Precambrian mineralising events in central West Greenland (66°–70°15′N)

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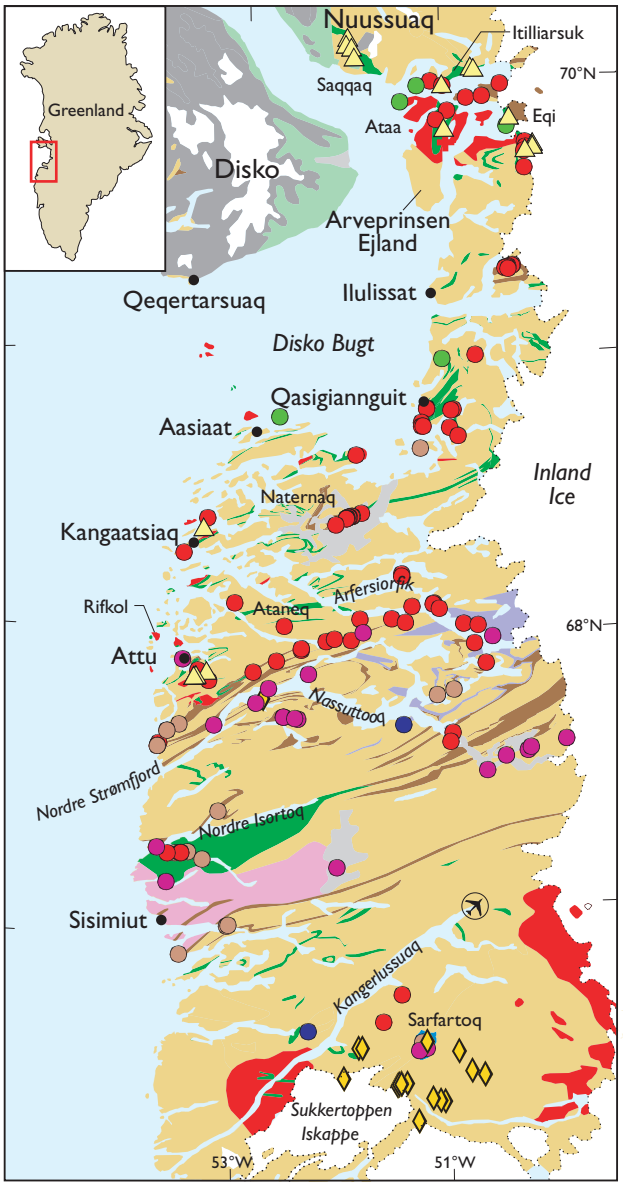
During the past decade the Geological Survey of Denmark and Greenland (GEUS) has carried out two major resource evaluations in the Precambrian basement terranes of South and West Greenland in order to locate potential areas of mineral deposits (Steenfelt *et al.* 2000, 2004; Stendal & Schønwandt 2003; Stendal *et al.* 2004). Based on geological field work and geochemical and geophysical data, these evaluations have assessed the interplay between the magmatic, tectonic and metamorphic evolution in the study areas and their mineralising events.

As a result of the second of these evaluations it is now possible to outline a succession of mineralising events in the northern part of the Nagssugtoqidian orogen and in the Disko Bugt area of central West Greenland (Fig. 1), and relate them to the general Archaean and Palaeoproterozoic geological evolution of this region. However, uncertainties still exist concerning the age and detailed setting of many epigenetic mineralisations.

Geological background

The Precambrian rocks of central West Greenland north of the North Atlantic craton, consist of Archaean orthogneisses and supracrustal rocks together with localised belts of juvenile Palaeoproterozoic intrusive complexes and supracrustal rocks. The whole region was reworked to varying degrees during a major Palaeoproterozoic orogenic event. In West Greenland the Palaeoproterozoic has traditionally been divided into the Nagssugtoqidian orogen between Kangerlussuaq and Disko Bugt (Fig. 1) and the Rinkian fold belt farther north. However, more recent studies suggest that these two belts are largely contemporaneous and probably



Ice
Quaternary
Palaeogene basalt
Cretaceous–Palaeogene sediments
Cambrian Sarfartoq carbonatite
Palaeoproterozoic Sisimiut charnockitte
Palaeoproterozoic Arfersiorfik quartz diorite
Palaeoproterozoic supracrustal rocks
Archaean granite
Archaean undifferentiated rocks
Archaean supracrustal rocks

Precious metals
Base metals
Iron and iron alloys
Speciality metals
Light metals
Industrial minerals
Gemstones
Town
Kangerlussuaq Airport

Fig. 1. Simplified geological map of central West Greenland with mineral occurrences (modified from van Gool *et al.* 2002b).

Table 1. Proterozoic mineralising events and commodities in West Greenland

Age (Ma)	Geological setting	Locality and type of mineralising event	Commodity
~ 600	Rifting – carbonatite Rifting – kimberlite	Sarfartoq – igneous Kangerlussuaq – igneous	Niobium, tantalum, phosphor Diamond
1775–1600	Cooling of the crust from *c.* 600–400°C	Hydrothermal activity in the whole region from 66° to 70°15´N. Albitisation in Disko Bugt area	Mainly minor sulphide showings with minor base metal contents and low in gold
1870–1775	Main Nagssugtoqidian metamorphism and deformation. Pegmatite formation ~ 1800 Ma	Remobilisation of metals during metamorphism and deformation in the whole region. Monazite and allanite in pegmatite	Copper-zinc, graphite and formation of magnetite during metamorphism in mafic rocks. Cesium in pegmatite
1920–1870	Subduction – calc- alkaline magmatism. Peak metamorphism in Disko Bugt region	Arfersiorfik diorite and Sisimiut charnockite. Hydrothermal activity n the Disko Bugt region	Minor oxide occurrences (Fe-Ti-V) in Arfersiorfik. In Disko Bugt region minor copper, zinc and gold occurrences
2000–1920	Drifting and sedimentation	Naternaq, Nordre Strømfjord supracrustal rocks (Ataneq). Exhalative volcanic massive sulphides	Banded iron formation, Cu-Zn and gold
~ 2040	Rifting	Kangâmiut dykes	Copper
~ 2650	Granite intrusion into gneiss	Rifkol, at Attu intrusive related mineralisation	Gold
~ 2800	Continental rift or active continental margin	Eqi and Arveprinsen Ejland. Exhalative volcanic massive sulphides and hydrothermal activity	Copper, zinc, lead, gold and banded iron formation
~ 3000	Continental rift or active continental margin	Southern part of Nuussuaq (Saqqaq) and Itilliarsuk. Exhalative volcanic massive sulphides and hydrothermal activity	Copper, zinc, gold and banded iron formation

represent the southern and northern parts of a single, E–W-trending, *c.* 1850 Ma collisional orogen. Geological descriptions and additional references may be found in Garde & Steenfelt (1999), Connelly *et al.* (2000, in press), Garde *et al.* (2002, 2004) and van Gool *et al.* (2002a).

The Nagssugtoqidian orogen is dominated by reworked Archaean orthogneisses in the south (between c. 66°30´N and 69°N; Fig. 1) with original emplacement ages of around 2870–2700 Ma (Connelly *et al.* 2000). It also incorporates two juvenile, calc-alkaline Palaeoproterozoic plutonic magmatic complexes, namely the 1920–1870 Ma Arfersiorfik quartz diorite and the more or less contemporaneous Sisimiut charnockite (van Gool *et al.* 2002a). These must have been emplaced during subduction and prior to the continent–continent collision, and the presence of a suture in the central part of the Nagssugtoqidian orogen has therefore been suggested. Based on new zircon and titanite U-Pb age determinations of the Archaean basement and mylonites in the Disko Bugt area, Connelly et al. (in press) have recently proposed that the main suture between the Rinkian and Nagssugtoqidian components lies in the Disko Bugt area; in the new model these components would represent the northern and southern colliding continents.

The southern part of the Nagssugtoqidian orogen hosts a rift-related mafic dyke swarm (the Kangâmiut dykes) dated at *c.* 2040 Ma (van Gool *et al.* 2002a); the central and northern parts of the orogen contain Palaeoproterozoic metasedimentary and metavolcanic belts of limited geographical extent, including the Naternaq supracrustal belt (Østergaard *et al.* 2002) which has been dated at around 1950 Ma. These belts are thought to have been deposited along the margin of the rifted Archaean continent.

The northern part of the Nagssugtoqidian orogen, the area east of Disko Bugt, and the Precambrian rocks of eastern Nuussuaq are all characterised by very variable Palaeoproterozoic reworking. The Archaean gneisses in southern Nuussuaq are about 3000 Ma old and include the Itilli diorite dated at 3030 Ma (Connelly *et al.* in press).

The northern part of the area east of Disko Bugt hosts two Archaean, E–W-trending, amphibolite facies metavolcanic and metasedimentary belts, including a large sill complex and a low-grade Palaeoproterozoic sedimentary succession (Fig. 1; Garde & Steenfelt 1999; Marshall & Schønwandt 1999; Stendal *et al.* 1999). The northern of the two Archaean belts was probably deposited unconformably on the gneisses of southern Nuussuaq and has been dated at *c.* 2950 Ma (Garde & Steenfelt 1999; Connelly et al. in press).

Following the Palaeoproterozoic orogeny, a suite of E–W-trending ultramafic lamprophyres and small plugs was emplaced in the Ataa area about 1750 Ma ago (Larsen & Rex 1992). Much later, at *c.* 600 Ma, the Sarfartoq carbonatite complex and numerous lamprophyric and carbonatitic dykes were intruded at the southern margin of the Nagssugtoqidian orogen (see Jensen *et al.* 2004), an event that has been associated with the opening of the Iapetus ocean (Larsen & Rex 1992).

Timing of mineralising events

The timing of mineralising events in relation to the geological evolution of the study area is summarised below and in Table 1.

> 3000 Ma

The oldest known mineral occurrence of the region, at Itilliarsuk in southern Nuussuaq, comprises syngenetic banded iron formation (BIF) and associated semi-massive sulphide occurrences, whereas the age of epigenetic gold occurrences in the same area is not known (Stendal *et al.* 2004).

2800–2000 Ma

A Pb isotope study of pyrite in the Disko Bugt area has yielded an age of *c.* 2800 Ma (Stendal 1998). Gold occurrences related to syngenetic, semi-massive sulphide occurrences at Eqi are presumed also to be of this age.

A gold mineralisation at Attu is interpreted to be of Middle Archaean age. The age of the Pb source in the associated ore minerals is compatible with that of the nearby Rifkol granite (Kalsbeek *et al.* 1984), suggesting gold mineralisation at around 2650 Ma.

The pre-Nagssugtoqidian continental break-up is represented by the well-known *c.* 2040 Ma Kangâmiut dyke swarm. The dykes themselves carry copper mineralisation with no economic significance.

2000–1920 Ma

Several 1950–1920 Ma old supracrustal suites in the northern Nagssugtoqidian orogen (van Gool *et al.* 2002a), e.g. at Naternaq and Ataneq, contain syngenetic massive sulphide occurrences (Fig. 2), and the latter area also contains prominent graphite deposits. Unpublished Pb isotopic compositions of magnetite from amphibolite and banded iron formation yield intercept ages around *c.* 1940 and 2140 Ma, in agreement with the syngenetic nature of the sulphide occurrences.

1920–1870 Ma

The 1920–1870 Ma Arfersiorfik and Sisimiut intrusive suites are associated with Nagssugtoqidian convergence and subduction of oceanic lithosphere prior to the main collision. The only known mineral occurrences resulting from this major event are minor igneous oxides (magnetite, ilmenite), although remobilisation and recrystallisation of previously formed mineral occurrences may also have taken place. In the Disko Bugt region, epigenetic fault zones and shear zones

Fig. 2. Outcrop of volcanogenic-exhalative, semi-massive sulphides of Palaeoproterozoic age at Naternaq in the northern Nagssugtoqidian orogen, with formation of gossan and sulphide weathering.

with small occurrences of base metals, nickel and gold are hosted in Palaeoproterozoic supracrustal rocks, and have yielded a pyrite Pb-Pb model age of *c.* 1900 Ma (Stendal 1998). This important mineralising event was probably contemporaneous with the Palaeoproterozoic thermal event recorded by K-Ar and Ar-Ar ages in parts of the Disko Bugt region (Rasmussen & Holm 1999).

1870–1600 Ma

The Nagssugtoqidian collisional orogeny is dated by early fabric-forming deformation at 1860–1840 Ma, large-scale folding at *c.* 1825 Ma, and formation of steep shear belts in the Nassuttooq region at *c.* 1775 Ma (van Gool *et al.* 2002a). Unpublished Pb-Pb ratios obtained by stepwise leaching of allanite and monazite indicate emplacement of pegmatites at *c.* 1800 Ma in both central (Nassuttooq) and northern (Attu and Qasigiannguit) regions of the orogen.

Metamorphic conditions in the central part of the Nagssugtoqidian orogen reached temperatures above 650°C at 1800 Ma, declining to 540°C at *c.* 1740 Ma and 420°C at *c.* 1670 Ma (Connelly et al. 2000; Willigers *et al.* 2001). Pb-Pb isochron ages of *c.* 1740 Ma from magnetite in amphibolites probably represent closure of the U-Pb system in magnetite, and post-date the formation of prominent shear belts at around 1775 Ma. The magnetite was probably formed during several different stages of metamorphism. Signs of hydrothermal activity have been observed along NE- to NNE-striking fault zones throughout the region. The cooling history of the orogen indicates that hydrothermal activity in the temperature range 650°–400°C extended from the time of pegmatite emplacement at *c.* 1800 Ma until *c.* 1600 Ma.

In the Disko Bugt region, lamproites and ultramafic lamprophyres intruded the basement gneisses in the Ataa area at around 1750 Ma, and extensive post-kinematic albitisation was reported by Kalsbeek & Taylor (1999). However, mineralisations of this age are not known.

600 Ma

The formation of diamondiferous kimberlites and related carbonatite Nb-Ta mineralisation took place around 600 Ma in the Sarfartoq area (Jensen & Secher 2004; Jensen *et al.* 2004).

Concluding remarks

Mineralising events in the Precambrian basement terrain of central West Greenland are confined to certain periods, of which some are more economically promising than others. The most prospective areas are the Archaean greenstone belts in the Disko Bugt region, especially with respect to syn- and epigenetic gold occurrences. Known Palaeoproterozoic metal occurrences are all small, and probably without economic significance, with the possible exception of graphite deposits in the Palaeoproterozoic supracrustal rocks in the Sisimiut – Nordre Strømfjord region. Niobium-tantalum and diamond occurrences in the Neoproterozoic, *c.* 600 Ma alkaline intrusions are currently under investigation and may be economically feasible.

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