DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2008/61

The Thule Iron Province, North-West Greenland. A compilation of geological data

Bjørn Thomassen

2. revised edition

(1 CD-Rom included)

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

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Frontispiece. *Typical banded iron formation displaying mesobanding and small-scale folds, including refolded isoclines. Pingorsuit south. Magnet pen is 12 cm long.*

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1. Abstract

This report presents a compilation of geological data from the widespread iron occurrences in the Precambrian shield of the Thule region, North-West Greenland. The aim is to facilitate an evaluation of the iron potential of the so-called Thule Iron Province. The main effort has been on the collection of information on 30 individual mineralised localities which are described along with locality coordinates and a map. Furthermore, the report summarises the regional geology and exploration history, and lists relevant company reports, publications and maps.

The Thule region is underlain by a high-grade Archaean–Palaeoproterozoic crystalline shield comprising seven major complexes overlain by the intracratonic mainly Mesoproterozoic Thule Basin.

Only limited mineral exploration has been carried out and no commercial mineral deposits are known in the Thule region. Iron enrichment is the only mineralisation of significance in the crystalline shield and this composes a Neoarchaean iron province which is spatially the largest in Greenland. It forms a WNW–ESE-trending belt traceable for more than 350 km along the Melville Bugt coast and into the Thule (Pituffik) Air Base area, with more scattered iron occurrences for another 150 km towards the north. This belt correlates with the iron-rich rocks of Baffin Island, Canada, that host the Algoma-type Mary River deposits with proven and probable direct-shipping iron oxide reserves of 365 Mt grading 64.7% Fe.

Iron in the form of magnetite and lesser hematite occurs both as oxide-facies quartz banded iron formation (BIF), as massive lenses and layers, and disseminated, mainly in pelitic and mafic schists of the Lauge Koch Kyst supracrustal complex. BIF occurs in units of varying thickness, from less than a metre and up to 40 m; iron concentrations are typically 25–35%. Furthermore, scattered silicate-facies BIF with minor iron sulphides occur in the northern part of the region.

Enriched hematite mineralisation comparable to the Mary River deposits, or thick lower-grade deposits, have not been located in the Thule region but in view of the relatively poor exposure due to ice and Quaternary cover, and the very limited exploration carried out, they may indeed exist.

2. Introduction

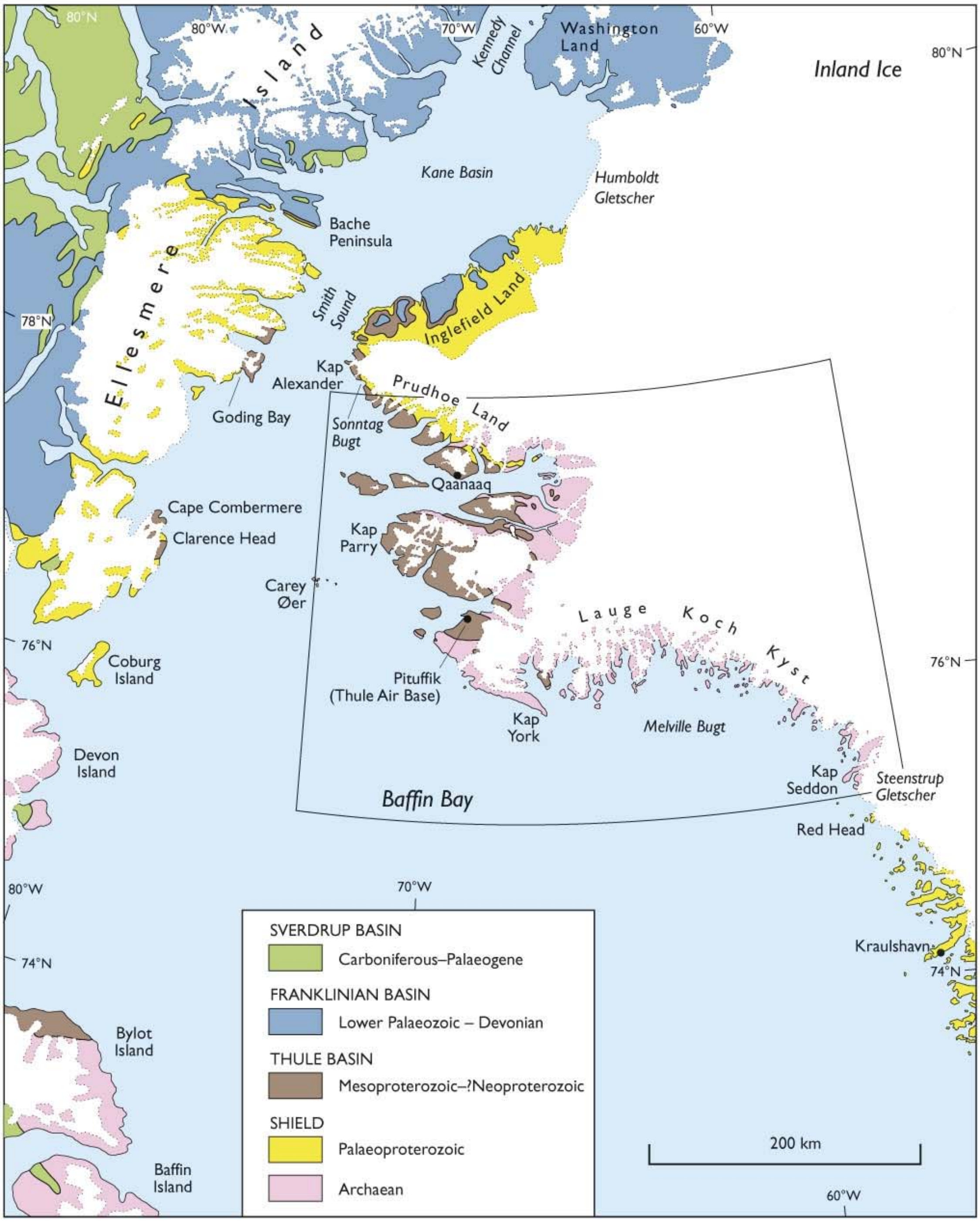
Geological data from the widespread iron occurrences in the Precambrian shield of the Thule region, North-West Greenland, are compiled in this report. The aim is to facilitate an evaluation of the iron potential of what is referred to herein as the Thule Iron Province.

The region dealt with stretches from Kap Seddon (75°15′N) to Smithson Bjerge (77°45′N) comprising most of the Qaanaaq (Thule) municipality (Map 1). For practical reasons limits corresponding to the geological 1:500,000 map sheet 5, Thule, are used in the study: 75°15′–78°00′N, 57°00′–73°00′W. This represents an ice-free area of *c*. 9,115 km^2 (Map 2).

The northern part of the region is dominated by 400–800 m high plateaus capped by local ice caps. In the south, high dissected terrain occurs on the Kap York peninsula, and to the east the Inland Ice reaches the sea on a broad front where the coast consists for the most part of islands, peninsulas and nunataks along the Lauge Koch Kyst. The highest altitude is in the south-east at 1483 m (Haffner Bjerg). Good bedrock exposures are restricted to costal cliffs, nunataks, the sides of glaciers and along valley walls. On the rolling upland and plateau terrain there is a widespread surficial cover of glacial deposits. The Inland Ice margin is retreating and recently deglaciated land is often covered by a continuous blanket of drift. The climate is high arctic and the whole area is underlain by permafrost

This report draws heavily on the works of Peter R. Dawes, especially his geological map of the region (Dawes 1991) and the accompanying comprehensive map sheet description which also contains the most complete description of the Thule Iron Province hitherto published (Dawes 2006). The main effort in the present report has been on the collection of information on the individual mineralised localities (Chapter 5).

The report was prepared on contract to NunaMinerals A/S.



Map 1. *Geological map of North-West Greenland and adjacent parts of Canada, modified from Dawes (2006). The project area – corresponding to the published 1:500,000 geological map (Dawes 1991) – is framed.*

3. Regional geology and mineralisation

The Thule region exposes a high-grade Archaean–Palaeoproterozoic crystalline shield, overlain by the intracratonic Mesoproterozoic Thule Basin (Map 1). The shield is composed of seven major complexes, while the Thule Basin comprises an unmetamorphosed succession at least 6 km thick – the Thule Supergroup (Dawes 1997). The profound unconformity between these two provinces is well preserved through the region. The Thule Supergroup is a multicoloured, continental to shallow marine sequence with one interval of basaltic volcanic rocks. Basic sills are common at several levels. The entire basin is dissected by the Thule half-graben system dominated by WNW–ESE-trending faults. Along master faults displacement of several kilometres has taken place (Dawes 1997, 2006). The Thule Supergroup is outside the scope of this report and it will not be dealt with further. A 1630 Ma dyke swarm transects the shield but pre-dates the Thule Basin (Nielsen 1990).

The Thule region was mapped by the Geological Survey of Greenland (GGU) between 1971 and 1980, mainly by shoreline investigations with limited helicopter traversing inland. The westernmost areas, exposing large tracts of Thule Basin strata, were mapped at 1:100,000; other areas, composed mainly of shield rocks are available at 1:200,000 (Dawes 1988). Unpublished maps at these scales form the basis of the Survey's 1:500,000 geological map, Thule, sheet 5 (Dawes 1991). Unless otherwise stated, rock unit names in this report are taken from this map, to which the reader is referred for further geological information. The only detailed mapping undertaken was of Smithson Bjerge (Nutman 1984). Areas around Pituffik/Thule Air Base were mapped by geologists from US Geological Survey in the 1950s, with emphasis on the Quaternary (Davies *et al.* 1963, Fernald & Horowitz 1964).

3.1. Precambrian crystalline shield

The existing geochronological information suggests that most of the crystalline shield of the study region is composed of Neoarchaean rocks that have been subjected to Palaeoproterozoic reactivation (Nutman *et al.* 2008). Palaeoproterozoic crust occurs to the north in Prudhoe Land and it could also be present in one or more of the other map units recognised. Deformation, metamorphism and migmatisation with gneiss formation occurred in the late Archeaen and polyphase deformation with isoclinal folding and regional metamorphism up to granulite-facies grade affected the region *c*. 1900 Ma ago. The following geological summary is mainly based on Dawes (1991, 2006).

Thule mixed-gneiss complex. This Archaean complex of highly deformed amphibolite- to granulite-facies gneisses outcrops in the north-central part of the study area. It is composed of quartzo-feldspathic to pelitic paragneisses, multiphase orthogneisses with genetically related granitic rocks, as well as minor mafic and ultramafic bodies. Para- and multiphase orthogneisses are structurally complex and intricately associated on all scales. In many places the gneisses show pronounced compositional layering and the distinction of para- and orthogneisses can only be unravelled by detailed mapping.

Smithson Bjerge magmatic association. This Archaean meta-igneous association comprises the Qaqujârssuaq anorthosite and various basic, dioritic and granitic intrusions, including the Heilprin Gletscher complex of Nutman (1984). The main body is predominantly anorthosite *senso stricto* with minor leucogabbro, gabbro and ultramafic rocks. The magmatic association was intruded into the Thule mixed-gneiss complex and affected by granulite-faces metamorphism.

Kap York meta-igneous complex. This plutonic suite occupying the whole of the Kap York peninsula contains metagabbro, metadolerite, diorite and tonalite with smaller units of light-coloured granodioritic and granitic rocks. The rocks are thought to have been emplaced into the gneisses of the Thule mixed-gneiss complex (Dawes 1976).

Melville Bugt orthogneiss complex. This complex forming the coastland of Melville Bugt is composed of massive to foliated amphibolite-facies gneisses and granitoids with conspicuous mafic components. It contains at least some rocks that have been derived from the previous unit.

Lauge Koch Kyst supracrustal complex. These supracrustal rocks, exposed mainly on nunataks and ice-draped peninsulas, make up a rusty-weathering succession of pelitic and mafic schists, quartzites and siliceous schists with banded iron formation (BIF) as well as amphibolite and pyribolite. The precise Archaean age of the rocks is unknown; some could be Palaeoproterozoic.

Prudhoe Land granulite complex. The gneisses of this unit are deemed to be mainly of Palaeoproterozoic age but it cannot be excluded that Archaean gneisses, corresponding to those of the Thule mixed-gneiss complex, are interleaved. In the study area, the main rocks are high-grade, polydeformed and polymetamorphosed orthogneisses with thin units of quartzo-feldpathic to pelitic paragneiss. The pelitic gneisses are commonly graphitic, made conspicuous by rusty weathering. The paragneisses are considered to be correlatives of supracrustal rocks that make up the next map unit.

Prudhoe Land supracrustal complex. These supracrustal rocks of supposed Palaeoproterozoic age comprise a thick succession of pelitic, semi-pelitic and quartzitic rocks with marble and mafic units (amphibolite and pyribolite) forming rusty-weathering outcrops. The supracrustal rocks are probably a correlative of the Etah Group of Inglefield Land in which marble is a conspicuous lithology (Dawes *et al*. 2000, Dawes 2004). The supracrustal rocks display large-scale recumbent isoclines so that they now occur as shallow-dipping units flanked both below and above by gneiss. The contacts examined between supracrustal rocks and the gneisses are tectonised but structural considerations suggest that the supracrustal rocks represent a cover sequence to the Thule mixed-gneiss complex .

3.2. Mineralisation in the crystalline shield

Iron enrichment is the only known mineralisation of significance in the crystalline shield. The southern part of the Thule region hosts a major iron province which stretches from Kap Seddon in the east for more than 350 km along the Melville Bugt coast (Lauge Koch Kyst) to Wolstenholme Ø. Signs of BIF from Carey Øer (Map 2) extends the province beyond the mainland far to the west. This belt correlates with the iron-rich rocks on northern Baffin Island, Canada, that host the Algoma-type Mary River iron ore deposits (Dawes & Frisch 1981; Jackson 2000). More scattered iron occurrences have also been found in the northern part of the region.

Iron, mainly magnetite and lesser hematite, occurs in a number of lithologies. These vary from mm- to cm-scale interbedded (mesobanded) magnetite/hematite, silicates and quartz rocks, i.e. oxide-facies banded iron formation (BIF), to near massive magnetite-silicate rocks without any obvious macrostructure, as well as disseminated, mainly in pelitic and mafic schists of the Lauge Koch Kyst supracrustal complex but also in paragneiss of the Thule mixed-gneiss complex. BIF occurs in units of varying thickness, from less than a metre and up to 40 m. Analyses of 17 magnetite-rich samples from the northern part of the region had a median value of 28% Fe (max. 36% Fe) (Dawes 2006; Thomassen *et al*. 2002b).

Rocks of ferruginous quartzite, perhaps silicate-facies BIF, were described from Smithson Bjerge by Nutman (1984). Similar blocks of often banded quartz-garnet (-pyroxene-amphibole) rocks with disseminated pyrrhotite, magnetite and traces of chalcopyrite are common in the northern part of the region and occur outcropping east of Hubbard Gletscher. Analyses of 17 samples show a median value of 15% Fe (max. 20% Fe) (Thomassen *et al.* 2004).

4. Previous mineral exploration

Limited mineral exploration has been carried out in the Thule region and no major mineral occurrences are known. The most publicised occurrence has been the ilmenite placer deposits (Ghisler & Thomsen 1971; Dawes 1989). A brief historical review of mineral discovery and exploration is given below.

19th century: The early expeditions to the region in the late 19th century found that the eskimos used pyrite from Steensby Land as 'firestone'. A main locality at Nuulliit (Nûgdlît) was described by Peary (1898, vol. 2, p. 219).

Pre-war: Early expeditions reported pyrite, arsenopyrite and iron-sand (ilmenite-rich) from southern Steensby Land (Koch 1920) and boulders of hematite from Kap York (Bøggild 1953).

1950: During ship-based geological reconnaissance by the former Geological Survey of Greenland (GGU), sand samples were collected at sporadic localities along the coast during geological reconnaissance. This resulted in detection of ilmenite- and magnetite-rich sands at North Star Bugt at Pituffik (Ghisler & Thomsen 1971).

1952: GGU reconnaissance noted iron ore in Meteorbugt and near Parker Snow Bugt (Bøggild 1953).

1953: Geologists of the U.S. Geological Survey working around Thule Air Base noted a magnetite 'vein' at four localities from Wolstenholme Ø to the margin of the Inland Ice (Davies *et al.* 1963).

1969: The commercial company Greenarctic Consortium investigated a rust zone at Ironstone Fjeld, Lauge Koch Kyst, during regional reconnaissance (Stuart Smith & Campbell 1971).

1971–80: During regional mapping by GGU, a number of mineralised localities were recorded (e.g. Dawes 1975, 1976, 1979; Dawes & Frisch 1881). Main localities are indicated on the 1:500,000 map sheet (Dawes 1991).

1974: Cominco Ltd. followed up on previously reported Au (and Pb-Zn) showings at Ironstone Fjeld with negative results. Finding of Naajat (Naujat) Cu-showing (Gill 1975).

1975 and 1977: Selected mineral occurrences found during the regional mapping mentioned above became the focus of GGU investigations (Cooke 1978).

1985: Greenex A/S investigated ilmenite placers in Steensby Land (Christensen 1985).

1989–2002: Several mineralised rock samples from the region collected by Greenlandic residents were submitted to the Greenland mineral hunt programme, *Ujarassiorit* (Dunnells 1995; Olsen 2002).

1992: *Ujarassiorit* follow-up programme carried out by Nunaoil A/S (Ujarassiorit 1993).

1994–1995: Nunaoil A/S explored the region and reported a number of mineral indications (Gowen & Sheppard 1994; Gowen & Kelly 1996).

2001: Systematic stream sediment sampling and reconnaissance mineral exploration, partly guided by a pre-season Landsat study, were carried out in the northern part of the region by GEUS and Bureau of Minerals and Petroleum during *Qaanaaq 2001* (Steenfelt 2002; Steenfelt *et al*. 2002; Thomassen *et al*. 2002a,b).

2003: Follow-up on the most promising finds of the *Qaanaaq 2001* project was carried out by GEUS (Thomassen & Krebs 2004).

2003: A remote sensing study based on Landsat 7 scenes was undertaken by GEUS over the central part of the region. Twenty-four anomalies with mineralisation potential were outlined, six in shield lithologies with 18 in the Thule Supergroup, mainly Dundas Group (Krebs *et al.* 2003).

2007: A reconnaissance project, *Pituffik 2007*, involving check of Landsat/Aster anomalies and of known mineralisation was carried out by GEUS in the central part of the region (Thomassen 2007; Thomassen & Tukiainen, *in prep*.).

5. Overview of known iron occurrences

Thirty iron occurrences within the Precambrian shield are briefly described in this section. They are numbered 1–30, listed with coordinates in Table 1 and localised on Map 2. Twenty-four of the occurrences are indicated on the regional geological map (Dawes 1991). Analyses without references stem from the GEUS archives; GGU sample numbers are given in brackets. The distribution of known iron occurrences reflects the limited investigation of the hinterland and, particularly in the nunatak terrain of Lauge Koch Kyst, the selection of helicopter landing sites. Thus mineralisation is probably much more widespread than indicated by the map.

5.1. Kap Seddon west

Iron mineralisation was mapped by Dawes (1991) and sampled by Thomassen *et al*. (1999). A 0.5–1.0 m thick BIF unit is hosted by paragneiss of the Lauge Koch Kyst supracrustal complex. In addition to magnetite, quartz and iron silicates, minor disseminated pyrrhotite and chalcopyrite were observed. Five grab samples returned 25.0–32.3% Fe (457646–47, 458119–20, 458328).

5.2. Kap Seddon east

Iron mineralisation was mapped by Dawes (1991) and sampled by Thomassen *et al*. (1999). A 0.5–1.0 m thick BIF unit is hosted by paragneiss of the Lauge Koch Kyst supracrustal complex. In addition to magnetite, quartz and iron silicates, minor disseminated pyrrhotite and chalcopyrite were observed. A chip sample over 1 m returned 30.3% Fe (457648) and two grab samples gave 25.3–28.7 Fe (458329–30).

5.3. Thom Ø

Iron mineralisation was mapped and sampled by Dawes (1991). Classical banded ironstone in discrete layers up to 5 m thick occur within a succession of garnetiferous quartz-rich gneiss and schistose rocks (Dawes & Frisch 1981). Massive magnetite occurs in beds up to 20 m thick (P.R. Dawes, pers. comm. 2008). Three grab samples returned 30.8–38.6% Fe (272140–42).

5.4. Stenersen Ø

Iron mineralisation was noted by Dawes (1991).

Table 1. *Iron-mineralised localities in the Thule region. The coordinates are compiled from available maps and the author's own GPS readings.*

Locality number	**Locality name**	**N lat.**	**W Long.**	**GPS locality**
1	Kap Seddon west	75.3468	-58.5866	
2	Kap Seddon east	75.3786	-58.3206	
3	Thom Ø	75.7256	-60.5989	
4	Stenersen Ø	75.7374	-59.2868	
5	Kap Walker	75.8325	-59.6213	
6	Nordenskiöld Getscher	75.8665	-59.1126	
7	Döcker Smith Gletscher	76.3546	-61.6798	+
8	Morell Gletscher	76.2091	-62.5355	
9	Sorte Fjeldvæg	76.1110	-63.8027	
10	Bushnan Ø	75.9737	-65.1352	
11	Ironstone Fjeld east	76.1427	-64.9328	
12	Ironstone Fjeld west	76.1498	-65.1166	+
13	Savissuaq Gletscher	76.1432	-65.2846	
14	Salve Ø	76.0628	-65.8232	
15	Sidebriksfjord east	76.2839	-65.4526	
16	Sidebriksfjord west	76.2928	-66.1401	
17	De Dødes Fjord south	76.1083	-67.0683	
18	De Dødes Fjord west	76.2650	-67.1439	
19	De Dødes Fjord north	76.3123	-67.0174	
20	Pingorsuit east	76.3776	-68.4042	
21	Pingorsuit south	76.3402	-68.6094	+
22	Hans Nielsen Fjeld	76.3594	-68.8412	
23	Magnetitbugt area	76.4054	-69.5687	+
24	Wolstenholme Ø	76.4271	-70.0001	
25	Magnetitbjerg	76.6858	-67.3500	
26	Kap Trautwine	77.2404	-70.1756	+
27	'Mount Gyrfalco'	77.1704	-66.6885	+
28	Smithson Bjerge	77.5656	-65.6192	+
29	Hubbard Gletscher	77.5227	-67.6324	+
30	Carey Øer	76.7000	-73.2000	

5.5. Kap Walker

Iron mineralisation was noted by Dawes (1991).

5.6. Nordenskiöld Gletscher

Iron mineralisation was mapped by Dawes (1991). Three grab samples returned 30.8–33.1% Fe (272181–82, 272250).

5.7. Döcker Smith Gletscher

Iron mineralisation was mapped by Dawes (1991). Two grab samples from *in situ* BIF of unknown thickness returned 27.7–55.0% Fe (478613–14) (Thomassen & Tukiainen, *in prep.*).

5.8. Morell Gletscher

Iron mineralisation was mapped by Dawes (1991). On the peninsula in front of Morell Gletscher, a thick unit of garnet-biotite-sillimanite schists contains intercalated layers of rusty-weathering magnetite-quartz rocks, garnet amphibolite, pelitic schists and porphyroblastic paragneiss (Dawes 1979). Two grab samples returned 27.6–29.9% Fe (195015, 243280).

5.9. Sorte Fjeldvæg

Iron mineralisation was mapped by Dawes (1991). Up to 2 m thick units of well-developed banded BIF, composed of intercalated discrete bands of quartz and magnetite several millimetres thick, and intercalated with garnet amphibolite and leucocratic gneiss, were reported by Dawes (1979) and depicted in Dawes (2006, figs 17 & 46). A grab sample returned 31.3% Fe (243265).

5.10. Bushnan Ø

Iron mineralisation was mapped by Dawes (1991). On this island, Dawes (1979) reported a succession of quartz-rich gneisses and schists containing several units of magnetite-rich melanocratic gneiss and magnetite-bearing quartzite. A grab sample returned 29.9% Fe (243245).

5.11. Ironstone Fjeld east

Iron mineralisation was mapped by Dawes (1991). This was based on information from V.F. Buchwald, who searched the peninsula for meteorites 1962–63. The area was investigated in 2007 by Thomassen & Tukiainen (*in prep*), who only located BIF erratics.

5.12. Ironstone Fjeld west

Iron mineralisation was mapped by Dawes (1991). This was based on information from V.F. Buchwald, who searched the peninsula for meteorites 1962–63. The locality was investigated in 2007 by Thomassen & Tukiainen (*in prep*) but only BIF erratics were found. However, BIF rubble was found *c*. 2 km to the NNE (coordinates in Table 1). Four scree samples from this locality returned 15.7–31.0% Fe (478557–58, 495826–27).

5.13. Savissuaq Gletscher

Iron mineralisation was noted by Dawes (1991).

5.14. Salve Ø

Copper mineralisation seen as malachite staining is indicated on the geological map of Dawes (1991), with magnetite-rich metasediments on neighbouring islands.

5.15. Sidebriksfjord east

Iron mineralisation was mapped by Dawes (1991). Supracrustal rocks composing nunataks at the head of Sidebriksfjord invariably contain anomalous magnetite. For example, the succession of pelitic schists, amphibolites and ultramafic rocks lying above multiphase gneisses and forming the core of the spectacular synform featured by Dawes (1976, fig. 7; 2006, fig.18; Schønwandt & Dawes 1992, fig. 3) contain iron-formation and magnetite-rich units.

5.16. Sidebriksfjord west

Iron mineralisation was mapped by Dawes (1991). Supracrustal rocks cropping out on nunataks at the head of Sidebriksfjord invariably contain anomalous magnetite.

5.17. De Dødes Fjord south

Iron mineralisation was mapped by Dawes (1991).

5.18. De Dødes Fjord west

Iron mineralisation was mapped by Dawes (1991). Magnetite-rich rocks, often as BIF and in places with hematite and sulphides, occur in metasediments on nunataks and semi-nunataks at De Dødes Fjord. Some of the rocks resemble classical banded iron formation, and the total thickness of iron-rich rocks probably exceeds 40 m (Dawes 1976). Four grab samples returned 27.8–34.9% Fe (212458–59, 61, 64). The locality is depicted in Dawes (2006, fig. 19) and Schønwandt & Dawes (1993, fig. 3).

5.19. De Dødes Fjord north

Iron mineralisation was noted by Dawes (1991).

5.20. Pingorsuit east

An east-trending magnetite-quartz 'vein' was mapped at the front of the ice cap 1.6 km south of Sioqqap Kuua and on the east flank of Peder Marcus Fjeld by Davies *et al.* (1963). Written information from W.E. Davies (to P.R. Dawes 1975) suggests that the occurrence is not a 'vein' in a cross-cutting sense but a tract of gneiss rich in magnetite. A sample returned 49.9% Fe_2O_3, 52.0% SiO_2 and 0.28% P_2O_5

Dawes (1976) reported iron-rich gneiss and schist as several tracts in association with amphibolites and basic schists near the Inland Ice south of the Air Base.

From a locality in this area, Nunaoil A/S reported an outcropping massive magnetite band up to 20 cm thick within a banded sequence of quartzite and amphibolite, as well as haematitic iron formation float (Gowen & Sheppard 1994).

5.21. Pingorsuit south

The area is underlain by pelitic gneisses and amphibolites of the Lauge Koch Kyst supracrustal complex that have general WNW-directed trend. To the east, there is an outlier of Thule Supergroup (Baffin Bay Group) clastic sediments. Davies *et al.* (1963) indicate a WNW-trending fault south of the sediments which downdrops these against crystalline rocks. Dawes (2006) interprets this fault as the eastwards continuation of the Magnetitbugt Fault which forms the southern border of his Qeqertarsuaq half-graben.

Numerous 'veins' of magnetic gneiss up to 0.7 m thick occur in grey gneiss in an east–west orientated belt west of Freuchen Nunatak (W.E. Davies, written communication to P.R. Dawes 1975).

In 1994, Nunaoil A/S investigated the area west of Freuchen Nunatak**.** They reported a thick sequence of highly folded supracrustals comprising amphibolites, magnetic iron formations and siliceous, sericite, fuchsite and ultramafic schists aligned along a major NW lineament. Numerous sulphide-bearing rocks were located, and of particular note was the amount of BIF at this location with classic banded appearance (Gowen & Sheppard 1994). Follow-up investigations in 1995 in an east–west-orientated valley exposing mafic, felsic and magnetite schists revealed rust zones up to 20 m in width comprising silicification and dm-wide bands of mylonitised country rock with semi-massive pyrite in lenticular zones (Gowen & Kelly 1996).

In 2007, the western end of the east–west-orientated valley west of Freuchen Nunatak was investigated by Thomassen & Tukiainen (*in prep*.) and BIF was located intermittently for 1.7 km in an E–W striking belt along the steep north slope of the valley. The strongly deformed BIF with minor pyrite, that displays pinch-and-swell 0.5–5.0 m thick, is E–W striking with dips 20º–40º to the north (Frontispiece). The foot and hanging walls consist of mica schist and the unit is located on a transition zone between pelitic gneiss and amphibolite. Two chip samples returned 17.9% Fe over 1.8 m (478540) and 29.1% Fe over 1.4 m (495816), respectively. Six grab samples gave 22.4–36.4% Fe, median 23.8% Fe (478537, 49– 50, 52–54).

About 1.5 km further north, BIF crops out intermittently over *c.* 800 m in an NW-SE-oriented belt. This poorly exposed belt is characterised by sub-outcrops and local block fields of pyritiferous BIF and siliceous mica schist with pyrite. The horizon is relatively flat-laying, 2–3 m thick with small-scale folding. A chip sample over 10 m along strike returned 33% Fe (495822). Five grab samples gave 18.0–34.7% Fe, median 28.6% Fe (478542– 43; 495819–20, 23)

5.22. Hans Nielsen Fjeld

A zone of magnetitic gneiss occurs in this area (W.E. Davies personal communication to P.R. Dawes 1975). It is also indicated on the 1:500,000 map (Dawes 1991).

5.23. Magnetitbugt area

The Magnetitbugt area is underlain by rocks of the Thule mixed-gneiss complex with an outlier of Thule Supergroup (Baffin Bay Group) clastic sediments. An E–W to WNW–ESE-orientated fault – the Magnetitbugt Fault – was mapped by Davies *et al*. (1963) on Wolstenholme Ø and east of Magnetitbugt, where it juxtaposes the Thule Supergroup sediments against the shield with a downthrow of *c*. 300 m to the north. Dawes (2006) extrapolated the fault eastwards to the Freuchen Nunatak area and employed it as the southern bounding fault for his Qeqertarsuaq half-graben.

An east-trending magnetite-quartz ‘vein’ was mapped at Magnetitbugt by Davies *et al.* (1963). They also indicated that magnetite rubble occurs for 3–5 km eastwards from Magnetitbugt. A sample returned 53.2% Fe_2O_3, 45.4% SiO_2 and 0.24% P_2O_5. Written information from W.E. Davies (to P.R. Dawes 1975) suggests that the occurrence is not a ‘vein’ in a cross-cutting sense but a tract of gneiss rich in magnetite

In 1974, P.R. Dawes collected magnetite-rich rocks at the base of the cliff on the south side of Magnetitbugt (Dawes 1975). In 1977, H.R. Cooke visited Magnetitbugt and traced the magnetite float on the beach to its source near the top of the cliff. Here, several conformable massive magnetite bands up to 3 m thick occur in the folded gneiss, with an exposed strike length of 200 m, dipping shallowly west (Cooke 1978).

In 2007, a magnetite-rich unit was localised near the top of the coastal cliff of Magnetitbugt by Thomassen & Tukiainen (*in prep*.). It is flat-laying, with pinch-and-swell involving thicknesses of 0.5–2.5 m and exposed over *c.* 200 m laterally. It is a typical BIF, consisting of finely laminated magnetite/hematite, quartz and amphibole with minor pyrite and vein quartz. At the top of the cliff, BIF was located semi-outcropping as rubble and as scattered boulders. Five grab samples returned 17.9–31.2% Fe, median 24.6% Fe (478517; 495807–10).

East of the cliff, exposure is poor. About 3–4.5 km SSE of the Magnetitbugt outcrop, float and rubble of BIF occurs intermittently in the poorly exposed terrain over 1.5 km (Thomassen & Tukiainen *in prep*.). These are taken to represent a continuous, WNW–ESE-orientated BIF unit linking up with the Magnetitbugt outcrop. The probable along strike continuation of the BIF horizon to the east has not been checked. The country rocks are flat-lying gneiss and amphibolite. The 1–2 m thick BIF unit consists of fine-grained, laminated quartz-magnetite/hematite rock with minor vein quartz. The footwall is highly altered gneiss, the hanging wall is composed of grey gneiss and skarnoid amphibolite A chip sample over 4 m representing *c*. 1.5 m true thickness returned 32.1% Fe (495812). Seven grab samples gave 16.6–32.5% Fe, median 23.4% Fe (478511, 19–22, 29; 495811).

5.24. Wolstenholme Ø

A 6–15 m thick magnetite-quartz 'vein' was mapped with an easterly direction across the centre of the island by Davies *et al.* (1963). Written information from W.E. Davies to P.R. Dawes (1975) suggests that the occurrence is not a 'vein' in a cross-cutting sense but a tract of gneiss rich in magnetite and hematite. Two analysed samples gave 56.2–65.0% Fe_2O_3, 34.9–45.0% SiO_2 and 0.22–0.30% P_2O_5.

5.25. Magnetitbjerg

Fernald & Horowitz (1964) describe layers of quartzitic rocks outcropping south of Magnetitbjerg. These contain considerable disseminated magnetite and cummingtonite, possibly representing a BIF unit.

5.26. Kap Trautwine

At Kap Trautwine, screes from the Thule mixed-gneiss complex contain abundant blocks of magnetitic BIF with minor disseminated iron sulphides and 24.4–32.5% Fe (485815, 19–21) (Thomassen *et al.* 2002b).

5.27. 'Mount Gyrfalco'

North-east of 'Mount Gyrfalco', a conspicuous rust zone is associated with a *c.* 20 m thick BIF unit with a strike length of *c.* 500 m (485729–34) (Thomassen *et al.* 2002b). To the west, the unit ends in the east wall of a major valley, to the east it is involved in a tight fold closure. It comprises cm-scale interbedded quartz, magnetite, pyroxene and garnet with minor iron sulphides. Semi-quantitative XRD analyses on two samples (485729 and 485731) show 45–70% quartz, 15–30% orthoferrosilite $(Fe,Mg)SiO_3$ and 15–30% magnetite. Chip samples over 6.5 m returned 30.5% Fe, 2.1% Mn, 0.8% S and 8 ppb Au.

5.28. Smithson Bjerge

At Smithson Bjerge, Nutman (1984) reported layered rusty-weathering quartzofeldspathic paragneisses interlayered with subordinate units of ferruginous meta-quartzite. The ferruginous quartzites containing quartz, orthopyroxene, clinopyroxene, amphibole, magnetite, garnet and sulphides are interpreted as chemical sediments, perhaps akin to silicate facies banded iron formation. The sequence is depicted in fig. 10 of Dawes (2006).

In 2001, blocks of often irregular cm-banded quartz-garnet-pyroxene-hornblende rocks were collected by Thomassen *et al.* (2002b) in two deltas west of Smithson Bjerge (485741–47). They contain disseminated pyrrhotite, magnetite and graphite, minor chalcopyrite and traces of arsenopyrite, with up to 83 ppb Au. In central Smithson Bjerge, blocks of similar rocks, and more magnetite-rich rocks with 18.1–28.2% Fe, were collected (485722–25).

5.29. Hubbard Gletscher

Hubbard Gletscher moraines are enriched in magnetitic BIF blocks with traces of iron sulphides and 16.7–28.2% Fe (470022, 485766, 69, 71) (Thomassen *et al.* 2002b). In the well-exposed north–south section in the Thule mixed-gneiss complex along the east side of the glacier, the shallow northwards-dipping gneissic units comprise abundant 0.5–4.0 m thick units of rusty weathering garnet quartzite with disseminated pyrrhotite, pyrite, magnetite and minor chalcopyrite. A 1–2 m thick BIF-unit composed of interbedded, 5–10 mm thick layers of quartz and hornblende-pyrrhotite-magnetite occurs in a coastal section of banded gneisses *c*. 3 km further to the east (470952).

Analysis of 17 samples of sulphide-magnetite-bearing garnet-pyroxene-amphibole quartzite (silicate-facies banded iron formation) gave the following median values, with maximum values in brackets: 15.1 (20.0)% Fe, 1.6 (13.3)% S, 148 (545) ppm Cu, 17 (1057) ppm Pb, 112 (4139) ppm Zn and 8 (90) ppb Au (Thomassen *et al*. 2004)

5.30. Carey Øer

Magnetite-bearing gneiss possibly developed as BIF has been reported from Nordvestø by Bendix-Almgreen *et al.* (1967). They describe a sample of red schistose gneissic rock composed of quartz, feldspar and magnetite. The rock shows a clear banding due to the higher concentrations of the dark minerals in broad bands which alternate with relatively narrow pink bands. This locality is 85 km NW of Wolstenholme Ø.

6. Iron potential

The Thule region hosts a Neoarchaean (*c*. 2.9–2.7 Ma) iron province which is spatially the largest in Greenland. It forms a WNW–ESE-trending belt traceable for more than 350 km from Kap Seddon in the south-east throughout the Lauge Koch Kyst to Wolstenholme Ø, and perhaps incorporating Carey Øer. Iron in the form of magnetite and hematite occurs both as oxide-facies quartz banded iron formation, as massive lenses and layers, and also disseminated, mainly in pelitic and mafic schists of the Lauge Koch Kyst supracrustal complex. BIF occurs in units of varying thickness, from less than a metre and up to 40 m; iron concentrations are typically 25–35%. Furthermore, more scattered oxide-facies BIF, as well as silicate-facies BIF with minor iron sulphides, occur for another 150 km in a northerly direction.

This belt is an obvious correlative of the iron-rich rocks on Baffin Island, Canada, that host the Algoma-type Mary River iron ore deposits. The Mary River iron deposits on north central Baffin Island is being developed by Baffinland Iron Mines Corporation. The company envisages a direct-shipping iron ore operation based on proven and probable high-grade iron oxide reserves of 365 Mt grading 64.7% Fe, hosted by augen gneiss, schist and amphibolite (www.baffinland.com).

High-grade enriched hematite iron mineralisation comparable to the Mary River deposits has not been located in the Thule region but, in view of the relatively poor exposure and the limited exploration carried out, it may well exist. Lower-grade iron deposits mostly of a few metres thickness are widespread, but again, thick units may well exist. A first attempt to test these possibilities would be a regional aeromagnetic survey followed by a gravity survey in order to pick up the hematite.

7. Overview of GGU/GEUS samples

This overview covers all samples collected in the project area, including samples of Thule Supergroup lithologies, basic intrusions, Quaternary, etc. GEUS databases register the following GGU/GEUS samples collected in the Thule region between 1971 and 2007:

- 2557 (mainly) rock samples, of which 445 have coordinates, and with 1342 analyses. A part of the sample localities are registered as “map sheets 72-75 V1”, i.e. some of these samples are from south of the Thule region.
- 451 stream sediment samples, all with coordinates, with 1731 analyses of which 333 are gamma radiation measurements.
- 46 heavy mineral concentrates, all with coordinates, with 131 analyses.

8. Company reports

Christensen, K. 1985: Greenex' prospektering 1985, 3 pp. Internal report, Greenex A/S, Copenhagen (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 20058).

Dunnells, D. 1995: Ujarassiorit: 1989 to 1994. A summary report of years 1–6, 41 pp. Unpublished report, Nunaoil A/S, Nuuk, Greenland (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 21421).

Gill, F.D. 1975: Report on the Melville Bugt reconnaissance project - 1974, 4 pp. Internal report, Cominco Ltd., Canada. (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 20255).

Gowen, J. & Kelly, J.G. 1996: Follow-up mineral exploration in the Thule area, North West Greenland, 1995, 10 pp. Unpublished report, Nunaoil A/S, Nuuk, Greenland (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 21449).

Gowen**,** J. & Sheppard, B. 1994: Reconnaissance mineral exploration in the Thule area, North West Greenland, 24 pp. Unpublished report, Nunaoil A/S, Nuuk, Greenland (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 21418).

Stuart Smith, J.H. & Campbell, D.L. 1971: The geology of Greenland north of latitude 74°30´N. Report No. 2, **2**. Mineral prospects of northern Greenland, 62 pp. + 3 map folios. Unpublished report, J.C. Sproule and Associates Ltd., Calgary, Canada for Greenarctic Consortium (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 20811).

9. Survey (GEUS/GGU) publications

This section lists publications of BIF relevance only. For a more complete publication list for the Thule region, see Dawes (2006). The unpublished field diaries of P.R. Dawes from 1975, 1978 and 1980 contain additional information on iron mineralisation in the Thule region. They are accessible at GEUS.

Cooke, H.R. 1978: Mineral reconnaissance of the Thule district, North-West Greenland. Rapport Grønlands Geologiske Undersøgelse **90**, 17–22.

Dawes, P.R. 1975: Reconnaissance of the Thule Group and underlying basement rocks between Inglefield Bredning and Melville Bugt, western North Greenland. Rapport Grønlands Geologiske Undersøgelse **75**, 34–38.

Dawes, P.R. 1976: 1:500 000 mapping of the Thule district, North-West Greenland. Rapport Grønlands Geologiske Undersøgelse **80**, 23–28.

Dawes, P.R. 1979: Field investigations in the Precambrian terrain of the Thule district, North-West Greenland. Rapport Grønlands Geologiske Undersøgelse **95**, 14–22.

Dawes, P.R. 1989: The Thule black sand province, North-West Greenland: investigation status and potential. Open File Series Grønlands Geologiske Undersøgelse **89/4**, 17 pp.

Dawes, P.R. 1997: The Proterozoic Thule Supergroup, Greenland and Canada: history, lithostratigraphy and development. Geology of Greenland Survey Bulletin **174**, 150 pp.

Dawes, P.R. 2004: Explanatory notes to the Geological map of Greenland, 1:500 000, Humboldt Gletscher, Sheet 6. Geological Survey of Denmark and Greenland Map Series **1**, 48 pp. + map.

Dawes, P.R. 2006: Explanatory notes to the Geological map of Greenland, 1:500 000, Thule, Sheet 5. Geological Survey of Denmark and Greenland Map Series **2**, 97 pp. + map.

Dawes, P.R. & Frisch, T. 1981: Geological reconnaissance of the Greenland shield in Melville Bugt, North-West Greenland. Rapport Grønlands Geologiske Undersøgelse **105**, 18–26.

Dawes, P.R. *et al.* 2000: Kane Basin 1999: mapping, stratigraphic studies and economic assessment of Precambrian and Lower Palaeozoic provinces in north-western Greenland. Geology of Greenland Survey Bulletin **186**, 11–28.

Ghisler, M. & Thomsen, B. 1971: The possibility of ilmenit placers in the Thule district, North Greenland. A preliminary examination of the heavy fractions of some sands. Rapport Grønlands Geologiske Undersøgelse **43**, 15 pp.

Krebs, J.D., Thomassen, B. & Dawes, P.R. 2003: A Landsat study of the Pituffik region, North-West Greenland. With a summary of mineral occurrences and potential. Danarks og Grønlands Geologiske Undersøgelse Rapport **2003/92**, 37 pp.

Nutman, A.P. 1984: Precambrian gneisses and intrusive anorthosite of Smithson Bjerge, Thule district, North-West Greenland. Rapport Grønlands Geologiske Undersøgelse **119**, 31 pp. + 1 map.

Steenfelt, A. 2002: Geochemistry of southern Steensby Land, North-West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2002/56**, 25 pp.

Schønwandt, H.K. & Dawes, P.R. 1992: Geological setting of Precambrian supracrustal belts: a fundamental part of mineral resource evaluation in Greenland. Rapport Grønlands Geologiske Undersøgelse **155**, 19–23.

Schønwandt, H.K. & Dawes, P.R. 1993: An overview of Greenland's mineral exploration potential. Rapport Grønlands Geologiske Undersøgelse **159**, 10–16.

Steenfelt, A., Dawes, P.R., Krebs, J.D., Moberg, E. & Thomassen, B. 2002: Geochemical mapping of the Qaanaaq region, 77°10´ to 78°10´ N, North-West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2002/65**, 29 pp. + 48 maps.

Thomassen, B. 2001: Feltrapport for Qaanaaq 2001 projektet. September 2001. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2001/101**, 8 pp.

Thomassen, B. 2003: Feltrapport for *Guld i Thule* projektet. September 2003. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2003/78**, 8 pp.

Thomassen, B. 2007: Feltrapport for Pituffik 2007 projektet. Internal GEUS-note (GEUS-notat), 5 pp.

Thomassen, B., Kyed, J. & Tukiainen. T. 1999: Upernavik 98: Mineral exploration in the Upernavik – Kap Seddon region, North-West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1999/35**, 72 pp.

Thomassen, B., Dawes, P.R., Steenfelt, A. & Krebs, J.D. 2002a: *Qaanaaq 2001*: mineral exploration reconnaissance in North-West Greenland. Geology of Greenland Survey Bulletin **191**, 133–143.

Thomassen, B., Krebs, J.D. & Dawes, P.R. 2002b: *Qaanaaq 2001*: mineral exploration in the Olrik Fjord – Kap Alexander region, North-West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2002/86**, 72 pp.

Thomassen, B. & Krebs, J.D. 2004: Mineral exploration of selected targets in the Qaanaaq region, North-West Greenland: follow-up on *Qaanaaq 2001.* Danmarks og Grønlands Geologiske Undersøgelse Rapport **2004/42**, 64 pp.

Thomassen, B. & Tukiainen, T. *in prep*: Pituffik 2007: mineral reconnaissance in the Pituffik region, North-West Greenland.

10. Other publications

Bendix-Almgreen, S.E., Fristrup, B. & Nichols, R.L. 1967: Notes on the geology and geomorphology of the Carey Øer, North-West Greenland. Meddelelser om Grønland **164**(8), 19 pp.

Bøggild, O.B. 1953: The mineralogy of Greenland. Meddelelser om Grønland **149**(3), 442 pp.

Davies, W.E., Krinsley, D.B. & Nicol, A.H. 1963: Geology of the North Star Bugt area, Northwest Greenland. Meddelelser om Grønland **162**(12), 68 pp. + 3 maps.

Fernald, A.T. & Horowitz, A.S. 1964: Bedrock geology of the Nunatarssuaq area Northwest Greenland. Meddelelser om Grønland **172**(6), 44 pp. + map.

Jackson, G.D. 2000: Geology of the Clyde–Cockburn Land map area, north-central Baffin Island, Nunavut. Geological Survey of Canada Memoir **440**, 303 pp. + 7 figs.

Koch, L. 1920: Stratigraphy of Northwest Greenland. Meddelelser Dansk Geologisk Forening **5**(17), 78 pp.

Nielsen, T.F.D. 1990: Melville Bugt dyke swarm: a major 1645 Ma alkaline magmatic event in west Greenland. In: Parker, A.J., Rickwood, P.C. & Tucker, D.H. (eds): Mafic dykes and emplacement mechanisms, 497–505. Rotterdam: Balkema.

Nutman, A.P., Dawes, P.R., Kalsbeek, F. & Hamilton, M.A. 2008: Palaeoproterozoic and Archaean gneiss complexes in northern Greenland: Palaeoproterozoic terrane assembling in the High Arctic. Precambrian Research **161**, 419–451.

Olsen, H.K. 2002: Ujarassiorit 2001. The mineral hunt in Greenland, 29 pp. Unpublished report, Greenland Resources A/S, Nuuk, Greenland (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 21807).

Peary, R.E. 1898: Northward over the 'Great Ice'. A narrative of life and work along the shores and upon the interior of Icecap of Northern Greenland in the years 1886 and 1891–1897. **1**, 521 pp; **2**, 618 pp. New York: Frederick A. Stokes Company.

Ujarassiorit 1993: Ujarassiorit 1992. Årsrapport og opfølgning, 6 pp. + 4 appendices. Unpublished report, Nunaoil A/S, Nuuk, Greenland (in archives of Geological Survey of Denmark and Greenland, GEUS Report File 21543).

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Nutman, A.P. 1984: Precambrian gneisses and intrusive anorthosite of Smithson Bjerge, Thule district, North-West Greenland. Rapport Grønlands Geologiske Undersøgelse **119**, 31 pp. + 1 map. (1:20,000 map in archives of Geological Survey of Denmark and Greenland).