0.33	5.1127	1.10	0.32720	1.05	1853.5	6.0	-1.8
<b>33</b>	590	40	0.067	0.01	0.11614	0.24	5.3841	1.05	0.33622	1.03	1897.6	4.2	-1.8
480616 1907 ± 3 Ma (2σ), MSWD = 0.69, n = 15 of 19 (laser ICP-MS data)													
30	171	41	0.24		0.1245	1.21	6.6309	1.80	0.3863	1.34	2021.4	42.8	-2.1
<b>31</b>	131	72	0.55		0.1169	0.34	5.5137	1.36	0.3420	1.31	1910.0	12.4	0.3
<b>32</b>	117	50	0.42		0.1165	0.36	5.7763	1.37	0.3596	1.33	1903.5	13.1	-1.9
<b>33</b>	138	41	0.30		0.1167	0.42	5.4532	1.38	0.3390	1.31	1905.8	14.9	0.6
34	93	33	0.35		0.1186	1.24	5.8762	1.86	0.3593	1.38	1935.4	44.5	-1.1
<b>35</b>	113	39	0.34		0.1167	0.36	5.8424	1.37	0.3632	1.32	1905.8	13.0	-2.3
<b>36</b>	87	42	0.48		0.1164	0.36	5.6892	1.38	0.3545	1.33	1901.5	12.8	-1.4
<b>37</b>	87	42	0.48		0.1175	0.55	5.7351	1.43	0.3540	1.32	1918.3	19.7	-0.9
38	121	65	0.54		0.1185	0.35	5.7116	1.41	0.3495	1.36	1934.2	12.5	0.1
<b>39</b>	194	118	0.61		0.1168	0.27	5.6543	1.53	0.3510	1.50	1908.3	9.6	-0.8
<b>43</b>	128	64	0.50		0.1166	0.34	5.6268	1.42	0.3499	1.38	1905.2	12.3	-0.7
<b>44</b>	100	44	0.44		0.1174	0.31	5.8832	1.36	0.3636	1.33	1916.5	11.0	0.3
45	90	36	0.41		0.1181	0.59	5.6210	1.56	0.3452	1.44	1927.6	21.2	1.3
<b>46</b>	122	54	0.44		0.1165	0.32	5.6166	1.37	0.3496	1.34	1903.5	11.3	2.3
<b>47</b>	119	45	0.38		0.1161	0.41	5.6503	1.49	0.3529	1.43	1897.2	14.9	3.3
<b>49</b>	103	31	0.30		0.1171	0.36	5.8049	1.41	0.3595	1.36	1912.4	13.0	4.3
<b>50</b>	162	52	0.32		0.1163	0.39	5.6161	1.47	0.3502	1.41	1900.4	14.0	5.3
<b>51</b>	92	39	0.42		0.1168	0.43	5.4347	1.41	0.3375	1.35	1907.7	15.3	6.3
<b>52</b>	118	69	0.58		0.1170	0.46	5.7776	1.39	0.3582	1.31	1910.9	16.6	7.3

Spot numbers in bold have been included in the age calculations.

f<sub>206</sub>: common Pb (not measured with ICPMS due to <sup>204</sup>Pb-interference with mercury; see the main text).

n = number of analysed spots.

growths or recrystallised rims, though fracture healing has occurred in some high-U oscillatory and patchy zones in a few grains (bright zones in backscatter-electron (BSE) images).

Twelve spots in 12 grains were analysed (Table 1), of which seven grains yielded a precise age of 1897 ± 8 Ma. This is interpreted as the intrusive age of these rocks, which falls well within the range of known ages of the Arfersiorfik intrusive suite. Of the remaining grains three have ages that are close to the age of peak metamorphism in the region.

**480616**: The zircons are typically 150–400 μm long with aspect ratios of 1:2–1:4 and subhedral to rounded terminations. They commonly show moderately developed oscillatory zonation. Many grains have partial BSE-bright rims that may be metamorphic in origin. Some grains also have less common patchy, BSE-bright internal zones. Nineteen spots in 19 grains were analysed (Table 1), all within the oscillatory zoned cores. No bright rims or patchy zones were analysed. Fifteen grains yielded a precise age of 1907 ± 3 Ma, which is interpreted as the intrusive age of the rock (Fig. 21). This age is within the known age range of the Sisimiut intrusive suite.