

# Crystalline rocks older than 1600 Ma: the Greenland Precambrian shield

About half of the ice-free area of Greenland consists of Archaean and Palaeoproterozoic crystalline basement rocks, mainly orthogneisses with enclaves of supracrustal rocks. They belong to three distinct kinds of basement provinces (Fig. 2): (1) Archaean rocks (3200–2600 Ma with local older units, up to >3800 Ma in the Godthåbsfjord region), strongly deformed during the Archaean but almost unaffected by Proterozoic or later orogenic activity; (2) Archaean terrains reworked during the Palaeoproterozoic around 1900–1800 Ma ago; (3) terrains mainly composed of juvenile Palaeoproterozoic rocks (2000–1750 Ma). Terrains of categories (2) and (3) often

contain high-grade Palaeoproterozoic metasedimentary successions.

Nearly all unreworked Archaean gneisses occur within the Archaean craton of southern Greenland (Fig. 2). They are cut by swarms of mafic dykes (see Fig. 20), most of which were emplaced between 2200 and 2000 Ma ago; these dykes are generally undeformed and unmetamorphosed, demonstrating that the surrounding gneisses cannot have been significantly affected by Palaeoproterozoic orogenic activity 1900–1800 Ma ago.

Reworked Archaean orthogneisses are prominent in the Nagssugtoqidian orogen and the Rinkian fold belt north of the Archaean craton in West Greenland, and in the Ammassalik region in South-East Greenland (Fig. 2). Reworked Archaean gneisses are also exposed in a small area at Victoria Fjord in northernmost Greenland (*c.* 3400 Ma, Nutman *et al.* 2008a) and similar rocks have been found at a locality beneath the Inland Ice by drilling (Weis *et al.* 1997).

Juvenile Palaeoproterozoic gneisses and granitoid rocks (2000–1750 Ma) make up most of the Ketilidian orogen of South Greenland and parts of the Inglefield orogenic belt in North-West Greenland. They also form a large proportion of the crystalline basement within the Caledonian orogen of North-East Greenland.

Before the opening of the Labrador Sea and Baffin Bugt the Precambrian basement of Greenland formed an integral part of the Laurentian shield. A recent interpretation of the relationships between geological provinces in eastern Canada and Greenland (St-Onge *et al.* 2009) is shown in Fig. 3.



Fig. 2. Simplified map showing the distribution of Archaean and Palaeoproterozoic basement provinces in Greenland. Large areas within the Rinkian fold belt are dominated by metasedimentary rocks (⊗: Karrat Group) and granites (+: Prøven igneous complex). Black dots and open circles indicate localities where the presence of, respectively, Archaean and Palaeoproterozoic rocks have been documented in poorly known areas, as well as in cases where these ages are in contrast to the age of the surrounding rocks. Slightly modified from Kalsbeek (1994).

## Archaean craton

Together with smaller areas along the coast of Labrador and in north-western Scotland, the Archaean rocks of southern Greenland (Figs 2, 3) form the North Atlantic craton. The Greenland Archaean is largely made up of tonalitic to granodioritic orthogneisses [72, 73], amphibolites [68] and anorthositic rocks [85]. Most of these rocks are of Meso- to Neoproterozoic age, 3200–2600 Ma,

but Eoarchaeon orthogneisses [76] and supracrustal rocks [69] (3850–3600 Ma) are widely exposed in the Godthåbsfjord region.

Before geochronological data became more widely available, the whole of the Greenland Archaean craton was envisaged to represent a more or less homogeneous geological entity. Detailed field investigations combined with U-Pb zircon age determinations, however, have

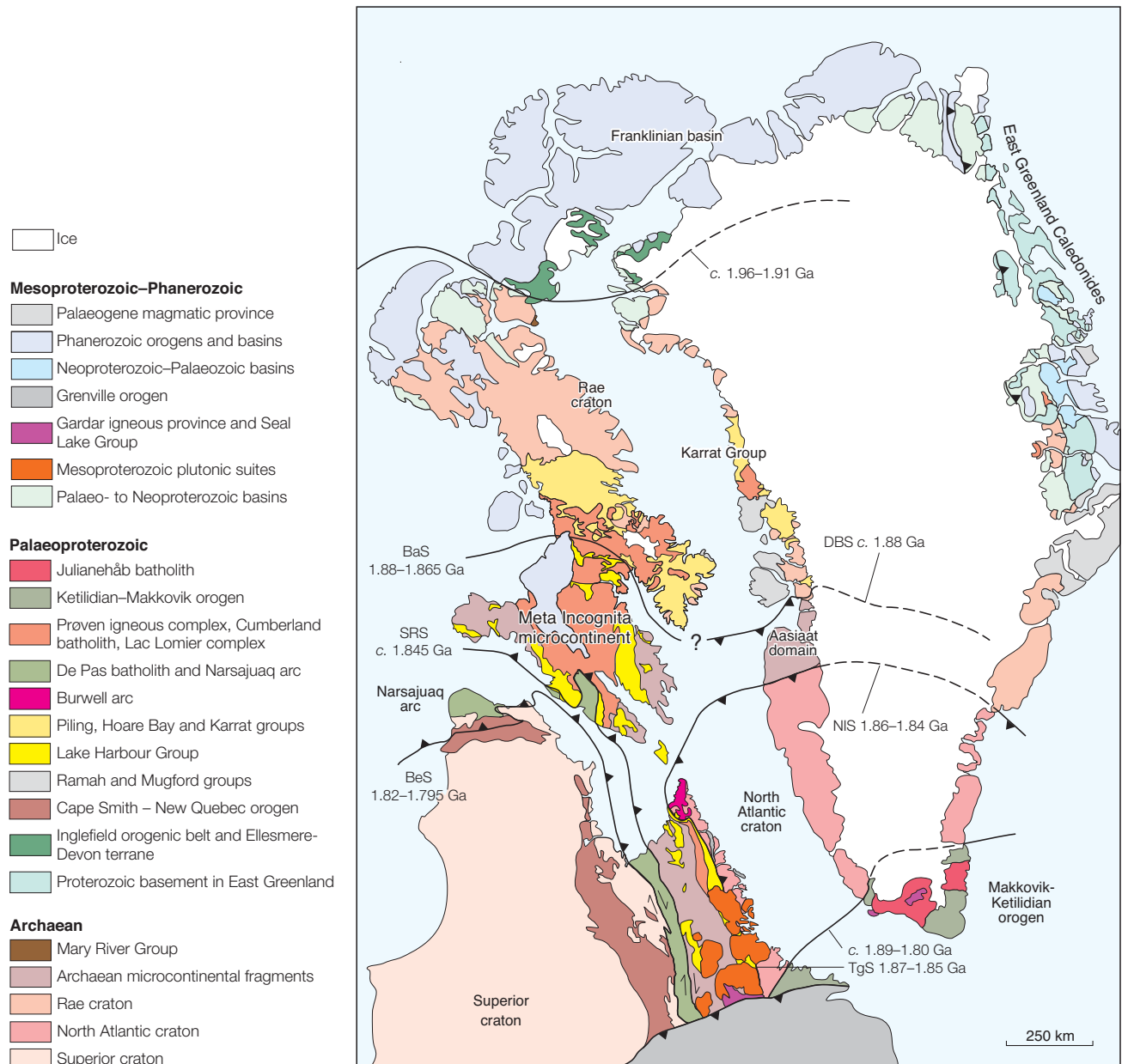


Fig. 3. Map showing the presently preferred correlation of principal geological units of eastern Canada and Greenland, shown with Greenland in its pre-drift (pre-late Cretaceous) position relative to eastern Canada, simplified after St-Onge *et al.* (2009).

BaS: Baffin suture; BeS: Bergeron suture; DBS: Disko Bugt suture; NIS: Nordre Isortoq steep belt; SRS: Soper River suture; TgS: Tasiuyak gneiss suture. The approximate ages of the different sutures illustrate the progressive accretion of crustal blocks from north to south in Greenland during the Palaeoproterozoic. For details see St-Onge *et al.* (2009) and papers referred to therein.

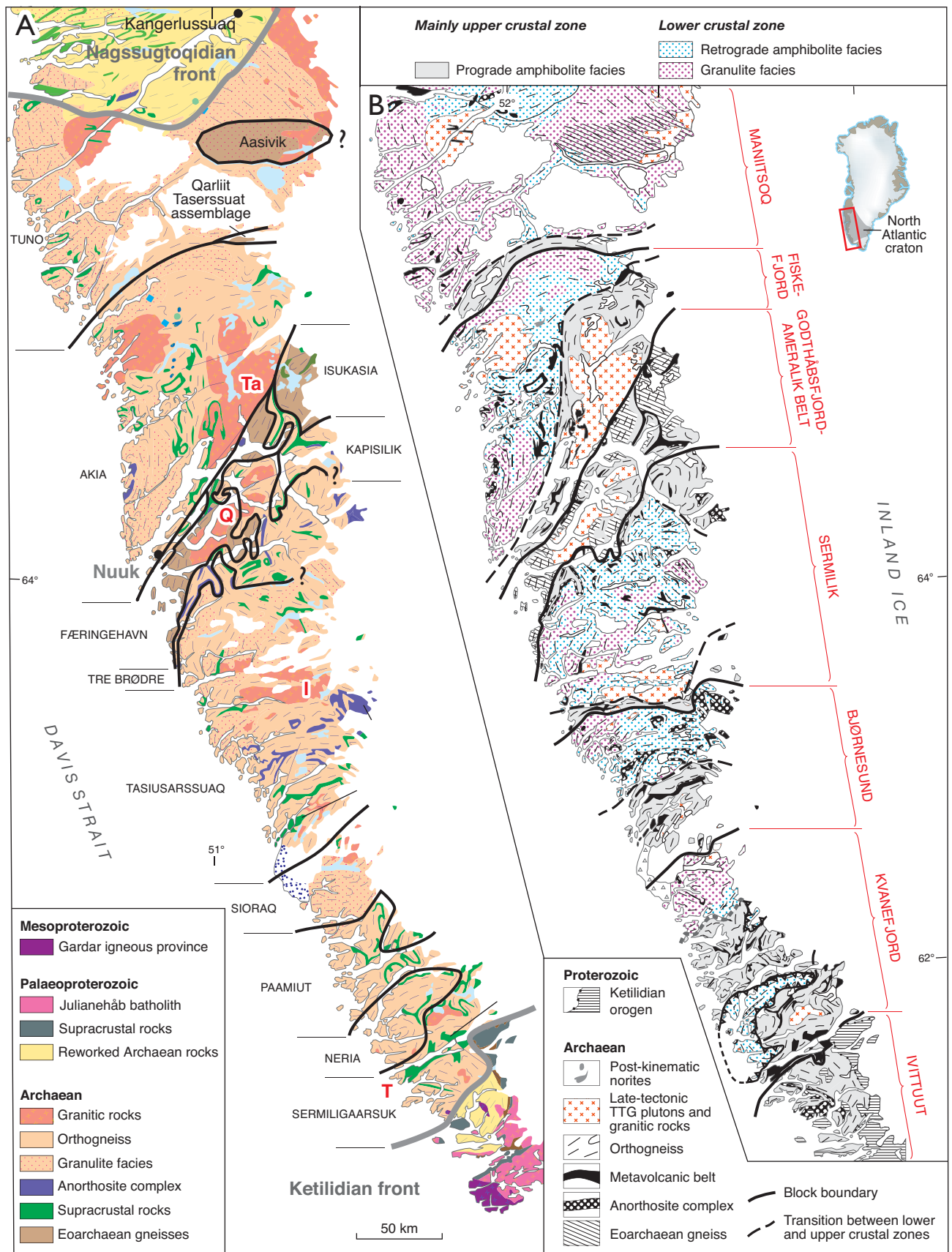


Fig. 4. Maps of the Archaean craton, southern West Greenland. A: The subdivision in terranes/blocks with distinct geological histories (see text) after Friend & Nutman (2001). T, Tårtoq Group; I, Ilivertalik augen granite; Q, Qôrqtut granite complex; Ta, Taserssuat tonalite. B: The subdivision in tilted blocks, each of which has granulite facies rocks in its northern parts and rocks at amphibolite facies in the south after Windley & Garde (2009).



shown that areas with contrasting tectonometamorphic histories ('terranes') occur side by side, separated by folded mylonite zones (Friend *et al.* 1987, 1988). In the Godthåbsfjord region Friend *et al.* (1987) recognised three such terranes, the Færingehavn, Tre Brødre, and Tasiussarssuaq terranes, each with its characteristic rock association and metamorphic history. The subdivision of the Godthåbsfjord region into terranes has since been repeatedly revised and refined as more geochronologic information became available (e.g. Friend & Nutman 2005; Nutman & Friend 2007). The validity of the terrane model has locally been verified (Crowley 2002) but elsewhere questioned (Hanmer *et al.* 2002). After its introduction in the Godthåbsfjord region the terrane model has also been applied to other parts of the Archaean craton (Friend & Nutman 2001), see Fig. 4A. Because of the large areal extent of the Archaean rocks many details of the subdivision of the craton into terranes are still to be clarified. The different terranes are envisaged once to have formed independent crustal blocks (perhaps fragments of an earlier Archaean continent) that were amalgamated during the Neoproterozoic.

Recently, Windley & Garde (2009) have subdivided the Archaean craton of western Greenland into six slightly tilted blocks, separated by shear zones, each of which expose granulite facies rocks in the north and (prograde) amphibolite facies rocks in the south (Fig. 4B). Rock units interpreted as remnants of island arcs are exposed in supracrustal belts in the low-grade parts of these blocks. Rocks retrograded from granulite facies to amphibolite facies commonly occur in the northern and central parts of these blocks. The paper of Windley & Garde (2009) contains an extensive overview of research carried out in the region.

### Eoarchaeal supracrustal rocks

The Isua supracrustal sequence [69] (3700–3800 Ma, Moorbath *et al.* 1973) in the Isukasia area (Fig. 2) at the head of Nuup Kangerlua/Godthåbsfjord is the most extensive occurrence of Eoarchaeal supracrustal rocks known on Earth. It forms a zone up to 4 km wide and up to *c.* 35 km long and has been investigated in considerable detail. A recent review of earlier studies together with new data and geological maps at 1:20 000 is presented by Nutman & Friend (2009). These authors subdivide the Isukasia area into two tectonic units (terranes), with rocks up to 3700 Ma in the north and >3800 Ma in the south. The supracrustal rocks comprise: (1) layered and massive amphibolites, within which pillow structures are locally preserved; (2) metacherts and a

major body of banded iron formation (Fig. 5); (3) biotite-muscovite schists, some of which preserve graded bedding; (4) units of talc schist, up to 100 m wide, with relics of dunite; (5) layered carbonate and calc-silicate rocks, strongly affected by metasomatic activity and (6) bodies of pale chloritic amphibolite ('garbenschiefer') up to 1 km wide, which form *c.* 25% of the supracrustal belt, and probably represent metasomatically altered metavolcanic rocks. All these rocks have been strongly deformed and metamorphosed at amphibolite facies conditions. Geochemical studies of the least altered amphibolites have shown that they have tholeiitic and boninitic compositions, similar to modern basaltic rocks formed in oceanic island arcs (Polat *et al.* 2002; Polat & Hoffman 2003).

Outside the Isukasia area enclaves of supracrustal rocks, mainly amphibolites of tholeiitic or komatiitic composition, occur as thin units within Eoarchaeal gneisses. These supracrustal rocks have been collectively



Fig. 5. Eoarchaeal banded iron formation consisting of interlayered magnetite (dark layers) and chert (light layers). Isua supracrustal sequence, Isukasia, inner Godthåbsfjord, southern West Greenland. Pen for scale. Photo: A.A. Garde.



termed the Akilia association [69], and are thought to represent remnants of a disrupted greenstone belt (McGregor & Mason 1977). Studies of graphite particles in samples of Isua metasedimentary rocks have yielded evidence of very early life on Earth (Rosing 1999).

### Eoarchaean ('Amîtsoq') gneisses

Eoarchaean orthogneisses (Fig. 6), previously known as Amîtsoq gneisses and shown under that name on the geological map [76], occur in an area stretching north-east from Nuuk/Godthåb to Isukasia. They are characterised by the presence of abundant remnants of metamorphosed basic dykes (Ameralik dykes, Fig. 20; McGregor 1973). The precursors of the gneisses were formed during a number of distinct intrusive events between *c.* 3800 and 3600 Ma (Moorbath *et al.* 1972; Nutman *et al.* 2004). Because of the diversity in age and origin of the Eoarchaean rocks Nutman *et al.* (1996) introduced the term Itsaq Gneiss Complex to include all Eoarchaean

rocks in the Godthåbsfjord region. The term Amîtsoq gneisses is rarely used in newer publications.

Two main types of Eoarchaean orthogneisses (not differentiated on the geological map) can be recognised: (1) Grey, banded to homogeneous tonalitic to granodioritic orthogneisses of calc-alkaline affinity (commonly with secondary pegmatite banding) which form at least 80% of the outcrop. The oldest of these have been dated at *c.* 3850 Ma (for overview see Nutman *et al.* 2004), although these very old dates have been questioned (e.g., Whitehouse *et al.* 1999); (2) Microcline augen gneisses with associated subordinate ferrodiorites (*c.* 3600 Ma), which have been referred to as the Amîtsoq iron-rich suite (Nutman *et al.* 1984). The latter resemble Proterozoic rapakivi granites and were intruded after strong deformation of the surrounding grey banded gneisses. Most Eoarchaean gneisses are in amphibolite facies, but locally the rocks have been affected by *c.* 3600 Ma granulite facies metamorphism possibly related to emplacement of the Amîtsoq iron-rich suite.

After compilation of the geological map Eoarchaean orthogneisses have also been found north of the Godt-



Fig. 6. Heterogeneous, polyphase Eoarchaean (Amîtsoq) gneiss in the central part of northern Godthåbsfjord, southern West Greenland. Fragments of dark homogeneous amphibolite are interpreted as remnants of disrupted mafic (Ameralik) dykes. The hammer is *c.* 45 cm long. Photo: A.A. Garde.

håbsfjord region, at Qarliit Tasersuat (65°49'N, 50°44'W) and in a larger area east of Sukkertoppen Iskappe, the Aasivik terrane (Rosing *et al.* 2001; Fig. 4A).

### Meso- and Neoarchaean supracrustal rocks

Ten to twenty per cent of the Archaean craton is made up of a variety of supracrustal rocks [68], mainly amphibolites with subordinate paragneisses (often garnetiferous  $\pm$  cordierite  $\pm$  sillimanite) and ultramafic layers and pods. Amphibolites represent the oldest rocks recognised within each terrane; primary cover–basement relationships with underlying rocks have not been observed. Few reliable age determinations for these rocks are available, but it is evident that they belong to several different age groups. Amphibolites locally show well-preserved pillow structures indicating a submarine volcanic origin. Intense deformation, however, has generally obliterated all primary structures and produced finely layered amphibolites. More massive amphibolites may represent original basic sills within the volcanic pile. The amphibolites range from andesitic to komatiitic in composition; the majority are chemically similar to low-K tholeiitic basalts.

Two typical examples of Mesoarchaean supracrustal units are: (1) Andesitic metavolcanic rocks in the southeastern Akia terrane (Fig. 4A) that have been dated at 3070 Ma. On the basis of field observations and chemical data they have been interpreted as parts of a Mesoarchaean island arc (Garde 2007a). (2) A several kilometres thick, relatively well preserved succession of supracrustal rocks in the southernmost part of the Archaean craton, the Tårtoq Group (T, Fig. 4A; Higgins 1968; Berthelsen & Henriksen 1975), which consists of metavolcanic greenschists and metasedimentary rocks. While the youngest detrital zircons in a metasedimentary sample are *c.* 2840 Ma (Nutman *et al.* 2004), greenschists at a different locality are cut by sheets of 2940 Ma tonalite (Nutman & Kalsbeek 1994). Apparently the Tårtoq Group consists of supracrustal packages of varying ages, illustrating once more the geological complexity of the Archaean craton.

Metasedimentary rocks occur only locally. Geochronological data on detrital zircons suggest a variety of ages (Nutman *et al.* 2004). While the youngest zircons in most of the investigated samples are *c.* 2800 Ma (in samples from the Godthåbsfjord region *c.* 3000 Ma), a sample from Hamborgerland, north of Maniitsoq/Sukkertoppen, has zircons as young as 2720 Ma. Eoarchaean zircons are rare or absent in all of the investigated samples, supporting the view that the Eoarchaean terranes

were separated from the other terranes until the Archaean craton was united by terrane amalgamation during the Neoarchaean. Most supracrustal units are complexly folded and, since they form good marker horizons, they have been used to reveal the intricate structure of the enveloping gneiss complexes.

### Anorthositic rocks

Metamorphosed calcic anorthosites and associated leucogabbroic, gabbroic and ultramafic rocks [85] form one of the most distinctive rock associations in the Archaean craton. Such rocks are present in all the terranes, and detailed investigation has revealed subtle geochemical variations between anorthosites from different terranes (Dymek & Owens 2001). Anorthositic rocks occur as concordant layers and trains of inclusions within gneisses, and provide some of the best marker horizons for mapping structures on a regional scale. They are generally bordered by amphibolites into which they are believed to have been intruded.

Anorthosites and associated rocks are most spectacularly developed in the Fiskensæset area of southern West Greenland where they form *c.* 5% of the total outcrop. Here they appear to belong to a single stratiform intrusion, the Fiskensæset complex (Myers 1985), which has been dated at *c.* 2850 Ma (Ashwal *et al.* 1989). The main rock types are metamorphosed anorthosites, leucogabbros and gabbros (<10%, 10–35% and 35–65% mafic minerals, respectively), together with minor proportions of ultramafic rocks and chromitite (Ghisler 1976). Although the rocks are commonly strongly deformed, magmatic structures are preserved in low-strain areas: cumulus textures with plagioclase up to 10 cm in size are common and igneous layering can be observed at many localities. The Fiskensæset complex has undergone complex folding. The earliest major folds were recumbent isoclines; these were refolded by two later fold phases producing structures with steeply inclined axial surfaces (Myers 1985).

### Meso- and Neoarchaean gneisses

Most of the Archaean craton is composed of Mesoarchaean grey orthogneisses [72, 73]. In accordance with the notion that the craton comprises a number of individual terranes, variable ages have been reported (for a detailed overview see Windley & Garde 2009). In the Akia terrane (Fig. 4A) of West Greenland ages up to



3220 Ma occur (Garde 1997), whereas farther south isotopic ages are generally less than 3000 Ma. The 2825 Ma Ikkattoq gneisses in the Tre Brødre terrane, Godthåbsfjord region (Friend *et al.* 2009), are an example of these younger gneisses. The Ikkattoq gneisses are mainly of granodioritic composition, with subordinate quartz diorite. Sm-Nd isotope data indicate that Eoarchaeon sources played a significant role in their petrogenesis.

The igneous precursors of the Archaean gneisses were intruded as sub-concordant sheets and larger complexes that penetrated and disrupted ('exploded') pre-existing basic metavolcanic units and anorthositic rocks (Fig. 7); the gneisses commonly occupy much larger volumes than the older rocks into which they were intruded. Individual gneiss sheets range from a few metres to several kilometres in width. It has been suggested that intrusion of granitoid magmas was associated with periods of thrusting (Bridgwater *et al.* 1974).



Fig. 7. Amphibolite agmatite with numerous sheets of tonalite, granodiorite, granite and pegmatite, dated at 3.0–2.97 Ga. South-facing, c. 40 m high cliff in central Godthåbsfjord, southern West Greenland. Person in red anorak for scale. Photo: A.A. Garde.

Most of the gneisses are tonalitic to granodioritic in composition and form typical TTG (Tonalite, Trondhjemite, Granodiorite) suites. A statistical study in the Fiskebøl area (c. 4000 km<sup>2</sup>) has shown that such gneisses make up c. 85% of the outcrop area. Tonalitic gneisses (K-feldspar <10%) form c. 57%, granodioritic gneisses (K-feldspar 10–20%) c. 9%, and granitic gneisses (K-feldspar >20%) c. 16% of the terrain (Kalsbeek 1976).

Large parts of the craton are occupied by granulite facies gneisses [73]. Granulite facies metamorphism, however, was not synchronous throughout the area: north of Nuuk/Godthåb it is 3000–3100 Ma (Garde 1990; Friend & Nutman 1994), whereas in the Fiskebøl area it is c. 2800 Ma (Pidgeon & Kalsbeek 1978) and north of Maniitsoq/Sukkertoppen c. 2750 Ma (Friend & Nutman 1994). Commonly the age of granulite facies metamorphism is similar to that of the igneous precursors of the gneisses. In granulite facies terrains hypersthene is most common in amphibolites, whereas in orthogneisses its presence depends on chemical composition. Regional surveys of stream sediment geochemistry have shown that the distribution of several lithophile elements is strongly correlated with metamorphic facies variations (Fig. 8; Steenfelt 1994).

Two kinds of amphibolite facies gneisses [72] can be distinguished: those formed by retrogression of granulite facies rocks, and those that were formed by prograde metamorphism and never experienced granulite facies conditions. These two kinds have not been differentiated on the geological map because criteria to recognize retrograded granulite facies rocks (McGregor & Friend 1997) were not available during the early mapping. An overview of the distribution of prograde and retrograde amphibolite facies gneisses in southern West Greenland is presented by Windley & Garde (2009) and is here shown in Fig. 4B.

Commonly the gneisses show complex fold interference structures (e.g. Berthelsen 1960; Fig. 9). Formation of gneisses by deformation and migmatization of their igneous precursors has been described in detail by Myers (1978), and a detailed description of the complex evolution of the Fiskebøl area, north of Godthåbsfjord, has been presented by Garde (1997).

## Intrusive rocks

Within the Archaean craton a variety of homogeneous granitic to tonalitic rock units have been differentiated on the map as felsic intrusions [80]. These rocks were emplaced at various times during the tectonic evolution of the areas in which they occur. Some, e.g. the c. 2980

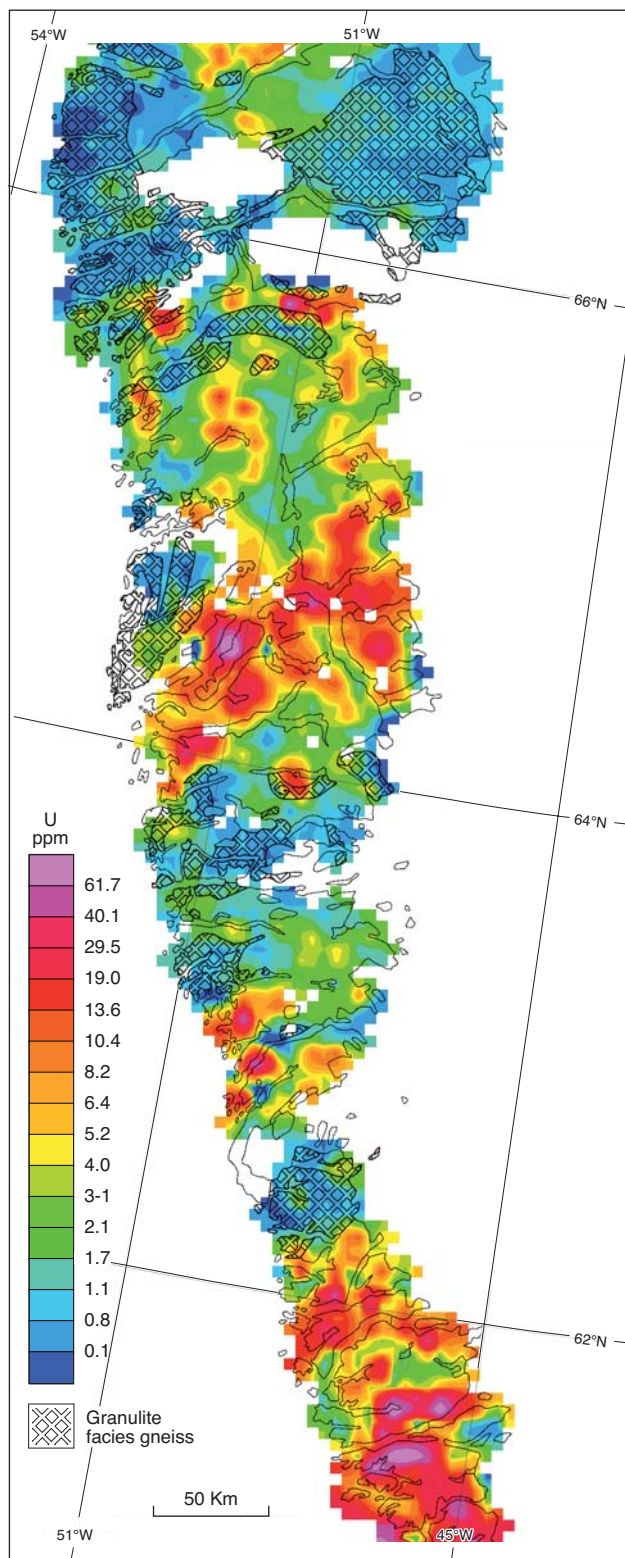


Fig. 8. Map showing the variation in uranium concentrations in the <0.1 mm fraction of stream sediments from the Archaean craton of southern West Greenland (Steenfelt 2001). There is a close correlation between U concentrations and the metamorphic grade of the underlying rocks (Fig. 4 B), stream sediments from granulite facies terrains having low U compared to those from amphibolite grade areas.

Ma Tasersuaq tonalite north of inner Godthåbsfjord (Ta, Fig. 4A; Garde 1997), represent late phases of the igneous precursors of the gneisses in areas where deformation was less intense than elsewhere. Others, e.g. the 2835 Ma Ilivertalik augen granite in the Tasiarsuaq terrane (I, Fig. 4A; Pidgeon *et al.* 1976) are younger than the surrounding gneisses, but have been strongly overprinted by later deformation and metamorphism. One rock unit, the 2550 Ma Qôrqt granite complex [79] east of Nuuk/Godthåb (Q, Fig. 4A; Friend *et al.* 1985), was formed by late crustal melting and is clearly post-tectonic.

A distinct 2700 Ma suite of very well-preserved post-tectonic intermediate and mafic intrusions, including gabbros and diorites [82] as well as syenites and granites [80], occurs within Archaean gneisses in the Skjoldungen district of South-East Greenland (Nielsen & Rosing 1990; Blichert-Toft *et al.* 1995). It is associated with older syenitic gneisses [80] and with a late nephelinite body, the 2670 Ma Singertât complex [83].

Small norite bodies [82] occur within an arcuate belt east of Maniitsq/Sukkertoppen (Secher 1983), and a small 3007 Ma carbonatite sheet [84] (the oldest carbonatite known on Earth) has been found at Tupertalik, 65°30'N in West Greenland (Larsen & Pedersen 1982; Larsen & Rex 1992; Bizzarro *et al.* 2002).

### Palaeoproterozoic orogenic terrains

About forty per cent of the ice-free area of Greenland is underlain by Palaeoproterozoic orogenic terrains (Fig. 2). North of the Archaean craton lies the Nagssugtoqidian orogen, which continues beneath the Inland Ice to South-East Greenland. Still farther north are the Rinkian fold belt and the Inglefield orogenic belt of West and North-West Greenland, and south of the Archaean craton lies the Ketilidian orogen (Fig. 2). The Nagssugtoqidian orogen and Rinkian fold belt largely consist of reworked Archaean rocks that underwent strong deformation and metamorphism during the Palaeoproterozoic 1900–1850 Ma ago, while the Inglefield and Ketilidian orogens contain large proportions of juvenile Palaeoproterozoic crust.

Recent investigations have suggested that the Greenland shield was formed by progressive accretion of crustal blocks, from northernmost Greenland to the south (Nutman *et al.* 2008b; St-Onge *et al.* 2009). Archaean rocks of the Rinkian fold belt were united with an Archaean block in northernmost Greenland along the Inglefield orogenic belt around 1920 Ma (Nutman *et al.* 2008a). Archaean gneisses of the Nagssugtoqidian orogen were then accreted



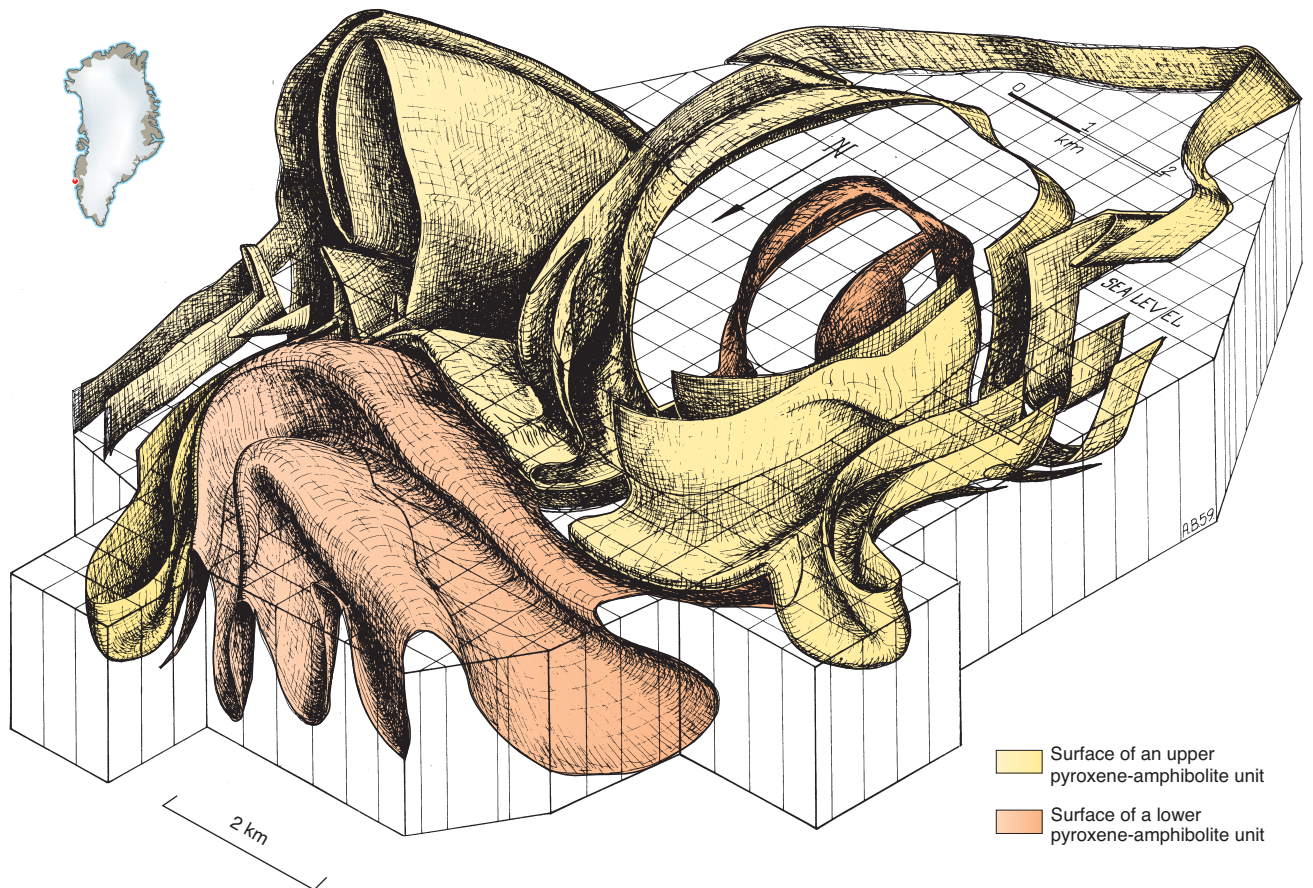


Fig. 9. Structural stereogram of the western Toqqusap Nunaa area north of Atammik ( $c. 65^{\circ}\text{N}$ ), southern West Greenland, showing complex fold structures in the late Archaean gneiss complex. Slightly modified from Berthelsen (1960).

to the Rinkian/Inglefield/North Greenland block at  $c. 1870$  Ma along a suture within Disko Bugt (Connelly & Thrane 2005; Thrane *et al.* 2005; Connelly *et al.* 2006). Collision within the Nagssugtoqidian orogen followed around  $1850$  Ma (Connelly *et al.* 2000), and batholithic rocks of the Ketilidian orogen were accreted to the Archaean craton  $1850$ – $1800$  Ma ago (Garde *et al.* 2002). Many details of this process are still uncertain.

The largest area of juvenile Palaeoproterozoic rocks in Greenland ( $600$  km along strike and up to  $300$  km in width) occurs in the Caledonian thrust sheets of North-East Greenland. Its relationships with the other Palaeoproterozoic terrains in Greenland are unknown.

### Nagssugtoqidian orogen, West Greenland

The distinction of the Nagssugtoqidian orogen in West Greenland from the Archaean craton to the south was first noted by Ramberg (1949). A swarm of basic dykes,

the Kangâmiut dykes ( $2040$  Ma; Nutman *et al.* 1999; Mayborn & Lescher 2006), which are well preserved in the Archaean craton to the south, become increasingly deformed and metamorphosed on entering the Nagssugtoqidian orogen (see Fig. 20). This orogen (Fig. 2; van Gool *et al.* 2002) extends from Søndre Strømfjord to Disko Bugt in West Greenland and continues south-eastwards beneath the Inland Ice to the Ammassalik region in South-East Greenland. It mainly consists of reworked Archaean gneisses [74, 75] (Connelly & Mengel 2000) but also includes Palaeoproterozoic supracrustal and intrusive rocks [67, 78, 81]. In West Greenland main structures trend ENE–WSW, and the orogen exhibits a number of prominent ENE-trending shear zones (among which is the Nordre Strømfjord shear zone; K. Sørensen *et al.* 2006) that separate areas characterised by open folding. The peak of Proterozoic tectonic and metamorphic activity was at  $c. 1850$  Ma (Taylor & Kalsbeek 1990) when large parts of the orogen underwent granulite facies metamorphism. High-grade meta-

morphism was followed by an extended period of uplift and cooling (Willigers *et al.* 2002). Palaeoproterozoic orogenic activity is believed to be related to collision of two Archaean continents, with one or more sutures present within the Nagssugtoqidian orogen (Kalsbeek *et al.* 1987; van Gool *et al.* 2002; Garde & Hollis in press). The reconstruction of St-Onge *et al.* (2009) shown in Fig. 3 displays two main sutures, which delimit an inter-jacent region termed the Aasiaat domain. The north-western part of this region appears only to have been little affected by Palaeoproterozoic deformation and metamorphism (e.g. Mazur *et al.* 2006; Stendal *et al.* 2006). Tectonically emplaced lenses of metaperidotite of apparent mantle origin are common along thrusts that separate Archaean and Palaeoproterozoic rocks in the central part of the orogen (Kalsbeek & Manatschal 1999).

### Supracrustal rocks

Palaeoproterozoic supracrustal units, dominated by pelitic and semipelitic metasedimentary rocks, are prominent

in the central part of the Nagssugtoqidian orogen [67]. Marble and calc-silicate rocks are common within these units, and pelitic rocks may be rich in graphite. Deposition of these units took place between *c.* 2000 and 1920 Ma ago: they are cut by sheets of 1910 Ma quartz diorite, and the youngest detrital zircons are *c.* 2000 Ma old (Nutman *et al.* 1999). Small islands NE of Aasiaat/Egedesminde expose well preserved *c.* 1850 Ma tholeiitic pillow lavas, chloritic and aluminous shales, manganeseiferous BIF etc., interpreted to represent ocean floor and distal turbidite deposits (Garde & Hollis in press).

Within the Nagssugtoqidian orogen Archaean meta-sedimentary rocks [68] are also present, for example at the southern shore of Disko Bugt (Hollis *et al.* 2006). They are not easily distinguished in the field from Proterozoic rocks and, since isotopic age determinations were few at the time of map compilation, not all supracrustal sequences shown on the map have been assigned to the correct age category. For example, a metasedimentary unit at Lersletten, south-east of Aasiaat/Egedesminde (68°24'N, 51°14'W), indicated as Archaean on the geological map, has been shown to be



Fig. 10. Nagssugtoqidian orogen. Rock face at south side of inner Nordre Strømfjord/Nassuttooq, southern West Greenland, showing tectonic contact between pale Archaean tonalitic gneisses and overlying dark dioritic gneisses (Arfersiorfik quartz diorite) and supracrustal rocks of Palaeoproterozoic age. Thin slices of marble and calc-silicates occur at the contact and within the Archaean gneisses. The height of section is *c.* 350 m. Photo: J.A.M. van Gool.



Palaeoproterozoic in age (*c.* 1900 Ma; Thrane & Connelly 2006). The involvement of Palaeoproterozoic supracrustal rocks in complex fold structures and shear zones in the central part of the belt shows that the deformation was of Proterozoic age.

### Felsic and intermediate intrusions

Only a few granitic and quartz-dioritic intrusive bodies are shown on the map. Some are Archaean [80], whereas others are of Palaeoproterozoic age [78]. A large sheet of quartz diorite [81], the Arfersiorfik quartz diorite, dated at 1910 Ma, occurs close to the border of the Inland Ice at 68°N (Henderson 1969; Kalsbeek *et al.* 1987; K. Sørensen *et al.* 2006; van Gool & Marker 2007); it is folded and strongly deformed at its margins, but igneous textures and minerals are preserved in its centre. Strongly deformed Proterozoic quartz-dioritic to tonalitic rocks (not shown on the map) also occur within reworked Archaean gneisses south of the main quartz-diorite body. Together they have been interpreted as remnants of a Palaeoproterozoic arc, tectonically interleaved with the Archaean rocks (Fig. 10; Kalsbeek *et al.* 1987; van Gool *et al.* 2002). They range in age from 1920 to 1885 Ma (Connelly *et al.* 2000).

A large area (*c.* 30 × 50 km) east and north-east of Sisimiut/Holsteinsborg is made up of Palaeoproterozoic (1910–1870 Ma) hypersthene gneisses, the Sisimiut intrusive complex (Kalsbeek & Nutman 1996; Connelly *et al.* 2000; van Gool *et al.* 2002). In the field these cannot easily be distinguished from Archaean rocks that occur farther east and, since no age determinations on these rocks were available at the time of map compilation, all the rocks in this area are shown on the map as Archaean, overprinted by Proterozoic granulite facies metamorphism [75].

### Nagssugtoqidian orogen in South-East Greenland

Aeromagnetic data show a continuation of the Nagssugtoqidian orogen from West Greenland beneath the Inland Ice to South-East Greenland (Fig. 11). Here Palaeoproterozoic orogenic activity has been documented from 64°30'N to 68°N (Fig. 2) on the basis of deformation and high-grade metamorphism, up to eclogite facies, of mafic dykes. This region, centred around the town of Tassilaq/Ammassalik, is dominated by reworked Archaean gneisses [74, 75] which were tectonically interleaved with

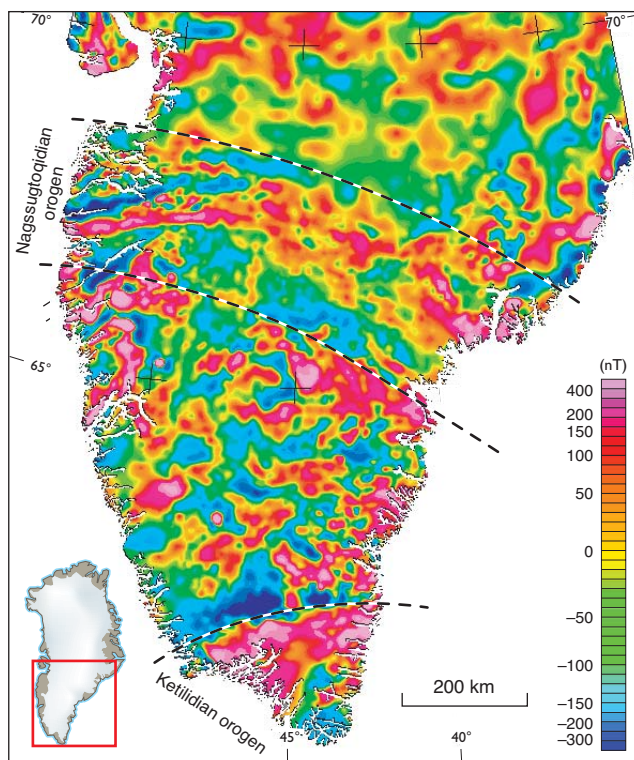


Fig. 11. Aeromagnetic map of southern Greenland showing the continuity of the Nagssugtoqidian orogen from West to South-East Greenland. Data from Verhoef *et al.* (1996).

metasedimentary rocks during the Palaeoproterozoic (Fig. 12; Chadwick *et al.* 1989; Kalsbeek 1989). Juvenile Palaeoproterozoic intrusive rocks [81] and post-tectonic (*c.* 1680 Ma) granite bodies [78] are also present. Palaeoproterozoic pelitic metasedimentary rocks [67] are common and locally contain abundant kyanite; thick marble units also occur. Archaean anorthositic rocks [85] are present in a few places. A detailed geochronological study of rocks and structures in the Ammassalik region has recently been reported by Nutman *et al.* (2008b). Before the continuity of the Nagssugtoqidian orogenic belt from West- to South-East Greenland was satisfactorily documented, the latter area was termed the Ammassalik mobile belt (Kalsbeek 1989), but this term should now be abandoned.

### Palaeoproterozoic plutonic rocks

A suite of 1885 Ma leuconoritic and charnockitic intrusive rocks [81], the Ammassalik Intrusive Complex (AIC), occurs as a row of WNW–ESE-trending intrusions at 65°30'N in the centre of the East Greenland Nag-

ssugtoqidian orogen (Friend & Nutman 1989). It was emplaced into a succession of sedimentary rocks, in which it caused widespread anatexis and produced garnet-rich granitic gneisses [71]. The AIC is interpreted by Nutman *et al.* (2008b) as a Palaeoproterozoic arc, which was caught between Archaean crustal units during the Nagssugtoqidian collision *c.* 1870 Ma ago.

Palaeoproterozoic quartz-dioritic to tonalitic intrusions [81] occur locally; one is shown just north of latitude 66°N and has been dated at 1900 Ma (Nutman *et al.* 2008b). Palaeoproterozoic gneisses, formed locally by deformation of such intrusive rocks, are not distinguished on the map.

Scattered post-tectonic granite plutons [78] associated with diorite and local gabbro occur over the central part of the East Greenland Nagssugtoqidian orogen. Their isotopic age is about 1680 Ma (Kalsbeek *et al.* 1993a), much younger than the peak of tectonic and

metamorphic activity in the belt at *c.* 1870 Ma (Nutman *et al.* 2008b). Isotopic data show that the granites contain major proportions of crustally derived material (Taylor *et al.* 1984).

### Rinkian fold belt

The Rinkian fold belt (Henderson & Pulvertaft 1987; Grocott & Pulvertaft 1990) lies to the north of the Nagssugtoqidian orogen in West Greenland between latitudes 69°30'N and 75°N (Fig. 2). North of Nuussuaq it is characterised by the presence of a several kilometres thick Palaeoproterozoic sedimentary succession, the Karrat Group [62], which overlies and is interfolded with reworked Archaean gneisses [74]. It has been difficult in the field to define a distinct boundary between the Nagssugtoqidian and Rinkian belts. However,

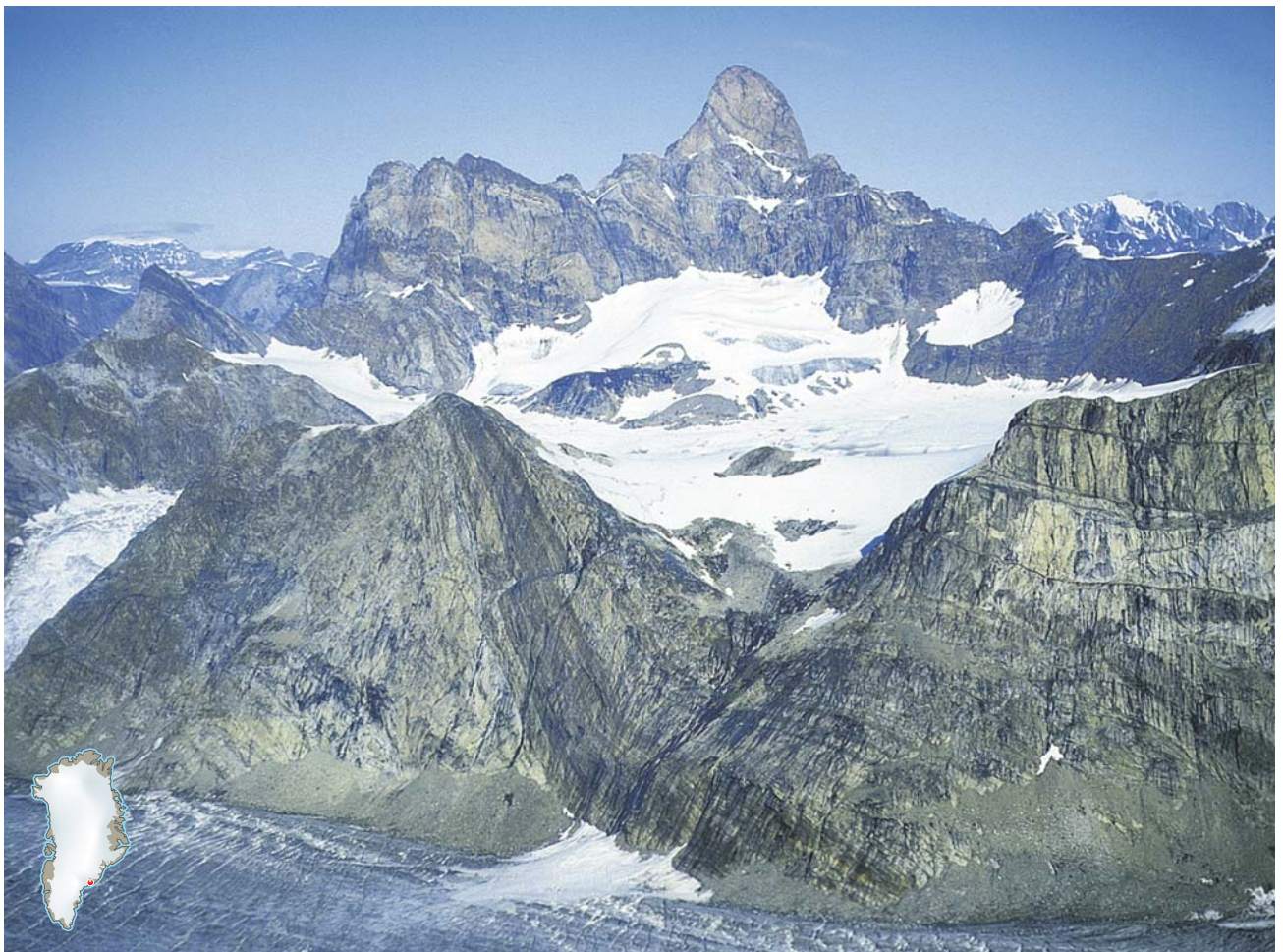


Fig. 12. Nagssugtoqidian orogen in South-East Greenland. Archaean gneisses reworked during the Palaeoproterozoic in granulite and retrograde granulite facies, with supracrustal layers consisting of amphibolite and paragneiss. East of northernmost Sermilik (*c.* 66°30'N), South-East Greenland. The prominent summit is 1750 m high; relief seen is *c.* 1500 m. Photo: J.C. Escher.



Connelly & Thrane (2005) observed a significant change in Pb-isotopic compositions of K-feldspar in granitoid rocks across a high-strain belt at *c.* 69°30'N in Disko Bugt, and suggested that this belt of strong deformation represents the suture between two large crustal blocks. They proposed that the northern, Rinkian block forms part of the Rae craton of northern Canada, and that the southern, Nagssugtoqidian block is the northernmost (deformed) part of the North Atlantic craton (Fig. 3). The areas around Qeqertarsuup Tunua/Disko Bugt and the region north of Nuussuaq are described separately below.

### *Archaean and Palaeoproterozoic supracrustal rocks: Disko Bugt and Nuussuaq*

The geology of the area around Disko Bugt has been described in detail by Garde & Steenfelt (1999) and a geological map at 1:250 000 (Garde 1994) is included in their paper. Supracrustal rocks occur throughout the area. Two representative examples: (1) In north-eastern Disko Bugt an arcuate Archaean greenstone belt consists of basic and acid metavolcanic rocks [68, 66]. The basic rocks, mainly greenschists and meta-pillow lavas, contain a subvolcanic sill complex of gabbros and dolerites [82] (Marshall & Schönwandt 1999). This belt is intruded by the 2800 Ma Atâ igneous complex (Kalsbeek & Skjernaa 1999; see below). (2) Another supracrustal belt runs along the south coast of Nuussuaq. In contrast to most other supracrustal units this belt was demonstrably deposited upon older gneisses. It consists of mafic and ultramafic metavolcanic rocks with rhyolites, metasedimentary schists, banded iron formation and minor exhalative rocks with widespread, but low-grade gold mineralisation. A rhyolite from this belt has yielded an age of *c.* 2850 Ma (Connelly *et al.* 2006).

The Archaean rocks of north-eastern Disko Bugt are unconformably overlain by a Palaeoproterozoic sedimentary succession [62], the Anap nunâ Group, which has been correlated with the Karrat Group farther north (see below). The Anap nunâ Group consists of a lower unit of marble and orthoquartzite overlain by thick shallow-water siltstones and sandstones. Although the rocks are folded, Palaeoproterozoic deformation and metamorphism are at a minimum (Garde & Steenfelt 1999). Parts of the succession have suffered intensive metasomatic albitisation (Kalsbeek 1992).

### *Gneisses and intrusions: Disko Bugt and Nuussuaq*

Reworked Archaean gneisses [74] in the Disko Bugt region are similar to those of the Nagssugtoqidian orogen. On Nuussuaq they show flat-lying tectonic fabrics and contain anorthosite bodies [85] and dioritic intrusions [82] (Garde & Steenfelt 1999). North-east of Disko Bugt, 2800 Ma tonalitic rocks of the Atâ intrusive complex [80] hardly show any signs of Archaean or Proterozoic deformation. This complex was emplaced into the arcuate Archaean greenstone belt [68] mentioned above and retains many magmatic features (Kalsbeek & Skjernaa 1999). New geochronological data for the Disko Bugt region, together with an overview of earlier information, have been presented by Connelly *et al.* (2006). The oldest age (3030 Ma) was obtained from a dioritic intrusion within amphibolites on south-eastern Nuussuaq.

### *Palaeoproterozoic supracrustal rocks north of Nuussuaq: the Karrat Group*

The geology of the Rinkian fold belt in the area north of Nuussuaq is depicted on the 1:500 000 Geological map of Greenland, Sheet 4, Upernavik Isfjord (Escher 1985). In this region, the Karrat Group [62] is widely exposed over a 400 km coastal stretch north of Ummannaq (Fig. 2). It was deposited unconformably on Archaean crystalline basement rocks between *c.* 2000 Ma (U-Pb ages of the youngest detrital zircons; Kalsbeek *et al.* 1998a) and the emplacement of the Prøven igneous complex [78] at *c.* 1870 Ma (Thrane *et al.* 2005). The Karrat Group underwent high-grade metamorphism at relatively low pressure at around 1870 Ma (Taylor & Kalsbeek 1990).

The Karrat Group has been divided into three formations (Henderson & Pulvertaft 1987). The two lower formations, the Marmorilik Formation (up to 1.6 km, Garde 1978) and Qeqertarsuaq Formation (more than 2 km, Fig. 13), comprise shelf and rift-type sediments, dominated respectively by marbles and clastic sediments with minor volcanic rocks. These two formations may be correlatives, originally separated by a basement high. At 71°07'N, 51°W the Marmorilik Formation hosted the now exhausted Black Angel lead-zinc mine (Thomassen 1991). Lead-zinc mineralisation has also been observed at other localities in the region.

The upper formation, the Nûkavsak Formation, with a minimum structural thickness of 5 km, is a typical turbidite flysch succession. Extensive tight folding makes estimates of the stratigraphic thickness of the Karrat Group uncertain. Proterozoic sedimentary successions

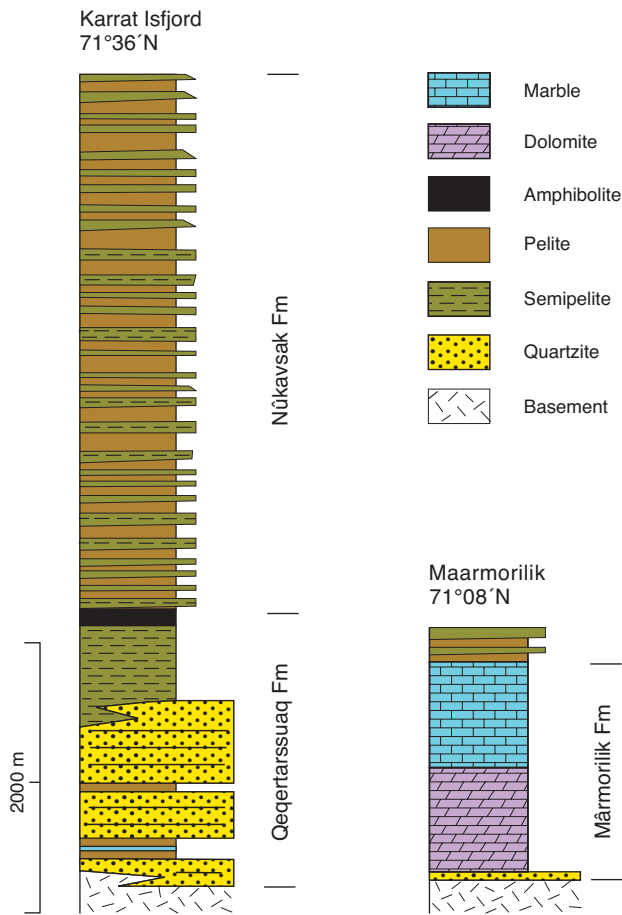


Fig. 13. Schematic lithostratigraphic sections of the Palaeoproterozoic Karrat Group in the Maarmorilik – Karrat Isfjord region. The Nûkavsak Formation consists of a flysch succession of interbedded greywacke and mudstone, now metamorphosed at amphibolite facies. Based on Garde (1978) and Henderson & Pulvertaft (1987).

similar to the Karrat Group occur in the Foxe fold belt on the western side of Baffin Bugt in north-eastern Canada (the Piling and Penhryn Groups; Henderson & Tippet 1980; Henderson 1983) suggesting correlation of the Rinkian belt of Greenland and the Foxe fold belt of Canada (see Fig. 3). Connelly *et al.* (2006) suggest that the Karrat Group was deposited on the passive margin of the Rae craton before collision with the North Atlantic craton.

The Karrat Group and its underlying crystalline basement are complexly interfolded into gneiss-cored fold nappes (Fig. 14; Henderson & Pulvertaft 1987) which were subsequently refolded into large dome structures. Tectonic interleaving of cover rocks with basement gneisses by thrusting has also taken place so that locally Proterozoic supracrustal rocks occur as enclaves within Archaean gneisses. The extent of this process is exemplified by an

isolated occurrence of Pb-Zn mineralised marble at 70°30'N, 52°30'W in the centre of Nuussuaq (Garde & Thomassen 1990).

### Gneisses and intrusive rocks north of Nuussuaq

Reworked Archaean gneisses [74] north of Nuussuaq are similar to those elsewhere. Commonly they display flat-lying fabrics related to Palaeoproterozoic thrusting. North of Nuussuaq sheets of Archaean augen gneiss (not distinguished on the map) have been used as structural markers to unravel the complex thrust tectonics of that area (Pulvertaft 1986).

The 1870 Ma Prøven igneous complex [78] (Thrane *et al.* 2005) in the Upernavik area (*c.* 72°30'N) consists mainly of charnockitic rocks emplaced into Archaean gneisses and metasedimentary rocks of the Karrat Group, which are here at granulite facies. Samples from the Prøven igneous complex have an A-type geochemical signature, and isotope data indicate that the magma was formed by anatexis of Archaean gneisses and Palaeoproterozoic sedimentary rocks at depth. Melting is suggested to have been induced by upwelling of hot asthenospheric mantle due to delamination of mantle lithosphere following continental collision in the Disko Bugt area (see above).

### North-West Greenland and the Inglefield orogenic belt

The region between 75°15' and 81°N in North-West Greenland is covered by the Geological map of Greenland, Sheet 5, Thule (Dawes 1991, 2006) and Sheet 6, Humboldt Gletscher (Dawes 2004; Dawes & Garde 2004). The region up to *c.* 77°30'N has not been investigated in detail. It consists mainly of reworked Archaean gneisses [74] with local amphibolites and banded iron formation. The Karrat Group has not been recognised in this region. The *c.* 2700 Ma Kap York meta-igneous complex [82] at 76°N is composed of a suite of plutonic rocks ranging from gabbro to granite, and a major anorthosite complex [85] is exposed at 77°30'N (Nutman 1984). An overview of available geochronological information is given in Nutman *et al.* (2008a).

The area between *c.* 77°30' and 79°N contains the Palaeoproterozoic Inglefield orogenic belt which mainly consists of high-grade Palaeoproterozoic supracrustal and intrusive rocks that are overlain by Mesoproterozoic sedimentary rocks with basaltic sills, the Thule Supergroup



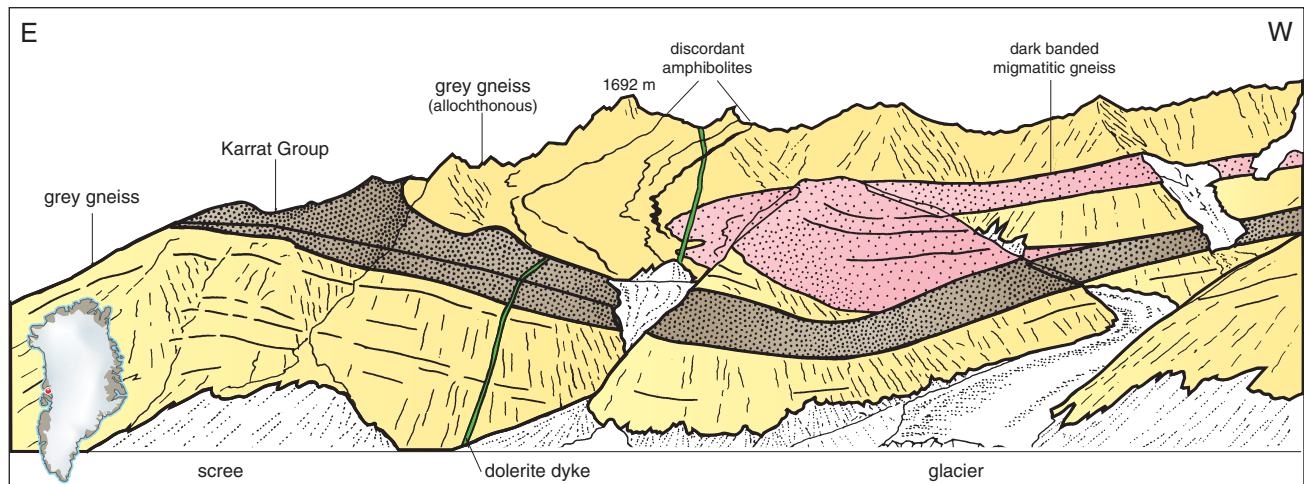


Fig. 14. Sketch of part of one of the characteristic Palaeoproterozoic nappes in the Rinkian fold belt (Kigarsima nappe seen from the north). North side of Upernivik Ø (71°20'N), central West Greenland. Slightly modified from Henderson & Pulvertaft (1987).

[3, 4, 5], and by Cambrian deposits [23, 25] of the Franklinian Basin. The Inglefield belt is divided into two parts by the E–W-trending Sunrise Pynt Straight Belt (SPSB, not shown on the map) at *c.* 78°20'N. Archaean rocks south of the SPSB have been intruded by *c.* 1980 Ma tonalites and diorites (Nutman *et al.* 2008a). The oldest rocks in Inglefield Land, north of the SPSB, are high-grade metasedimentary rocks of the Etah Group. Most of the Group is composed of variably migmatized paragneisses, shown as granulite facies gneisses [71] on the geological map, while better preserved marble-dominated units are shown as supracrustal rocks [67]. Zircon geochronology brackets deposition of the Etah Group between 1980 and 1950 Ma (Nutman *et al.* 2008a). The Etah Group has been intruded by a variety of metaplutonic rocks (not shown on the map), mainly of intermediate to felsic composition, the Etah meta-igneous complex. Most of these rocks are strongly deformed, but less deformed syenitic and monzonitic rocks are also present, and post-tectonic granites occur locally. Dioritic and granitoid rocks were emplaced during several periods, *c.* 1950–1940 Ma and *c.* 1920 Ma, with high-grade metamorphism around 1920 Ma, while late granites have ages of 1780 and 1740 Ma (Nutman *et al.* 2008a).

Sm–Nd isotopic data show that the older intrusive rocks are of juvenile origin, whereas some of the late intrusions were formed by crustal melting (Nutman *et al.* 2008a). The Inglefield belt is interpreted as a Palaeoproterozoic orogen, formed by collision of Archaean crustal blocks.

### Ketilidian orogen

Orthogneisses cut by dolerite dykes at the southern margin of the Archaean craton are unconformably overlain by Palaeoproterozoic sedimentary rocks [64] and basalts [63]. Towards the south these supracrustal sequences, together with the underlying Archaean gneisses and dykes, are progressively affected by deformation and metamorphism as the Ketilidian orogen (Fig. 3) is approached. The centre of the Ketilidian orogen consists mainly of juvenile Palaeoproterozoic granitic rocks, the Julianehåb batholith [70, 78]. In the southern part of the orogen high-grade metasedimentary rocks [67] and large intrusions, shown as rapakivi granites [77] on the map, are prominent. The Ketilidian orogen is covered by the Geological Map of Greenland, Sheet 1, Sydgrønland (Allaart 1975; Garde 2007b). During the 1990s the Ketilidian orogen was reinvestigated in more detail. A comprehensive report on this new information has been presented by Garde *et al.* (2002).

### Palaeoproterozoic supracrustal rocks in the northern border zone

The best preserved Ketilidian supracrustal rocks occur in Grønsele and Midternæs, north-east of Ivittuut, where they are locally almost unmetamorphosed and only superficially deformed (Fig. 15); the age of deposition is not precisely known. The succession has been divided into (1) a lower sedimentary part, the Vallen Group, with *c.* 1200 m of shales and greywackes with



Fig. 15. The basal part of the Ketilidian supracrustal succession in central Grønland, South-West Greenland, with the Archaean basement in the left background, viewed towards west-north-west. The unconformity forms the red-brown slope in the middle distance, with sporadic sub-Ketilidian regolith and Ketilidian carbonate deposits. The dark layer just above the contact is iron formation. Relief is about 500 m. Orange tent in the right foreground indicates the scale. Photo: A.A. Garde.

subordinate quartzite, conglomerate and carbonate rocks [64], and (2) an upper volcanic part, the Sortis Group [63], which consists mainly of basic pillow lavas and contemporaneous basic sills (Bondesen 1970; Higgins 1970), and has been interpreted to represent ocean floor related to initial rifting. The two groups are in tectonic contact, and it is likely that the Sortis Group was thrust upon the Vallen Group. Southwards these supracrustal rocks become progressively deformed and intruded by Ketilidian granites.

#### *Palaeoproterozoic granitoids and basic–intermediate intrusions, the Julianehåb batholith*

The central part of the Ketilidian orogen is mainly built up of granites, granodiorites and tonalites, commonly with porphyritic textures, collectively known as the Julianehåb batholith ('Julianehåb granite' in older publications). Large parts of the batholith were emplaced between 1868

and 1796 Ma in a sinistral transpressive setting (Chadwick & Garde 1996; Garde *et al.* 2002; Pulvertaft 2008). Major shear zones were formed during emplacement of the batholith, giving rise to tectonic fabrics of variable intensity. The most intensely deformed parts of the batholith are shown as gneisses [70] on the geological map, less deformed varieties as foliated and non-foliated granitic rocks [78]. Basic and intermediate intrusions [81] of various ages are also present. These were commonly emplaced simultaneously with felsic magmas, and may occur as mixed rocks in net-veined intrusions. Many of the basic and intermediate plutonic rocks are appinites (see Fig. 20), i.e. they contain hornblende as the main primary mafic mineral (e.g. Pulvertaft 2008). Isotopic data show that the Julianehåb batholith is of juvenile Proterozoic origin (van Breemen *et al.* 1974; Patchett & Bridgwater 1984; Kalsbeek & Taylor 1985; Garde *et al.* 2002) and does not represent reworked Archaean rocks as previously believed.





Fig 16. Part of the Ketilidian orogen on the north side of Lindenow Fjord ( $c. 60^{\circ}30'N$ ) viewed towards the east. Massive outcrops of a sub-horizontal,  $c. 1740$  Ma sheet of the rapakivi suite (R) form the steep cliffs to the north-west (left), above flat-lying metasedimentary rocks (MS) [67]. Highest summits are about 2500 m. Photo: A.A. Garde.

### *Metasedimentary rocks in the south-eastern part of the Ketilidian orogen*

High-grade supracrustal units [67] are prominent in the south-eastern part of the Ketilidian orogen. They are composed of psammitic and semipelitic gneisses with local marbles and basic metavolcanic rocks. Acid volcanic rocks [65] occur in the inner fjord area north-east of Qaqortoq/Julianehåb ( $61^{\circ}30'N$ ). The clastic sediments are composed mainly of erosion products of the Julianehåb batholith, produced more or less contemporaneously with its emplacement; they are interpreted to represent a fore-arc basin. The rocks underwent high-grade, low-pressure metamorphism, up to granulite facies, and widespread anatexis occurred at  $c. 1790$  Ma (Garde *et al.* 2002).

### *The Ketilidian rapakivi suite*

Flat-lying sheets of rapakivi 'granite' [77], folded into kilometre-scale arcs and cusps, are a prominent constituent of the south-easternmost part of the Ketilidian orogen (Fig. 16). The rocks are characterised by mantled K-feldspar phenocrysts, high Fe/Mg ratios and high levels of incompatible elements. Rather than true granites, the suite mainly includes quartz monzonites, quartz syenites, and norites. Isotopic ages between 1720 and 1750 Ma have been obtained from these rocks (Gulson & Krogh 1975; Garde *et al.* 2002).



## Archaean–Palaeoproterozoic basement in the East Greenland Caledonian orogen

The East Greenland Caledonian orogen is built up of far-travelled allochthonous thrust sheets overlying the eastern margin of the Greenland shield. An overview of the geology of the orogen has recently been provided by Higgins *et al.* (2008), and the region is covered by a new geological map at a scale of 1:1 000 000 (Henriksen 2003). Crystalline basement rocks are prominent both within the thrust sheets and the underlying foreland. They were overlain by Neoproterozoic and Palaeozoic sedimentary successions prior to involvement in the Caledonian orogeny (Higgins & Leslie 2008).

In the Scoresby Sund region, 70–72°N, Archaean basement gneisses with mafic dykes [74] are prominent. North of *c.* 72°50'N the crystalline basement consists mainly of Palaeoproterozoic orthogneisses [70] (Kalsbeek *et al.* 1993b). In the border region, 72–73°N, Palaeoproterozoic granitoid rocks have been intruded into Archaean gneisses (Thrane 2002). An overview over the Precambrian evolution of this region is given by Kalsbeek *et al.* (2008a).

The Archaean basement complex [74] in the inner Scoresby Sund region and areas immediately to the north, 70°–72°50'N, consists of a variety of migmatitic gneisses (Fig. 17) with scattered foliated granitoid plutonic rocks [80]. In the Charcot Land tectonic window in the north-western part of the Scoresby Sund region (72°N) the Archaean basement of the foreland is overlain by a Palaeoproterozoic supracrustal succession [67] consisting of low-grade metasedimentary and metavolcanic rocks (Steck 1971); these are cut by two major post-kinematic granodioritic–granitic intrusions [78] emplaced *c.* 1840 Ma ago (Hansen *et al.* 1980). Similar rocks [45] occur in the Eleonore Sø window (*c.* 74°N), where they are cut by sheets of quartz porphyry, dated at *c.* 1915 Ma (Kalsbeek *et al.* 2008).

The basement gneisses in the central and northern parts of the fold belt (north of 74°N), mainly comprise rock units formed *c.* 2000 Ma ago during a Palaeoproterozoic event of juvenile crust formation. Both older migmatitic gneisses and younger, more homogeneous granites are present. Some of the latter have been dated at *c.* 1750 Ma. Most of the gneisses are at amphibolite



Fig. 17. Crystalline basement within the Caledonian orogen. Archaean gneisses with dark amphibolite layers, affected by Palaeo- and early Neoproterozoic orogenic events, and subsequently reworked during the Caledonian orogeny. South of inner Nordvestfjord/ Kangersik Kiatteq, Scoresby Sund region (71°30'N), central East Greenland. The profile height is *c.* 1000 m.

facies [70], with occasional areas of granulite facies [71]. Large parts of the region underwent Caledonian eclogite facies metamorphism (Gilotti *et al.* 2008) which, however, is not registered in the gneisses. Supracrustal rocks [67] occur locally. A few isolated intermediate and mafic intrusions [81] occur in the Dove Bugt region (76–78°N; Hull *et al.* 1994).

Within this large region of Palaeoproterozoic rocks Archaean orthogneisses [74] have been documented at two localities: at Danmarkshavn (76°40'N; Steiger *et al.* 1976) and in Payer Land (74°30'N, 23°W; Elvevold *et al.* 2003). The relationships of these Archaean rocks with the surrounding Proterozoic gneisses are uncertain.

### **Archaean–Palaeoproterozoic basement beneath the Inland Ice**

Little is known about the geology of the area now covered by Greenland's central ice sheet – the Inland Ice

(Dawes 2009b). However, in 1993 a 1.5 m core of bedrock was retrieved from beneath the highest part of the ice sheet (> 3000 m) at the GISP 2 ice core locality (Fig. 2; 72°35'N, 38°27'W). The rock is a leucogranite, and SHRIMP U-Pb zircon data on a few poorly preserved zircons indicate that it is of Archaean origin, but strongly disturbed by one or more subsequent tectonometamorphic events, most likely during the Palaeoproterozoic (A.P. Nutman, personal communication 1995). These results have been confirmed by Sm-Nd, Rb-Sr and Pb-Pb isotope data (Weis *et al.* 1997).

Three samples from ice-transported blocks of granitoid rocks from the area south and south-east of Independence Fjord, North Greenland, have yielded Sm-Nd model ages (DePaolo 1981) of 3.04–3.38 Ga (Kalsbeek & Frei 2006) and support the view that significant parts of the hidden basement of north-eastern Greenland may consist of Archaean rocks.