DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2013/11

Geological and geophysical data of the Kobberminebugt area between Sermiligaarsuk and Sermilik

A report to Pyhäsalmi Mine Oy

Jochen Kolb (Editor)

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Contents

Abstract

The Kobberminebugt area in South and South-West Greenland, reaching from the Sermiligaarsuk Fjord in the north to the Sermilik Fjord in the south, was mapped by GEUS in the 1970s and later studied in more detail in terms of orogenic evolution and ore geology. This was supported by regional geophysical surveys in the 1990s and by a regional geochemical stream sample program.

The geology is characterized by Archaean orthogneisses and greenstone belts in the north, which are structurally and unconformably overlain by Palaeoproterozoic metasedimentary and metavolcanic rocks. The Kobberminebugt shear zone system separates this northern terrane from the Ketilidian granitoids of the Julianehåb Batholith in the south. The Julianehåb Batholith is interpreted as the Palaeoproterozoic magmatic arc of the Ketilidian Orogen and the northern terrane as the foreland in the North Atlantic Craton. Late- to post-tectonic granites intruded the different terranes in the Palaeoproterozoic.

The Kobberminebugt area was reactivated by rifting in the Mesoproterozoic, and dykes and intrusions of the alkaline Gardar Province were emplaced. Small basins were filled by sedimentary rocks of the Eriksfjord Formation.

The exploration and exploitation history began already in the 1850s with mining of cryolite and copper form the Ivigtut Cryolite and Josva mines. Several exploration programs followed the mining activity targeted at discovering cryolite, Fe, Cu, precious metals, Nb, P, Ni using different exploration models.

Geophysical data mainly outlines the geologically different terranes, where the Julianehåb Batholith and the late- to post-tectonic granites as well as dykes and intrusions of the Gardar Province are characterized by positive magnetic anomalies. The two parallel shear zones in the Kobberminebugt and at Blindtarmen are outlined by linear magnetic anomalies. The intrusions of the Gardar Province and the Palaeoproterozoic metasedimentary rocks are characterized by positive anomalies in the radiometric equivalent of potassium.

Similarly, the geochemical stream sediment data reflects characteristics of the geologically different terranes. The regional data set confirms Au and Cu anomalies on Arsuk Ø and around Josva Mine, but does not outline other obvious anomalies in the study area.

Different potentially interesting mineralization sites have been identified, such as kimberlites with micro-diamonds, banded iron formations in the Palaeoproterozoic strata, and alkaline rocks of the Gradar Province hosting REE, F, P, etc. enrichment. The three main types of base metal sulphide ores are distinguished: (1) disseminated, syngenetic, stratabound sulphides in (meta)volcanic rocks and marbles; (2) sulphides associated with orogenic quartz veins; and (3) shear zone-hosted, mesothermal copper sulphide – iron oxide possible IOCG-type mineralisation.

The regional geology defines three main different tectonic settings, which may relate to different ore potential: (1) orogenic gold in Archaean greenstone belts; (2) Palaeoproterozoic arc to retro-arc setting; and (3) Mesoproterozoic continental rift setting.

Introduction

This is a report compiling data from GEUS' archives for the Kobberminebugt area in South and South-West Greenland, reaching from the Sermiligaarsuk Fjord in the north to the Sermilik Fjord in the south. The content was agreed on in a meeting between researchers from GEUS and Timo Mäki, chief geologist at Pyhäsalmi Mine Oy. The content of this report will remain confidential for 12 months after it was realised until February, the 1st 2014.
In the following chapters different GEUS geologists and geophysicists summarize the regional geology, structural geology, exploration history, ore geology, stream sediment geochemistry, geophysical investigations and list the available literature, reports, maps and data.

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Regional geological setting (Næraa)

The “Kobberminebugt area” is situated in South-West and South Greenland, and geologically it consists of the northwestern zone of the Palaeoproterozoic Ketilidian Orogen and the southernmost rocks of the Archaean North Atlantic Cration (Fig. 1 and 2, Allaart 1975). The area includes intrusive rocks related to the Mesoproterozoic Gardar Province including the Ivigtut granite well-known for hosting the historic kryolite mine (Goodenough *et al.* 2000; Upton *et al.* 2003). The Ketilidian Orogen is described as an accretionary orogen related to north directed subduction, and the magmatic arc mainly formed in the period from ca. 1850–1800 Ma, with later mainly post tectonic magmatism at ca. 1720 Ma (Chadwick & Garde 1996; Garde *et al.* 2002a). The Ketilidian Orogen divides into four zones, namely Border Zone, Julianehåb Batholith, Psammite Zone and Pelite Zone (Garde *et al.* 2002a). The two northern zones, the Border Zone and the Julianehåb Batholith, are present in the Kobberminebugt area.

In the Border Zone, the Archaean basement is overlain by a sedimentary and volcanic cover of low metamorphic grade (Fig. 1) which, together with the Archaean basement, is increasingly overprinted by Ketilidian deformation towards the south (Garde *et al.* 2002a). The Archaean basement consist of mainly felsic orthogneiss (Friend & Nutman 2001) and greenstone belts of metavolcanic and metasedimentary rocks of the Tartoq Group (Szilas *et al.* 2013). The late intrusive Gardar Province formed in an extensional setting in the period from ca. 1350 to 1140 Ma (Upton *et al.* 2003).

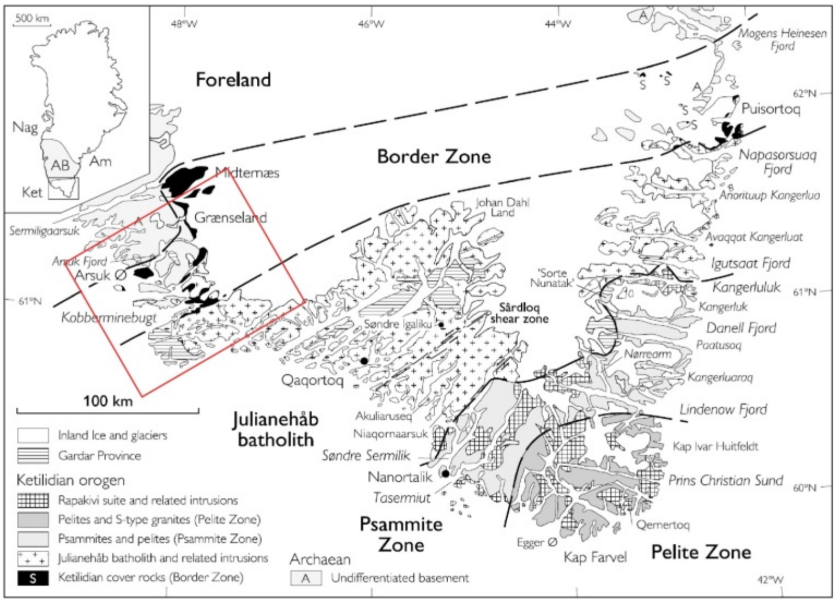

Figure 1. *Geological map of southwest Greenland. The red square represents the area focused on this report. From Garde et al. (2002).*

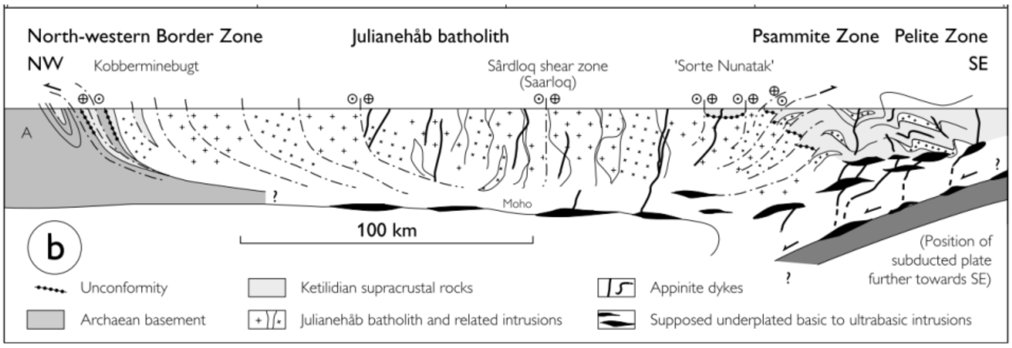

Figure 2. *Cross section of the Ketilidian orogen; from Garde et al. (2002).*

The Archaean Foreland

The overall understanding of the crustal development in the Archaean of western Greenland is generally explained by two early periods of crustal growth by TTG intrusion of tonalite, throndhjemite and granodiorite (TTG) from around 3900 to 3500 Ma and again from ca. 3200 to 2840 Ma (Næraa *et al.* 2012). These two growth periods are followed by later periods of crustal reworking from ca. 2800 to 2500 Ma (Nutman *et al.* 2011).

The Archaean basement of the Kobberminebugt area is represented by the Sermiligaarsuk Block, which is defined on the basis of its generally low metamorphic grade (greenschist to amphibolite facies), compared to the amphibolite and granulite facies rocks, present towards the north (Friend & Nutman 2001). Felsic orthogneisses of TTG composition predominate. The Tartoq Group greenstone belts form synclines and are thrust on top of the orthogneisses in an Archaean accretionary complex (Fig. 1 and 3, Kisters *et al.* 2012; Szilas *et al.* 2013). Age wise the Sermiligaarsuk Block is poorly known, and recent zircon U/Pb age data have only been obtained from north of Sermiligaarsuk Fjord and within the Tatoq Group (Keulen *et al.* 2011). Recent whole rock Lu-Hf isotope data of metavolcanic rocks from the Tatoq Group yield a isochron age of 3189±65 Ma (Szilas *et al.* 2013). The zircon U/Pb data from felsic orthogneisses north of the Tatoq Group range from ca. 3000 Ma to ca. 2840 Ma (Keulen *et al.* 2011). Zircons from the orthogneiss basement, north of the Sermiligaarsuk Fjord, reveal U/Pb resetting and metamorphic ages that mainly cluster in the period from ca. 2800 to 2700 Ma, indicating Neoarchaean tectonism and metamorphism (Kisters *et al.* 2012; Kolb 2011). Late Archaean pegmatites and minor granitic intrusion have been dated at ca. 2600 to 2500 Ma (Kokfelt, unpubl. data).

The Archaean basement is cut by at least three generations of metadoleritic dykes (MD) that were emplaced after ca. 2500 Ma, and before the onset of the Ketilidian orogeny (Berthelsen & Henriksen 1975; Kalsbeek & Taylor 1985a). The three major generations of dykes occur as a N-S trending set (MD1), that is cut by a NE-SW trending set (MD2) which, in turn, is cut by a WNW-ESE trending set (MD3). Most of the MD dykes have a thickness of a few tens of metres but they can range up to more than 100 m in width. In the region, only MD2 and MD3 dykes sampled to the north of the Sermiligaarsuk Fjordhave been dated (Kalsbeek & Taylor 1985a). These two sets of dykes have, within the uncertainly (ca. ± 100 Ma), similar ages. Pooled together the MD2 and MD3 dykes yield a Rb–Sr isochron age of 2130 ± 65 Ma (Kalsbeek & Taylor 1985a). The two sets of dykes however yield resolvable differences in initial Sr isotope values (Sri), with the MD3 dykes having a significantly higher Sri value (0.70277±0.00012) than the MD2 dykes (0.70155±0.00018) (Kalsbeek & Taylor 1985a).

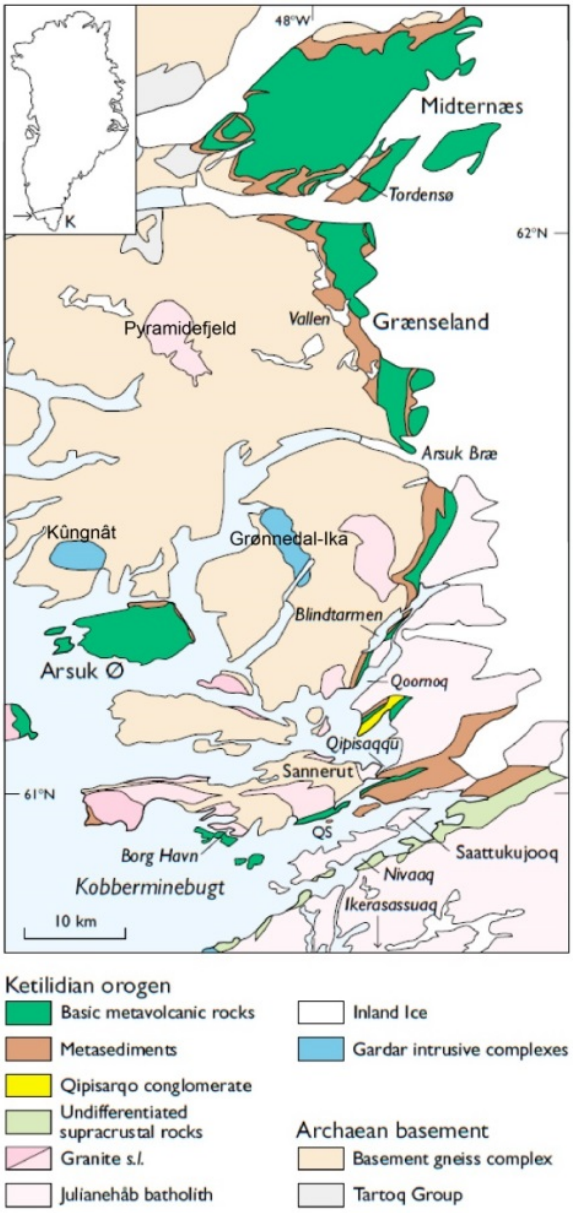

Figure 3. *Simplified geological map of the Border Zone of the Ketilidian Orogen. QS: Qaqortup Sallersua (from Garde et al. 1998).*

The Border Zone

The Border Zone is an up to 50 km wide belt consisting of Archaean basement unconformably overlain by Palaeoproterozoic metasedimentary and metabasaltic rocks of the Vallen and Sortis groups (Fig. 1 and 3, Bondesen 1970; Higgins 1970). The Palaeoproterozoic basic dykes of the the Iggavik Suite that crosscut the Archaean basement do not intrude into the cover (Berthelsen & Henriksen 1975). The Vallen and Sortis groups cover an area of around 80 km^2, mainly outcropping along the margin of the ice cap between Midternæs and Kobberminebugt, with a smaller area present on and around Arsuk Ø (Fig. 3 and 4). The northernmost occurrences on Midternæs are unmetamorphosed and unconformably overlying the peneplained surface of Archaean basement.

	MIDTERNÆS		GRÆNSELAND		ARSUK Ø	STORØ		
SORTIS GROUP	Thick pillow lavas	4800 m with c. 5% sediments	Qernertoq Formation					ARSUK GROUP
	Lavas and sediments including pyroclastics		Rendesten Formation	Banded semipelites and pelites (500 m) Pelites, semipelites (100 m) or bedded psammites with pelites and greywackes (300 m) Pyroclastics (200 m) Semipelites, graded greywackes (200 m) or pelites, pyroclastics (400 m) Pyroclastics (0–1000 m) Dolomites and pelites (0–100 m)	Pillow lavas, including pyroclastics, black pyritic phyllites and chert Amoeboid pillow lavas Pillow lavas and lavas, including pyroclastics, black pyritic phyllites and black cherts Banded chert with intercalated pyritic phyllites and quartzitic slabs (80–20 m)			
	Pillow lava (100–900 m) with thin sediments		Foselv Formation	Upper Pillow Member (700 m) Anthracite-Carbonaceous Shale Member (1–3 m) Lower Pillow Member (300 m)	Pillow lavas and pillow breccias, with lavas and/or sills			
VALLEN GROUP	Principally limestone with shales and thin quartzites. *Vallenia* bed in NE Midternæs		Grænsesø Formation	Cherty quartzite, pelite and dolomite Massive dolomite with *Vallenia* Carbonaceous pelites 20–100 m	Pyritic and graphitic phyllites, cherts Black banded phyllites (locally pyritic and graphitic). 80 m At the base a large sill	Massive quartzites, banded quartzites, cherts, phyllites in beds of 1–14 m. Total 70 m including minor sills. Large sill at the base (200 m)	Isua Formation	IKERASÂRSSUK GROUP
	Shales, semipelites and graded greywackes (including calcareous bands, cherty quartzites and a 75 m thick arkose) 50–700 m		Blåis Formation	Rock unit with strong facies variations: Graded or banded greywackes Semipelites – banded shales and slates Pelites – finely laminated, interbedded Shales and slates	(Covered by sea or missing) Top unknown Graphitic and pyritic schists Orthoquartzites and arkoses Dolomite quartzite Calcareous dolomite Biotite-garnet schists Arkosic schists and quartzitic phyllites Volcanic tuff	Banded quartzites Banded phyllites Arkosic quartzites Base unknown	Inugsugtût Formation Unexposed Taylers Havn Formation	
	Calcareous shales, and sandstones (< 35 m) Quartzites and sandstones (0–100 m) Conglomerate (0–4 m)		Zigzagland Formation – Upper	Dolomite Shale Member (0–150 m) Banded Quartzite Member (3–140 m) Ore-Conglomerate Member (1–10 m)	Calcareous dolomite (7 m) Banded phyllites (50 m) Banded phyllites and dolomitic quartzites (80–100 m) Quartzites (80–100 m)			
			Zigzagland Formation – Lower	Rusty Dolomite Member (0–8 m) Varved Shale Member (2–10 m) Lower Dolomite Member (3 m) Residual deposits on the sub-Ketilidian surface	Banded dolomitic quartzites Calcareous dolomitic phyllites	10–15 m only exposed on Evqitsut island		
	Unconformity			Unconformity	Structural discordance at Taylers Havn			

Figure 4. *Stratigraphy of the Palaeoproterozoic volcanic and sedimentary rocks of the Border Zone (Allaart 1976).*

The Vallen Group consists of a roughly 1.2 km-thick sequence of sedimentary rocks showing increasing grades of metamorphism to the south reaching amphibolite facies grades in the Kobberminebugt (Bondesen 1970; Higgins 1970). The lower part consists of shallow marine quartz-pebble conglomerates, quartzites, dolomites, mudstones, cherts, and banded iron formations. The upper part of the group consists of deeper marine greywackes. Sand-sized spherules in a dolomite of the Grænsesø Formation have been interpreted as distal impact ejecta (Chadwick *et al.* 2001).
The Vallen Group is overlain along a thrust by the > 4 km thick Sortis Group, largely consisting of metabasaltic pillow lavas, pillow breccias and sills, with minor intercalations of mudstone and calcareous rocks (Bondesen 1970). The Sortis Group may be interpreted as a lateral oceanic equivalent of the Vallen Group tectonically superimposed on the latter during early Ketilidian crustal shortening (Garde *et al.* 2002a).
The cover on Arsuk Ø is composed of metabasaltic pillow lavas and sills of the Arsuk Group, which tectonically overly a thin, intensely deformed succession that includes quartzites, phyllites, ferruginous cherts, and metagreywackes of the Ikerasârssuk Group (Fig. 4). They are regarded as stratigraphic equivalents of the Vallen and Sortis groups that have been metamorphosed in the epidote-amphibolite facies (Garde *et al.* 2002a).

The Qipisarqo and Ilordleq groups in the Kobberminebugt region (Fig. 3, Berthelsen & Noe-Nygaard 1965) have been interpreted as deformed and amphibolite facies equivalents of the Vallen and Sortis groups, intruded by granitoids of the Julianehåb Batholith (Garde *et al.* 2002a).

The precise depositional and eruptive ages of the Palaeoproeterozoic rocks described above are unknown. Unpublished conventional U–Pb data of detrital zircons from a quartzite from the Vallen Group in Midternæs yield Neoarchaean ages, pointing towards a provenance derived from the Neoarchaean basement, present to the north (mentioned in Garde et al 2002). A granite clast from the Qipisarqo conglomerate, east of Qipisaqqu (Fig. 3), provides a maximum depositional age of 1880 ± 2 Ma for the upper part of the Qipisarqo Group. A lower age limit of 1848 ± 2 Ma is given by the Qôrnoq augen granite that intruded the Qipisarqo Group (Berthelsen & Henriksen 1975). Geochemical data from metavolcanic rocks in Midternæs, Grænseland, and Arsuk Ø indicates very primitive major and trace element compositions, and flat chondrite-normalized REE patterns, with REE abundances only 3–10 times chondritic, which point to basaltic magmatism during rifting or in an incipient back-arc at an early stage of Palaeoproterozoic convergence (Garde *et al.* 2002a).

The Julianehåb Batholith

The Julianehåb Batholith is 100–200 km wide and was emplaced into and adjacent to the southern margin of the North Atlantic Craton (Garde *et al.* 2002a). The batholith is dominated by granite and granodiorite, with subordinate tonalite, hornblende diorite and gabbro. On normalised trace element diagrams (Fig. 5), the igneous rocks show negative Nb, Ta, P, and Ti anomalies and light REE enrichment, a signature that is typical of subduction related rocks. Thus, the batholith is calc-alkaline and has a geochemistry typical of magmatic arc batholiths. Most granodiorites and granites are medium-grained and weakly porphyritic, and a small percentage of the batholith consist of kilometre-scale dioritic and gabbroic plutons. Dioritic enclaves, present within leucocratic batholith members and synplutonic appinite dyke swarms, are common (Chadwick & Garde 1996). U–Pb zircon and titanite geochronology suggest that the granitoids were largely emplaced in two major pulses between 1854–1836 Ma and 1818–1799 Ma (Garde *et al.* 2002a).

The boundary between the Julianehåb Batholith and the Border Zone is marked by steeply dipping, NE-trending ductile shear zones at Kobberminebugt (Garde *et al.* 2002a). The granitic rocks of the area are characterized by near-vertical magmatic-state planar fabrics, trending NE and with shallow lineations. These fabrics are defined by the preferred orientation of feldspars, hornblende and flattened dioritic enclaves (Chadwick *et al.* 1994). Steeply dipping, NE-trending ductile shear zones, a few centimetres to ca. 1.5 km wide, with high-temperature crystal-plastic fabrics and shallow linear fabrics are also common. High-strain orthogneisses and mylonites in the shear zones have S-C fabrics and shear criteria, which indicate a predominant sinistral strike-slip sense of displacement. These criteria, combined with the predominantly flattening fabrics defined by dioritic enclaves and magmatic-state fabrics, suggest that the batholith was emplaced during sinistral transpression, probably in a regime of oblique convergence (Chadwick & Garde 1996).

The geochemical and isotopic signatures of the Julianehåb Batholith suggest that it consists of mainly juvenile crustal additions (Chadwick & Garde 1996; Kalsbeek & Taylor 1985b; Patchett & Bridgwater 1984; Stendal & Frei 2000). In more detail, results from Sm/Nd isotope studies on whole rock powders show that initial εNd values range from about 0 to +5 (Fig. 6). Amphibolites from the Psammite Zone have the highest values of εNd = + 4, which suggest a depleted mantle source (Fig. 6). All other Ketilidian samples have εNd around zero, and as the amphibolites are low in volume and Nd content, the overall Ketilidian Orogen had εNd = 0 at 1900-1700 Ma (Fig. 6). This suggest that a depleted mantle, with εNd = +4 to + 5, was present beneath a developing Keti lidian arc. Thus the Ketilidian Orogen consists largely of juvenile Palaeoproterozoic crust, however an admixture with ~10–15% Archaean crust seems possible from the isotope data (Patchett & Bridgwater 1984).

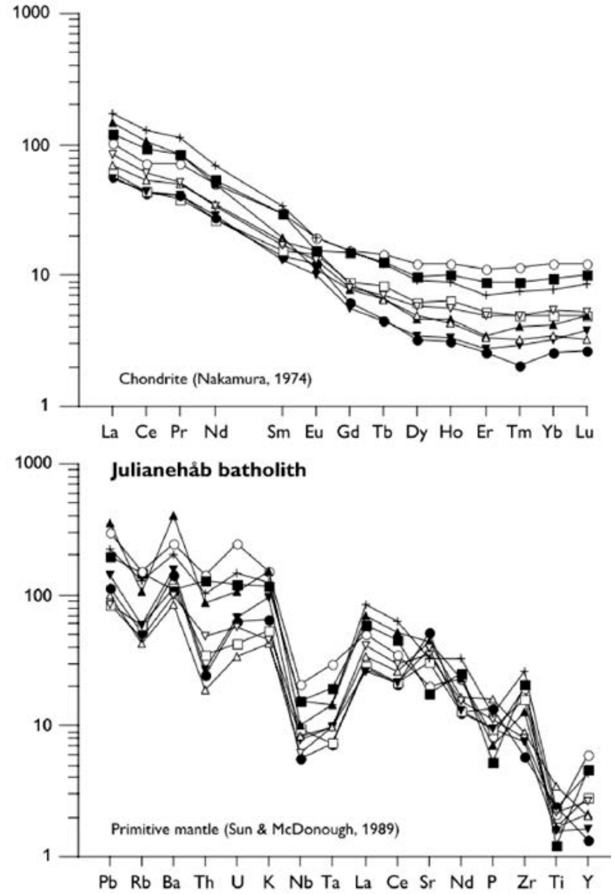

Figure 5. *Normalized trace element patterns of igneous rocks from the Julianehåb Batholith (Garde et al. 2002)*

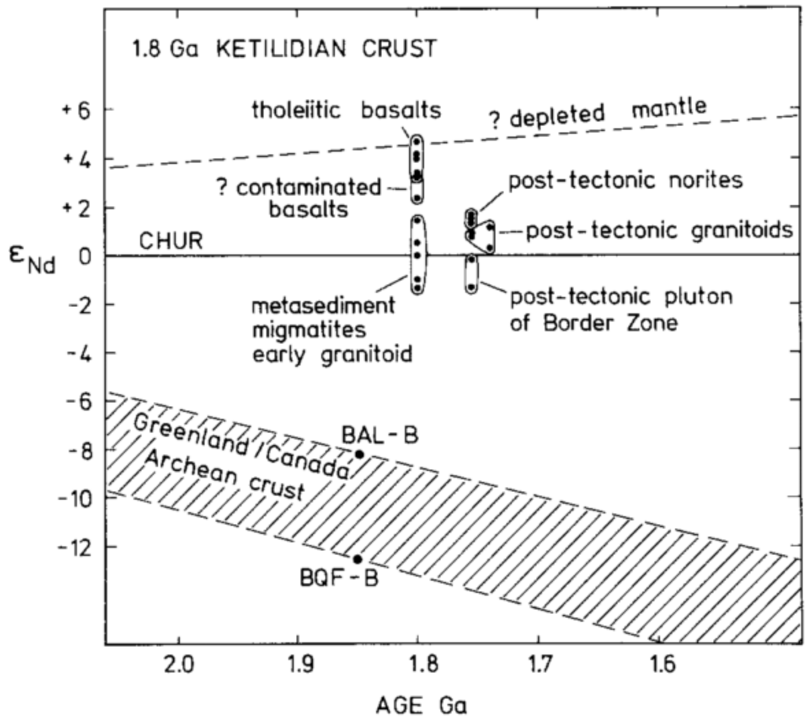

Figure 6. *Nd isotopic data plotted as initial εNd against age known from U-Pb zircon data or otherwise inferred. CHUR = Chondritic Uniform Reservoir (Patchett & Bridgwater 1984).*

The Psammite and Pelite zones

South of the Julianehåb Batholith, outside the Kobbeminebugt area, the Psammite and Pelite zones hava a width of > 100 km. These zones mainly include deformed and metamorphosed feldspathic sandstones and siltstones, with minor components of conglomerates, mudstones, and volcanic rocks (Chadwick & Garde 1996). The zones have an estimated present day thickness of > 10 km. Sediments were largely derived from erosion of the batholith on parts of which they were unconformably deposited between ca. 1795–1790 Ma (Garde *et al.* 2002a). Within a few million years, the sediments were deformed, metamorphosed, intruded by Julianehåb Batholith-related magmas, and metamorphosed at high grades. The Psammite and Pelite zones are interpreted as the proximal parts of a fore-arc basin.

Rapakivi and post-kinematic granites

Rapakivi granites occupy a large extent of South Greenland (ca. 3000 km^2) and were emplaced between 1755–1723 Ma (Garde *et al.* 2002a; van Breemen *et al.* 1974; Windley 1991), mainly as extensive flat-lying sheets within the fore-arc and along its boundary with the Julianehåb Batholith. Post-kinematic granites intruded contemporaneous with the Rapakivi suite and are located both in the northwestern Border Zone (e.g. the Quiartorfik and the Pyramidefjeld granite, Fig. 3) and within the Julianehåb Batholith.

The Gardar Province

Southern Greenland underwent repeated rifting from 1350–1140 Ma during which the Gardar Province alkaline magmatism and sedimentation of the Eriksfjord Formation occurred (Upton *et al.* 2003). The Gardar Province mostly is situated within the Julianehåb Batholith, although its northern extension transgresses the Border Zones and the Archaean foreland (Allaart 1976). The Gardar structures were, to a large extent, controlled by the earlier Ketilidian structural patterns (Fig. 1), and the principal dyke swarms are inferred to occupy zones of Mesoproterozoic lithospheric thinning and graben development. An estimated 2–5 km of Proterozoic cover has been eroded and rift-fill successions, the Eriksfjord Formation, have been preserved in early fault-bounded basins (Upton *et al.* 2003). The concentration of Gardar dykes within the Nunarssuit–Isortoq area and along the axis of the Julianehåb Batholith may imply that these zones marked the sites of subsiding rift basins with higher ground to the north and south and with the two rift basins separated by a central horst structure {Fig. 7, \Upton, 2003 #54}.

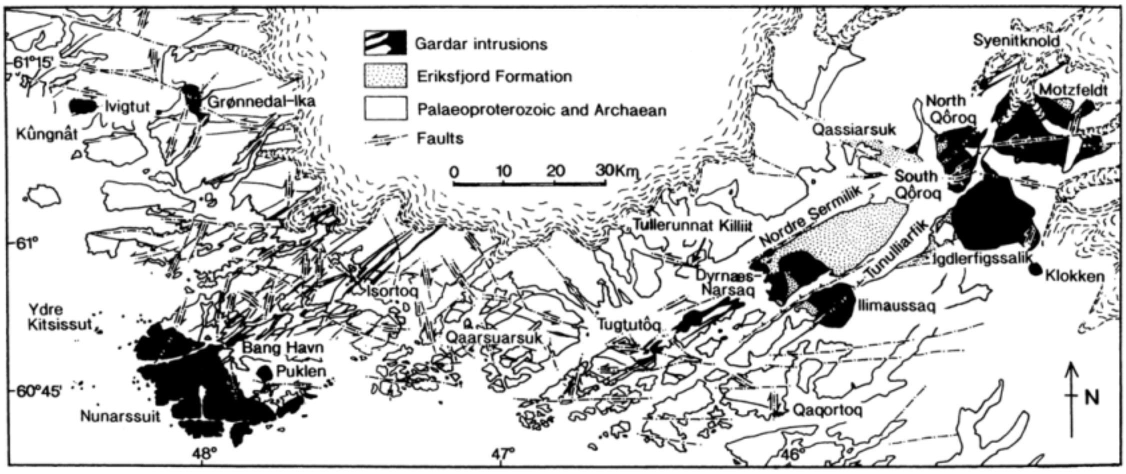

Figure 7. *The Gardar Province with principal plutonic centres, dykes and the main outcrops of the Eriksfjord Formation (Upton et al. 2003).*

The Gardar intrusions principally consist of dykes (mainly mildly alkalic or transitional dolerites) and subcylindrical plutons (mainly syenites) (Berthelsen & Noe-Nygaard 1965; Emeleus 1964). Three cycles of magmatic activity are recognized, each commencing with basaltic magmatism and ending with the emplacement of more evolved plutons (Upton & Blundell 1978). During the Early Gardar, ca. 1350 Ma (Paslick *et al.* 1993), basaltic lavas erupted and syenitic plutons were emplaced. During the Middle Gardar, ca. 1280 Ma (Upton *et al.* 2003), swarms of dolerite dykes were emplaced, together with subordinate alkaline and ultramafic lamprophyres. These are concentrated along the southern margin of the North Atlantic Craton. Late Gardar basic magmatism (1180 –1145 Ma) was concentrated in two southwest–northeast trending zones within in the Nunarssuit-Isortoq and the Tugtutôq zones (Fig. 7, Upton *et al.* 2003).

The oldest, WNW–ESE trending dykes are called “Brown Dykes” (BD0) due to their brown weathering colour. Their composition ranges from lamprophyric to (trachy)doleritic and gabbroic (Upton & Emeleus 1987). The BD0 dykes have an average U–Pb age of 1280 Ma and are succeeded by the “Giant Dykes” (GD), which are younger than 1200 Ma (Table 1, Upton *et al.* 2003). The GD dykes trend ENE–WSW, have a width of 200–800 m, and are mainly concentrated in the area around Nunarsuit–Isortoq and on Tuttutoq (Fig. 7). The latter comprises the Older and Younger Giant Dyke Complexes (OGDC and YGDC, respectively). The OGDC has an age of 1184±5 Ma, and acted as a precursor to the larger, 1163–1166 Ma old YGDC (Table 1, Upton *et al.* 2003). Generally, the GD dykes are composed of augite syenite, quartz syenite and alkali granite. Where they are composite, the dykes have a mafic (gabbroic) margin and a salic centre (Halama *et al.* 2004; Upton & Emeleus 1987). Due to their large width, the GD dykes can be regarded as the transitional link between dykes and the igneous complexes (Upton & Emeleus 1987).

Table 1. *Compilation of U–Pb radiometric dates from Gardar igneous rocks. Errors are quoted at the 2σ level (Upton et al. 2003).*

Unit	Location	Age (Ma)
BD_0 dyke	Qaqortoq	1284 ± 3
BD_0 dyke	Kangerluarssuk	1280 ± 3
BD_0 dyke	Tugtutôq	1279 ± 1.3
Syenite pegmatite	Motzfeldt	1275.3 ± 1.1
Gabbro ring dyke	Kûngnât	1275.2 ± 1.8
Older giant dyke	Tugtutôq	1184 ± 5
Syenite pegmatite	Nunarssuit	1171 ± 5
Granite (‘green’) sheet	Ilímaussaq	1166 ± 9
Syenite pluton	Klokken	1166 ± 3
Younger giant dyke	Tugtutôq	1165.7 ± 1.2
Younger giant dyke	Tugtutôq	1163 ± 2
Agpaite cumulate	Ilímaussaq	1160 ± 5
Granite pluton	Tugtutôq	1156 ± 1.1
Syenite intrusion	Østfjordsdal	1147.5 ± 3.2
Syenite pluton	Paatusoq	1144 ± 1

The Middle Gardar dyke swarm in the Isortoq area is part of a major regional swarm extending from the Nunarssuit Complex to the Inland Ice. It contains several generations of basic dykes (dolerites and gabbros), together with microsyenites, and culminates in four broad (up to 500 m) composite ‘giant dykes’ with granitic or syenitic centres with syenogabbroic margins (Upton *et al.* 2003). These giant dykes extend WSW to Bangs Havn and Eqaloqarfia where they are cut by the syenites and granites of the Nunarssuit Complex (Fig. 7). In the area between the Nunarssuit Complex and the Isortoq area, a complex array of basic and intermediate dykes intruded between the BD0 and the GD events. In the Julianehåb Batholith, however, intrusive activity was essentially absent during the approximately 100-Ma interval between the BD0 intrusions and the emplacement of the 1184 Ma Tugtutôq Older Giant Dyke (Table 1). The Older Giant Dyke event was a precursor to the much larger, 1163–1166 Ma intrusive complexes, largely of syenites and nepheline syenites, which reached shallow levels.

The gabbroic and doleritic intrusions and basic lavas crystallised from relatively evolved basaltic and hawaiitic magmas. These magmas were transitional to mildly alkaline and notably aluminous (Upton & Emeleus 1987). Their evolved state is attributed to a previous history of fractional crystallisation involving loss of olivine and spinel (pyroxene). A long history of crustal underplating beneath both the Julianehåb Batholith and the Border Zone, with generation of peridotitic cumulates, may be inferred. The ubiquitous high Al/Ca ratios of the basaltic magmas may denote derivation from mantle sources that had been largely depleted through earlier (Ketilidian) basalt extraction (Goodenough *et al.* 2002).

It is suggested that the Gardar basic magmas may represent melts from lithospheric mantle and that their high Al/Ca (troctolitic) signatures relate to an origin from dominantly diopside-poor peridotites residual after earlier melt extraction. Metasomatic enrichment of such refractory peridotites during lithospheric attenuation is inferred to have facilitated partial melting (Upton *et al.* 2003).

Carbonatite and lamprophyre magmas constituted only a very small percentage of total Gardar magmatism. These very silica-deficient lamprophyres and carbonatites occur as minor components in the Border Zone and the Julianehåb Batholith. In the former area, these are confined to intrusions while in the latter both the carbonatites and lamprophyres have extrusive as well as intrusive equivalents (Andersen 1997; Larsen 1977; Stewart 1970).

Sr and Nd isotopic work tend to support the broad division between Gardar intrusions formed from essentially uncontaminated mantle-derived magmas and those in which there has been a significant amount of crustal contamination. Various workers (Andersen 1997; Goodenough *et al.* 2002; Pearce & Leng 1996; Pearce *et al.* 1997) have shown that the most primitive Gardar magmas, including lamprophyres, dolerites and carbonatites, have initial $^{86}Sr/^{87}Sr$ ratios of around 0.703 and initial εNd values of + 2 to + 6. These ratios are consistent with derivation of all the parental Gardar magmas from lithospheric mantle that was moderately enriched relative to MORB.

The Grønnedal-Ika complex and the Ivigtut intrusion

The Grønnedal-Ika complex is the oldest intrusion of the Gardar magmatic province and consists predominantly of layered nepheline syenites, which were intruded by a xenolithic porphyritic syenite and a plug of carbonatite (Emeleus 1964). The complex was dated at ca. 1300 Ma by Rb–Sr (Blaxland *et al.* 1978). This age is consistent with field observations indicating that it predates emplacement of a suite of olivine dolerite dykes (BD0) for which an U/Pb age of 1280 ± 5 Ma has been determined (Table 1, Upton *et al.* 2003). Several intrusive stages can be distinguished, but gradational relationships between different rock types within intrusive units are common (Emeleus 1964). The carbonatite is xenolithic with fragments of syenites and other rocks. It consists essentially of varying amounts of calcite, siderite and magnetite; calcite is dominant. Towards the centre of the carbonatite plug, the amount of siderite increases. Large amounts of magnetite occur where mafic dykes cut the siderite-rich part of the carbonatite (Emeleus 1964). There is no field evidence for a significant time-gap between the emplacement of the syenites and the carbonatite. The last stage of magmatic activity, at about 1280 Ma, is represented by the intrusion of a variety of dykes, including lamprophyres, porphyritic dolerites and several olivine dolerites up to a few tens of meters wide (Halama *et al.* 2005).

The Ivigtut intrusion is composed of a granite stock approximately 300 m in diameter, surrounded by a thin intrusion breccia, and a second, cylindrical breccia body adjacent to the main stock. The Ivigtut granite hosts the fluoride-rich pegmatite body from which cryolite was mined. Prior to extraction, this complex pegmatite was not only rich in fluoride but also in carbonate (principally siderite) and sulphides (Pauly & Bailey 1999).

Kimberlites

Kimberlites have been found in the Pyramidefjeld area and principally occur as sheeted sills hosted in the Pyramidefjeld granite complex of Palaeoproterozoic age (Fig. 1 and 3, Hutchison *et al.* 2007). The sills contain megacrysts/phenocrysts of olivine in a groundmass composed of carbonate, serpentine, phlogopite and Fe-Ti oxides, with accessory clinopyroxene, perovskite and apatite (Larsen & Rex, 1992). The kimberlites have been dated at ca. 200 Ma (Andrews & Emeleus 1975)(Andrews & Emeleus, 1975; Emeleus & Andrews, 1975). Further north, in the Midternæs area, kimberlites occur as single, extensive and undulating sills hosted within pre-Ketilidian granodioritic gneiss and Palaeoproterozoic supracrustal rocks (Fig. 1 and 3, Hutchison *et al.* 2007). Microdiamonds have been found in bulk rock samples from Pyramidefjeld and Midternæs (Geisler 1972).

A GIS compilation of diamond exploration data from Greenland is available in a report by Jensen *et al.* 2004.

Structural Geology (Kolb)

The Archaean structures in the Border Zone are not well known and are generally characterized by a near-vertical gneissic foliation, trending NW-SE, and by mesoscopic fold structures. Three stages of Palaeoprotetozoic deformation can, however, be distinguished, where folds and thrusts are mainly restricted to the Palaeoproterozoic strata and a conjugate set of WSW-ENE and NW-SE trending faults is developed in the Archaean basement (Bondesen 1970; Higgins 1970).

During D_1 deformation, close to isoclinal shear folds formed mainly in the (meta)sedimentary units folding the bedding planes. The F_1 fold amplitude can vary between outcrop-scale to approximately 100 m. Fold axes and axial planes vary in orientation due to later transposition. The original F_1 orientation is interpreted to show shallow fold axis plunges to the NNW and the folds are generally WSW vergent (Bondesen 1970; Higgins 1970). A prominent thrust zone separating the Vallen and Sortis groups, in Midternæs and Grænseland, and at the base of the Palaeoproterozoic units on Arsuk Ø, developed during the D_1 deformation. The thrusting is to the SW and shows a displacement of several hundred metres (Bondesen 1970; Higgins 1970). In the south, close to the area around Blindtarmen (Fig. 3), a NNE-SSW trending, near-vertical belt of mylonites shows sinistral strike-slip deformation that is interpreted to be related to D_1 (Garde *et al.* 1998). In the Kobberminebugt region, a < 15 km parallel shear zone system is deformed by sinistral strike-slip, the local D_{K2}, postdating the intrusion of the Borg Havn Granite at 1845 ± 3 Ma (Fig. 3; Garde et al. 1998, 2002). The Borg Havn Granite was emplaced contemporaneously with dextral shearing in the Kobberminebugt shear zone system during the local D_{K1} (Garde et al. 1998, 2002a).

The D_2 deformation refolded the earlier structures into minor- to major-scale and open- to tight-shear folds with axial planes trending ENE-WSW. The axial planar foliation is generally dipping moderately to steeply to the NNW. Minor thrust zones parallel to the axial planar foliation show SSE-vergent displacement (Bondesen 1970). The Andesø thrust zone, in Midternæs, strikes E-W and dips moderately to the S. Along this thrust, higher metamorphic rocks are thrust on top of very low grade rocks to the north, which may be related to the D_2 deformation (Higgins 1970).

The D_3 deformation refolded earlier structures into minor folds with gently inclined axial planes. The deformation is brittle, forming brecciated rocks in the fold cores (Bondesen 1970; Higgins 1970). The Kobberminebugt shear zone system was reactivated by highly localised dextral transpression shortly before 1800 Ma, as indicated by the intrusion of the 1805 ± 2 Ma Sãtukujôq granite (Garde *et al.* 2002b).

The conjugate set of faults observed in the Archaean basement also partly transsects the Palaeoproterozoic strata, which indicates that structures are long-lived and were locally also active in the Mesoproterozoic (Bondesen 1970; Higgins 1970).

Geological map basis (Kokfelt)

The Kobberminebugt area was originally mapped out by GGU (later GEUS) during the late 1950's, through the 1960's and 1970's, resulting in a complete coverage of the area through the published 1:100 000 scale map series. The area is covered by seven sheets some of which have accompanying map sheet descriptions (Figure 1). Mapping was carried out at a 1:20 000 scale, implying that a higher level of detail is generally available from the original field maps than what is reflected on the published compiled 1:100 000 map sheets. Apart from the 1:100 000 sheets, GGU/GEUS has published a map series in scale 1:500 000 for entire Greenland (Fig. 1). For this map series South Greenland is covered (in two versions) by 'Sheet 1', first compiled by Allaart (1975) and later recompiled by Garde (2007). Other maps outside the general series have been published by GGU/GEUS workers through reports and bulletins, such as the 1:40 000 scale maps of the Midternæs (Higgins 1970) and Grænseland (Bondesen 1970) areas.

All published maps and field maps by GGU/GEUS relevant to the Kobberminebugt area are made available as electronic files, as appendices to this report. Examples of various map types are furthermore printed in this report.

Figure 1 shows the coverage of geological mapping in Greenland, on the 1:100 000 and 1:500 000 scales.

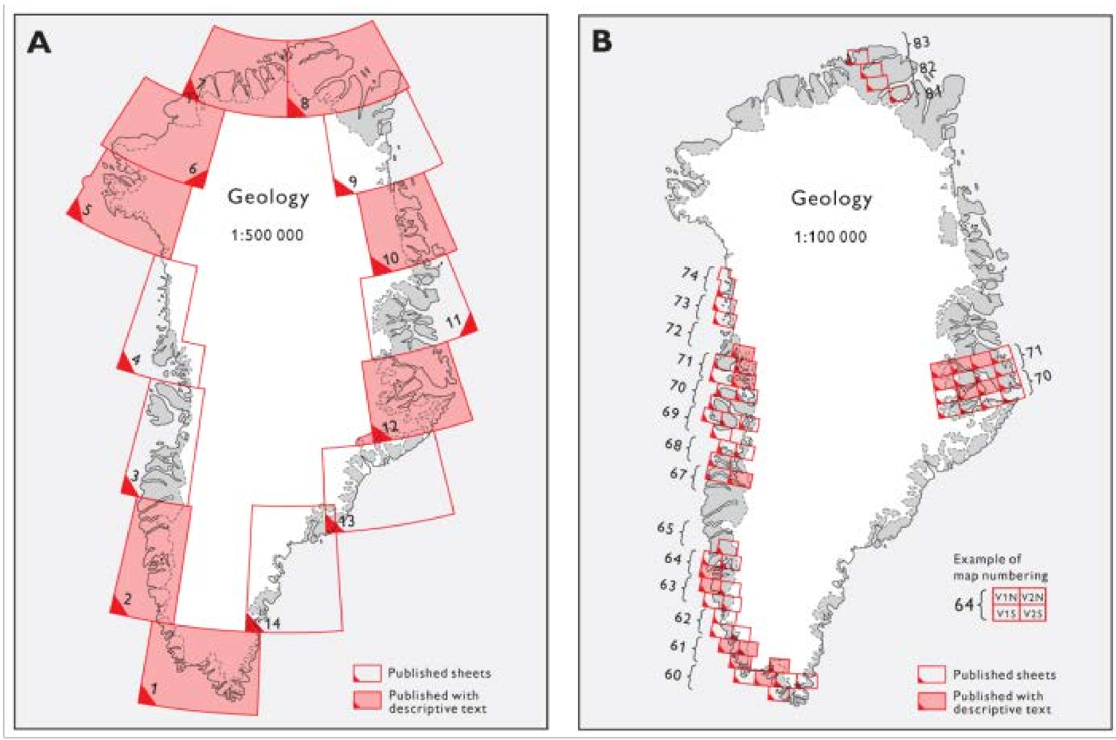

Figure 8. *Overview of available geological maps of Greenland in scales 1:100 000 (partial coverage) and 1:500 000 (complete coverage). Red filled symbol indicates map sheets that were published with a descriptive text.*

Published geological maps, scale 1:500 000

Sheet 1 – South Greenland

Compilation by J. H. Allaart, 1975.
Descriptive text by F. Kalsbeek, L. M. Larsen & J.Bondam, 1990. 36 p. and 28 figs.
62° 30' N - 59° 30' N; 50° 30' W - 42° 00' W
New compilation by A. A. Garde, 2007 (2nd edition).
62° 30' N - 59° 30' N; 50° 30' W - 42° 00' W

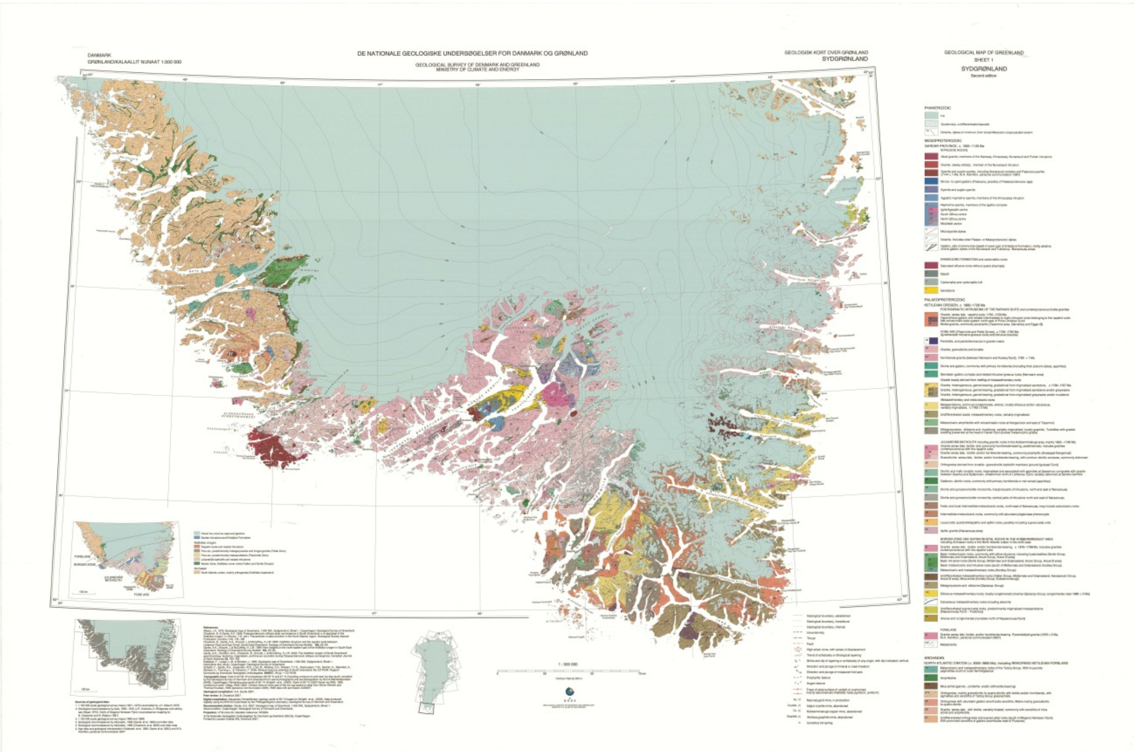

Figure 9. *Sheet 1 – South Greenland, scale 1 : 500 000 (Garde 2007).*

Published geological maps, scale 1:100 000

The greater Kobberminebugt area is covered by the following seven map sheets (all available in the appendix of this report):

61 V.1 Nord, Neria
(62° 00' N - 61° 30' N; 50° 00' W - 48° 30' W)
Compilation by S. Bak Jensen (1975).
Descriptive text (including Midternæs) by A. K. Higgins. 1990. 23 p.

61 V.2 Nord, Midternæs
(62° 00' N - 61° 30' N; 48° 30' W - 47° 00' W)
Compilation by J. C. Escher and S. Bak Jensen (1974).
Descriptive text (including Neria) by A. K. Higgins. 1990. 23 p.

61 V.1 Syd, Ivigtut
(61° 30' N - 61° 00' N; 49° 09' W - 47° 30' W)
Compilation by N. Henriksen (1968).
Descriptive text by A. Berthelsen & N. Henriksen. (1975). 169 p.

61 V.3 Syd, Narssarssuaq
(61° 30' N - 61° 00' N; 46° 00' W - 44° 30' W)
Compilation by J. H. Allaart,1973
Descriptive text by J. H. Allaart. (1983). 20 p.

60 V.1 Nord, Nunarssuit
(61° 00' N - 60° 30' N; 48° 30' W - 47° 00' W)
Compilation by T. C. R. Pulvertaft (1967).

60 V.2 Nord, Julianehåb
(61° 00' N - 60° 30' N; 47° 00' W - 45° 30' W)
Compilation by J. H. Allaart (1972).
Descriptive text by J. H. Allaart. (1973). 41p.

60 V.3 Nord, Søndre Sermilik
(61° 00' N - 60° 30' N; 45° 30' W - 44° 15' W)
Compilation by A. A. Garde & B. Chadwick (1996).

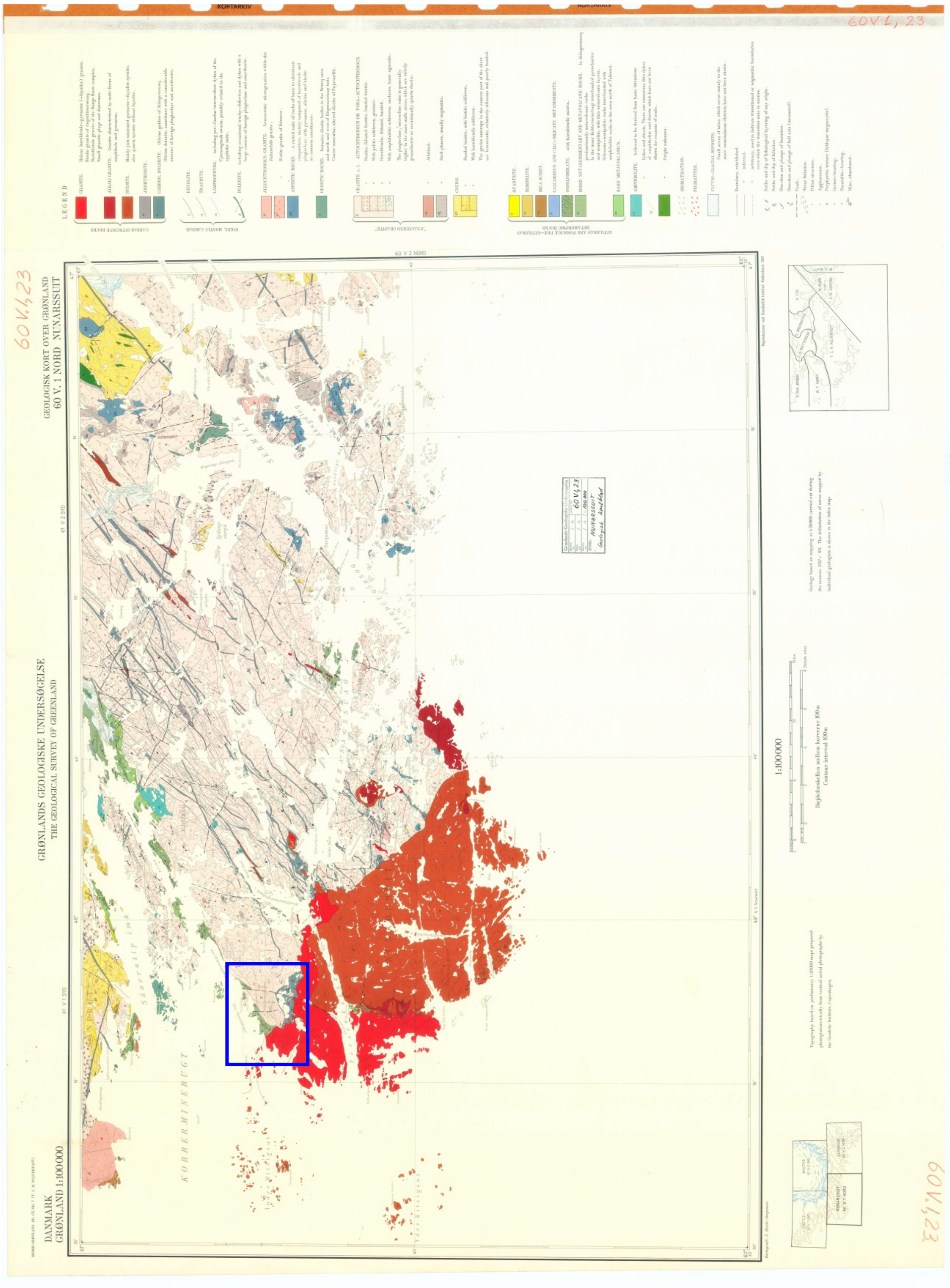

Figure 10. *Example of a 1:100 000 map sheet from the Kobberminebugt area: The Nunarssuit sheet (60 V. 1 Nord) by Pulvertaft (1967) covering the Nunarssuit intrusive complex. Blue box indicates the area displayed in Fig. 9.*

Field maps, scale 1:20 000

Electronic copies of scanned GGU/GEUS field maps are provided as an electronic appendix to this report. An overview of the field maps are given in appendix Table A.1 (Excel file). In the Excel file, field maps are allocated under different worksheets that refer to the respective 1:100 000 map sheets.

As an example of a field map Figure 4 shows the hand-colored map by M. Ghisler (1965) from the Alángorssuaq area covering the historical Josva and Lilian mine of the Kobberminebugt area.

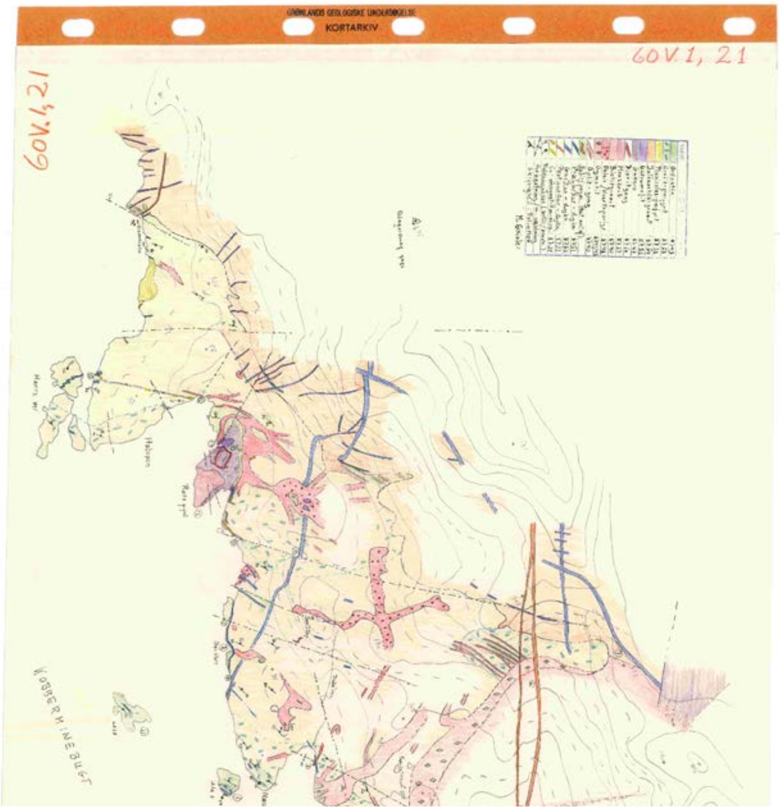

Figure 11. *Example of a field map (scale 1:20 000) from Alángorssuaq including the Josva and Lilian mines in the southern part of Kobberminebugt (location shown as blue insert box in Figure 3). Map by M. Ghisler (1965).*

Other published maps

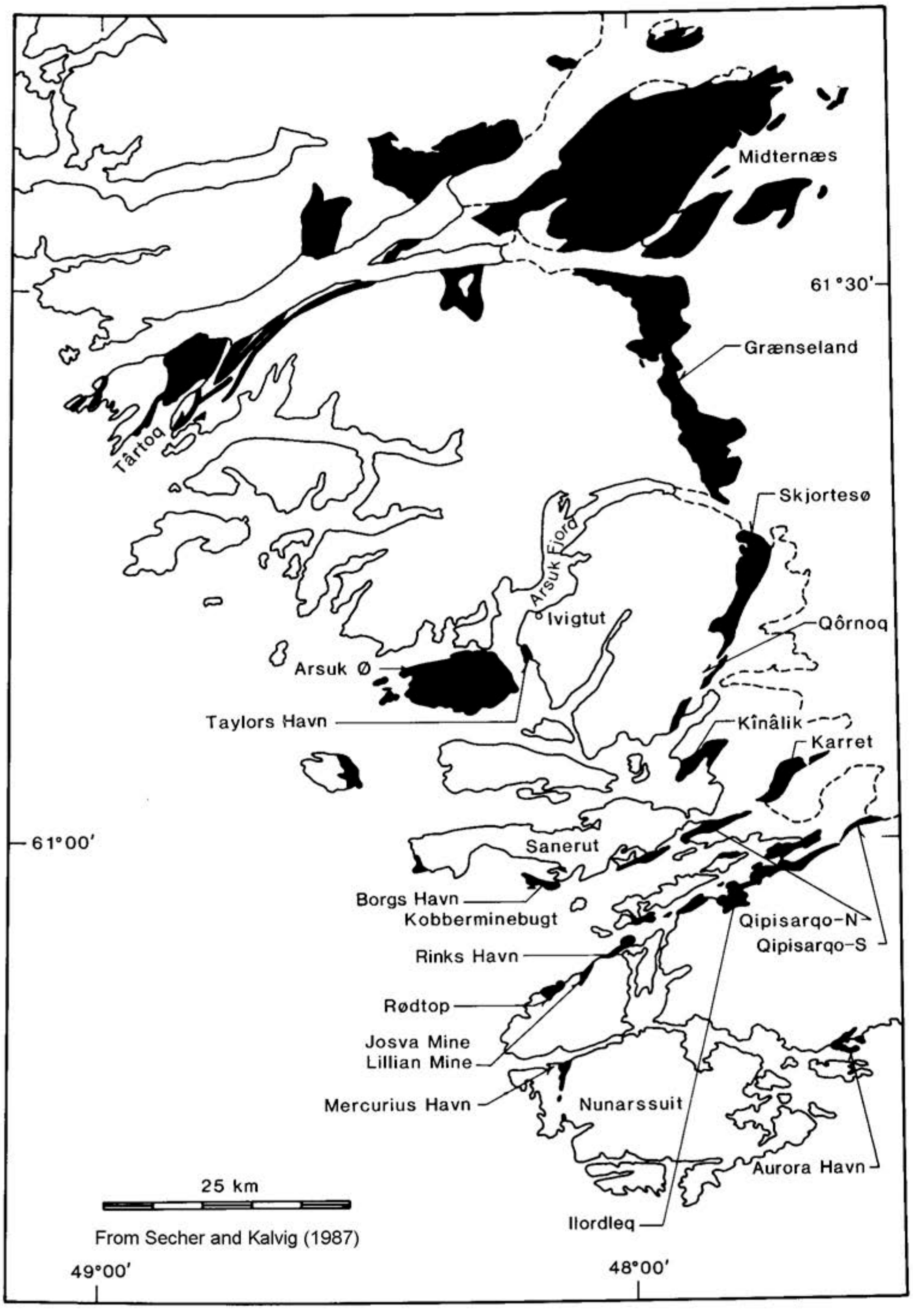

Figure 12. *Overview map of the Kobberminebugt area with major mineralisations in the Pre-cambrian supracrustal sequences (black) between Tartoq and Kobberminebugt (Secher & Kalvig 1987).*

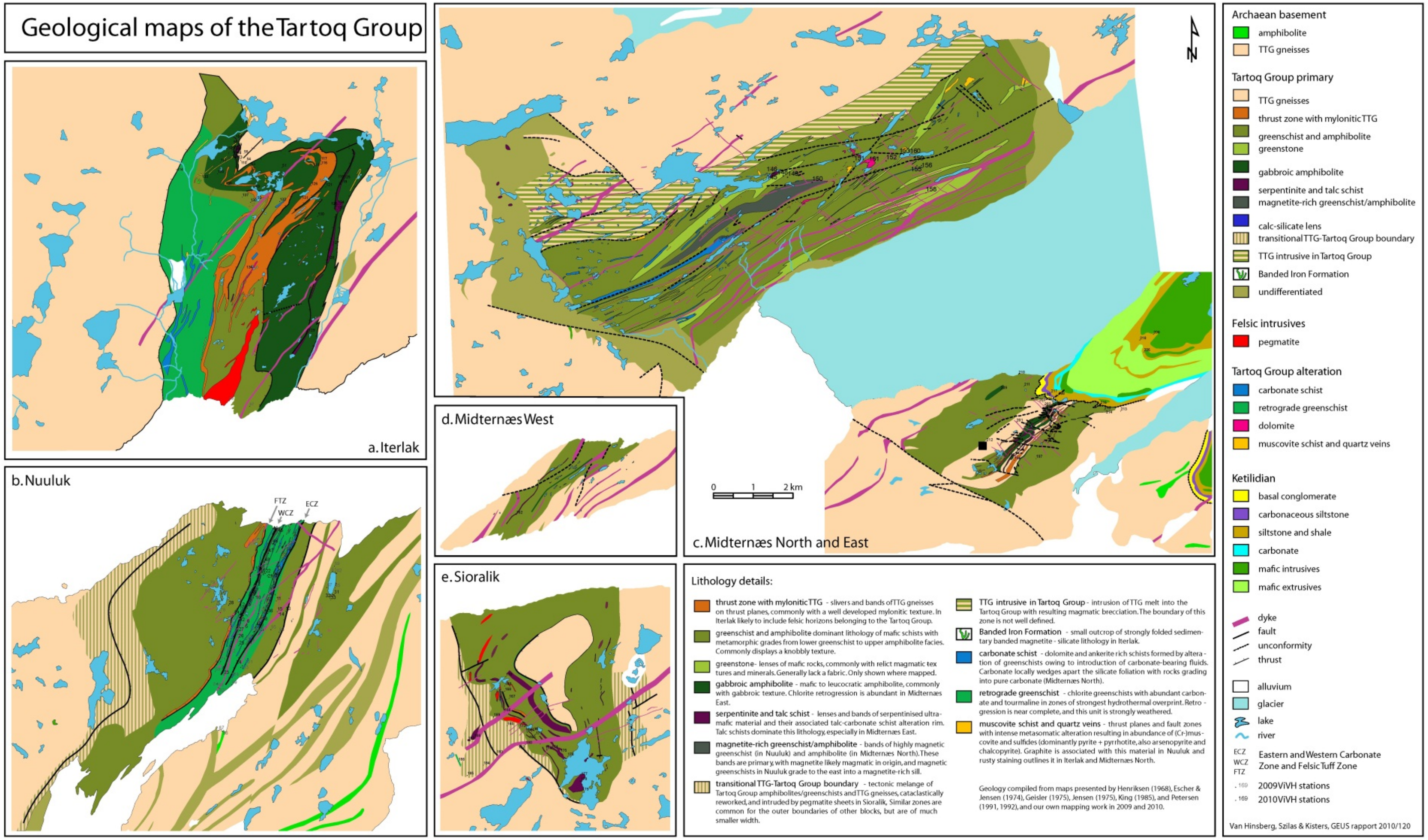

Figure 13. *Geological maps of the Archaean Tartoq Group (Van Hinsberg et al. 2010).*

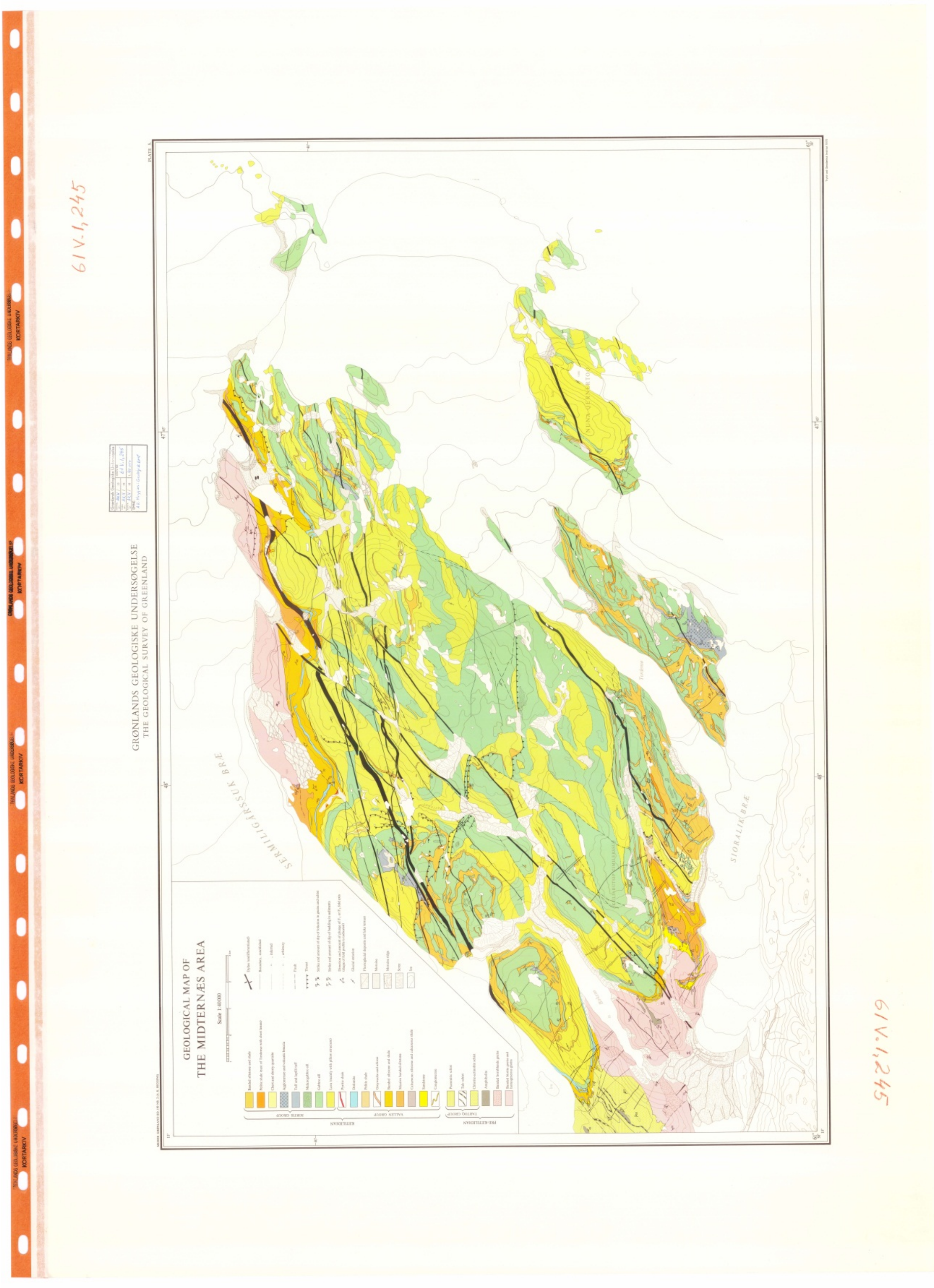

Figure 14. *Geological map of the Midternæs area (Higgins 1970).*

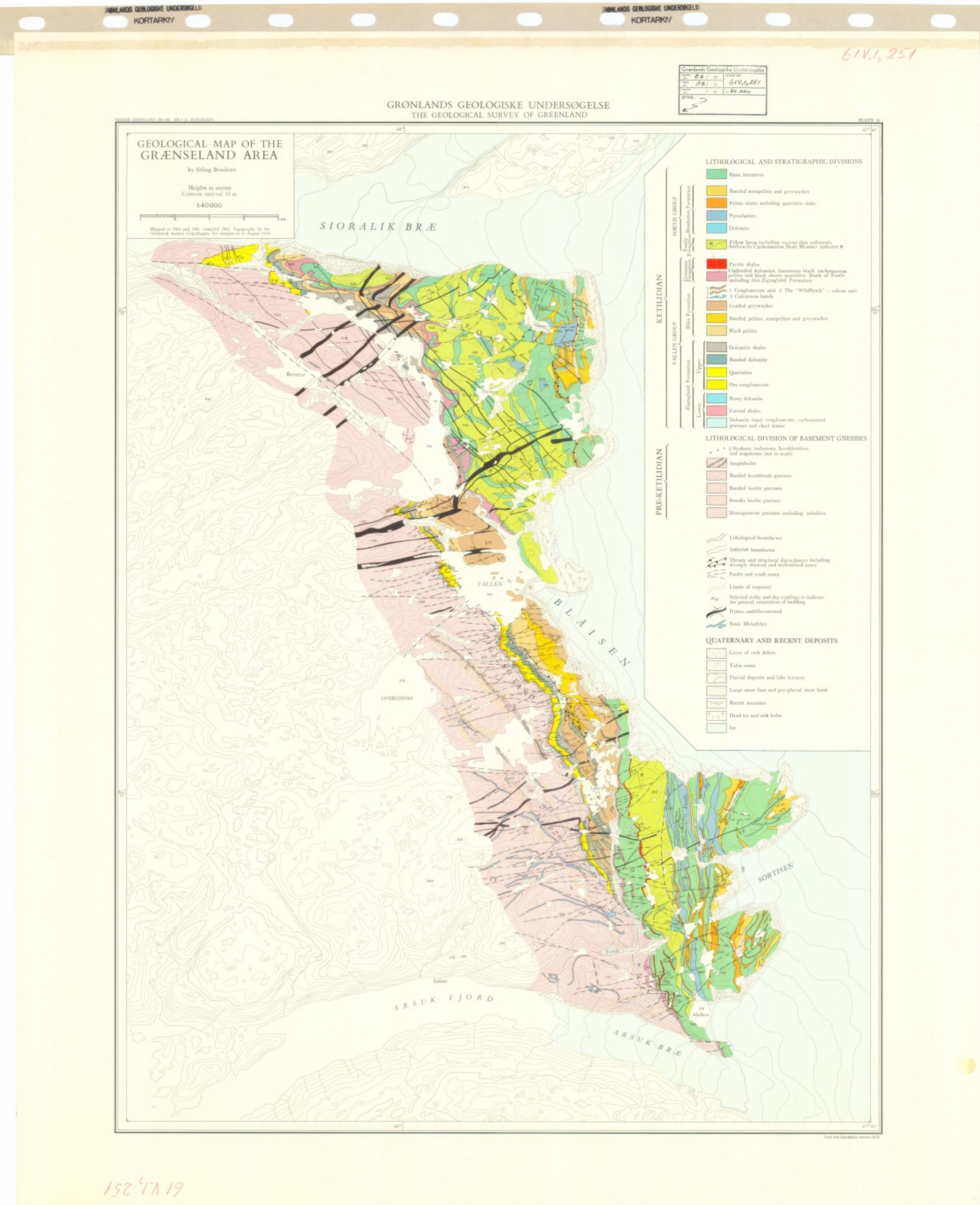

Figure 15. *Geological map of the Grænseland area in scale 1:40 000 (Bondesen 1970).*

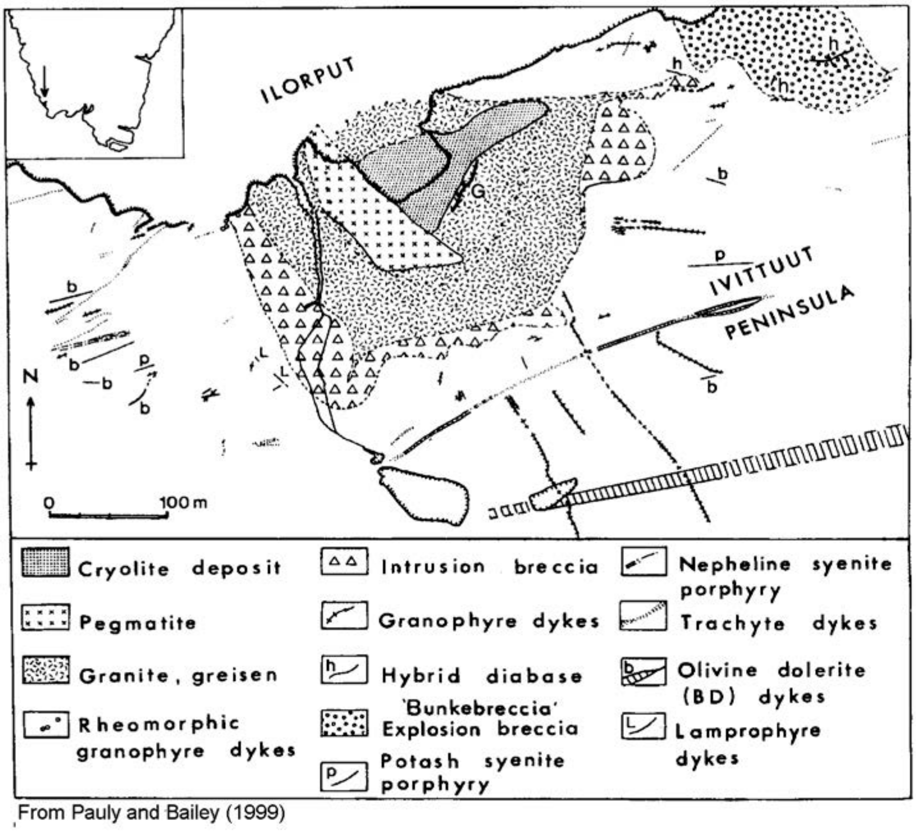

Figure 16. *Geological map of the Ivittuut area (Pauly & Bailey 1999)*

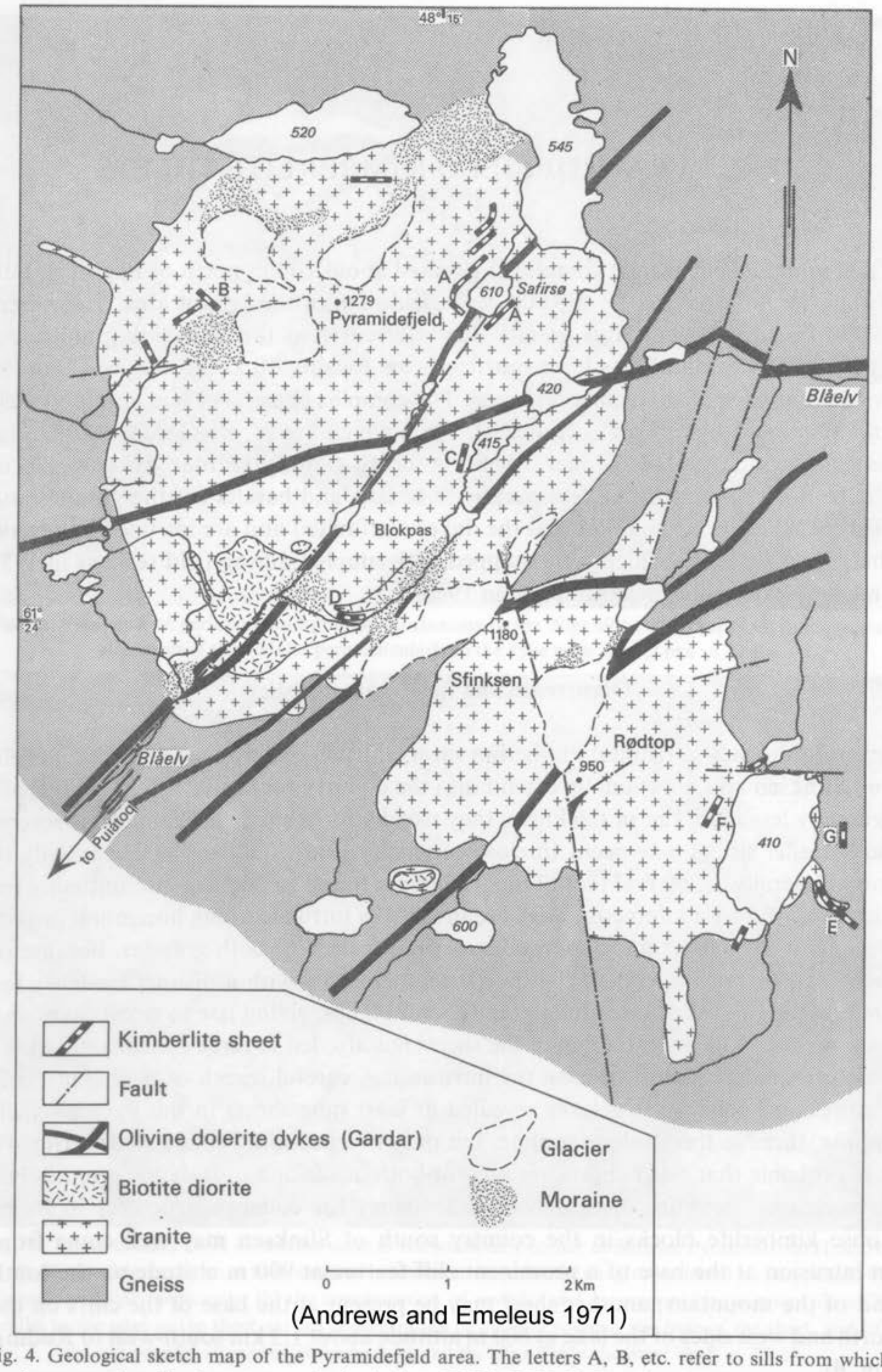

Fig. 4. Geological sketch map of the Pyramidefjeld area. The letters A, B, etc. refer to sills from which specimens mentioned in the text were obtained. (A = 39654, 39657, 39651; A[1] = 39660, 39660C, 39660/2; B = 27703, 126731 b & c, 126738; C = 39651; D = 31959; E = 39644; F = 39642).

Figure 17. *Geological sketch map of the Pyramidefjeld area (Andrews & Emeleus 1971).*

On-line map sources

An electronic web-based map of southern West and South-West Greenland between 61°30' and 64° N can be found at: **http://geuskort.geus.dk/gisfarm/gis_svgreenland.jsp**. The map covers the area between the Ameralik and Sermiligaarsuk fjords, and thus the very northernmost part of the area of interest in this report. The map represents a recompilation and reassessment of the existing map base in scale 1:100 000 and contains selected information about geological topics, such as (i) sample localities, rock types etc., (ii) geochronology, (iii) metamorphism, (iv) structural geology, and (v) geophysical data.

Geochemistry of stream sediments (Kokfelt & Møller-Stensgaard)

GGU/GEUS has carried out regional stream sediment program for entire Greenland and various reports have discussed aspects of the dataset in a regional context. A GEUS report used the regional stream sediment geochemistry distributions as basis for evaluating the mineral occurrence potential in South Greenland (Schjøth *et al.* 2000). Although this work had a more regional approach than is the goal of this report, some of their figures and conclusions are summarised here

Geochemistry of stream sediments in South Greenland

Based on a multi-element statistical spatial analysis (termed MAF – maximum autocorrelation spatial factor analysis; Nielsen et al. (1997)), applied to the stream sediment geochemical data, grids of the first three factors (MAF1, MAF2, MAF3) were combined to display the major features of the spatial information within the data set. The composite grid map (Fig. 18) shows the existence of three geochemically distinct domains with well-defined boundaries. The domains largely correspond to the main division of the Ketilidian Orogen.

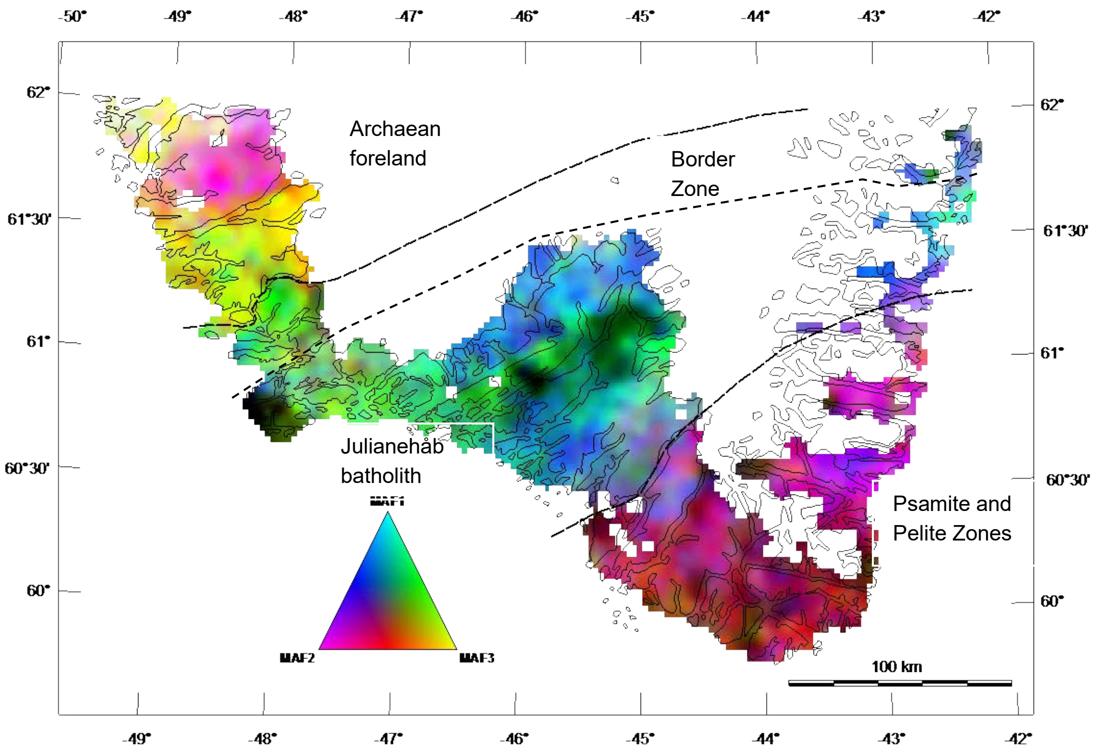

Figure 18. (previous page) *Geochemical domains of South Greenland, defined by multi-element spatial analysis of chemical data for the < 0.1 mm grain size fraction of stream sediment samples (MAF: maximum autocorrelation factorial kriging, Nielsen et al. (1997)). The ternary image is composed of grids of the first three factors. Grid cell size: 2500 m. The domains are named after the predominating litho-stratigraphical units (Schjøth et al. 2000).*

In Figure 18, the Archaean foreland is displayed in shades of yellow (MAF2) and pink (MAF2). It comprises the Archaean craton together with the northern part of the Palaeoproterozoic sequences of the Border Zone (Fig. 11). The Border Zone has a transitional signature between the southern part of the Archaean foreland and the Julianehåb Batholith and is dominated by yellow (MAF3) and green (MAF1). Inside the Julianehåb Batholith, the chemistry is influenced by the Palaeoproterozoic granites and syenites, carbonatites and doleritic dykes of the Gardar Province. Greenish or green-brown to black colours within the Julianehåb Batholith are influenced by the Gardar Province. The southeastern-most part of Greenland comprises the Psammite and Pelite zones that are dominated by reddish and purple colours (MAF2). These two zones are chemically indistinguishable from each other. The Rapakivi and post-kinematic granites within this domain are reflected by red-orange to brownish colors.

Figure 19 illustrates the main chemical differences between the domains, element by element. The means of measured element concentrations in stream sediments for each domain are normalised against the estimated average composition of the upper crust (Taylor & McLennan 1985). For a more detailed explanation please refer to Schjøth *et al.* (2000).

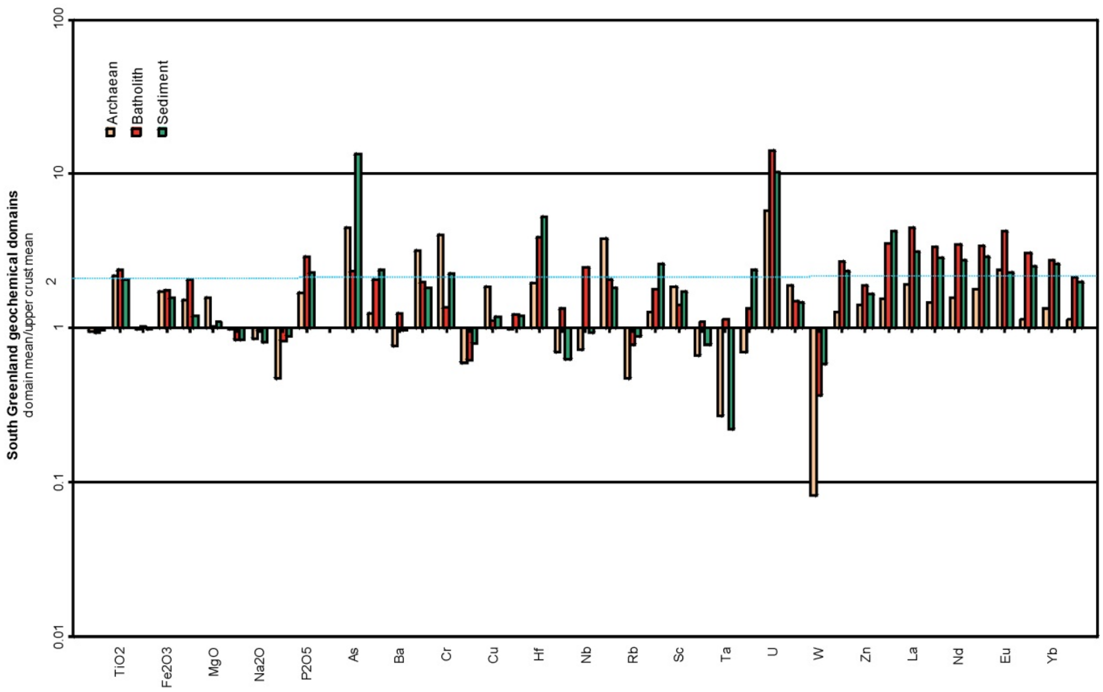

Figure 19. *Element variation between the three geochemical domains of South Greenland. The means of element concentrations in stream sediments from within each domain is normalised against the estimated average composition for the upper crust (Taylor & McLennan 1985). From Schjøth et al. (2000).*

Geochemistry of stream sediments in the Kobberminebugt area

For the preparation of this report a series of more detailed maps for selected elements (13 in total: As, Au, Cs, Cu, Fe_2O_3, MgO, Mo, Ni, P_2O_5, Sb, U, W, Zn) were generated, based on the GEUS stream sediment data base. The produced images and statistics on the selected geochemical element distribution were created by a gridding of extracted data from the geochemical atlas of West and South Greenland (Steenfelt 1999). The data was extracted as raw calibrated geochemical data which was subsequently gridded using minimum curvature procedure. The maps are displayed in Figs. 20-32 and the electronic files are provided as geo-referenced TIF-files in the appendix to this report.

Nickel (Ni) – magnesium (MgO) – total iron (Fe_2O_3)

High Ni and MgO values dominate the Archaean craton and the Border Zone, whereas distinctly lower values are seen for the Julianehåb Batholith to the south. The high nickel and magnesium contents presumably reflect the relatively high proportion of mafic metavolcanic rocks intercalated with the gneisses. The enrichment in Ni, MgO (Cr and Cu) reflects the abundance of mafic rock enclaves in the gneisses, the metavolcanic rocks of the Ketilidian foreland deposits, and in particular, the presence of numerous dolerite dykes of Ketilidian and Gardar ages. Iron is to some extent following the same distribution pattern as MgO, but with notably high values in the Nunarssuit Complex, which lies on the southwest tip of the peninsula south of Kobberminebugt.

Gold (Au) – asenic (As) – antimony (Sb)

As and Sb are usually used as a pathfinders for gold, and the distribution patterns for these elements do show some broad overall overlaps in the Kobberminebugt area. Enhanced As and, less clearly so, Sb values cluster in three (or four) sub-parallel WSE-ENE trending bands, extending from the coast to the inland ice. The northernmost band, at Sermiligaarsuk Fjord, relates to the orogenic gold mineralization in the Tartoq Group (Evans & King 1993; Kolb 2011). Further to the south gold mineralisation on Arsuk Ø has been found, which displays some generally low Au values (up to 300 ppb).

Copper (Cu) – zinc (Zn) – gold (Au)

The distribution patterns for Cu and Zn mimic those of Ni, MgO and Fe_2O_3. Highest Cu and Zn values are found in the Border Zone where it reflects the relatively high abundance of mafic rock enclaves in the gneisses. On Arsuk Ø, gold, zinc and copper contents are generally low and anomalies are found in two rock associations: 1) in rusty chert horizons; and 2) related to quartz. The copper content reaches close to 2000 ppm in rusty metabasaltic rocks, and zinc contents of up to 883 ppm are recorded in silicified tuff with minor quartz stringers and disseminated sulphides (Gowen 1992).

Molybdenum (Mo) – Tungsten (W)

Mo and W values are generally low in the stream sediments with up to 58 and 30 ppm, respectively. The highest values are found in the southern part of the study area, where they likely reflect the presence of granitic intrusions.

Phosphorus (P)

Enhanced levels of phosphorus typically reflect high abundances of monazite or apatite in the stream sediments, and these minerals (particularly apatite) are characteristic of the alkaline Gardar Province rocks. The potential for economic concentrations of apatite has been investigated at one known occurrence of carbonatite, at Grønnedal-Ika, where P_2O_5 concentrations of selected carbonatite profiles varied from 3.7 to 14.6 % (Morteani et al. 1986)

Cesium (Cs)

The distribution of Cs is largely controlled by the boundary between the Border Zone and the Julianehåb batholith area, with consistently higher values to the north and lowers to the south, notably with some high values in the Nunarssuit Complex. High Cs in the stream sediments appears to be associated with the metasedimentary and metavolcanic rocks of the Ketilidian Orogen.

Uranium (U)

The most anomalous areas with respect to uranium are within the Julianehåb Batholith, in the surroundings of the major intrusive complexes of the Gardar Province, where absolute concentrations reach high levels of up to 625 ppm. The governmental uranium exploration programme SYDURAN located pitchblende and brannerite mineralisation in fault structures, as the result of the follow-up of regional stream sediment uranium anomalies in the Julianehåb Batholith.

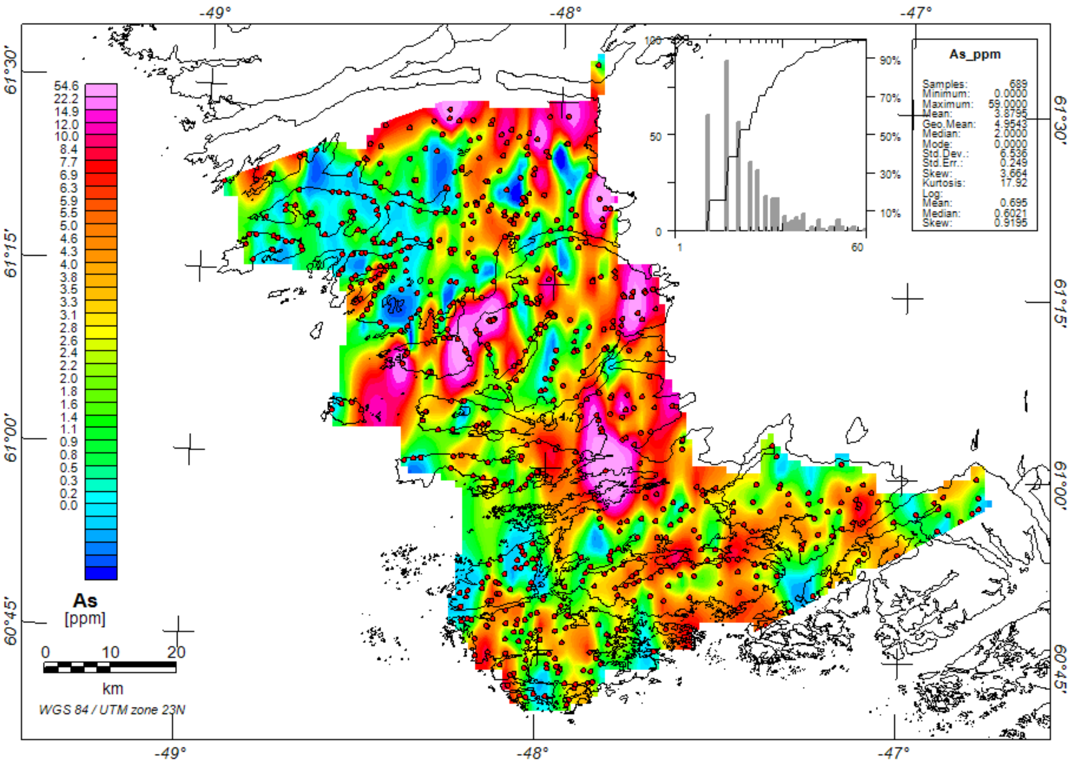

Figure 20. *Contoured distribution map for arsenic (As) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=689).*

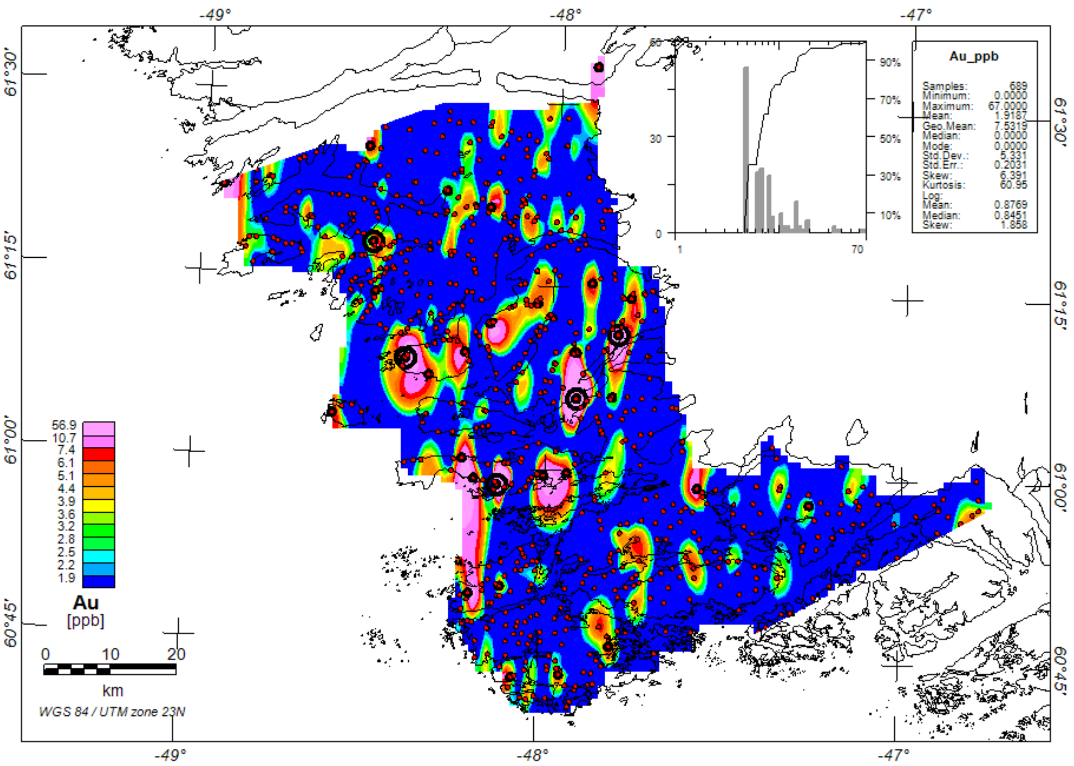

Figure 21. *Contoured distribution map for gold (Au) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=689).*

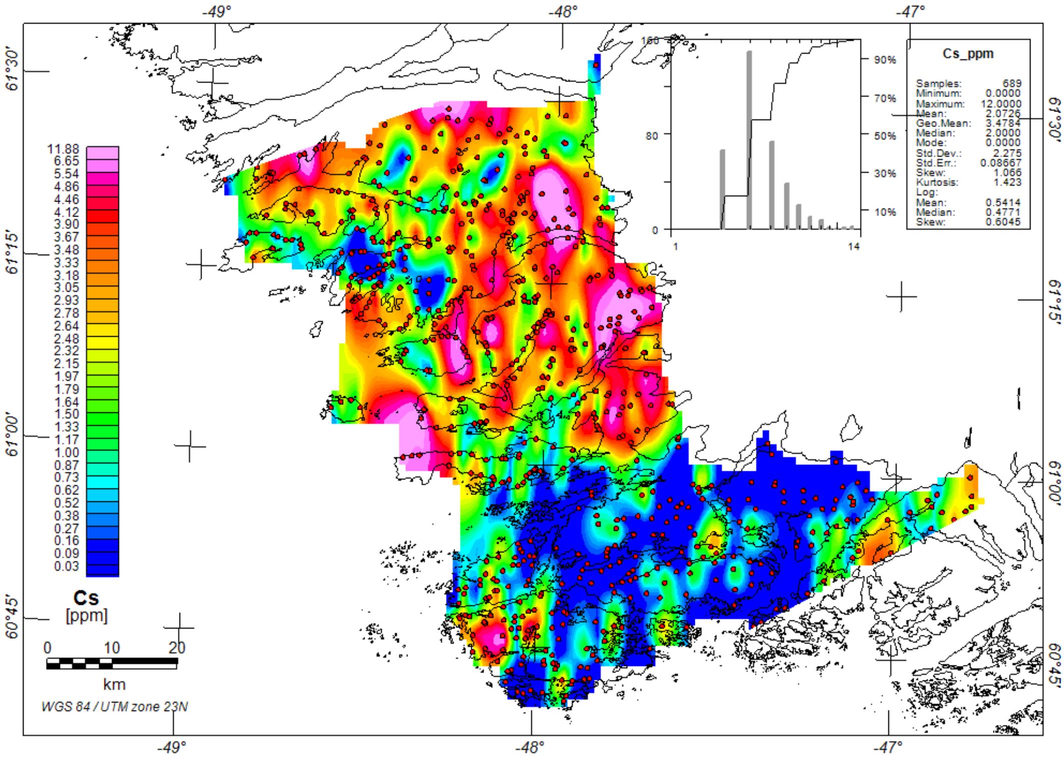

Figure 22. *Contoured distribution map for cesium (Cs) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=689).*

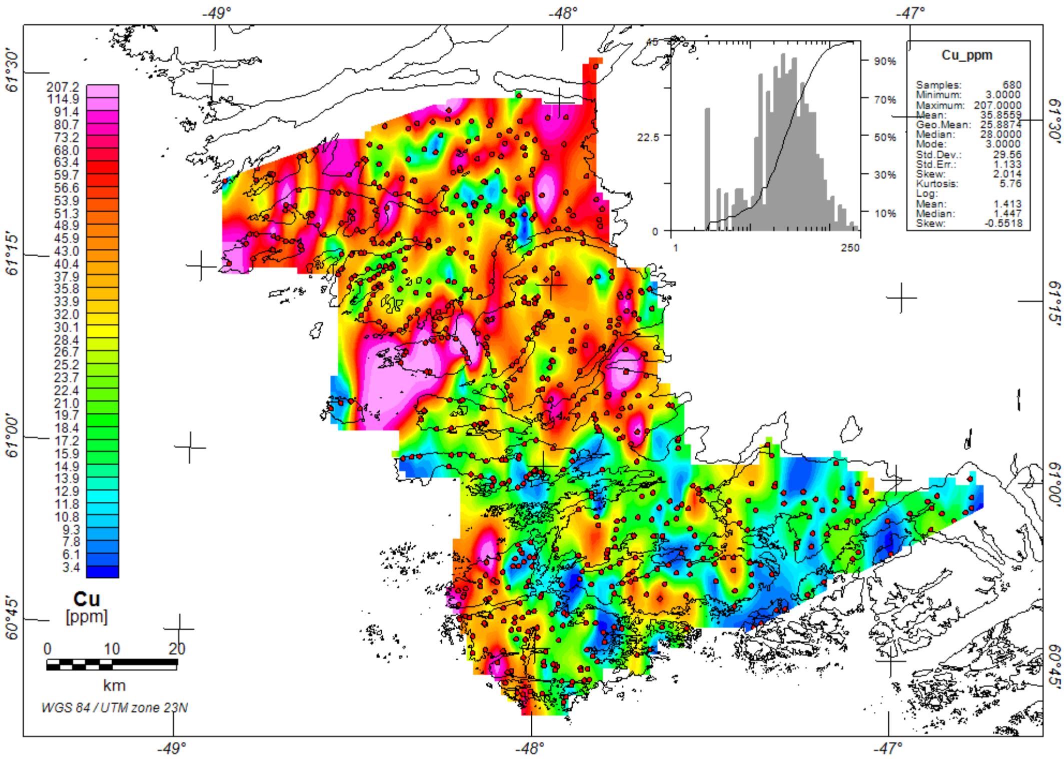

Figure 23. *Contoured distribution map for copper (Cu) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=680).*

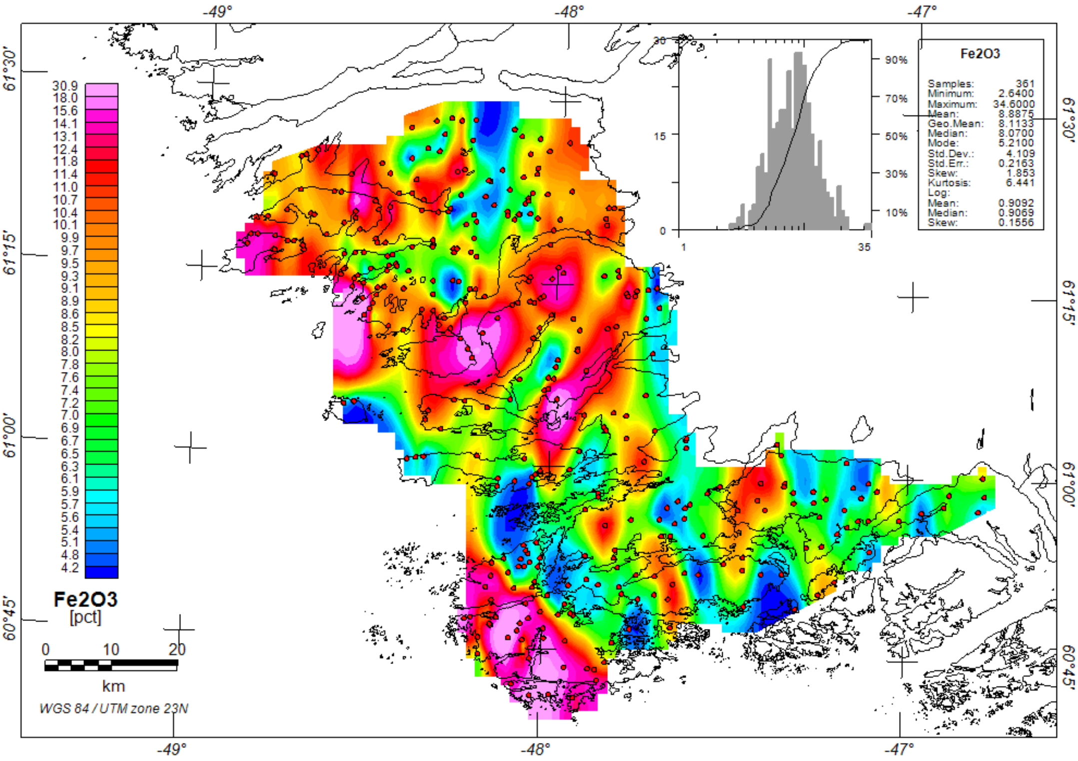

Figure 24. *Contoured distribution map for iron (Fe_2O_3) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=361).*

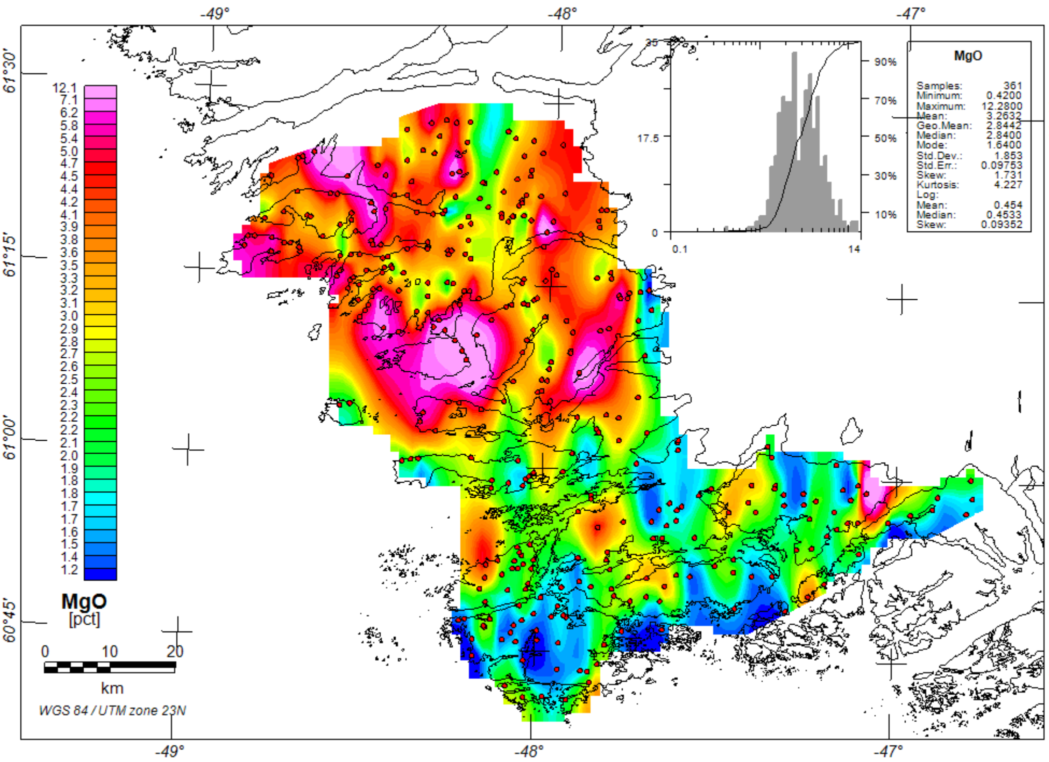

Figure 25. *Contoured distribution map for magnesium (MgO) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=361).*

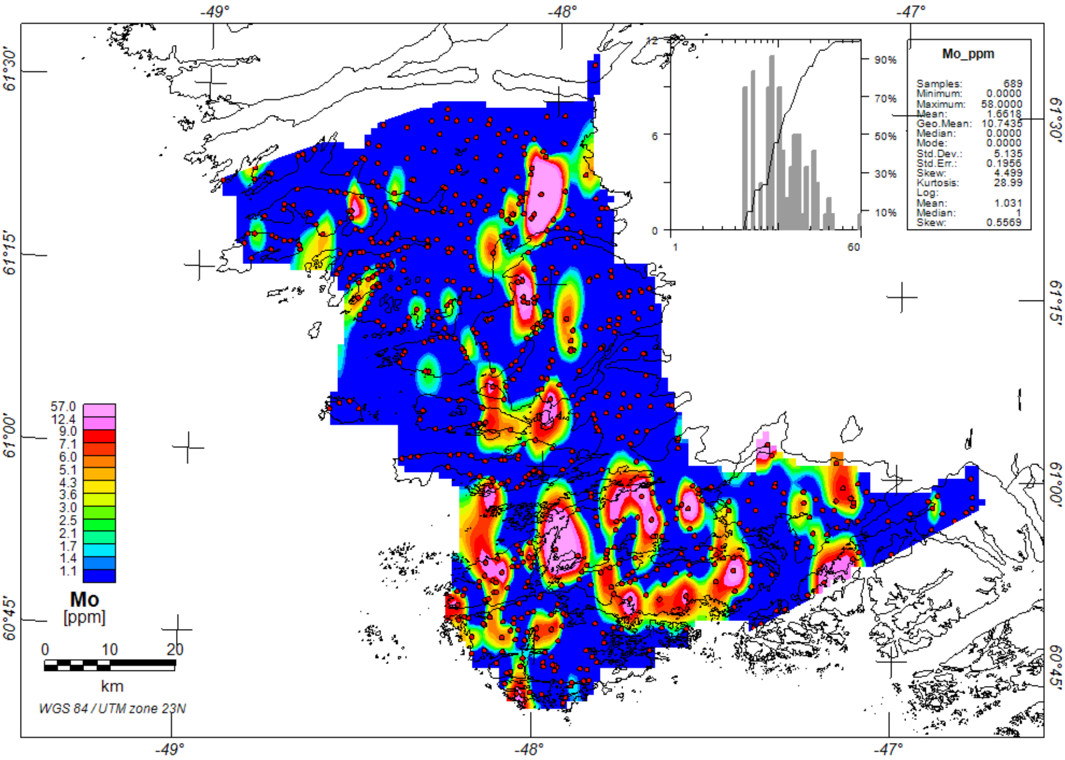

Figure 26. *Contoured distribution map for molybdenum (Mo) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=689).*

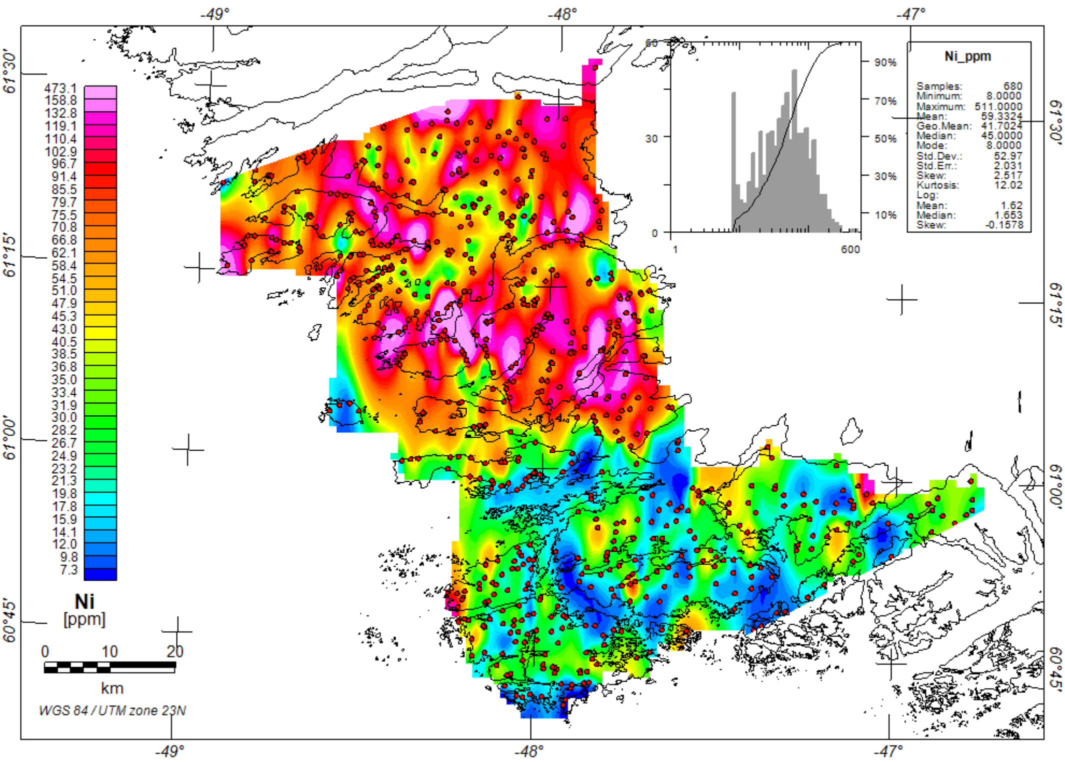

Figure 27. *Contoured distribution map for nickel (Ni) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=680).*

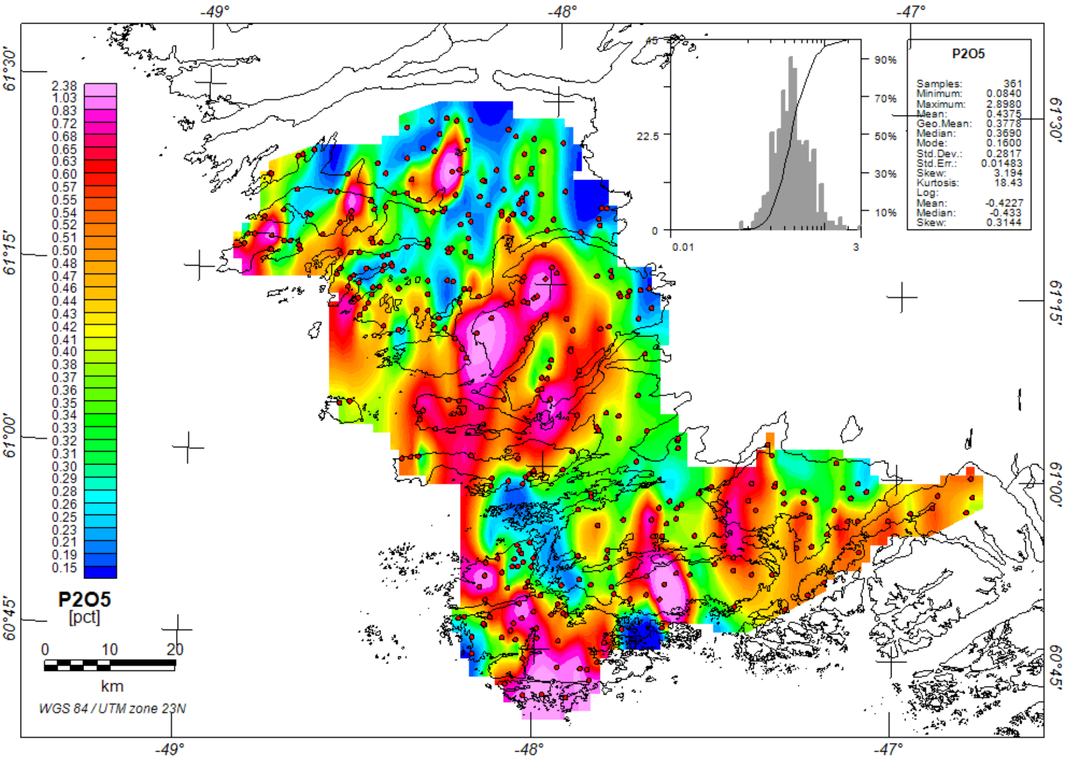

Figure 28. *Contoured distribution map for phophorus (P_2O_5) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=361).*

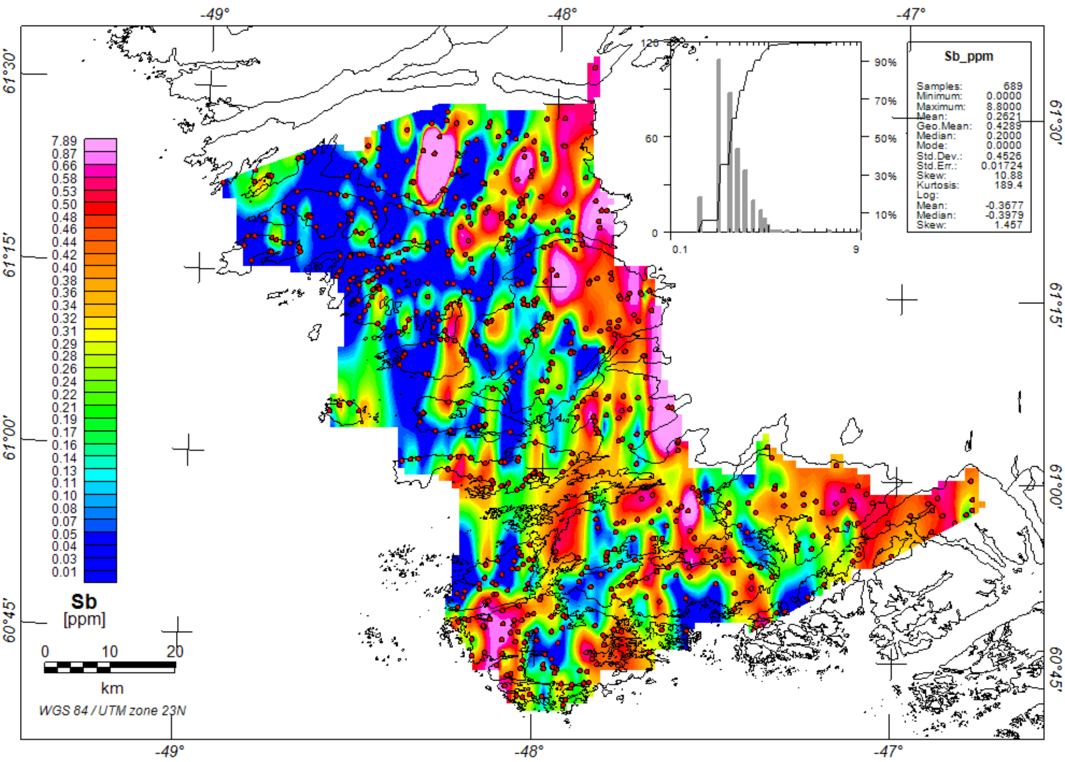

Figure 29. *Contoured distribution map for antimony (Sb) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=689).*

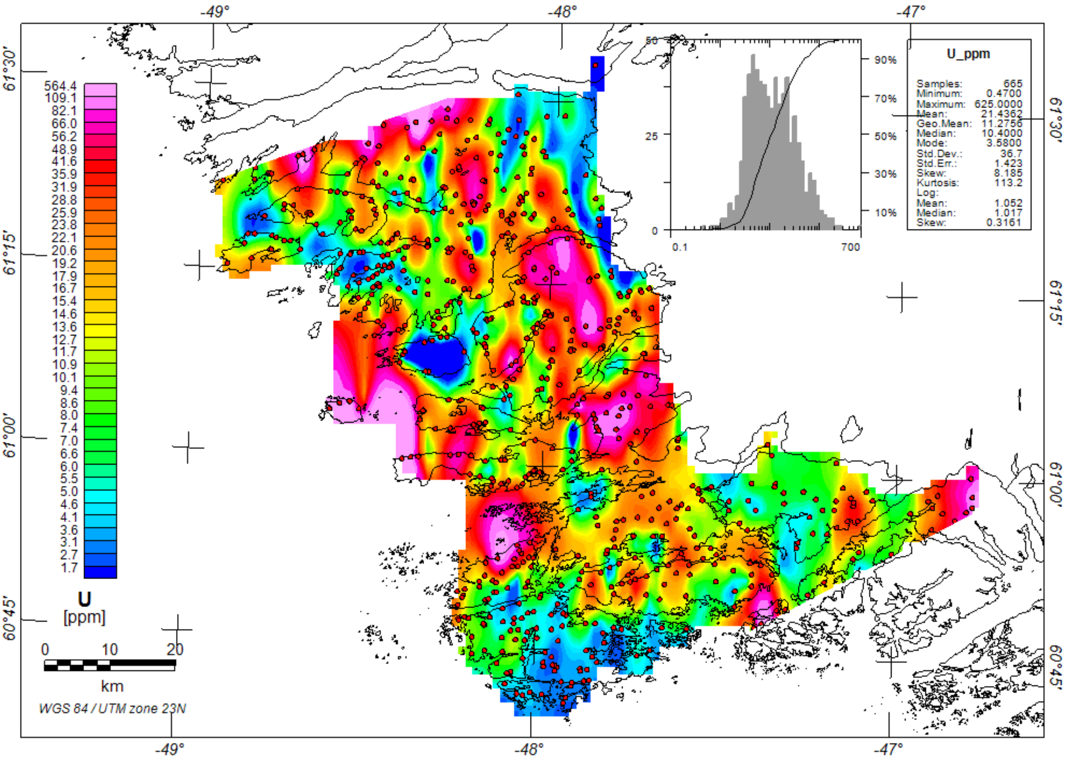

Figure 30. *Contoured distribution map for uranium (U) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=665).*

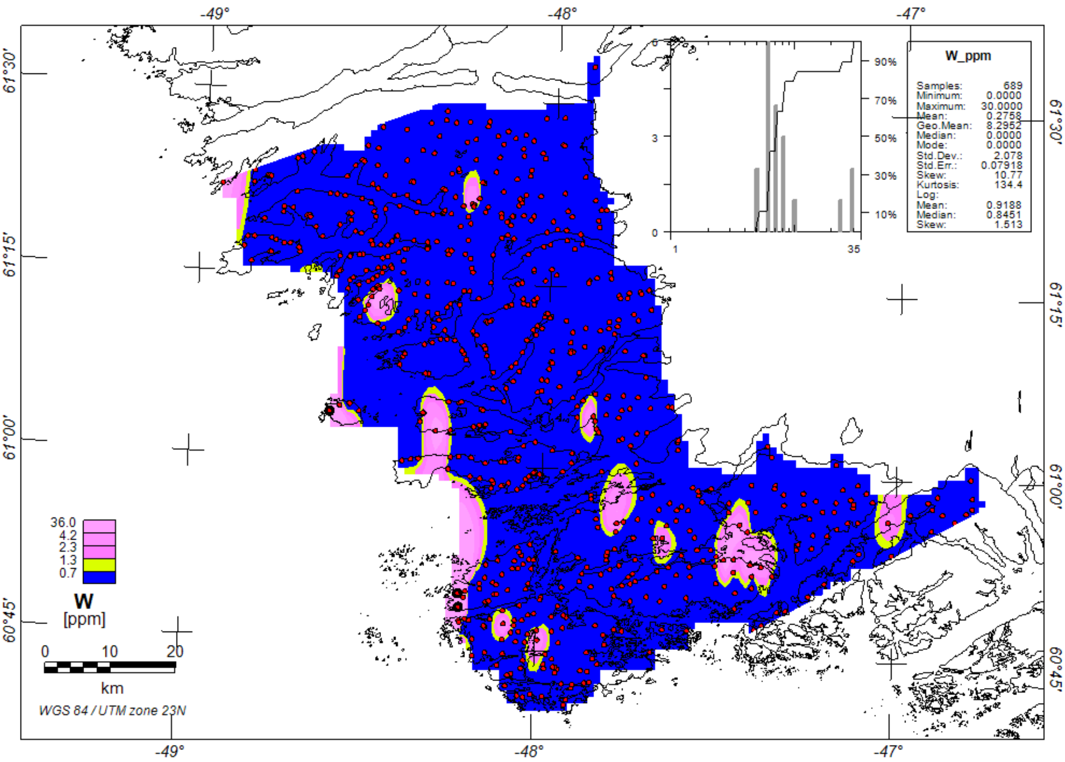

Figure 31. *Contoured distribution map for tungsten (W) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=689).*

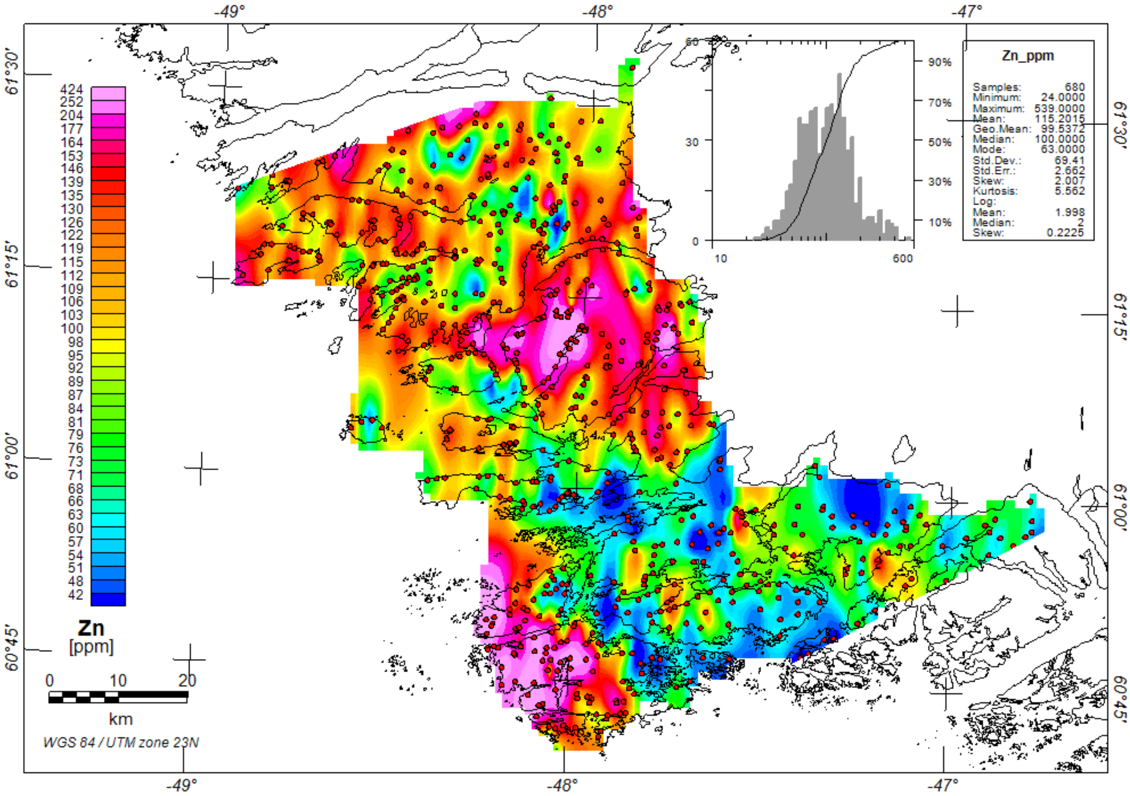

Figure 32. *Contoured distribution map for zinc (Zn) based on geochemistry of the fine fraction (<0.1mm) of stream sediments. Red dots indicate sample sites for the stream sediments (n=680).*

Geophysics (Riisager & Rasmussen)

Several geophysical datasets are available for the Kobberminebugt area, and are attached to the report in the form of geo-referenced tiff-files. In the following we will briefly discuss the geophysical data.

Airborne Magnetics

Magnetic anomaly maps from different sources exist for the Kobberminebugt area. The most comprehensive magnetic data set is from the regional, airborne geophysics projects Aeromag 1995 and Aeromag 1996, covering the coastal region from the Inland Ice to the ocean (Thorning & Stemp 1996, 1997). Both surveys were flown with fixed-wing aircraft at a gentle drape at a nominal height of 300 meters above ground level and with 500 meters between survey lines. The line direction was 30º NW for the Aeromag 1995 survey and 37º NW for the Aeromag 1996 survey. Orthogonal control lines were flown with a separation of 5000 meters for both surveys. The Aeromag 1995 survey was flown by Sander Geophysics Limited and the Aeromag 1996 survey was flown by Geoterrex-Dighem Limited.

The data from the two surveys have been merged into a uniform data set and are presented as magnetic total field anomalies and calculated first vertical derivative anomalies in grid form (Grids calculated at 100 meters cell sizes). Fig. 8 depicts the merged Aeromag 1995 and Aeromag 1996 magnetic total field for the area. Both the magnetic total field and the first vertical derivative maps are attached to this report in the form of geo-referenced TIF-files on the enclosed DVD.

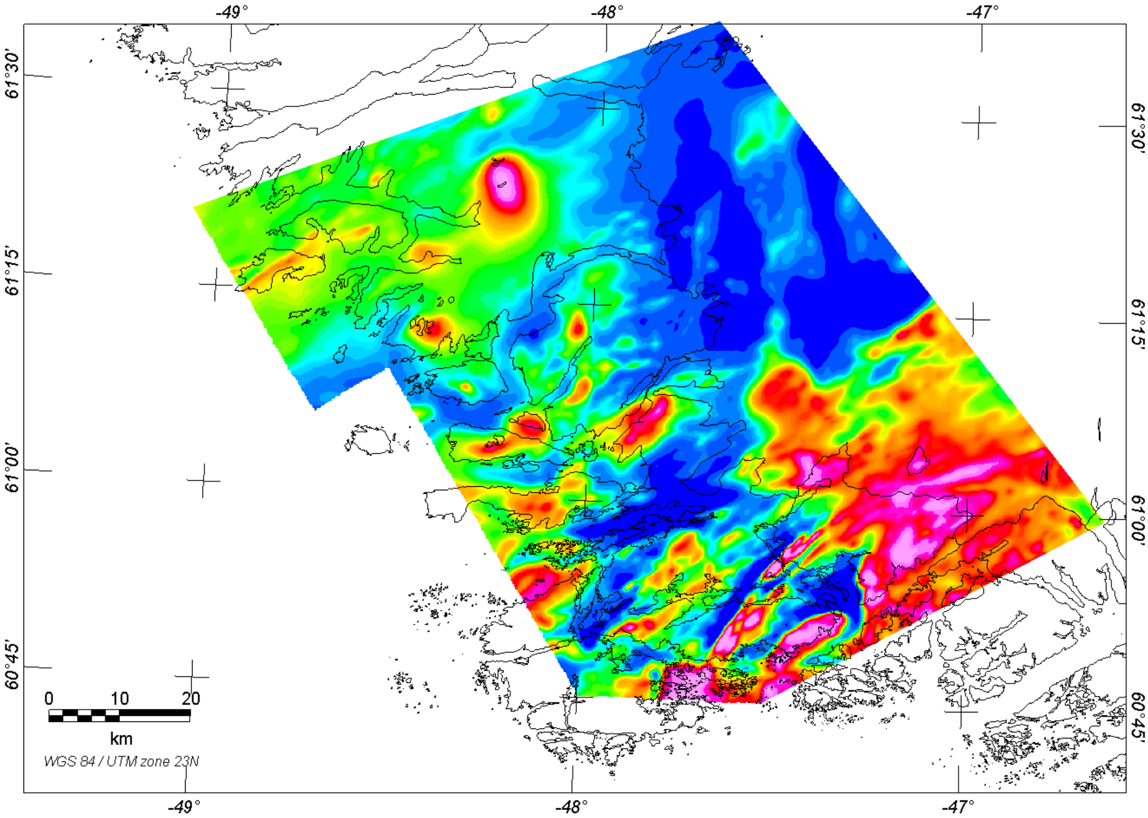

Figure 33. *The Total Magnetic field measured in the Kobberminebugt area from the Aeromag 1995 and Aeromag 1996 geophysical surveys.*

Another more detailed dataset covering the Kobberminebugt area stems from the project AEM Greenland 1996. AEM Greenland 1996 was a helicopter borne multi-sensor geophysical survey (Rasmussen *et al.* 2001; Stemp 1997), which included magnetic measurements in five detailed areas, four of which fall within the Kobberminebugt area (see Fig. 9). The survey was carried out by Aerodat Inc. using their helicopter borne frequency domain EM system. The magnetic data was collected at a nominal ground clearance of 45 meters, along flight lines spaced 200 meters apart and with orthogonal control lines at intervals of 2000 meters. The sampling interval of 0.1 second between measurements corresponds to a sampling distance of four meters.

To ensure consistency with Aeromag 1995-1996 data, the total field data for the AEM Greenland 1996 survey areas has been shifted by a constant value of 75 nT. This means that the data after upward continuation to the height of the Aeromag 1995-1996 surveys has a zero mean difference from the data of the Aeromag projects. The magnetic data sets from the AEM Greenland 1996 project are presented in a grid with 50 metres sampling distance. An Akima spline technique was used for the interpolation. Magnetic anomaly maps (total field and first vertical derivative) from the AEM Greenland 1996 survey are attached to this report in the form of geo-referenced TIF-files.

The calculations of the geophysical grids were mostly done using the Oasis Montaj geophysical software package from Geosoft Ltd.

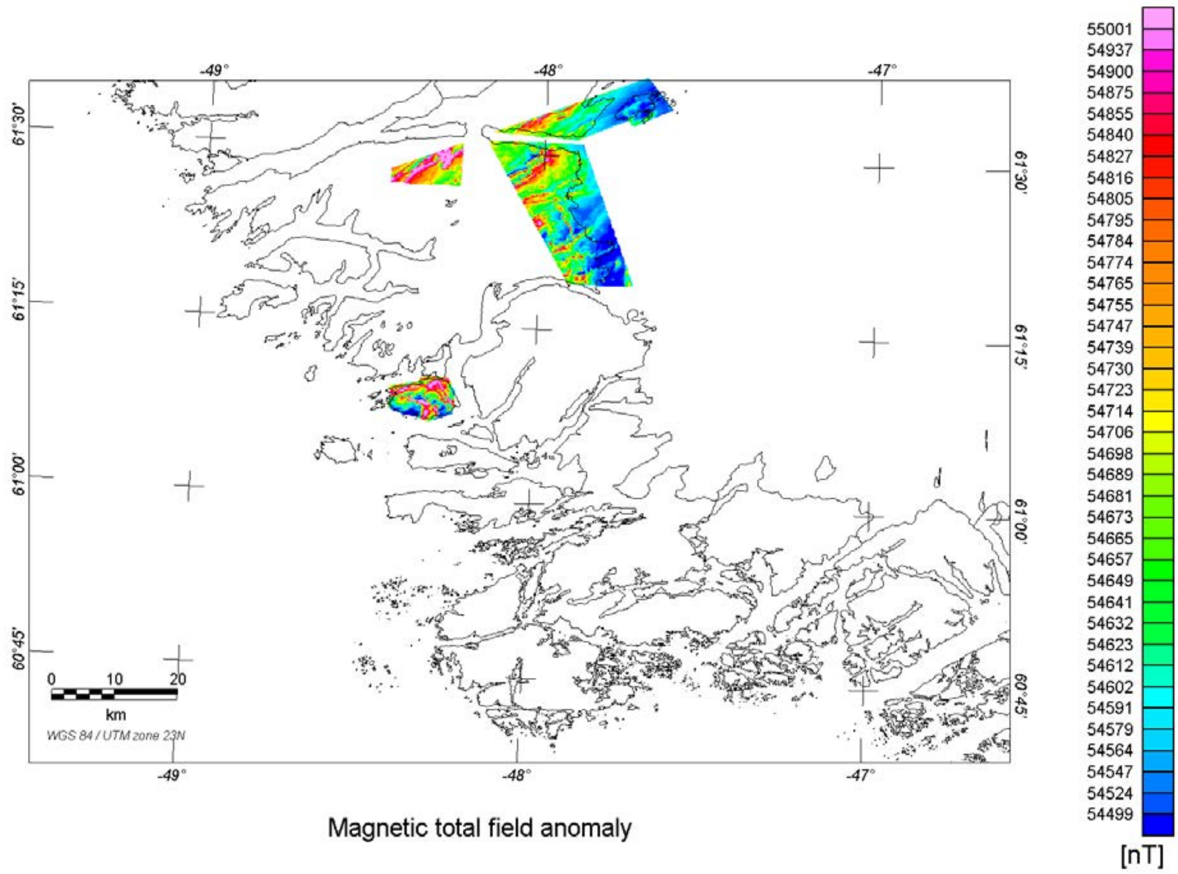

Figure 34. *Total Magnetic field in the Kobberminebug area measured during the AEM Greenland 1996 geophysical survey. The data is of higher resolution than Aeromag 1995-1996 (Fig. 8), but covers only parts of the Kobberminebugt area.*

Airborne Electromagnetics

Airborne electromagnetic data is also available from project AEM Greenland 1996 (Rasmussen *et al.* 2001; Stemp 1997). In the present report the results are presented in two anomaly maps, as apparent resistivity from controlled source measurements (e.g. Fig. 11), and as anomalies of measured VLF signals. The data is presented in 50x50 meters grid in the form of images.

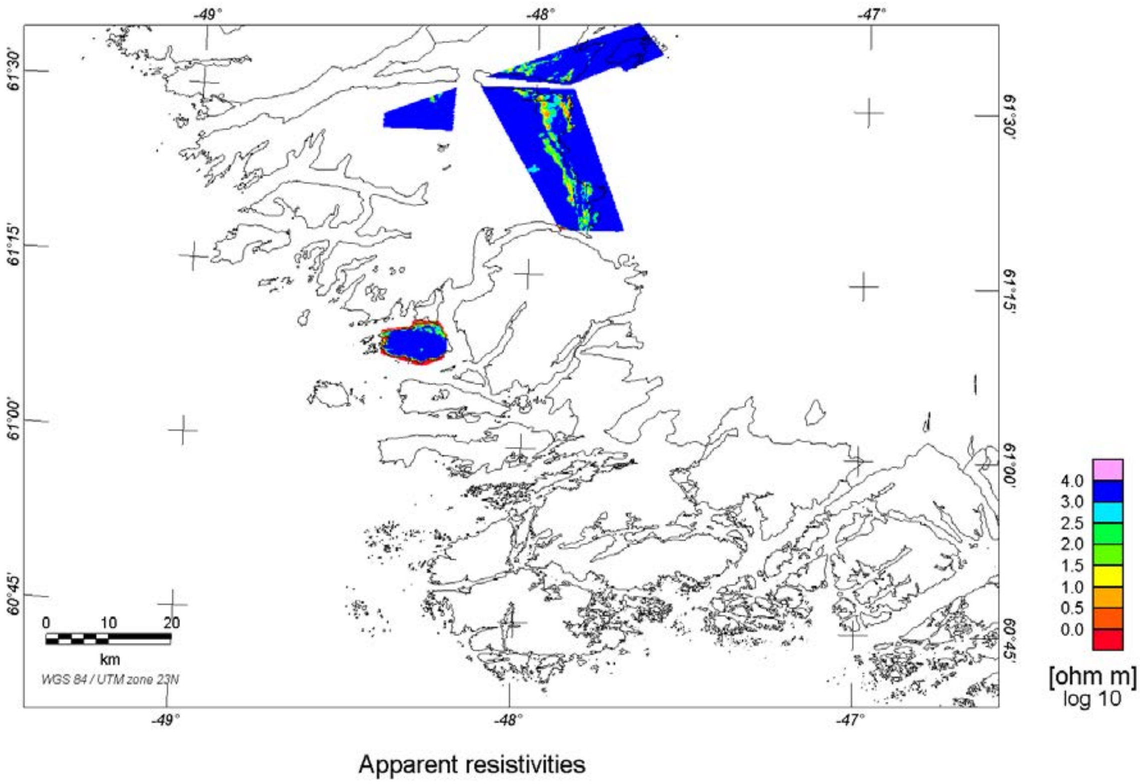

Figure 35. *AEM Greenland 1996 apparent resistivity calculated as the resistivity of a 200 metres thick layer above a resistive basement, which fit the measured in-phase and quadrature data at 4200 Hz for the co-planar loop.*

The survey was flown with the Aerodat Inc. helicopter EM system, with a five frequency vertical co-axial and horizontal co-planar loop at a nominal height of 30 meters above ground. The co-axial systems used frequencies of 920 Hz and 4 600 Hz, while the co-planar system used frequencies of 515 Hz (or 860 Hz), 4 200 Hz and 33 000 Hz. The nominal height of the VLF-sensors was 45 meters above ground level. The flight line separations and directions are as described above for the magnetic data.

The following anomaly maps are attached to the report in form of geo-referenced TIF-file images:

- Apparent resistivity calculated as the resistivity of a 200 meters thick layer above a resistive basement, which fit the measured in-phase and quadrature data at 4200 Hz for the co-planar loop.
- VLF-anomaly data from the Rugby (GBR) transmitter at 16.0 kHz and the Cutler (NAA) transmitter at 24.0 kHz. The data is presented as the ratio between the vertical and horizontal components of the measured field in percent.

The interpolation of the data sampled at intervals of four meters along flight lines was accomplished with an Akima spline technique.

Airborne Radiometrics

Radiometric data is available from project Syduran (Armour-Brown *et al.,* 1982) and from project AEM Greenland 1996 (Stemp, 1997). The data includes measurements from helicopter surveying of the radiation from uranium, thorium, potassium and total count.

An Exploranium GR820–256 channel gamma ray spectrometer (16.8 liter NaI crystal) was used for the measurements of the AEM Greenland 1996 project. The radiometric anomaly maps are presented as grids with 50 meters sampling distance. An Akima spline technique was used for the interpolation. The data was collected at a nominal height of 60 meters and with line separations and directions as described above for the magnetic data. Fig. 12 shows an example with counts corresponding to the potassium energy window. Similar maps are available for uranium, thorium and total count.

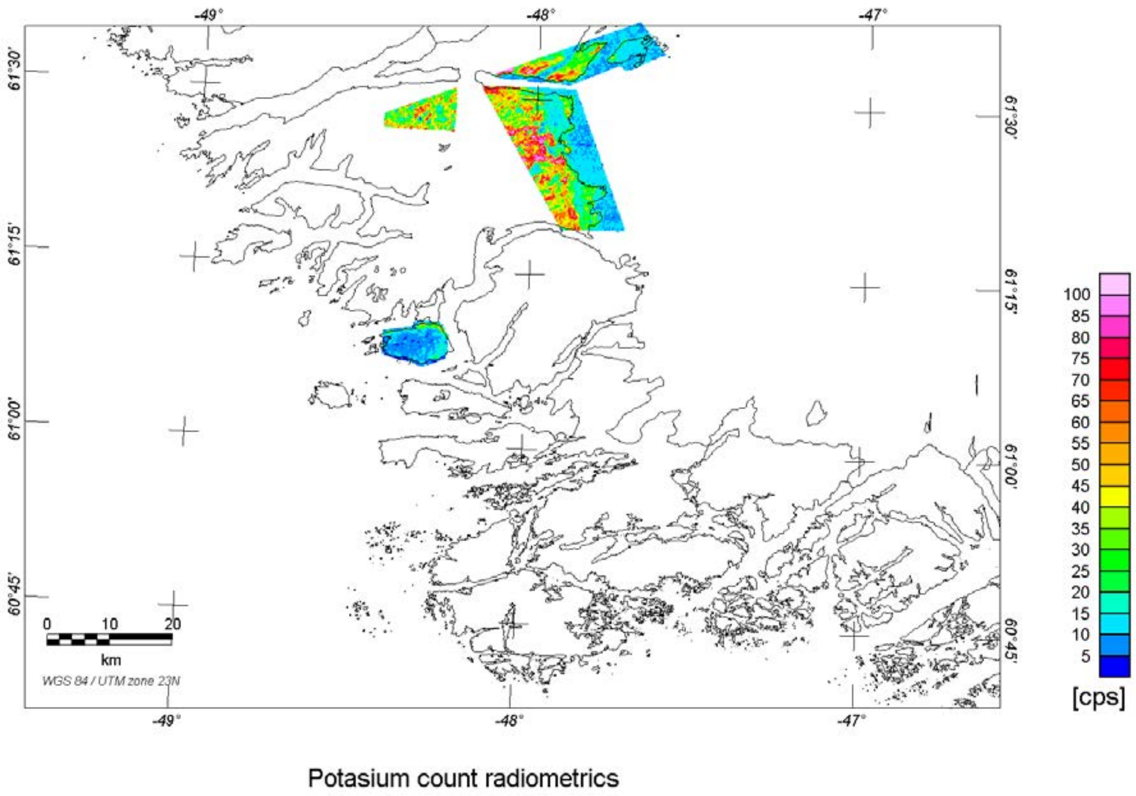

Figure 36. *AEM Greenland 1996 Radiometric Potassium counts per second (cps).*

The data from the Syduran project is described in (Armour-Brown *et al.* 1983). A four-channel gamma-ray spectrometer (7.413 liter NaI crystal) installed in a helicopter was flown at a nominal height of 30 meters over the terrain. The flying was not along straight lines, but done as ‘contour flying’. The grids based on the data from the Syduran project were calculated at 1060 meters grid cells using the minimum total curvature method.

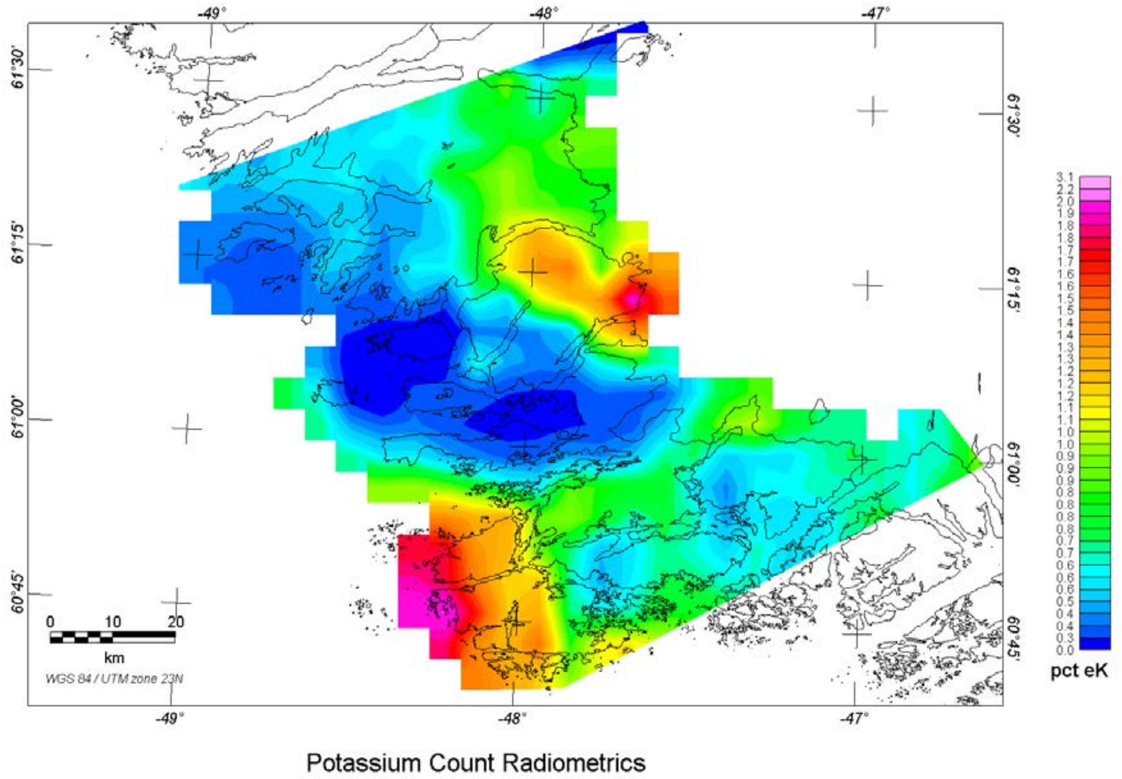

Figure 37. *Syduran Radiometric Equivalent Potassium (pct eK).*

Note that the units used for presentation of the results from the Syduran project (Fig. 13) differ from those of the AEM Greenland 1996 survey. In the Syduran results, measured counts per second are converted into estimates of mean surface concentrations of radioactive elements. Equivalent uranium (eU) and equivalent Th (eTh) are used to emphasize that the measured radiation is emitted from daughter products, ^{214}Bi and ^{208}Tl respectively, based on the assumption that the ^{238}U and ^{232}Th decay series are in equilibrium. The total count measurements from the Syduran project are presented as the internationally recommended 'unit of radioelement concentration (Ur)'. One Ur is defined as the radioactivity equivalent of one part per million of uranium in radioactive equilibrium.

Non-GEUS geophysical surveys

In addition to the geophysical surveys carried out by GEUS, and data presented above, private companies have carried out a few smaller surveys in the Kobberminebugt area (e.g.

Finnprospecting, 1986; McConnell, 1986). Unfortunately GEUS does not have access to the data from these surveys in digital format.

Digital geophysical data on accompanying DVD

The following Geo-referenced tiff-files with geophysical images are included on the DVD accompanying this report:

Aeromag_TMI.tif: Total Magnetic field from the combined Aeromag 1995-1996 geophysical surveys (similar to Fig. 8).

Aeromag_VG.tif: Magnetic field first vertical derivative from the combined Aeromag 1995-1996 geophysical surveys.

AEM96_TMI.tif: Total Magnetic field from AEM Greenland 1996 geophysical survey.

AEM96_VG.tif: Magnetic field first vertical derivative from AEM Greenland 1996 geophysical survey.

AEM96_VLF.tif: VLF-anomaly data from AEM Greenland 1996 geophysical survey. The data is presented as the ratio between the vertical and horizontal components of the measured field in percent.

AEM96_RES.tif: Apparent resistivity data from AEM Greenland 1996 geophysical survey. Data is calculated as the resistivity of a 200 meters thick layer above a resistive basement, which fit the measured in-phase and quadrature data at 4200 Hz for the co-planar loop.

SydUran_U.tif: Radiometric Equivalent Uranium data from the SydUran survey.

SydUran_K.tif: Radiometric Equivalent Potassium data from the SydUran survey.

SydUran_Gamma.tif: Radiometric Total Count data from the SydUran survey.

SydUran_Th.tif: Radiometric Equivalent Thorium data from the SydUran survey.

AEM96_U.tif: Radiometric Equivalent Uranium data from the AEM Greenland 1996 survey.

AEM96_K.tif: Radiometric Equivalent Potassium data from the AEM Greenland 1996 survey.

AEM96_Gamma.tif: Radiometric Total Count data from the AEM Greenland 1996 survey.

AEM96_Th.tif: Radiometric Equivalent Thorium data from the AEM Greenland 1996 survey.

Historical exploration and mining activities (Sørensen)

The Ivigtut Cryolite and Josva mines

The mining history in the project area goes all the way back to the 1850s, where there was an attempt to mine copper at the Josva Mine on the southern coast of Kobberminebugt (Fig. 38). Inadequately known quantities of ore, simple technology and a number of ship losses were significant reasons why the copper mine had to be abandoned.

From 1905–1914, the Josva Mine was re-opened and copper was also mined at the nearby Lillian Mine (Fig. 38). The orebody at the Josva Mine is a 32 cm wide NE-SW trending wedge-shaped body, which can be followed 120 m down dip and is exposed approx. 100 m along strike. According to Kolb & Stensgaard (2009) the Josva copper deposit is interpreted to be an IOCG-type deposit.

The known resource of the Josva Mine is now nearly exhausted and 2252 tons of copper ore were mined, yielding little more than a mere 60 tons of copper in 10 years of mining. Over 50 kg of silver and 0.5 kg of gold were also extracted. For a more comprehensive description of the historical evolution of the Josva deposit please refer to Secher & Burchardt (2000).

Mining began at Ivittuut with galena as the target (Fig. 38). Soon after, cryolite became the key commodity and during the period 1854 – 1987 approx. 3.7 million t of cryolite ore was mined. The Ivigtut Cryolite Mine is hosted in one of the Gardar intrusive complexes. The mined-out cryolite body was located within the roof zone of a 300 m wide pipe-like alkali-granite intrusion. The cryolite deposit was divided into a siderite-cryolite, a pure cryolite, a fluorite-cryolite, and a fluorite-topaz unit, above a large siderite and quartz mineralised unit. For a comprehensive description of the genesis and evolution of the cryolite deposit please refer to Pauly & Bailey (1999).

Company and survey activity

The region was mapped by GGU (former name of GEUS) in the late 1950s and early 1960s. Stream sediment surveys were carried out in the region in 1979, 1992 and 1993 by GGU. In the mid-1980s, GGU conducted reconnaissance work for noble and base metal mineralisation within the Precambrian supracrustal sequences. The results of this work are briefly summarised here but are described in more detail in Secher & Kalvig (1987). In 1997, GEUS investigated the area as part of a reassessment of the north-western border zone of the Palaeoproterozoic Ketilidian Orogen.

There are several known mineralisations in the supracrustal sequences in the project area (Fig. 38). Sulphide mineralisation is found within the major volcanic and sedimentary lithologies. Tables 2 & 3 include a list of all localities and a brief description of the mineralisation type. Table 2 includes localities that were covered during GGU´s mid-1980s reconnaissance work as described in Secher & Kalvig (1987). Table 3 includes additional localities described in GEUS' GMOM database.

The typical ore mineral assemblage is classified into four main groups (Secher & Kalvig 1987): Pyrite ± magnetite (group I) occurs in schist, greenschist and banded iron formation (BIF) as disseminated to massive ore. Pyrite-pyrrhotite±chalcopyrite (group IIA) forms approx. 20 vol.% sulphide mineralisation in greenschist and quartzite as host rocks. Late quartz veins are common and often mineralized when cutting the sulphide-enriched schist. Pyrite-chalcopyrite (group IIB) mineralisation is hosted in micaceous and graphitic schists. The graphite content may reach 20 vol.%. Locally, < 50 vol% sulphides are hosted in shear zones. In the group II assemblage, chalcopyrite is the dominant mineral. Chalcopyrite ± galena (group III) form disseminated sulphide mineralisation in marble. Quartz veins contain a chalcopyrite-bornite-chalcocite assemblage (group IV) at Josva Mine, Lilian Mine and Rødtoppen. The suphides are often accompanied by a suite of accessory minerals such as epidote and fluorite. Malachite is common as coatings on the copper-sulphide-bearing rocks. Stilbite has been recognized as a supergene product in the area around Josva Mine, but is also found at several localities all over the survey area as vein fillings in greenstone (Harry & Oen 1964).

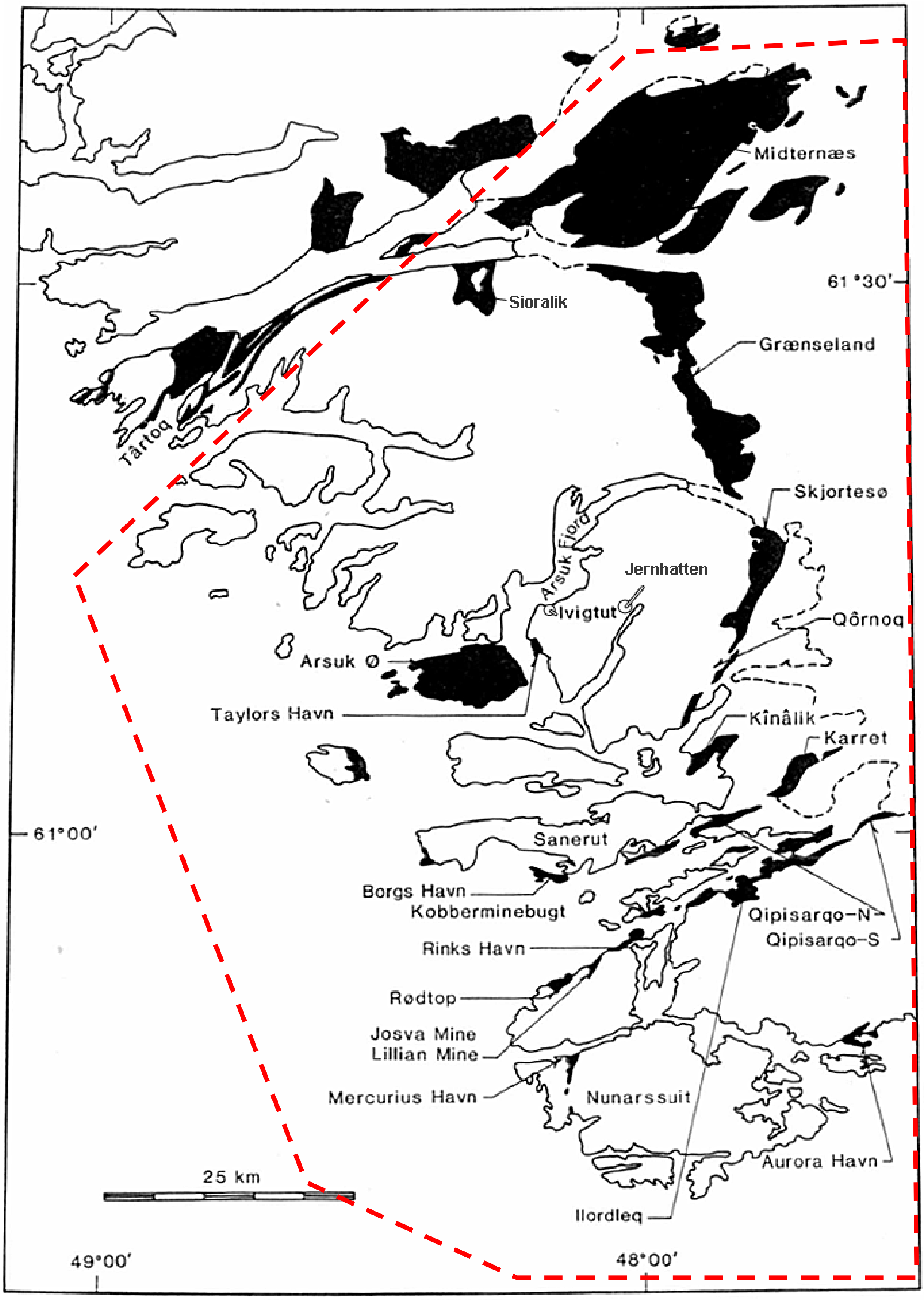

Figure 38. *Map of supracrustal sequences (black areas) with known mineralisation. A summary of all localities are included in tables 2 & 3. Red stippled line marks the project area of this report. Modified after Secher & Kalvig (1987).*

Table 2. *Sulphide mineralisation in the Ivittuut – Kobberminebugt region, modified after Secher & Kalvig (1987).*

Locality	Longitude	Lattitude	Ore minerals or commodity	Para-genesis	Host rock	Texture of ore minerals	Sulphide vol. %	Thickness m	Description
Skjortesø	-47.7775	61.27181	py, cp	II	Marble	dissem, massive	5-50	<1	Massive sulphides within the dolomitic marble form lenticular bodies traceable for several m along strike. The quartzite carries fuchsite in unmineralised layers. Qz-veins, carrying pyrite and chalcopyrite, cross-cutting the supracrustals are quite common.
Skjortesø	-47.7775	61.27181	py	I	Pyrite schist	dissem	5-10	>1	
Skjortesø	-47.7775	61.27181	py, cp	II	Quartzite	dissem	5-15	<1	
Skjortesø	-47.7775	61.27181	py, cp	II	Qz-vein	patchy	1-5	<1	
Qôrnoq	-47.91442	61.11514	cp, ga	III	Marble	patchy	<1	<1	Sulphides are scattered and only found in a few layers. The area, however, is interestning because of galena mineralisation within the marble, found locally together with chalcopyrite in calc-silicate nodules. Additionally concordant magnetite stringers are observed in mylonitisied greenschist.
Qôrnoq	-47.91442	61.11514	py, mg	I	Schist	stringer	<1	<1	
Qôrnoq	-47.91442	61.11514	py	I	Mica schist	dissem	1-5	>1	
Kînâlik	-47.89476	61.07175	cp	III	Marble	dissem	1-5	<1	The chalcopyrite is hosted in a sequence of marble - containing ultrabasic lenses and cut by quartz veins. All rock units are chalcopyrite bearing.
Kînâlik	-47.89476	61.07175	cp	II	Qz-vein	patchy	<1	<1	
Karret	-47.68393	61.06676	py, ph	IIA	Mica schist	dissem, massive	5-25	>1	Mica schist layers up to 50 m wide in gneiss are very rusty due to large amounts of weathered pyrite and pyrrhotite, locally with sulphide contents up to 25% by volume.
Qipisarqo-N	-47.88394	61.00627	cp	II	Conglomerate	dissem	1-5	>1	Chalcopyrite is found at the flanks of what is supposed to represent a narrow sequence of BIF. The Qipisarqo conglomerate is found locally to contain chalcopyrite disseminated in the green matrix. Additionally a few grains of chalcopyrite are observed in the cherty pebbles, thus supporting the hypothesis that it belongs to the youngest Ketilidian unit, with a reworked older copper content.
Qipisarqo-N	-47.88394	61.00627	py	I	Quartzite	dissem, stringer	1-5	>1	
Qipisarqo-N	-47.88394	61.00627	py, mg	I	Greenschist	dissem	1-5	<1	
Qipisarqo-S	-47.66056	61.00624	cp, py, ph	IIA	Black schist	dissem, massive	10-20	>1	The dominating sulphide-bearing rock type is a black graphitic schist which is only exposed to a limited extent. The content of pyrrhotite-pyrite-chalcopyrite may reach 20% by volume. Rockes with metagabbroic appearance and even larger sulphide contents are observed in floats.
Borgs Havn	-48.16352	60.96192	cp, py	IIB	"Tectonite"	massive	10-50	>1	The sulphides in this area deserve special attention because of the sulphide content and the size of the mineralised layers. Combined Cu-Fe sulphides of 5-10% by volume can be traced for several 100 metres along strike in widths of 0.5 - 5 m. The 'ore tectonite' mentioned above is remarkable because of a matrix with up to 50% pyrite and chalcopyrite.
Borgs Havn	-48.16352	60.96192	cp, py	II	Greenschist	dissem, massive	5-15	>1	
Borgs Havn	-48.16352	60.96192	py	I	Quartzite	dissem	1-10	>1	
Ilordleq	No data	No data	cp, py	II	Greenschist	dissem	<1	<1	These two areas also deserves attention because of the frequent appearance of chalcopyrite, although the grains are small and very scattered. At Rinks Havn a 1 m layer of mica schist with quartz veins shows disseminated type and stringers of bornite.
Rinks Havn	-48.01341	60.91006	cp, bo	IV	Mica schist	stringer, dissem	5-10	<1	
Josva Mine	-48.11808	60.8766	cp, bo, mg	II-IV	Greenschist	dissem, stringer	1-5	>1	Bornite is found disseminated in greenstone, as well as in quartz veins, giving rise to this well known copper deposit. Chalcocite is found accessory but also occurs alone in qz-veins up to 2 m wide. Rhyolitic layers contain disseminated pyrite in accessory amounts.
Josva Mine	-48.11808	60.8766	cp, bo, co	IV	Qz-vein	patchy	5-20	>1	
Lillian Mine	-48.12324	60.86928	cp, bo, co	IV	Qz-vein	patchy	<1	<1	
Rødtop	-48.15942	60.86142	cp, co	IV	Qz-vein	patchy	1-5	>1	
Rødtop	-48.15942	60.86142	py	I	Rhyolite	dissem	<1	<1	
Mercurius Havn	No data	No data	py	II	Greenstone	dissem	1-5	<1	Sulphides are scattered and disseminated when observed. They are located in metabasic rocks often within epidotised nodules.
Aurora Havn	No data	No data	py	I	Metabasite	dissem	1-5	<1	
Taylors Havn	No data	No data	py	I	Graphite schist	dissem	5-10	>1	Imposing layers of graphite schist contain locally moderate amounts of pyrite, which might be comparable to the Skjortesø rocks.

py = pyrite, cp = chalcopyrite, ga = galena, ph = pyrrhotite, mg = magnetite, bo = bornite, co = chalcocite

Table 3. *Known mineralisation in the Midternæs, Grænseland, Ivittuut, Arsuk Ø and Jernhatten areas as described in the GMOM-database.*

Locality	Longitude	Lattitude	Ore minerals or commodity	Host rock	Description
Ivittuut	-48.17005	61.20632	Cry, Sid, F	Granite	The Ivittuut cryolite mine is hosted in one of the Gardar intrusive complexes (Pauly and Bailey 1999). The cryolite body is located within the roof zone of a 300 m wide pipelike alkali-granite intrusion. The cryolite deposit is divided into a siderite-cryolite, a pure cryolite, a fluorite-cryolite, and a fluorite-topaz unit, above a large siderite and quartz mineralised unit (Pauly and Bailey 1999). The genesis of the cryolite deposit is described by Pauly and Bailey (1999). The deposit formed when F-rich post-magmatic fluids from deeper parts of the Ivittuut granite intensively leached, metasomatised and re-mobilised the central top part of the granite pipe to form a homogeneous supercritical fluoride-rich melt. The melt may have undergone immiscible separation into upper fluor-bearing fluid and a lower siliceous mass. The capped and narrow Ivittuut granite pipe contained and retained the F-rich fluids that formed the economic body of cryolite in the deposit. (Pauly and Bailey 1999). The cryolite deposit originally contained 3.8 million tons of ore with 58% cryolite including the fluorite-topaz unit underlying the western part of the deposit. To this is added an underlying mass of quartz with siderite of 8.5 million tons to a total resource of 12.3 million tons of ore (Pauly and Bailey 1999). The remaining in situ reserve of probable ore is calculated to be at least 22,000 t of cryolite ore (average 45.9% cryolite), 501,000 t of fluorite ore (average 49,9% F) and 691,000 t of siderite ore (average 65% siderite) (Bondam, 1991).
Jernhatten	-48.03813	61.22249	Fe	Gneiss	The Grønnedal-Ika complex belongs to the Gardar intrusive suite and is emplaced into the regional Archaean gneiss. It comprises four, steeply dipping, ring structures of nepheline syenite, with late, central plugs of xenolitic syenite, and carbonatite. The carbonatite is formed by a single event as a Ca- and Fe carbonatite plug surrounded by carbonate impregnated and brecciated nepheline syenite. The central carbonatite contains siderite, magnetite and a little sphalerite. Magnetite is most abundant adjacent to younger doleritic dykes. Magnetite-bearing Ca-carbonatite merges into siderite-bearing Fe-carbonatite at the eastern extension of the prospected area (Emeleus 1964; Bondam 1992). The magnetite mineralisation is suggested to have formed by contact metamorphism of siderite-bearing carbonatite during dyke intrusion. The amount of ore with grades of 25-30% iron is estimated to 800 000 tons. Apatite is present in both Ca- and Fe-carbonatite and drill core samples have yielded 0.5 – 1.5 % P.
Grænseland (West)	-47.97913	61.44146	Fe	Conglomerate	A quartz-pebble conglomerate occurs in the Grænseland area near the base of the Vallen Group sediments. The conglomerate is one to six metres thick and can be followed 12 kilometres along strike. Bondesen (1970) describes the conglomerate as an oligomict conglomerate consisting of boulders of grey to white cherty quartzite in a matrix of magnetite or locally pyrite with minor hematite and ilmenite. Garde et al. (1998) suggest that the unit is a chert-podded banded iron formation, in which some chert pods superficially resemble rounded clasts of chert. The total thickness is 16 m and the horizon is largely composed of variably podded chert layers 8-10 cm thick and alternating 2-3 cm thick layers of recrystallised, fine-grained magnetite. Planar millimetre-scale chert-magnetite layering occurs in a c. ten-cm thick zone near the base of the member. The magnetite content ranges from about 70% by volume at the base to 30% at the top of the conglomeratic unit (Geisler 1975). Southwards, matrix magnetite is replaced by pyrite. Only trace amounts of 10 ppb gold have been observed (Geisler 1975).
Grænseland (East)	-47.92549	61.43883	Graphite	Sediments of the Foselv Fm	The area is located within the north-western border zone between the Palaeoproterozoic Ketilidian orogen and the Archaean basement gneiss complex. An anthracite-graphite occurrence is located in the sedimentary units of the Ketilidian Foselv Formation in Grænseland. The southern part of the deposit is located in graphite schist and the northern part in an anthracite coal layer. The occurrence is estimated to contain 10,000 tons of graphite, but has not been found to be of economic importance.
Midternæs (Perledal)	-48.00467	61.60838	py, cp, ph	Supracrustals, siltstone, graphitic argillite	The mineralisation is hosted in Ketilidian supracrustals of the Sortis Group and includes a thick succession of basaltic pillow lavas cut by gabbro sills. Sulphidic horizons can be followed for more than 6 km along strike. Eleven sedimentary horizons have been identified within the metavolcanics. The sedimentary horizons can be traced along strike for distances up to 1.5 km and are up to 16 m thick. They consist of siltstone, graphitic argillite and chert-sulphide horizons with pyrite, pyrrhotite, and chalcopyrite.
Midternæs	-48.21114	61.57384	Fe	Unconformity, Supracrustals	The area lies within the north-western border zone between the Palaeoproterozoic Ketilidian orogen and the Archaean basement gneiss complex. The border between the Archaean and Ketilidian rocks is an unconformity. Iron-formation in the Midternæs area is found on Nuna Qernertoq and "Nunatak 810". On Nuna Qernertoq the iron-formation is interlayered between a thin pyroclastic unit and a thick sequence of pillow lavas. It can be followed for some hundred metres, is 15 m wide, but pinches out towards the north and disappears under the ice towards south. At "Nunatak 810" two iron-formations occur separated by an intrusive gabbro sill. The iron content is approximately 33%. The dominant mineral is greenalite, with minor amounts of magnetite, siderite, and quartz. The iron-formation is suggested to be of submarine-exhalative origin, and precipitated in a moderately deep sea at low atmospheric O2 pressure.
Arsuk Ø	-48.34186	61.12261	Au	Supracrustals	Arsuk Ø is located within the Border zone of the Ketilidian mobile belt. The supracrustal successions comprise graphitic schist, shale, phyllite, dolomitic limestone, and quartzite. Mafic metavolcanics, up to 300 m thick, are intercalated within the metasediments. They are succeeded by a transitional unit of gabbro diorite sills which in turn is followed by thinly banded pyritic phyllite with chert lenses. This mixed sequence of volcanics and sediments is overlain by more than 3000 m of pillow lavas, volcanic breccias, agglomerates, tuffs and massive mafic lava flows (Gowen 1992). The supracrustal sequence is correlated with the Sortis and Vallen Groups in the Grænseland region (Mosher 1995). The structural development and the kinematics of the border zone from Midternæs to Arsuk Ø are described in Garde et al. (1998). A number of mineralisations are located on Arsuk Ø. Gold, zinc and copper contents are in general low and found in two settings: 1) in rusty chert horizons in the pillow lava sequence and 2) related to quartz veins in the pillow lava sequence. Samples show up to 300 ppb gold. The copper content reaches close to 2000 ppm in rusty metabasites and zinc contents up to 883 ppm are recorded in silicified tuff with minor quartz stringers and disseminated sulphides (Gowen 1992).

py = pyrite, cp = chalcopyrite, ga = galena, ph = pyrrhotite, mg = magnetite, bo = bornite, co = chalcocite, Cry = Cryolite, Sid = Siderite, F = Fluorite

The project area has been investigated by various exploration companies through time. In the following an overview of historical exploration activities in the project area is presented. The overview does not cover the exploration and mining history of the Ivigtut Cryolite Mine at Ivittuut as this is covered in details by Pauly & Bailey (1999).

The overview is based on public company reports identified in GEUS´s DODEX database:

1914	Grønlandsk Minedrifts Aktieselskab published a report on the mining concession and their Josva Mine.
1948 – 50	The siderite and magnetite-bearing carbonatite in the Jernhatten (Grønnedal-Ika) area was investigated by Kryolitselskabet Øresund A/S on behalf of the Danish State. The investigation included magnetic ground surveys, trenching and drilling of the main magnetic anomalies.
1956	The Geological Survey of Greenland carried out a reconnaissance radiometric survey of the Jernhatten carbonatite close to and around the drilling sites.
1964	Kryolitselskabet Øresund A/S investigated the copper mineralisation at Kinalik and Qipisarqo.
1969	Little Elisabeth Prospecting Syndicate examined and assessed the known copper mineralisation in the Kobberminebugt area; e.g. at Josva, Lillian mines and Rinks Havn.
1971 – 77	Renzy Mines Ltd. and Cominco conducted a larger exploration programme looking for base and precious metals between Paamiut and Ivittuut including areas in Midternæs and Grænseland.
1983 – 86	The Grønnedal-Ika complex was investigated as part of an EEC funded project. The goal of this project was to assess the niobium and phosphorous potential. On behalf of Kryolitselskabet Øresund A/S, the company Finnprospecting carried out a regional airborne geophysical survey of the entire Ivittuut peninsula
1989 – 94	Nunaoil carried out their Kujataa-project in the region that among others included exploration activities on Arsuk Ø, Grænseland and Midternæs looking for base and precious metals.
1990	Platinova Resources Ltd. investigated the cryolite deposit with special emphasis on the ore potential of broken low-grade fill-materials.
1995	Diamond Fields Resources Inc. conducted a DIGHEM heliborne geophysical survey covering parts of the project area including Arsuk Ø. The survey was to detect zones of conductive mineralisation and to provide information that can be used to map geology and structure.
1997	Tertiary Gold Limited did a reconnaissance program of the Midternæs, Arsuk Ø and Grænseland areas including LANDSAT image processing looking for base and precious metals..
1999	Quadrant Resources Pty Ltd explored for Voisey´s Bay style mineralisation related to the Gardar dykes.
2006	Scandinavian Gold Prospecting AB followed up on a magnetic anomaly on Arsuk Ø to explore for IOCG-style mineralisation
2010	Platina Resources Limited carried out exploration in the Kobberminebugt region looking for a possible IOCG-style mineralisation.

Currently four exploration licences are granted for the Kobberminebugt area (Fig. 39; Table 4). For more information about the different licences or how to apply for a prospecting and exploration licence please visit Bureau of Minerals and Petroleum at: www.bmp.gl/minerals.

Active mineral exploration licences as of 4 February 2013:

2006/09 Nordic Mining Ltd
2007/45 Rimbal Pty Ltd
2009/38 Hunter Minerals Pty Ltd
2011/03 Hunter Minerals Pty Ltd
2012/35 West Melville Metals Inc.

Table 4. *Addresses of companies holding an exploration license in the Kobberminebugt area.*

Nordic Mining Ltd 64 Abinger Road, London W41EX United Kingdom Tel: (+44) 7876777666 Tel: (+44) 8452269387	Rimbal Pty Ltd 47 Labouchere Road South Perth, WA 6151 Australia Tel: (+61) 89 367 6855 Fax: (+61) 89 367 3038
Hunter Minerals Pty Ltd. PO Box 6126 Queanbeyan N.S.W. 2620 Australia Tel: (+61) 2 6238 2358 Fax: (+61) 2 6238 2553	West Melville Metals Inc. 1020-800 West Pender Street Vancouver, B.C., V6C 2V6 Canada Tel + 604 646-4727 Fax + 604 331-4526 www.wmiron.com

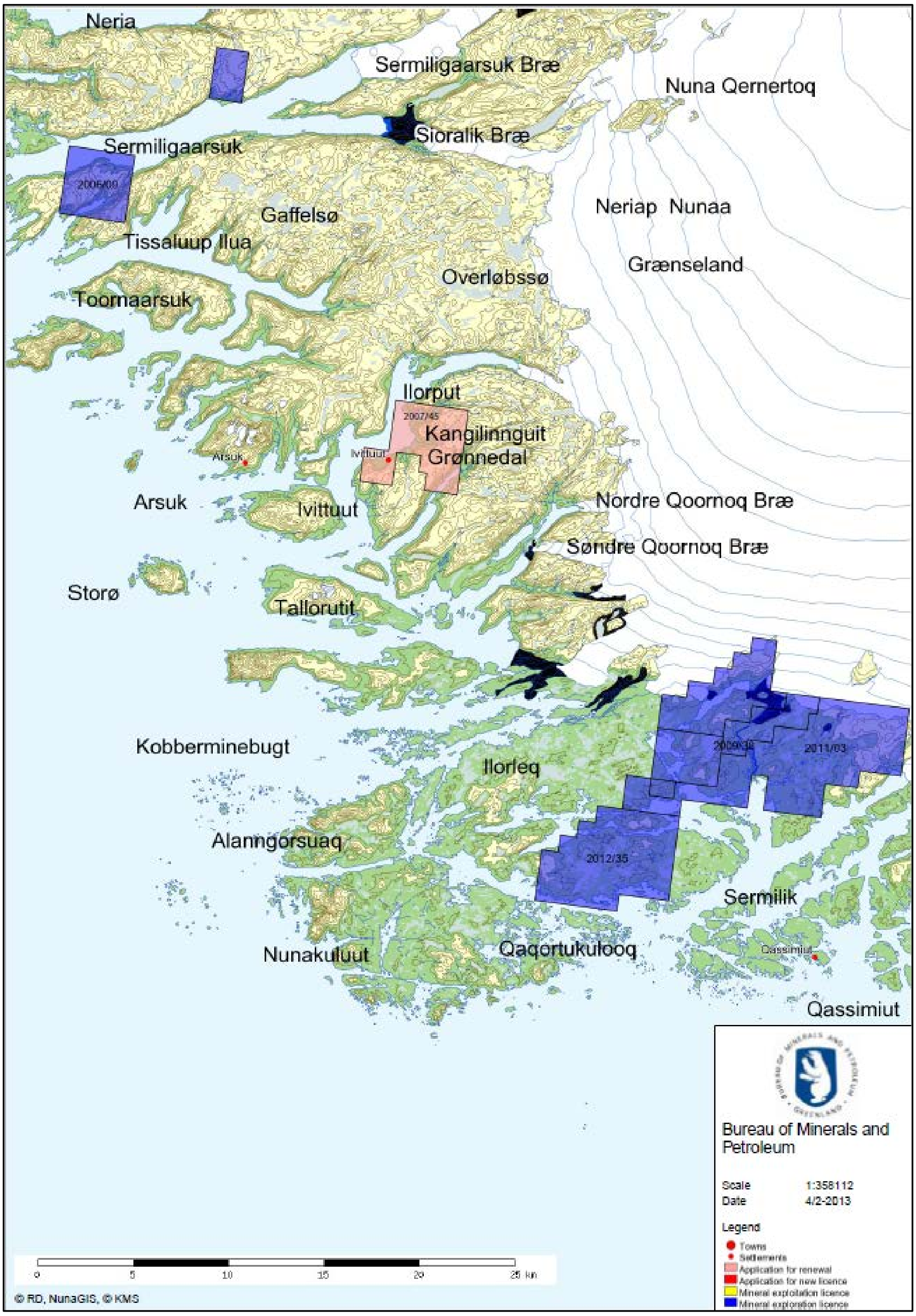

Figure 39. *Map showing the extent of exploration licenses in the Kobberminebugt area* (www.bmp.gl/minerals).

Ore geology (Kolb)

The Kobberminebugt area hosts a couple of different ore mineral occurrences and three abandoned mines, the Ivigtut Cryolite Mine, Josva Mine and Lilian Mine. Different potentially interesting lithologies have been identified, such as kimberlites with micro-diamonds, banded iron formations in the Palaeoproterozoic strata, and alkaline rocks of the Gardar Province displaying REE, F, P, etc. enrichment. In the following, the description is focused on Cu±Ni±Au mineralisation in association with sulphides.

Disseminated sulphides, mainly pyrite and chalcopyrite, have been recognized regularly in mafic and felsic (meta)volcanic rocks of the Palaeoproterozoic units, which are interpreted as representing syngenetic mineralisation (Secher & Kalvig 1987). Although no larger massive sulphide occurrence has been found on the surface, the mafic-felsic association together with the geochemical rift or back-arc signature (Garde *et al.* 2002b) may be regarded as favourable for VMS-like mineral systems. Additionally, galena and sphalerite has been described from marble in the Palaeoproterozoic units, which may be indicative of MVT systems. No major occurrence on the surface is known and the mineral showings are listed in tables 2 and 3.

Quartz veins containing traces of pyrite and chalcopyrite occur at Skjortesø and Tordensø (Fig. 3 and 38, Higgins 1970; Secher & Kalvig 1987). The veins have hydrothermal alteration halos of fuchsite, epidote, clinozoisite and pyrite. The strike of the veins is dominantly ENE-WSW, parallel to the D_2 structures. In the Tordensø area, the quartz veins are developed along the contact of competent mafic dykes within the Sortis Group (Higgins 1970). The vein formation is, thus, probably related to regional folding and thrusting to the north, representing an orogenic hydrothermal mineralisation setting. Regional sediment sampling and panning, however, did not return elevated gold grades, but no systematic exploration was done (Secher & Kalvig 1987).

To the north and to the south of the Kobberminebugt, several copper sulphide occurrences have been found and copper was mined for a few years from the Josva Mine. The area is characterized by Palaeproterozoic metasedimentary, metavolcanic and intrusive rocks, as well as Mesoproterozoic intrusions of the Gardar Province. Parallel to the fjord with an ENE-WSW strike, the < 15 km wide Kobberminebugt shear zone system represents the contact between the Border Zone and the Julianehåb Batholith. Copper sulphides are commonly hosted in veins and sheared migmatites and greenschists, constituting the occurrences of Rødtop, Josva Mine, Lilian Mine, Borgs Havn and other showings of the area (Ghisler 1968; Harry & Oen 1964; Secher & Kalvig 1987). The mineralisation occurs in veins, breccias, foliation-parallel stringers and vugs. The mineralised shear zone is characterized by an early albite alteration followed by a proximal garnet-calcite-ore ± epidote ± diopside ± actinolite ± apatite ± titanite assemblage and a distal hornblende-biotite-epidote assemblage (Harry & Oen 1964). The ore assemblage is bornite-chalcocite-ilmenite-magnetite-hematite-chalcopyrite±wittichenite±electrum±pyrite ±galena (Harry & Oen 1964). The hydrothermal alteration and ore assemblages are overprinted by chlorite-fluorite alteration and supergene alteration of the sulphides. The mineral assemblages indicate hydrothermal mineralisation at temperatures between 475°C and 660°C (Harry & Oen 1964). These authors relate the hydrothermal mineralisation to alkali-enriched fluids derived from intrusions belonging to the Gardar Province. The structural control by the mainly Palaeoproterozoic shear zone system and the high-temperature nature of the alteration assemblages suggest an earlier mineralisation during Ketilidian deformation (Stensgaard *et al.*

2011). The structural setting, the probable syn-metamorphic nature of mineralisation and the magnetite/hematite – copper sulphide/gold assemblage are the basis for a reinterpretation of this mineralisation as having formed in a metamorphic IOCG mineral system similar to Tennant Creek deposits in Australia (Stensgaard *et al.* 2011).

Nickel sulphides have not yet been described from the Kobberminebugt area, but the mafic dykes of the Gardar Province are known to contain disseminated nickel sulphide mineralisation elsewhere and a "Voisey's Bay" exploration model was used for mineral exploration of such mafic Gardar dykes further south.

The three main types of ores that have been observed are in summary: (1) disseminated, syngenetic, stratabound sulphides in (meta)volcanic rocks and marbles; (2) sulphides associated with orogenic quartz veins; and (3) shear zone-hosted, mesothermal copper sulphide – iron oxide, possible IOCG-type mineralisation.

Summary

The Kobberminebugt area in South and South-West Greenland reaches from the Sermiligaarsuk Fjord in the north to the Sermilik Fjord in the south. The three major geological terranes are:

- North Atlantic Craton (orthogneiss, greenstone belt)
- Border Zone (orthogneiss, greenstone belt, Palaeoproterozoic cover)
- Julianehåb Batholith (Palaeoproterozoic granitoids)

All terranes are intruded by late- to post-tectonic granites and Mesoproterozoic rift-related dykes and intrusions of the Gardar Province. Locally, small remnants of sedimentary basins of the Eriksfjord Formation are preserved. The tectonic evolution in the Palaeoproterozoic is characterized by sedimentation and volcanism in a foreland setting (Border Zone) and magmatism in an arc setting (Julianehåb Batholith) resulting from N-vergent tectonism, which terminated with late intrusions at approximately 1720 Ma. A continental failed-rift in the Mesoproterozoic is responsible for the Gardar Province magmatism and Eriksfjord Formation sedimentation.

Geophysical and geochemical data is of regional nature and outlines the major terranes, structures, intrusive units and known mineral occurrences. The major mineral occurrences and deposits of the area are:

- Ivigtut Cryolite Mine
- Josva and Lilian Mine (copper)
- kimberlites with micro-diamonds
- REE, F, P, etc. mineralisation in alkaline rocks
- disseminated, syngenetic, stratabound sulphides in (meta)volcanic rocks and marbles
- orogenic quartz veins
- shear zone-hosted, mesothermal copper sulphide – iron oxide, possible IOCG-type mineralisation

The area is well-covered by regional data sets, but generally detailed and targeted exploration with modern methods is lacking.

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