DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2007/58

Geological environments and hydrothermal mineralisation in Nunataarsuk, Qarliit Nunaat and Ameralik, Nuuk region, SW Greenland – a field report 2007

Mineral resource assessment of the Archaean Craton (66° to 63°30'N) SW Greenland Contribution no. 2

Jochen Kolb & Henrik Stendal

(1 CD included)

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DANISH MINISTRY OF THE ENVIRONMENT

G E U S

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GEUS

Abstract

This field report describes activities carried out in July-August 2007 on the GEUS 64V2Syd Kapisillit 1:100 000 geological map sheet project. Field investigations in the specified areas have focused on the geological environments and their mineral occurrences. The focus areas were the eastern Nunataarsuk, the north-eastern part of Qarliit Nunaat and a short visit to the Ameralik region.

At eastern Nunataarsuk the mafic meta-anorthosite to meta-leucogabbro complexes and associated mafic-ultramafic dykes, locally, contain small amounts of magnetite and sulphide occurrences that formed by igneous processes during the intrusion of these rocks into supracrustal rocks/greenstones of unknown age. In the greenstone lithology, rocks with a sulphide- and silica-rich mineralisation occur, which are associated with pillow structures in amphibolites, a calc-silicate mineral paragenesis and low gold contents (up to 200 ppb Au). This and the characteristic mineral assemblage of Py, Ccp, Apy and Po suggests that the mineralisation formed by hydrothermal processes on the seafloor similar to VMS-type of base metal deposits.

At Qarliit Nunaat another type of hydrothermal mineralisation occurs associated with mylonites in greenstone belts and TTG gneiss terranes. The epigenetic, syn-tectonic and syn-metamorphic nature of the occurrences observed in Qarliit Nunaat and on the northern side of Ameralik suggests an orogenic gold style of mineralisation. Geochemical analysis indicate low gold (≤ 20 ppb) and elevated Pd (≤ 16 ppb) and Pt (≤ 12 ppb), although the geological stetting along the Tarsiusarsuaq – Tre Brødre terrane boundary is regarded as promising for hydrothermal gold mineralisation.

Introduction

This is a field report from localities studied in July-August 2007 on the GEUS Kapisillit 1:100 000 geological map sheet project. The main aim is to report the field investigations in the specified areas with special focus on the geological environments and their mineral occurrences.

The background for the Kapisillit 1:100 000 geological map sheet project was initiated in 2004, with Julie Hollis as project leader (Hollis 2005; Hollis *et al.* 2006). Field work has been carried out since 2004 and during that time some of the mapping teams have reported areas with possible mineral occurrences. Some of these areas were chosen for visiting during the field season 2007. It turned out that the studies got more detailed than planned, which gave a good basis for interpretations about the geological environment where the mineralised rocks were hosted within three areas, namely eastern Nunataarsuk, north-eastern Qarliit Nunaat and the north side of Ameralik (Fig. 1).

John Myers (formerly Memorial University, now based in Western Australia) has mapped the eastern part of Nunataarsuk at 1:10 000 scale. This mapping work (in the 1990s) was funded by GEUS. The result of the mapping by John Myers has been drawn into the preliminary version of the 1:100,000 Kapisillit map sheet (Myers 2007). This preliminary compilation of eastern Nunataarsuk has been used as base for our work during the field season and in this report. The authors modified this preliminary version based on own observations.

The north-eastern part of Qarliit Nunaat in the south-western part of the Kapisillit map sheet has been remapped and detailed profiles were studied and sampled. A two day camp north of Ameralik investigated rusty rocks along the terrane boundary between the Tasiusarsuaq and Tre Brødre terranes.

All information about field localities, sample sites and photo records is gathered as supplementary material on the enclosed CD. Table 1 shows the sample list with brief descriptions and coordinates and sample sites are shown in figures 2-4.

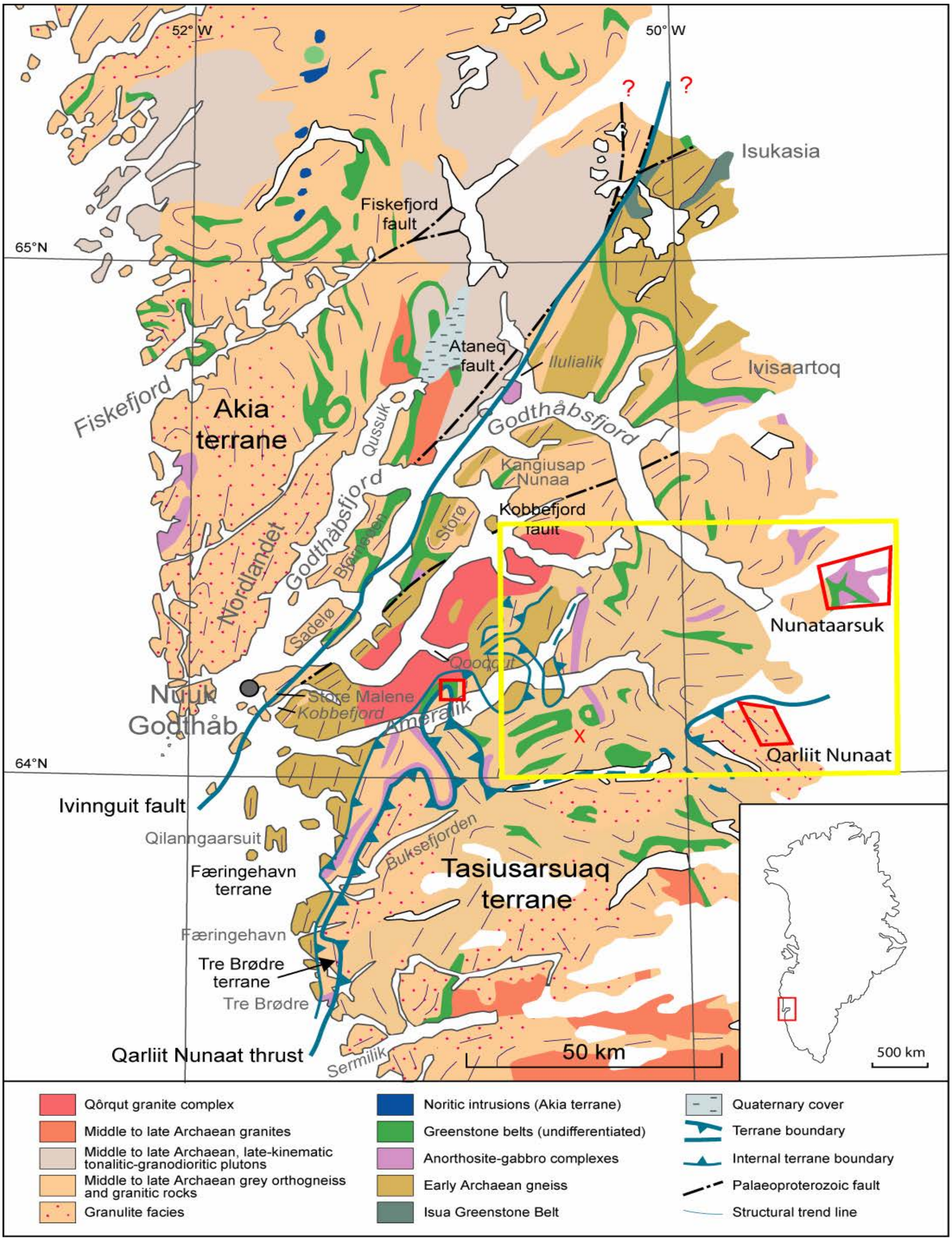

Figure 1. *Geological map of the Nuuk region and location of the study areas (modified after Escher & Pulvertaft 1995). The locations in Qarliit Nunaat and at the northern side of Ameralik are situated close to the terrane boundary between the Tasiusarsuaq terrane in the south and the Tre Bødre terrane in the north. The yellow frame shows the outline of the Kapisillit map sheet and the red X marks a helicopter reco stop.*

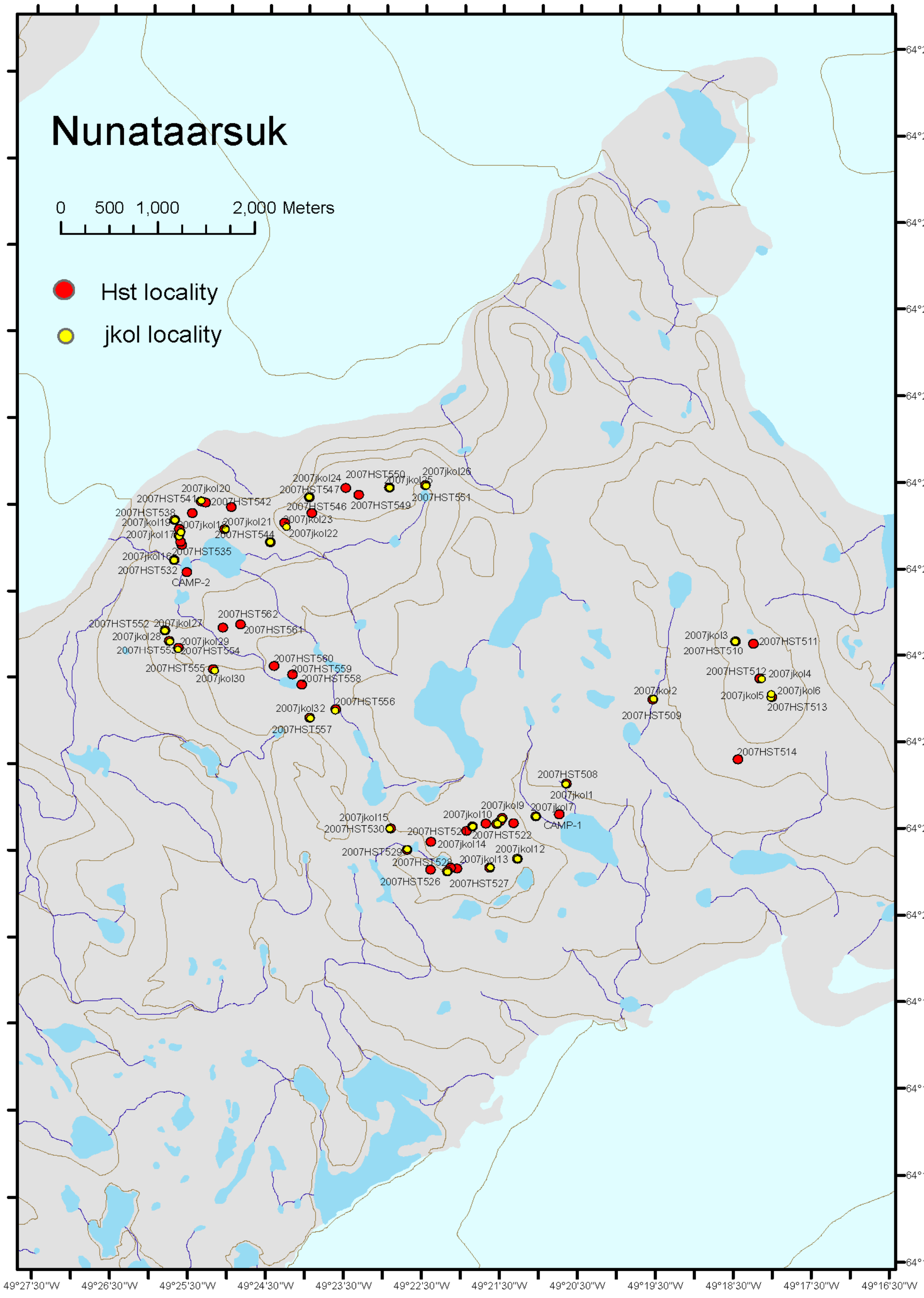

Figure 2. *Topographic map of Nunataarsuk showing locations studied in detail.*

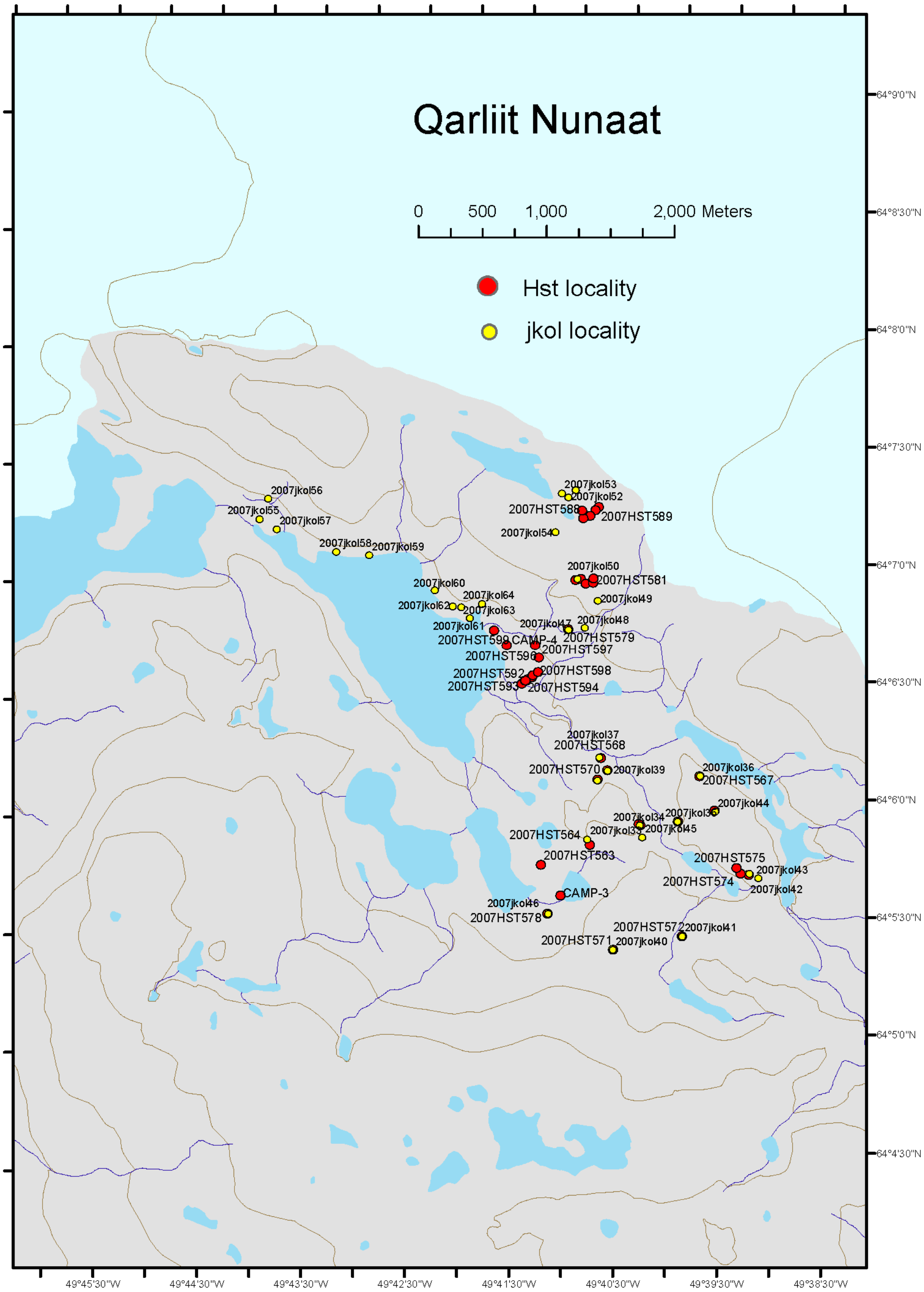

Figure 3. *Topographic map of Qarliit Nunaat showing locations studied in detail.*

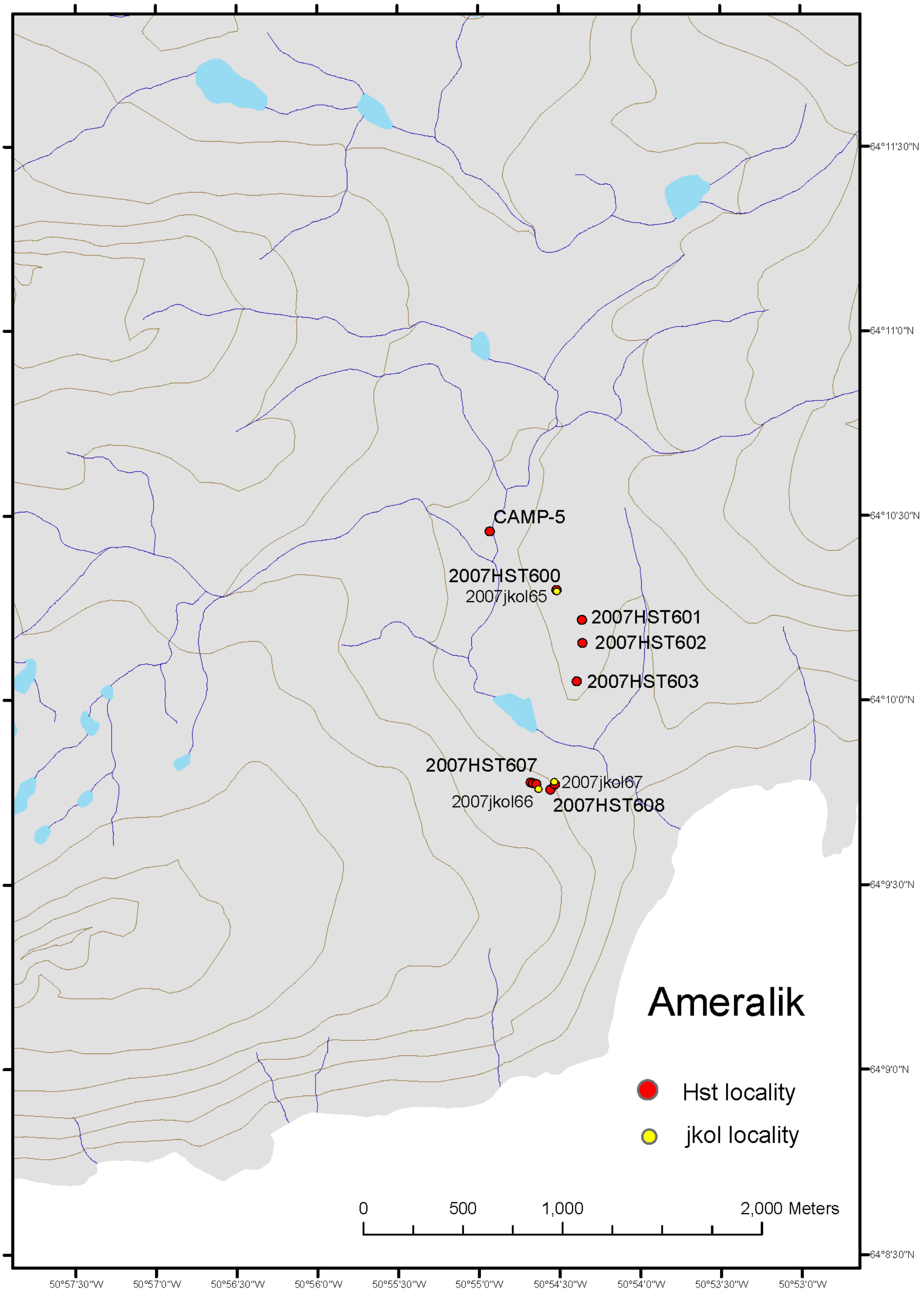

Figure 4. *Topographic map of the study area on the northern side of Ameralik showing locations studied in detail.*

Regional geological setting

Tasiusarsuaq terrane

The Tasiuarsuaq terrane (e.g. Friend & Nutman 2001; 2005) southeast of Kangerluarsunnguup tasersua (Kang) is dominated by mafic rocks (amphibolite) and tonalitic to granodioritic gneisses (Fig. 1). The age is assumed to be within the range of 2.92–2.86 Ga (e.g. Friend & Nutman 2001; 2005). The mafic rocks comprise pillowed amphibolite (calc-silicate alteration), massive amphibolite (gabbroic) and ultramafic pods and dykes. Dimensions of these mafic complexes range from 50 m up to more than 1000 m and they are intruded by granitoid gneisses and cross-cut by Palaeoproterozoic brown-weathered dolerite dykes (up to 30 m wide) with well developed chilled margins and a general E-W strike. Hydrothermal alterations are common within the amphibolites such as calc-silicate formation within pillowed lava sequences. The pillowed mafic sequences have intercalations of 1 – 2 m wide rusty, sulphide-bearing layers (exhalites), which consist of pyrite, pyrrhotite, chalcopyrite and, locally, arsenopyrite. Occurrences of garnet-sillimanite-biotite-sulphide rocks represent another prominent alteration type in the area, post-dating the granitoid formation (Stendal & Schérsten 2007). The Qarliit Nunaat study area is recognised as part of the Tasiusarsuaq terrane lying close to the northern terrane boundary (Fig. 1).

Tre Brødre terrane

The Tre Brødre terrane (e.g. Friend & Nutman 2001; 2005) mainly comprises amphibolite facies, late kinematic tonalitic-granodioritic plutons (Ikkattoq gneiss; Fig. 1). Unpublished SHRIMP U-Pb-zircon ages from Friend & Nutman (personal communication) on these gneisses suggest that their age range is narrow (2828 – 2820 Ma). These gneisses include abundant sequences of gabbro-anorthosite complexes and amphibolite (Frei & Konnerup-Madsen 2007). The Nunataarsuk area is suggested to be part of the Tre Brødre terrane (Fig. 1). The north side of the Ameralik investigated area is lying along the terrane boundary between the Tasiusarsuaq and Tre Brødre terranes (Fig. 1).

Eastern Nunataarsuk

The area originally mapped by John Myers was revisited in 2007 for six days of fieldwork in order to outline geological environments and related mineralisations. Eastern Nunataarsuk is characterised by an anorthosite-amphibolite-granitoid succession in the east and a gneiss succession in the west (Fig. 5). The former area is subdivided into 3 geologically different parts by N-S trending faults. Pegmatite and aplite dykes are ubiquitous and, locally, isoclinally folded. A Palaeoproterozoic dolerite dyke system outcrops in the southern part of the mapped area, striking E-W and predating the N-S trending faults.

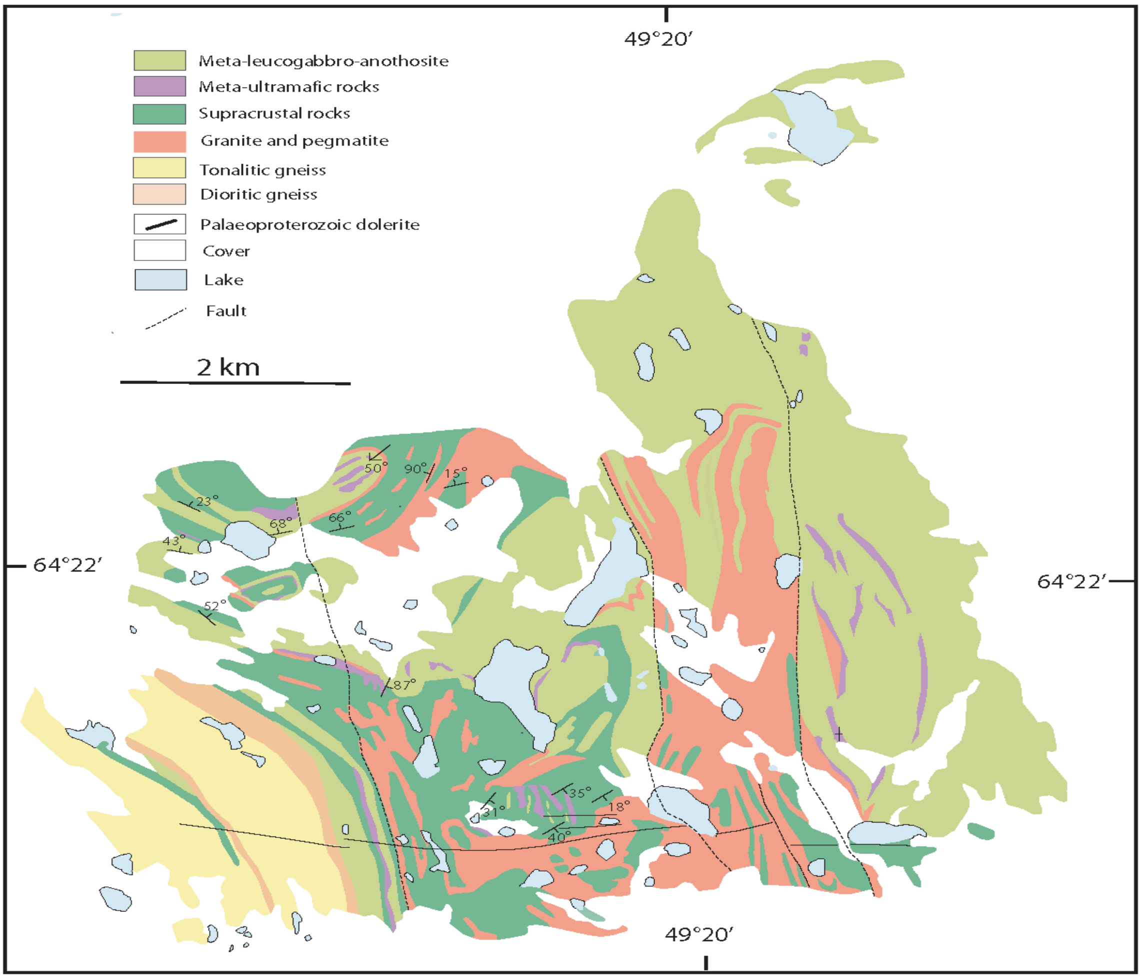

Figure 5. *Geological map of eastern Nunataarsuk (modified after Myers, 2007).*

Regional geology

In the eastern part of the mapped area, meta-leucogabbro and meta-anorthosite dominate (Fig. 5). The rocks are light to dark grey, medium-grained and mainly composed of plagioclase (Pl), hornblende (Hbl) and garnet (Grt). In low strain areas Pl forms cm-scale rounded grains with a cumulate fabric, in high strain areas Hbl defines a closely spaced, near vertical, N-S trending foliation. Parallel to the foliation and crosscutting several about 0.5 – 2 m wide meta-ultramafic dykes can be followed about 2 km along strike. They are medium-grained, black hornblendites with a 5 cm wide fine-grained chilled margin (Fig. 6). They are composed of Hbl, biotite (Bt), olivine (Ol), pyroxene (Px) +/- magnetite (Mag). Locally in the contact zones in meta-anorthosite, cm-scale Grt is observed (Fig. 7). This indicates that the hornblendite dykes probably intruded the meta-anorthosite synmetamorphic and syn- to post-tectonic. At the contact to the dykes, 10's of m scale pockets of an undeformed, medium-grained, white granite intruded the metamorphic rocks.

Figure 6. *Meta-anorthosite with closely-spaced foliation intruded by hornblendite dyke. Note the chilled margin at the dyke rim (2007jkol5).*

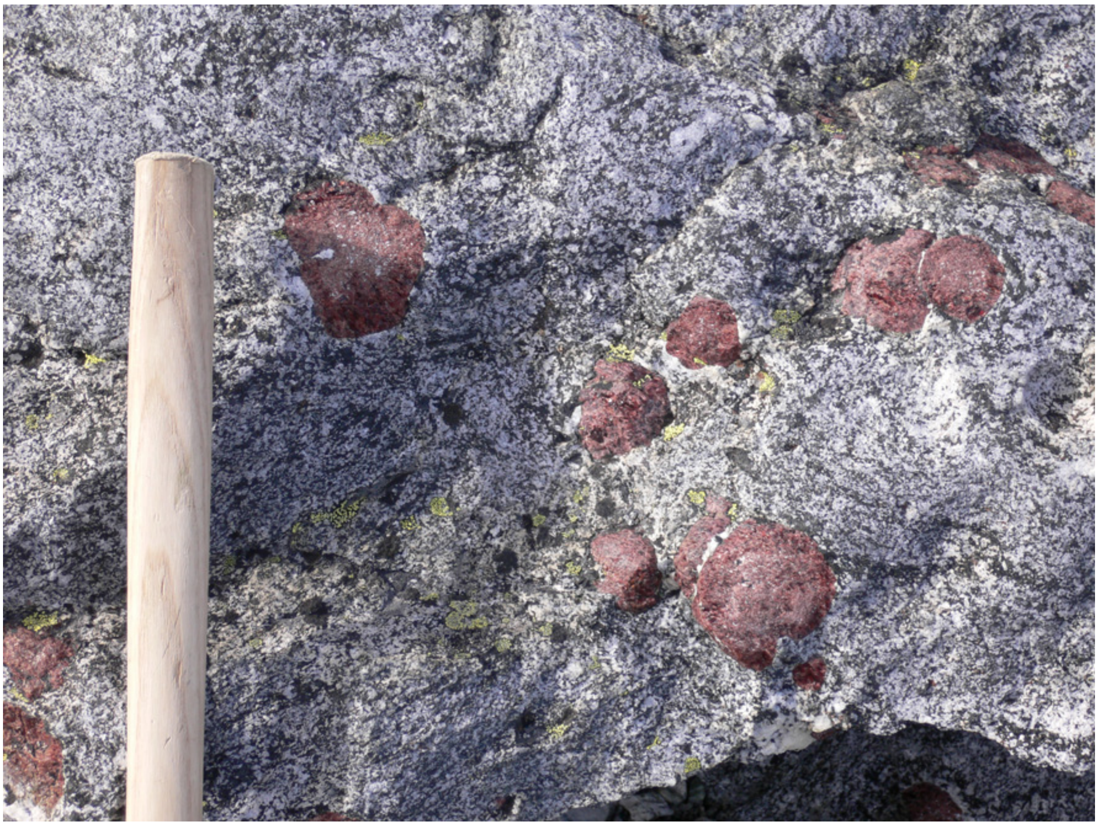

Figure 7. *Large Grt porphyroblasts in meta-anorthosite close to hornblendite dykes (2007jkol5).*

The central part of Nunataarsuk is also dominated by meta-anorthosite in the north. However, in the south, granite and slices of amphibolite form the major lithological successions (Fig. 5). The granite is a fine-to medium-grained white rock comprising Pl, K-feldspar (Kfs), quartz (Qtz) +/- Grt, Bt with an equigranular fabric. The contact with the amphibolite is either irregular intrusive or granite dykes are boudinaged parallel to the foliation (Fig. 8). The amphibolite is fine-grained, black, strongly foliated and comprises Hbl, Pl and Grt.

In the western part of the mapping area, the geology is more complex with meta-anorthosites in the central part and granite-greenstone (supracrustal) successions in the north and the south (Fig. 5). The meta-anorthosite and the granite are similar to those described above. In the meta-anorthosite, especially in the north, a compositional banding on a dm-scale from ultramafic, Hbl > 80 vol.% bands to more felsic, Pl > 80 vol.% bands is observed (Fig. 9). The meta-anorthosite succession is intrusive into diverse supracrustal rocks (Fig. 10). The most common supracrustal rock type is a medium- to fine-grained amphibolite, comprising Hbl, Pl +/- diopside (Di), Grt (calc-silicate amphibolite). A pillow texture was identified at location 2007HST554 (Figs 2 & 11). Along the profile 2007HST526 - 2007HST530 (Fig. 2), the amphibolite grades into more felsic, probably metavolcanic, rocks that are Pl-rich and further into fine-grained, grey Qtz-muscovite (Ms)-pyrite (Py) +/- Bt felses. Locally, strongly foliated, medium-grained, grey Grt-sillimanite (Sill) gneiss is observed, possibly representing a metasedimentary unit. Massive to foliated, dark green, medium-grained rocks, comprising Ol, Py, chalcopyrite (Ccp), form about 15 m wide lenses, which can be followed over 30 m along strike. These ultramafic rocks either represent komatiites forming competent bodies in the sheared amphibolite or deformed peridotite dykes that intruded into the amphibolite. They can be distinguished from the meta-ultramafic hornblendite dykes in the W and the N of Nunataarsuk by their geological setting and the mineralogical composition (Fig. 5).

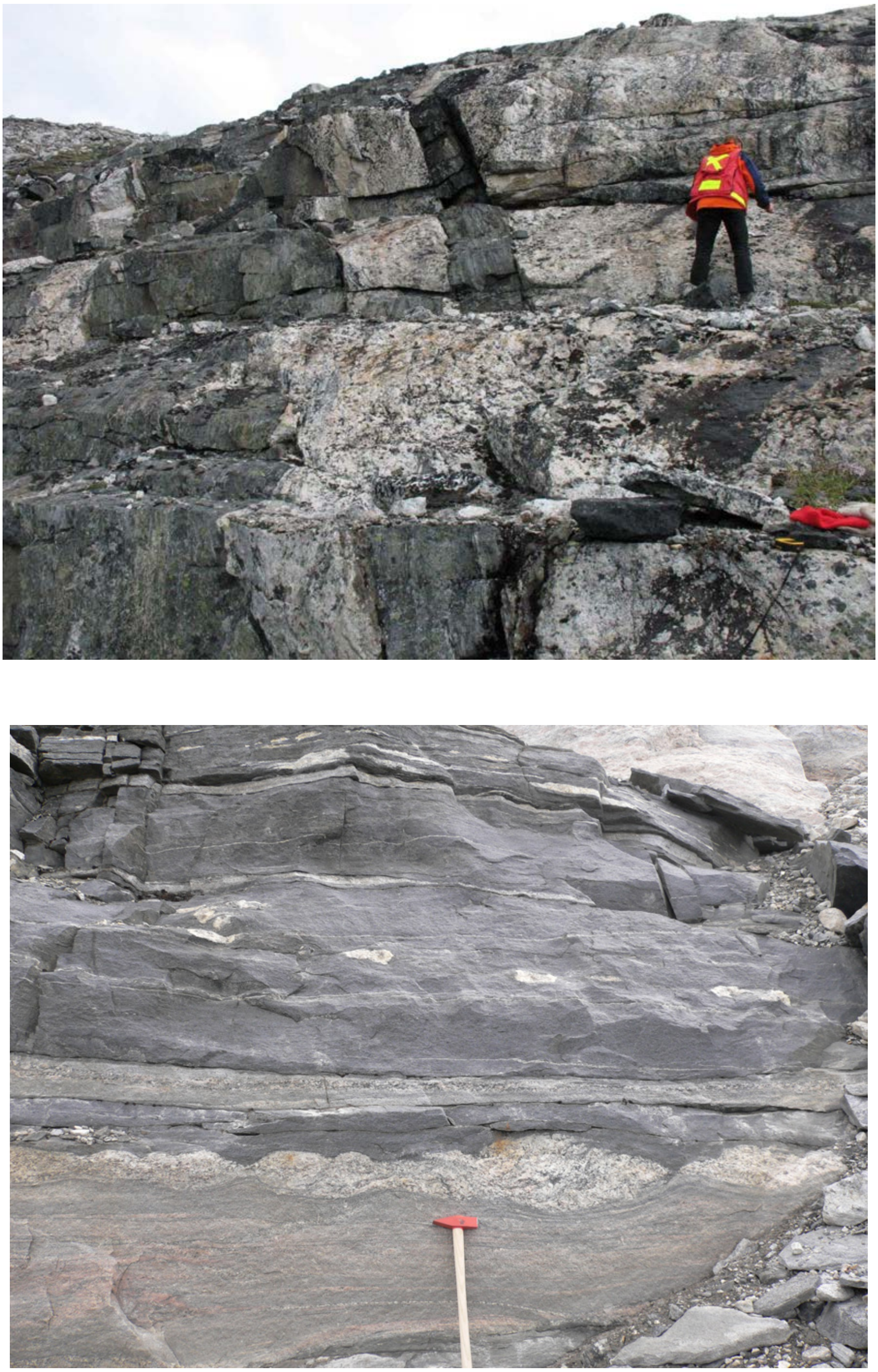

Figure 8. *Granite dykes intruded the amphibolite either crosscutting the foliation (upper, 2007HST511) or forming boudins parallel to the foliation (lower, 2007jkol2).*

Figure 9. *Meta-leucogabbro to meta-anorthosite compositional banding on a dm-scale (2007jkol23).*

Structure

The meta-anorthosite in the east is variably foliated with a N-S trending, near vertical foliation (Fig. 5). The rocks are characterised by anastomosing, cm- to m- scale high strain zones, encompassing lithons where the magmatic cumulate texture is preserved.

In the southern central area of Nunataarsuk, the supracrustal rocks have a closely spaced foliation that dips moderately to the southeast (Fig. 12a). The foliation is defined by the alignment of Hbl, Bt and Ms and is parallel to the compositional banding (Fig. 9). A down-dip mineral stretching lineation is observed. SC and SC' fabrics indicate a normal sense of shearing (Fig. 12b). Foliation-parallel Qtz-veins and pegmatites are boudinaged (Fig. 13).

Figure 10. *Intrusive contact between meta-anorthosite and amphibolite (2007jkol23).*

Figure 11. *Pillow structures (3 pillows) in amphibolite in a low-strain area (2007HST554).*

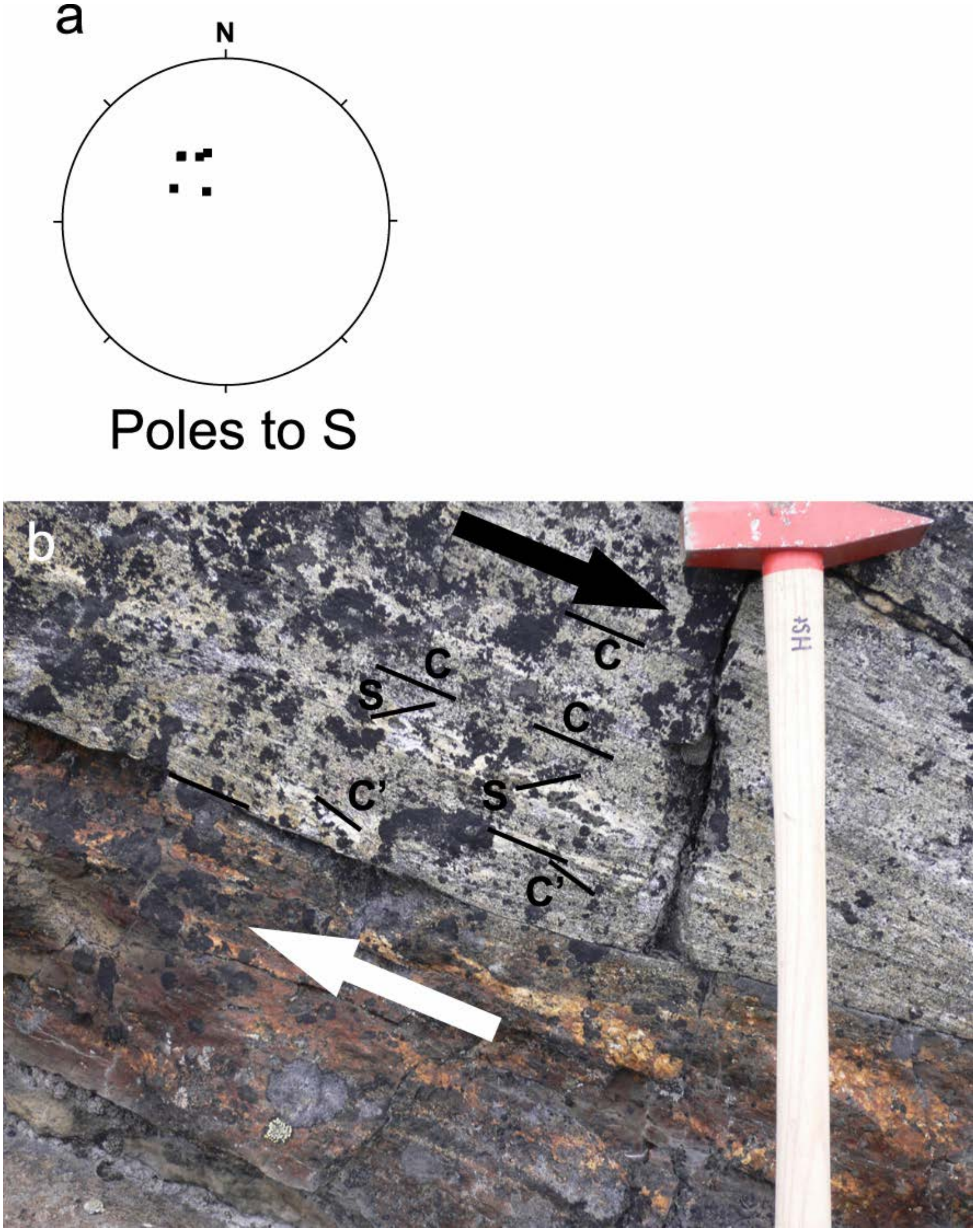

Figure 12. *(a) Lower hemisphere equal area projection of poles to the penetrative S_1 foliation. (b) Sheared meta-anorthosite with well developed SC and SC' fabrics, indicating normal sense of shear (2007jkol12).*

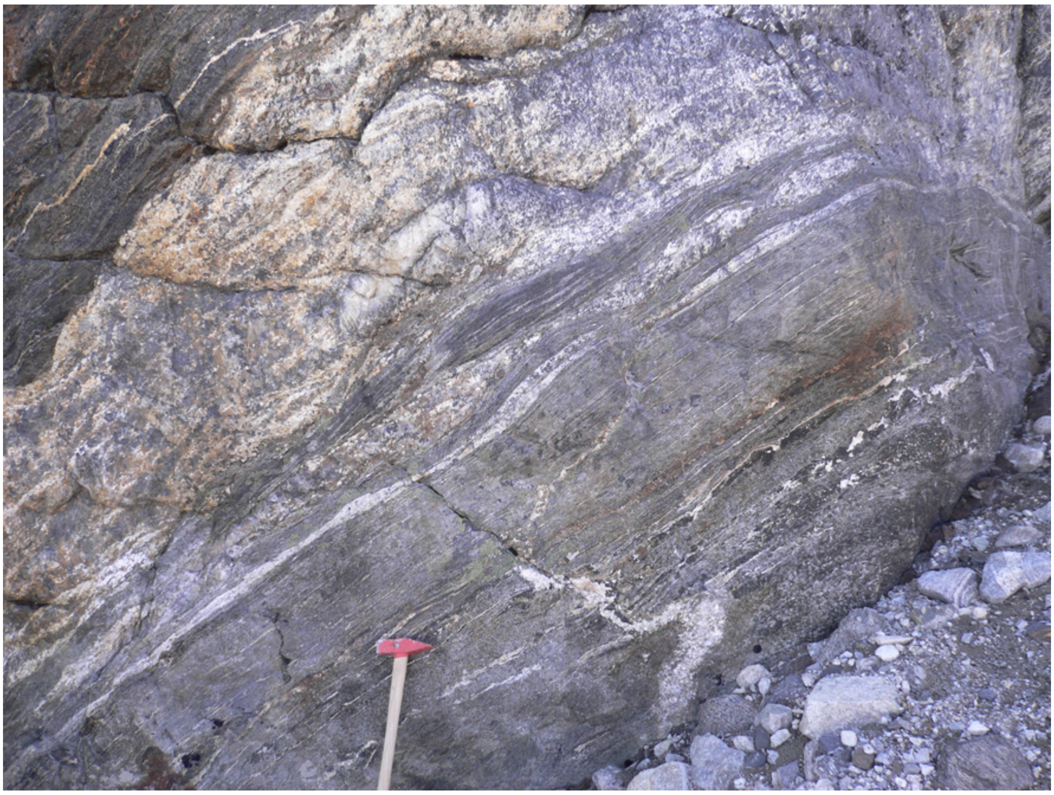

Figure 13. *Pegmatite parallel to the closely-spaced foliation in amphibolite with boudinage textures and folded, crosscutting pegmatite at outcrop bottom (2007jkol9). These fabrics indicate late-tectonic intrusion of the pegmatites.*

In the north, a folded structure that formed during three deformation stages dominates the map pattern. A closely-spaced S_1 foliation is folded into a tight, upright F_2 fold with a fold axis plunging 50° to the SW (Fig. 5). This F_2 structure is folded into an open F_3 fold with a F_3 fold axis plunging at about 70° to the NNW (Fig. 14). Doubly plunging F_2 fold axes in amphibolite are observed at the location 2007jkol20 (Figs 2 & 15). The near vertical S_1 foliation is very prominent in amphibolites and meta-anorthosites crosscutting the intrusive contact between the two lithologies and leading to a mylonitic fabric of these rocks. Mafic, more competent layers in the anorthosite form boudins aligned along S_1 (Fig. 16). A mineral stretching lineation is mainly defined by Hbl and is near horizontal to shallow ENE plunging. S-C and S-C' fabrics point to a sinistral strike- to oblique-slip deformation. Granite dykes crosscut the foliation but also are observed parallel to S_1 being slightly deformed and boudinaged. Thus the granite and abundant pegmatites and aplites are interpreted as late- to post-tectonic intrusions.

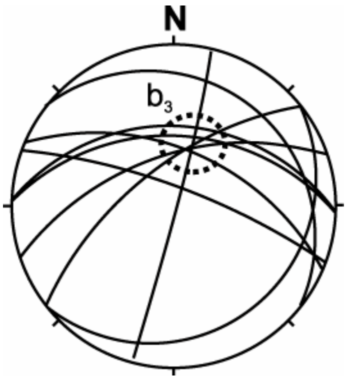

Figure 14. *Lower hemisphere equal area projection of great circles to the penetrative S_1 foliation. The marked intersection represents the b_3 fold axis of the F_3 fold. The data scatter results from transposition of the foliation by the late N-S fault (cf., Fig. 1).*

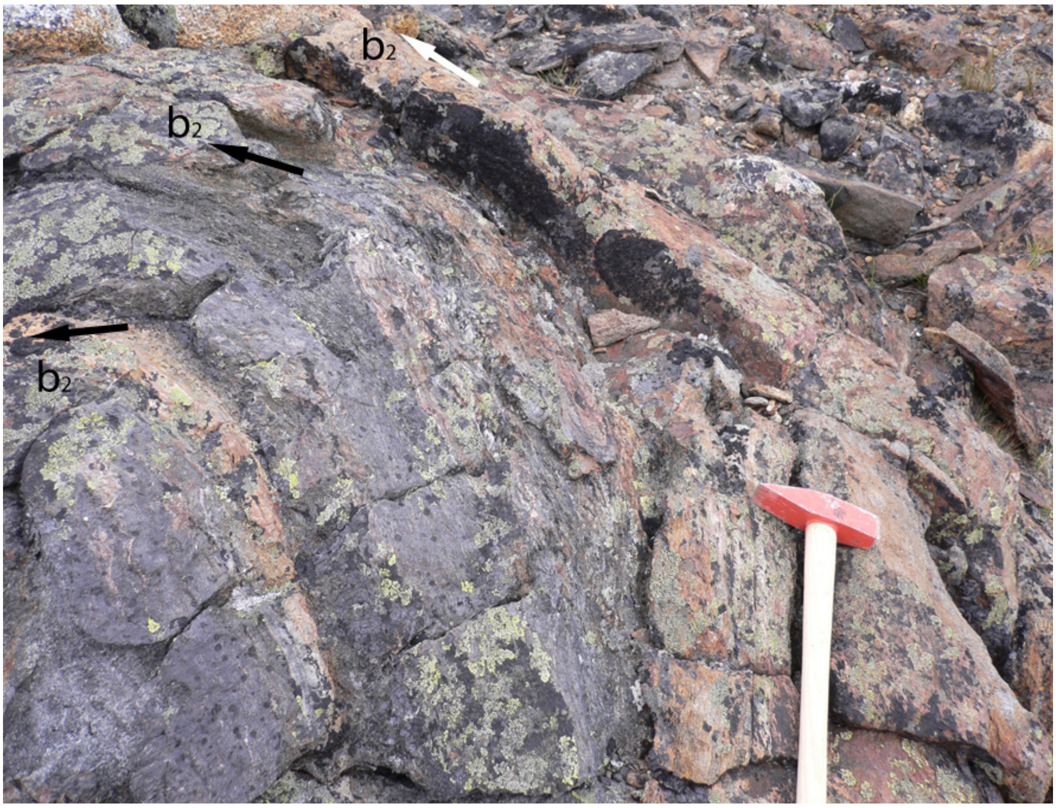

Figure 15. *Folded amphibolite with two rusty, mineralised layers (2007jkol20). The fold is non-cylindrical with a curved fold axis (b_2), similar to the regional scale fold structure shown in Fig. 5.*

Figure 16. *Boudins of competent mafic layers in sheared anorthosite. Sense of shear is sinistral strike-slip (2007jkol23).*

Mineralisation

Especially the east of Nunataarsuk is dominated by a meta-leucogabbro and meta-anorthosite succession, which is barren of any kind of mineralisation (Table 1). The hornblendite dykes contain Mag as a minor component, however, given the low content and the low strike continuation of this lithology, the significance of this mineralisation is regarded as very low. There appears also no significant mineralisation to be associated with the widespread granite, pegmatite and aplite intrusions (Table 1). At the location 2007HST525 (Fig. 2), granite intruded amphibolite and caused silification and mineralisation of the amphibolite with disseminated Py to < 10 vol.% in a relatively small area (Fig. 17), however, no enrichment in Pd, Pt or Au is recognized.

Figure 17. *White granite intruded amphibolite. Silification and mineralisation of amphibolite at the contact (2007jkol13).*

The supracrustal sequence in the south contains two types of mineralisation forming (1) rusty, foliation parallel zones with disseminated sulphides (Fig. 15) and (2) Qtz veins with alteration halos. The Qtz veins are up to 5 cm wide, parallel to the foliation and, locally, boudinaged. They contain < 5 vol.% Py and Ccp. The dm wide alteration halos comprise actinolite (Act)-Hbl-Bt-Ccp-Py and in places Grt-Di. This type of mineralisation is prominent in an about 50 m wide corridor, which can be traced for about 1 km along strike (Figs 2 & 18, 2007HST515 – 2007HST522). The rocks may contain elevated gold contents, with up to 200 ppb Au in a calc-silicate amphibolite at location 2007HST555 (Fig. 2, Table 1). In the area around 2007HST527 – 2007HST531 (Fig. 2), disseminated sulphides are observed in the various rocks of the supracrustal assemblage. The Qtz-Ms-Py +/- Bt, Ccp felses form 10-50 m thick units and contain up to 10 vol.% sulphides. These rocks are generally barren of Pd, Pt and Au, with only one sample weakly enriched in Pd and Pt (Table 1). The granite dykes cut the mineralised bands and clearly postdate the sulphide mineralisation. The ultramafic rock comprises about 5 vol.% disseminated pyrrhotite (Po) and Ccp, with no significant precious metal enrichment (Table 1). This mineralisation is most probably of a syngenetic type akin modern VMS settings with the Qtz-Ms-Py felses, representing metamorphosed exhalative rocks. It is observed in outcrop in an area of about 300 m by 1 km. A small outcrop with a similar mineralisation is observed in the north, at the locations 2007HST541 and 2007HST542 (Fig. 2).

Figure 18. *Several foliation parallel rusty mineralised zones with quartz veins in amphibolite (2007HST517).*

A 50 m wide shear zone is developed in the meta-anorthosite at location 2007jkol18 (Fig. 2). Over about 500 m along strike several 0.1 – 2 m wide, strongly weathered zones are mineralised with Py, malachite and azurite. Alteration minerals comprise Bt and Grt, but no elevated precious metal contents are observed (Table 1).

Concluding remarks

Compared to John Myers' map from 2007, we reinterpreted some of the lithologies based on new observations. The subdivision in anorthosite 1 and 2 by plagioclase grain size was given up, because the grain size of meta-anorthosite in the map area is largely controlled by strain and not by a compositional variation of the lithology. The interpretation that the amphibolite represents a mafic equivalent to the anorthosite and, therefore, the classification as anorthosite 3 was dropped because: (1) The amphibolite shows pillow structures; (2) The amphibolite, locally, comprises a Grt-Di assemblage, suggesting that it is a calc-alkaline supracrustal volcanic rock; (3) The lithological unit contains a sequence of rocks ranging from komatiite to felsic amphibolite, Qtz-Ms-Py fels, which is interpreted as a metamorphosed exhalative rock and Grt-Sil gneiss, which probably represents a meta-sediment; and (4) The style of sulphide mineralisation in the amphibolites and the Qtz-Ms-Py felses closely resembles modern exhalative, VMS-like mineralisations on the seafloor.

Mineralisation is restricted to relatively limited outcrop areas (≤ 1 km strike extent) in the supracrustal sequence and is subdivided into (1) a disseminated, hydrothermal sulphide mineralisation in up to 50 m wide layers that probably can be classified as VMS-type and (2) a hydrothermal, Qtz vein-hosted sulphide mineralisation associated with shear zones and wall rock alteration, resembling the orogenic gold mineralisation type. The geochemical analysis shows that precious metals (Pd, Pt, Au) are not significantly enriched in either mineralisation environments, but some elevated contents are observed locally. The potential for significant mineralisation in eastern Nunataarsuk is, therefore, considered as being low.

Qarliit Nunaat

The northern part of Qarliit Nunaat is dominated by a gneiss basement with elongated stringers of amphibolite and felsic metavolcanic rocks, which belong to the Tasiusarsuaq terrane (e.g. Friend & Nutman 2001; 2005). Locally, granitoid dykes are observed (Fig. 19). The general trend of the lithologies is NW-SE.

Regional Geology

The southwestern part of the mapped area is dominated by gneissic units (Fig. 19): (1) Brownish Bt-Grt-Mag gneiss and (2) grey banded migmatitic gneiss (Fig. 20). The former is a fine- to medium grained rock, comprising Qtz, feldspar (Fs), Bt, Hbl +/- Mag, Grt. Bt and Hbl define a closely spaced foliation that dips moderately to the NE. Locally, mafic Hbl-Bt-dominated bands are observed. The main area is covered by a strongly banded gneiss unit ranging from dark grey to white, fine- to medium grained rock with various proportions of Qtz, Fs, Bt, Ms, Hbl and Grt. The dominant fabric is a banded migmatitic fabric parallel to the dominant NW-SE trending foliation. Locally, spectacular agmatitic fabrics are developed (Fig. 20).

Fine-to coarse-grained, black amphibolites occur in several tens of m wide lenses in the north, which can be followed over several km along strike (Fig. 19). The amphibolite is composed of Hbl, Pl, Bt +/- Grt (Fig. 21) and, locally, retrogressed to Act, Ep, Chl (location 2007HST577, Fig. 3). Two lenses of a banded, dark grey, fine-grained Bt-Ms +/- Grt gneiss are spatially associated with amphibolite and, therefore may possibly represent metamorphosed felsic to intermediate volcanic rocks. At the location 2007HST571 (Fig. 3), a fine- to medium-grained, well foliated, brownish quartzite, comprising Qtz, Bt (10 vol.%), Grt (3 vol.%) and darker bands with Mag is observed, which possibly represents a metasediment. A medium-grained, white granitoid, comprising Fs, Qtz (10-20 vol%) +/- Grt intruded the gneisses and the amphibolite, mainly in foliation parallel dykes. Larger dykes are tens of m wide and up to 2 km along strike (Fig. 19). Smaller cm-scale dykes are ubiquitous and locally also crosscut the foliation (Fig. 21).

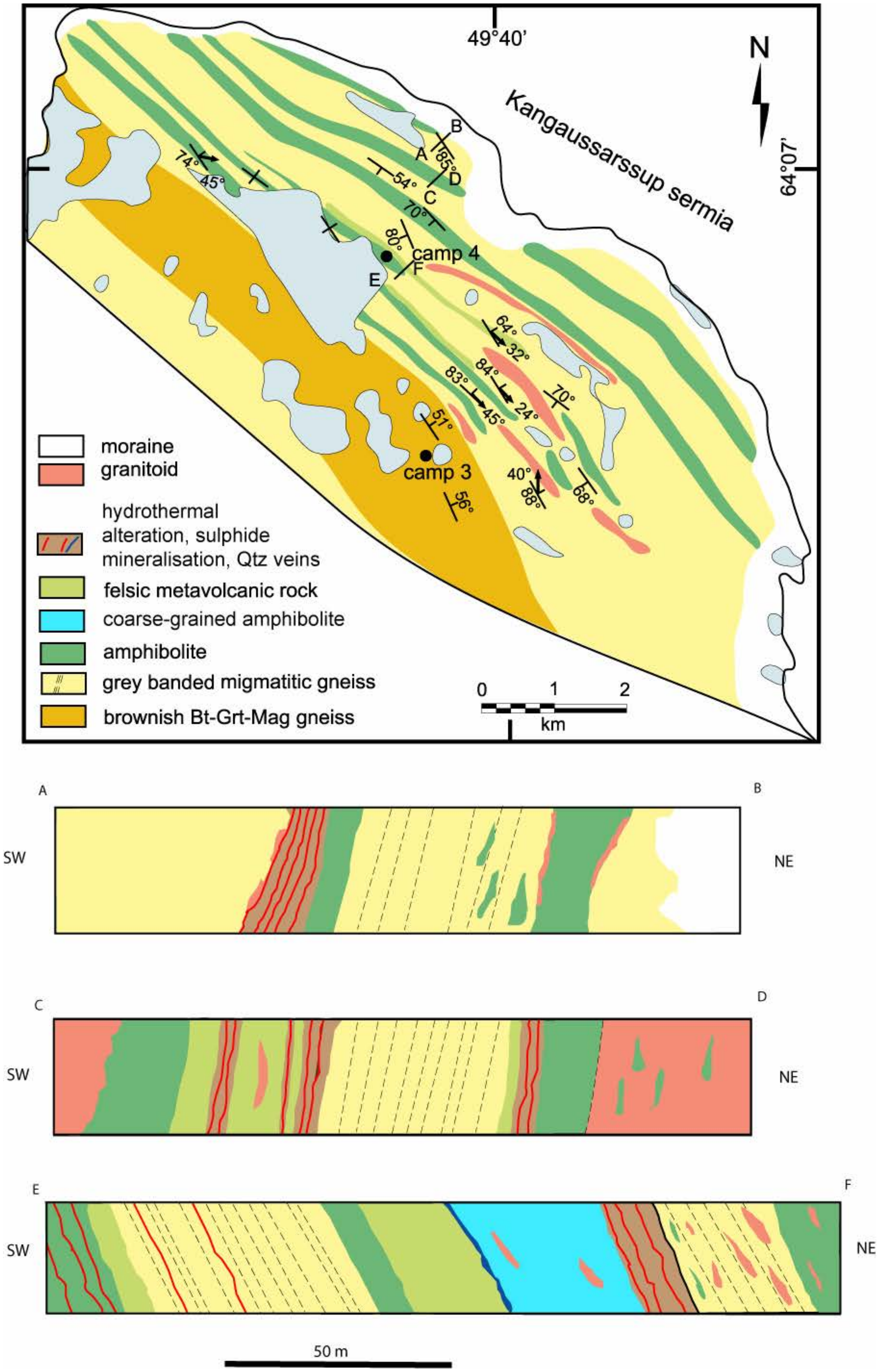

Figure 19. *Geological map and sections of northern Qarliit Nunaat.*

Figure 20. *Photograph of the banded to agmatitic grey gneiss, that dominates in the northern Qarliit Nunaat (2007jkol61).*

Figure 21. *Dykes of white Fs-Qtz granitoid intruded fine-grained, well foliated, black amphibolite. The main granitoid dyke is about 2 m wide (2007HST592).*

Structure

The mapped area is structurally relatively simple with one pervasive NW-SE trending S_1 foliation. To the N of the brownish Bt-Grt-Mag gneiss, the rocks are strongly deformed in a 2 km wide shear zone. In this shear zone, undulating highly strained areas are distinguished from less strained lithons with lensoid shape. The mylonitic S_1 foliation trends NW-SE and shows moderate to steep dips either to the SW or the NE (Figs 22-24). A mineral stretching lineation is mainly defined by Hbl and Bt and plunges at 20-40° to the SE (Fig. 24). S-C and S-C' fabrics point to an oblique sinistral sense of deformation. Locally, dextral shear sense indicators were also observed. In 0.5 – 6 m wide high strain zones, cm-scale foliation parallel Qtz veins are common. High strain zones and veins are well developed at lithological contacts of gneiss and amphibolite (Figs 23 & 24). Dilational jogs are developed at various scales where the foliation slightly undulates (Fig. 25). A 10's of m scale dilational jog is developed at the location 2007jkol43 (Fig. 3). The foliation changes from NW-SE trends to an E-W trend. The area with the E-W trending foliation is characterised by numerous Qtz veins and granitoid intrusions, representing the dilational jog. Discrete high strain zones are associated with cm-scale, en echelon, sigmoidal Qtz veins. The geometry of these extension veins points to dominant sinistral oblique slip in the high strain zones and WNW-ESE extension (λ_3, Fig. 26a).

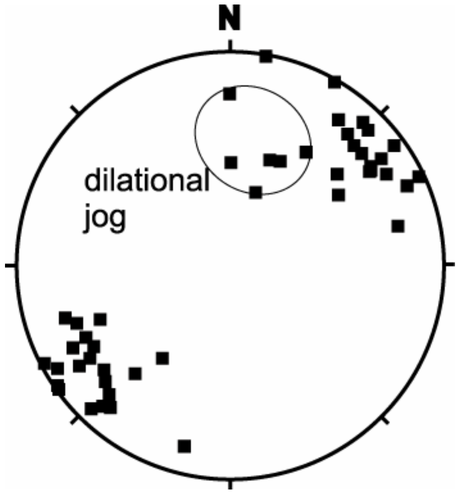

Figure 22. *Lower hemisphere equal area projection of poles to the penetrative* S_1 *foliation.*

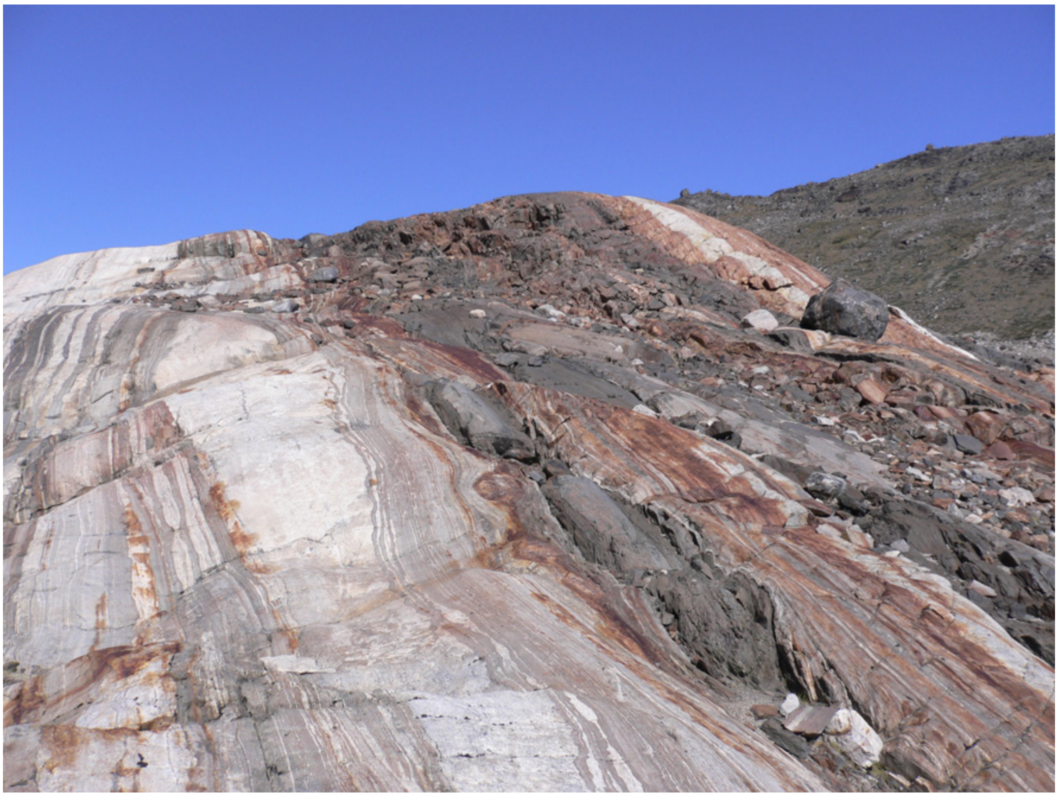

Figure 23. *Mineralised (rusty) shear zones at the gneiss-amphibolite contacts (2007jkol55).*

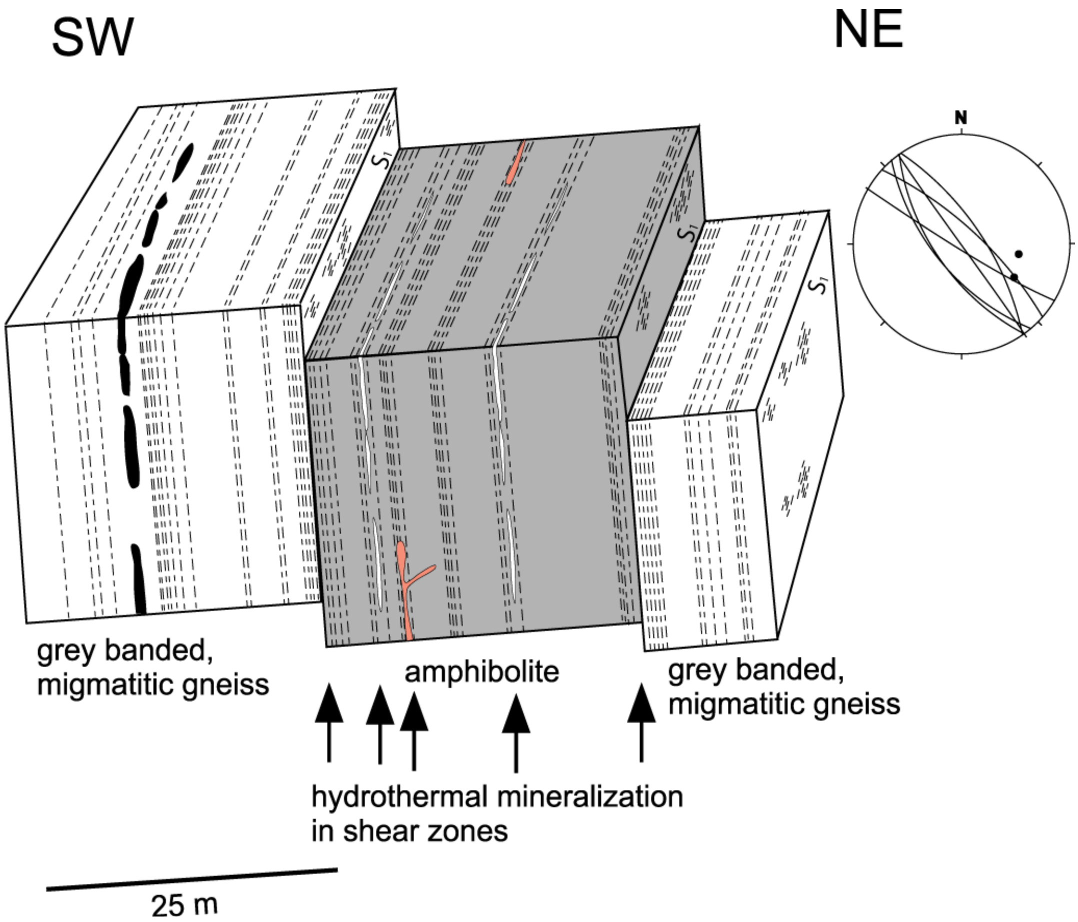

Figure 24. *3D sketch of the geological situation shown in Fig. 23. Hydrothermal mineralisation and alteration are spatially associated with shear zones at the lithological contact and within the amphibolites. Locally, Qtz veins and granitoid dykes are developed parallel to the S_1 foliation. Granitoids may also crosscut foliation owing to their late- to post-tectonic nature. The inset shows a lower hemisphere equal area projection of great circles for the S_1 foliation and the mineral stretching lineation.*

Figure 25. *Dilational jog in discrete sinistral oblique-slip shear zone marked by the lensoid body (magnet pen, 2007jkol41).*

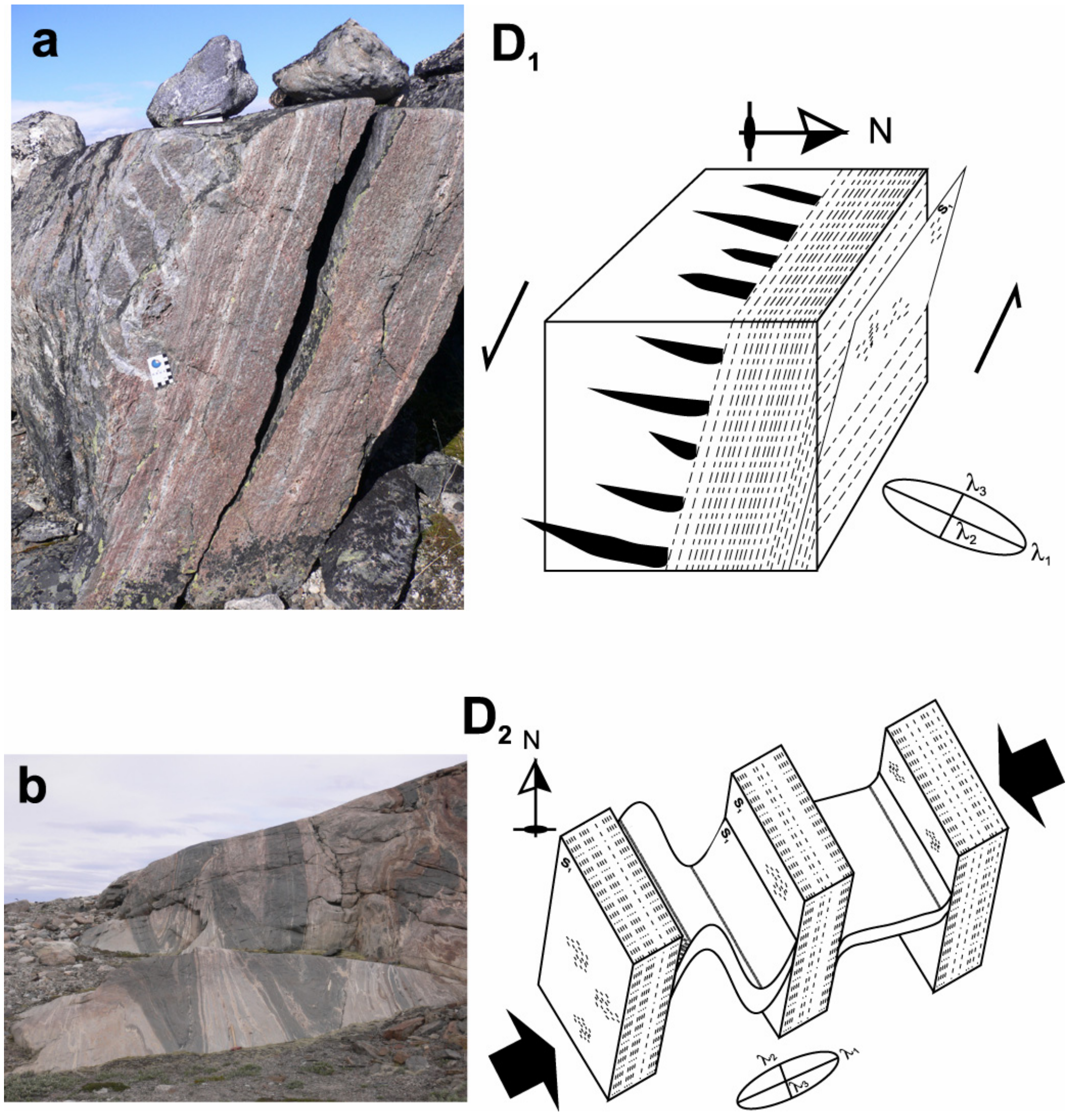

Figure 26. *(a) En echelon array of sigmoidal extension veins at the outer rim of a mineral-ised shear zone (2007jkol43). The 3D sketch shows the geometrical relationship: The Qtz veins dip moderately to the WNW close to perpendicular to the mineral stretching lineation of S_1, consistent with sinistral oblique slip during D_1. (b) Locally developed, upright folds of the penetrative S_1 foliation (2007HST594). Note that mineralised and altered zones are also folded. The 3D sketch shows that folds and sigmoidal foliations are consistent with D_2 WSW-ENE compression (λ_1). The F_2 fold axis lies in the plane of the sigmoidally deformed S_1 foliation, which points to contemporaneous deformation.*

The penetrative S_1 foliation is, locally, folded into upright folds with a F_2 fold axis plunging at 20-40° to the SE (Fig. 26b). This fold axis lies in the plane of sigmoidal S_1 that points to deformation of S_1 in a WSW-ENE oriented compressional regime and small-scale reverse D_2 deformation (Fig. 26b). The regional stress field, therefore, most probably slightly changed from NNE-SSW compression and a transcurrent regime during D_1 to a WSW-ENE oriented compression during D_2.

A D_3 low-angle normal fault is observed as a major structural feature (Figs 3 & 27, 2007jkol62). The fault dips at about 25° to the WNW and has a down-dip striation. Transposition fabrics of the foliation point to normal sense of movement. The displacement is in the order of 40 m.

Figure 27. *Outcrop situation of the D_3 low-angle normal fault (view to the N). The displacement is about 40 m (2007jkol62).*

Mineralisation

Especially in the northern area of Qarliit Nunaat elongate rusty zones mineralised with a sulphide assemblage are common. These mineralised zones are associated with Qtz veins and sinistral oblique-slip shear zones (Figs 19, 23 & 28). The Qtz veins represent shear veins parallel to the foliation (Fig. 29) or, locally, make up an en echelon array of extension veins in competent wall rocks (Fig. 26a). The mineralised zones are up to 6 m wide and can continuously be followed over several km along strike. Several, up to 4, parallel zones are preferably developed at the amphibolite-gneiss contact (Figs 19 & 23). In general, the mineralisation appears to be continuous along the entire strike extent of the amphibolite lenses (Fig. 19).

Figure 28. *Several discrete parallel mineralised (rusty) shear zones (2007jkol43).*

Figure 29. *Laminated, foliation parallel Qtz veins with sulphide alteration in amphibolite (2007jkol60).*

The sheared amphibolite and gneiss comprise a distinct alteration assemblage with disseminated sulphides of up to 20 vol.%. In the grey banded migmatitic gneiss, a Grt-Ms-Py-Ccp-Po alteration paragenesis is developed. An alteration zonation is developed on a cm-scale with proximal Ms and distal Grt. The gneisses are slightly enriched in Pd and Pt to values up to 16 ppb (Table 1). The amphibolite occurs as a fine-grained and a medium-grained variety with distinct alteration characteristics. The alteration paragenesis of the fine-grained amphibolite comprises Qtz-Bt-Grt-Po-Ccp-Py and numerous cm-scale Qtz veins that also contain some sulphides. In the coarse-grained amphibolite, less Qtz veins are developed and the Bt-Grt-Po-Ccp-Py alteration paragenesis lacks Qtz. The altered amphibolite, locally, is weakly enriched in gold < 10 ppb Au (Table 1). No enrichment of precious metals (Pd, Pt, Au) was observed in the quartz veins. The strongly sheared nature of the host rocks and the close association with Qtz veins point to a syn-tectonic hydrothermal origin of the mineralisation and alteration with D_1 deformation. The alteration parageneses developed in the different wall rocks point to a syn-metamorphic hypozonal hydrothermal event akin typical hypozonal orogenic gold systems (e.g. McCuaig & Kerrich 1998).
Intrusions of the white granitoid are ubiquitous in the mineralised shear zones, in which they intruded syn- to late-tectonically (Fig. 19). Locally, the white granitoid also contains mineralised Qtz veins that prove their syn-tectonic and syn-mineralisation nature (Fig. 30).

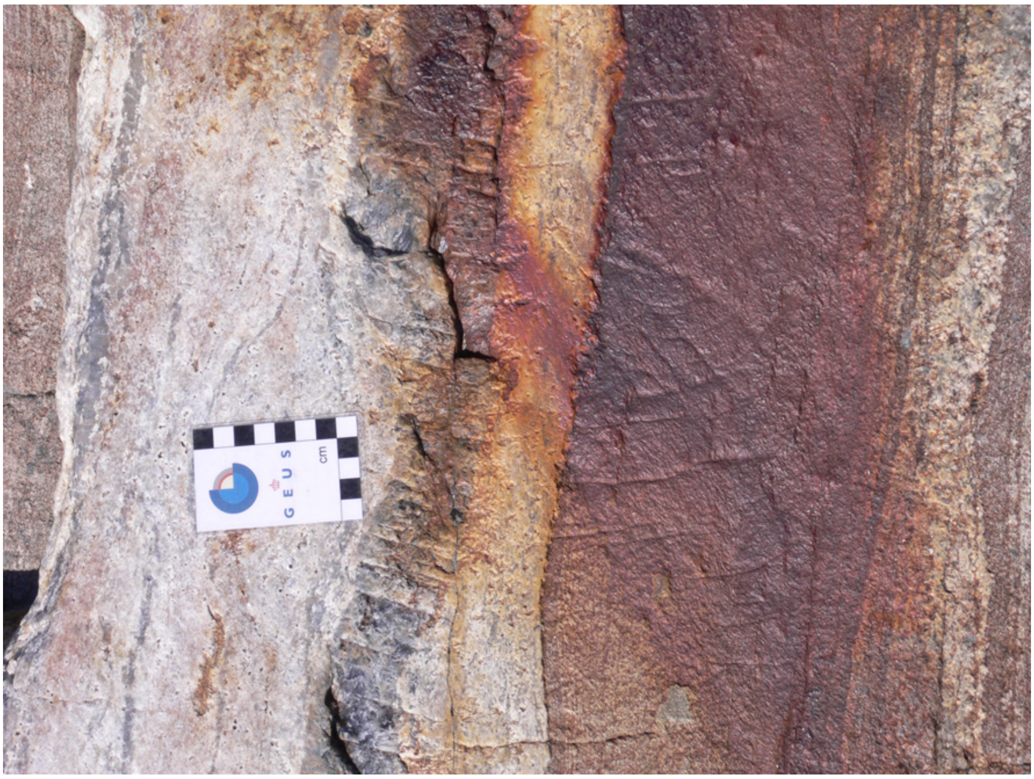

Figure 30. *White granitoid dyke with Qtz vein and sulphide mineralisation (2007jkol55).*

Concluding remarks

Compared to an earlier version of the map of northern Qarliit Nunaat, we reinterpreted the geology slightly. During our detailed work in the area, we were not able to identify any meta-anorthosite outcrop. We therefore deleted this lithology from our version of the map. Furthermore, we found that the amphibolite occurs as several parallel thin lenses, rather than one thick unit. Several dyke-like intrusions of a white granitoid, comprising an unusual mineral paragenesis of 75-90 vol.% Fs, up to 25 vol.% Qtz and up to 5 vol.% Grt, were newly mapped. These granitoids are syn- to late-tectonic with respect to the D_1 oblique sinistral deformation of gneisses and amphibolites.

The entire northern part of Qarliit Nunaat is characterised by parallel, up to 6 m wide, mineralised D_1 shear zones with a sinistral oblique-slip sense of movement, which might be part of the Qarliit Nunaat thrust at the Tasiusarsuaq terrane boundary (Fig. 1; Friend & Nutman 2001; 2005). These mineralised shear zones are best developed at lithological contacts between gneiss and amphibolite. Thick mineralised zones are developed at local bends of the foliation to an E-W strike, forming dilational jogs from m- to 10's of m scale. The mineralisation is characterised by disseminated Po, Py and Ccp and a general Qtz-Bt-Grt-Ms alteration. Sulphides also occur in Qtz veins. However, no significant geochemical enrichment of Pd, Pt and Au were detected. The mineral paragenesis, the Qtz veins and the control of mineralisation by D_1 shear zones strongly suggest that the mineralisation is syn-tectonic hydrothermal. These characteristics are similar to the orogenic gold type of mineralisation. The mineralised area is rather large and occurs in an about 2 km wide zone and can be followed about 10 km along strike. The low gold contents of the analysed samples, however, question a significant hydrothermal gold mineralisation.

Ameralik

In the study area north of Ameralik (Figs 1 & 4, 2007HST600), three lithologies dominate that strike NE-SW (Fig. 31): (1) A medium-grained, grey gneiss in the south; (2) A medium-grained, grey Grt-Bt schist; and (3) a fine-grained, black amphibolite in the north. All rocks are characterised by a near vertical to moderately N dipping, closely spaced foliation. This penetrating foliation is folded by two subsequent folding stages, resulting in a complex fold interference pattern (Fig. 32). One generation of fold axes is near vertical, the other generation plunges at about 40° to the SW. Pegmatites form cm-scale dykes mainly crosscutting the structures, but also deformed pegmatites are observed. It points to a late- to post-tectonic nature of these intrusions.

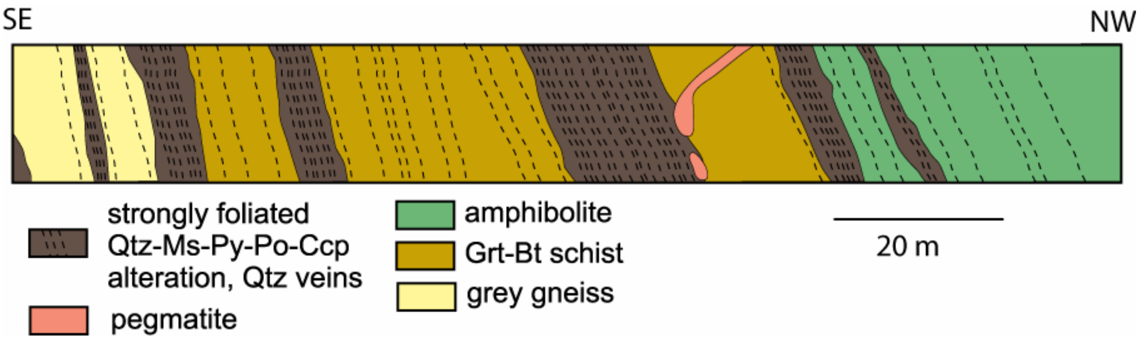

Figure 31. *Schematic NW-SE section through the contact zone of the three major lithologies. Note the sheared alteration zones that are well developed at the contact.*

A sulphide mineralisation together with Qtz veins is spatially associated with the lithological contacts. The mineralised zones can continuously be followed over several km along strike. The mineralisation comprises disseminated Py, Po, arsenopyrite (Apy) and Ccp in sheared Grt-Bt schists and amphibolite. The alteration is characterised by Qtz and Ms. Up to 20 ppb of gold are found in this mineralisation (Table 1). The cm-scale Qtz veins also contain Po and Py. A pegmatite is cut by the mineralised shear zone and contains some Apy and molybdenite (Mo) close to this contact.

Figure 32. *Outcrop situation showing the mineralised (rusty) zones and folding of the penetrative foliation, including mineralised horizons.*

The mineralisation is hosted by sheared rocks, is associated with Qtz veins and is located at lithological contacts. This suggests a hydrothermal shear zone controlled origin for sulphide mineralisation and alteration. The role of the pegmatite remains unresolved, but they are not mineralised with precious metals (Table 1). It is, however, to small to be responsible for the hydrothermal mineralisation with a strike extent over several km.

Reco – locality X

A short reco (red X in Fig. 1) was caused by another GEUS team, who reported sulphide mineralisation within some rust zones (2007HST609 – 2007HST611). A banded gneiss unit is cut by parallel shear zones striking N-S with moderate dips towards east. The rusty zones are from dm to m in width and can be followed tens of m along strike. They comprise a Qtz-Fs-Bt±Grt alteration assemblage accompanied by little Fe-sulphides, mainly pyrite. In one place, the gneiss is intruded by a one m thick dolerite dyke. This dyke is deformed and in the contact with the gneiss, a pegmatite intruded gneiss and dyke and altered the dyke. Along the pegmatite contacts small amounts of iron sulphides are observed. Geochemically, no mineralisation is detected (Table 1).

Table 1. *List of samples and locations with a brief sample description (cf.,* Figs *2-4).*

Locality	Latitude	Longitude	Sample number	Sample description	Pd [ppb]	Pt [ppb]	Au [ppb]
2007HST513	64.3546	-49.296717	514801	Hornblendite - chilled margin	bdl	bdl	bdl
2007HST513	64.3546	-49.296717	514802	Hornblendite - central part - Ol, Px, Hbl	bdl	bdl	bdl
2007HST515	64.3437	-49.347952	514803	Laminated amphibolite with little garnet	na	na	na
2007HST517	64.34364	-49.35513	514804	Biotite amphibolite with mm-scale quartz veins	bdl	bdl	8
2007HST517	64.34364	-49.35513	514805	Garnet amphibolite with pyrite	bdl	bdl	bdl
2007HST518	64.34334	-49.355634	514806	Garnet amphibolite with disseminated pyrite	bdl	bdl	bdl
2007HST519	64.34305	-49.356337	514807	Garnet-biotite pegmatite - 30 cm vein	bdl	bdl	bdl
2007HST521	64.34247	-49.362887	514808	Pyroxenite	na	na	na
2007HST522	64.34288	-49.361583	514809	Pyroxenite with chromite (?)	bdl	9	bdl
2007HST524	64.33886	-49.358155	514810	Hornblendite with garnet and diss Fe-sulphides	bdl	bdl	5
2007HST525	64.33889	-49.365102	514811	Silicified amphibolite with diss pyrite	bdl	bdl	bdl
2007HST526	64.33895	-49.36647	514812	Calc-silicate amphibolite - Di-Grt	na	na	na
2007HST527	64.33863	-49.367184	514813	Qtz-Ms fels (exhalite)	bdl	bdl	bdl
2007HST527	64.33863	-49.367184	514814	Qtz-Bt fels (exhalite)	bdl	bdl	bdl
2007HST527	64.33863	-49.367184	514815	Felsic gneiss (felsic meta-volcanic?)	na	na	na
2007HST528	64.33883	-49.370794	514816	Qtz-Bt fels (exhalite)	7	7	bdl
2007HST528	64.33883	-49.370794	514817	Grt-Sil gneiss	na	na	na
2007HST529	64.34077	-49.375713	514818	Peridotite with diss Po	bdl	bdl	bdl
2007HST530	64.34287	-49.379125	514819	Qtz-Grt-Sil gneiss	bdl	bdl	bdl
2007HST535	64.37161	-49.422796	514820	Amphibolite - Grt-Hbl-Bt	bdl	bdl	bdl
2007HST536	64.37197	-49.422523	514821	Rusty Bt anorthosite	bdl	bdl	2
2007HST537	64.37224	-49.422662	514822	Coarse-grained anorthosite	na	na	na
2007HST538	64.3731	-49.423655	514823	Garnet amphibolite	na	na	na
2007HST539	64.37372	-49.419841	514824	Grt-Fs-Qtz-Bt gneiss	na	na	na
2007HST541	64.37473	-49.41688	514825	Grt-Fs-Qtz-Bt gneiss with diss pyrite	bdl	bdl	bdl
2007HST541	64.37473	-49.41688	514826	Qtz-Bt fels (exhalite) with pyrite	bdl	bdl	4
2007HST542	64.37421	-49.41137	514827	Garnet amphibolite with diss pyrite	bdl	bdl	10

Table 1. *List of samples and locations with a brief sample description (cf.,* Figs *2-4).*

Locality	Latitude	Longitude	Sample number	Sample description	Pd [ppb]	Pt [ppb]	Au [ppb]
2007HST543	64.37209	-49.41299	514828	ultramafic rock, Bt-Tre	na	na	na
2007HST545	64.37257	-49.400089	514829	Pink granite	na	na	na
2007HST549	64.37509	-49.384033	514830	Gabbro - homogeneous amphibolite	na	na	na
2007HST549	64.37509	-49.384033	514831	Fine-grained amphibolite	na	na	na
2007HST550	64.37574	-49.377435	514832	Fine-grained homogeneous granite	na	na	na
2007HST553	64.36148	-49.425409	514833	Homogeneous amphibolite	na	na	na
2007HST554	64.3608	-49.423521	514834	Medium-grained dark amphibolite from pillow sequence	na	na	na
2007HST555	64.35863	-49.416177	514835	Calc-silicate amphibolite - with diss Po, Py, Ccp	bdl	bdl	203
2007HST555	64.35863	-49.416177	514836	Banded amphibolite with Qtz vein and diss Fe-sulphides	bdl	bdl	9
2007HST557	64.35373	-49.395835	514837	Komatiite (?) with diss Py	bdl	bdl	bdl
2007HST558	64.35694	-49.397294	514838	Komatiite (?) / peridotite	na	na	na
2007HST559	64.35794	-49.399241	514839	Garnet amphibolite with malachite and Ccp	bdl	bdl	42
2007HST562	64.36266	-49.413838	514840	ultrmafic rock Hbl-Grt	na	na	na
2007HST565	64.09852	-49.669061	514841	Silicified amphibolite with diss Fe-sulphides	bdl	bdl	bdl
2007HST566	64.09874	-49.663079	514842	Garnet-biotite gneiss with diss Po	bdl	bdl	bdl
2007HST567	64.1019	-49.659416	514843	Silicified banded, white gneiss	na	na	na
2007HST568	64.10334	-49.675225	514844	Fine-grained amphibolite with diss Ccp and Fe-sulphides	bdl	bdl	3
2007HST568	64.10334	-49.675225	514845	Medium grained dark amphibolite with Qtz vein and diss Ccp and Po	bdl	bdl	bdl
2007HST569	64.10247	-49.674195	514846	Silicified amphibolite with garnet, biotite and diss Po	bdl	bdl	bdl
2007HST570	64.10182	-49.675793	514847	Fine-grained dark gneiss with diss pyrite	13	12	bdl
2007HST570	64.10182	-49.675793	514848	Medium grained biotite-garnet gneiss with diss Po	14	6	bdl
2007HST571	64.08976	-49.673889	514849	Qtz-rich gneiss	na	na	na
2007HST572	64.0906	-49.662806	514850	White granite with garnet and amazonite	na	na	na
2007HST574	64.09494	-49.653139	514851	Metagabbro	na	na	na
2007HST574	64.09494	-49.653139	514852	Fine-grained amphibolite with diss Fe-sulphides and white mica	5	6	2
2007HST575	64.09535	-49.65381	514853	Garnet gneiss with mica and diss Fe-sulphides	5	bdl	2
2007HST578	64.09241	-49.68429	514854	Medium-grained homogenous gneiss with diss Mag	na	na	na

Table 1. *List of samples and locations with a brief sample description (cf.,* Figs *2-4).*

Locality	Latitude	Longitude	Sample number	Sample description	Pd [ppb]	Pt [ppb]	Au [ppb]
2007HST584	64.1161	-49.675745	514855	Medium-grained amphibolite, Qtz veining, Grt-Bt alteration and Fe-sulphides	bdl	bdl	2
2007HST584	64.1161	-49.675745	514856	Qtz-mica gneiss with diss Fe-sulpides	bdl	bdl	bdl
2007HST584	64.1161	-49.675745	514857	Qtz-mica gneiss with diss Fe-sulpides	bdl	bdl	bdl
2007HST584	64.1161	-49.675745	514858	Garnet gneiss with diss Fe-sulphides	bdl	bdl	bdl
2007HST589	64.12092	-49.677386	514859	Calc-silicate amphibolite	bdl	bdl	3
2007HST589	64.12092	-49.677386	514860	Qtz-Bt-Grt gneiss with diss pyrite	bdl	bdl	bdl
2007jkol51	64.122390	-49.678358	514861	Silicified amphibolite with diss pyrite	bdl	bdl	11
2007jkol52	64.121890	-49.679560	514862	Mineralised contact between gneiss and white granite with diss pyrite	9	11	7
2007jkol53	64.122180	-49.680577	514863	Altered and mineralised amphibolite with diss Fe sulphides	na	na	na
2007jkol54	64.119430	-49.681756	514864	Altered and mineralised contact between amphibolite and gneiss with diss Fe sulphides	na	na	na
2007HST590	64.1087	-49.6876	514865	20 cm rusty shear zone in amphibolite with diss pyrite	5	bdl	bdl
2007HST590	64.1087	-49.6876	514866	Garnet gneiss (felsic layer) in amphibolite	na	na	na
2007HST591	64.10892	-49.687069	514867	Laminated garnet gneiss	bdl	bdl	bdl
2007HST592	64.109	-49.686678	514868	Qtz vein	bdl	bdl	bdl
2007HST593	64.10914	-49.685943	514869	Medium- to coarse-grained gabbro	na	na	na
2007HST595	64.10951	-49.684982	514870	Fine-grained Qtz-bearing gneiss with diss Fe-sulphides	7	bdl	bdl
2007jkol55	64.120780	-49.729215	514871	Fine-grained black amphibolite with Mag	4	bdl	bdl
2007jkol55	64.120780	-49.729215	514872	Medium-grained black amphibolite and diss Fe-sulphides	bdl	bdl	4
2007jkol55	64.120780	-49.729215	514873	Qtz vein with sulphides	bdl	bdl	bdl
2007jkol56	64.122210	-49.727768	514874	Altered gneiss with diss Fe-sulphides	bdl	bdl	2
2007jkol57	64.120040	-49.726485	514875	White Fs-Qtz granite with Qtz vein and diss Fe-sulphides	bdl	bdl	bdl
2007jkol60	64.115500	-49.701349	514876	Medium-grained black amphibolite	bdl	bdl	bdl
2007jkol64	64.114460	-49.693757	514877	Felsic part of laminated gneiss	na	na	na
2007HST595	64.10951	-49.684982	514878	Grt-Bt gneiss with diss Fe sulphide	11	10	bdl

Table 1. *List of samples and locations with a brief sample description (cf.,* Figs *2-4).*

Locality	Latitude	Longitude	Sample number	Sample description	Pd [ppb]	Pt [ppb]	Au [ppb]
2007HST595	64.10951	-49.684982	514879	Fine-grained, dark Qtz-rich gneiss with diss sulphides	16	6	bdl
2007HST590	64.1087	-49.6876	514880	Rusty amphibolite and Qtz veins	bdl	bdl	bdl
2007HST598	64.10894	-49.687026	514881	White gneiss (meta-rhyolite?)	na	na	na
2007HST600	64.17164	-50.908612	514882	Biotite gneiss	na	na	na
2007HST600	64.17164	-50.908612	514883	Rusty Bt schist with diss Fe-sulphides (Apy?)	bdl	bdl	3
2007HST601	64.17029	-50.905978	514884	Rusty biotite schist	bdl	bdl	bdl
2007HST602	64.16925	-50.905967	514885	Reddish coloured Bt schist	bdl	bdl	bdl
2007HST603	64.16751	-50.906519	514886	Reddish coloured Bt schist	bdl	bdl	bdl
2007HST604	64.16295	-50.911321	514887	Rusty shear zone in amphibolite with diss Fe-sulphides	bdl	bdl	20
2007HST604	64.16295	-50.911321	514888	Fine-grained Qtz-bearing gneiss with diss Fe-sulphides	bdl	bdl	3
2007HST605	64.16291	-50.911068	514889	Fine-grained Qtz-bearing gneiss with diss Fe-sulphides	bdl	bdl	bdl
2007HST604	64.16295	-50.911321	514890	Pegmatite with molybdenite	bdl	bdl	bdl
2007HST608	64.16285	-50.908799	514891	Qtz-Bt schist with diss Po	bdl	bdl	bdl
2007HST609	64.08553	-50.42127	514892	Banded rusty gneiss	bdl	bdl	bdl
2007HST610	64.08537	-50.421565	514893	Deformed dolerite dyke	bdl	bdl	bdl
2007HST611	64.08559	-50.422869	514894	Qtz-Bt gneiss with diss pyrite	bdl	bdl	2

Notes: bdl - below detection limit, na - not analysed

Summary and conclusions

The geological environments studied here are typical of Archaean terranes, including: (1) greenstone belts; (2) TTG gneiss terranes; and (3) mafic layered intrusion complexes. The formation of the rocks in these various geological environments goes ahead with typical syngenetic mineralisation. The mafic meta-anorthosite to meta-leucogabbro complexes and associated peridotite dykes on Nunataarsuk, locally, contain small magnetite and sulphide occurrences that formed by igneous processes during the intrusion of these rocks into supracrustal rocks of the greenstone belts of unknown age. However, these occurrences have low sulphide contents, no Pd-Pt-Au enrichment and are not consistent along strike. In greenstone belt lithologies on Nunataarsuk, rocks with a sulphide- and silica-rich mineralisation are observed, which are associated with pillow structures in amphibolites. This and the characteristic mineral assemblage of Py, Ccp, Apy and Po suggests that the mineralisation formed by hydrothermal processes on the seafloor similar to VMS-type of base metal deposits. The limited area of mineralisation, the absence of massive sulphide horizons and the low gold contents make this type of geological environment and related mineralisation unlikely for a significant mineral occurrence.

Another type of hydrothermal mineralisation studied here is associated with mylonites in greenstone belts and TTG gneiss terranes. The epigenetic, syn-tectonic and syn-metamorphic nature of the occurrences observed in Qarliit Nunaat and on the northern side of Ameralik indicates an orogenic gold style of mineralisation, although geochemical data shows only low gold contents. Note that these locations and studied occurrences, namely the Kang mineralisation (Hollis *et al.* 2006) and hydrothermal alteration known from the Buksefjorden area (Stendal & Schérsten 2007), are located at or close to the terrane boundary of the Tasiusarsuaq and Tre Brødre terranes (Fig. 1). This is regarded as a favourable geological environment for the formation of orogenic gold deposits worldwide (e.g. McCuaig & Kerrich 1998).

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References

Escher, J.C. & Pulvertaft, T.C.R. 1995: Geological map of Greenland, 1:2 500 000, Copenhagen: Geological Survey of Greenland.

Frei, D. & Konnerup-Madsen, J. 2007: Magmatic environment: The Naujat gabbro-anorthosite complex and country rocks - Field report 2006. In: Stendal, H. (ed.): Characterisation of selected geological environments. Mineral resource assessment of the Archaean Craton SW Greenland. Contribution no. 1 **2007/20**, 41-58 Danmarks og Grønlands Geologiske Undersøgelse Rapport.

Friend, C.R.L. & Nutman, A.P. 2001: U-Pb zircon study of tectonically bounded blocks of 2940-2840 Ma crust with different metamorphic histories, Paamiut region, South-West Greenland: implications for the tectonic assembly of the North Atlantic craton. Precambrian Research **105**, 143-164.

Friend, C.R.L. & Nutman, A.P. 2005: New pieces to the Archaean terrane jigsaw puzzle in the Nuuk region, southern West Greenland: steps in transforming a simple insight into a complex regional tectonothermal model. Journal of the Geological Society, London **162**, 147 - 162.

Hollis, J.A., Schmied, S., Stendal, H., van Gool, J.A.M. & Weng, W.L. 2006: Supracrustal belts in Godthåbsfjord region, southern West Greenland. Progress report on 2005 field work: geological mapping, regional hydrothermal alteration and tectonic sections. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2006/7**, 171 pp.

McCuaig, T.C. & Kerrich, R. 1998: P-T-t deformation fluid characteristics of lode-gold deposits: evidence from alteration systematics. Ore Geology Reviews **12**, 381-453.

Myers, J. 2007: Map of eastern Nunataarsuk included in the preliminary version of the Kapisillit 1:100.000 geological map. Geological Suervey of Denmark and Greenland (GEUS).

Stendal, H. & Scherstén, A. 2007: Geological Environments: Oceanic crust and hydrothermal alterations - Field report 2006. In: Stendal, H. (ed.): Characterisation of selected geological environments. Mineral resource assessment of the Archaean Craton SW Greenland. Contribution no. 1 **2007/20**, 59-88 Danmarks og Grønlands Geologiske Undersøgelse Rapport.