DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2004/5

Miocæn stratigrafi i Sønder Vium forskningsboring i Ringkøbing Amt (102.948)

Stefan Piasecki, Karen Dybkjær og Erik S. Rasmussen

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Contents

Summary

The report presents the results of c. 280 analyses from sills, lavas and intrusions in the Palaeogene East Greenland magmatic province. The aim of the investigation is to illustrate the geochemical variability with special emphasis depletion in Cu and PGE and crustal contamination. The data can be used for the evaluation of the potential for Ni-Cu-PGE mineralisations.

The samples used for the investigation were made available by several institutions. Some of the collections were made more than 25 years ago. The background information is accordingly not always as complete as may be wished.

The programme focussed on the sill provinces in the Kangerlussuaq fjord areas (68^{o}N) and the Jameson Land Scoresby Land (70-72^{o}N). For comparison and general overview are included a suite of samples from the Plateau Basalts from the Nansen Fjord area, a suite from the Imilik gabbro complex and a suite from the Mikis Fjord macrodyke to which are related contact Cu-PGE mineralisations (contamination related mineralisations).

It is not the aim of the programme to provide a detailed discussion of the results, but the investigation confirms that contamination with crustal material occurs, although it is not common.

In contrast to the generally accepted view that all Palaeogene East Greenland magmas show no depletion in PGE, the present results seem to show that evolved tholeiitic compositions are depleted in PGE and Cu. The picture is not clear, but it is suggested that mostly, the observed depletion is similar to that of the late liquids in the Skaergaard intrusion. The depletion in PGE in the Skaergaard intrusion occurs after the formation of a large, low-grade, PGE-Au mineralisation.

Introduction

The objective of the project is to provide background information for the evaluation of Cu-Ni-PGE mineralisation potential in areas of the Palaeogene Igneous Province in East Greenland. The sill provinces in the Kangerlussuaq Basin (68-69^{o}N) and the Jameson Land – Traill Ø region attract special interest.

The impetus for the project is the recognition that most criteria for the prospectivity for Noril´sk type mineralisations (as established by, e. g., BHPBilliton; Diakov *et* al. 2002) are met in the East Greenland magmatic province. These include:

- Large igneous province.
- Proximity to craton edge.
- Regional faulting and volcanic-plutonic depressions.
- Large volumes of mafic magma with picrite components.
- Differentiated mafic sills in the province.
- Sulphur-enriched and / or carbonate country rocks.
- Occurrence of Ni-(Cu)-PGE deposits.
- Thermal and metasomatic aureoles around intrusions.
- Lavas with evidence for crustal contamination.

A final criterion is the occurrence of *lavas depleted in chalcophile elements and PGE*. Until recently all the analysed tholeiitic magma types were suspected to be enriched in these elements (Andersen *et* al., 2002). Evidence for depletion as the result of saturation and deposition of Ni-Cu-PGE minerals has been scarce. However, depletion in PGE has been recorded in the Skaergaard intrusion, that hosts a large, low-grade PGE and Au deposit.

The main objective of the programme is thus to illustrate the compositional variations among the basaltic magmas in sills, lavas and small intrusions in selected parts of the igneous province. Emphasis has been placed on the sill complexes and related dike swarms in the Kangerlussuaq Basin and the Jameson Land -Traill Ø region. A more detailed discussion of the obtained data is not included in the programme.

Regional geological framework

The Palaeogene igneous province in East Greenland (see Fig. 1 and reviews by Deer, 1976; Noe-Nygaard, 1976; Brooks and Nielsen, 1982; Nielsen, 1987 and 2002; Saunders *et* al., 1997) developed prior to and during the opening of the North Atlantic basin.

Late Palaeozoic to Mesozoic sedimentary basins in the Kangerlussuaq and Jameson Land – Traill Ø regions predate the continental breakup. The Kangerlussuaq basin is dominated by Cretaceous to Eocene clastic sediments of mainly marine origin, and including sulphide-bearing shales.

The Jameson land-Traill Ø region has a much longer history of subsidence and deposition. The basin exposes an almost complete section from Late Permian to Upper Cretaceous. The succession includes clastic sediments, shales, dolostones and evaporites. The region is part of a long-lived basin formation along the east coast of Greenland.

Pre-basaltic sedimentary basins

The Kangerlussuaq Basin

The Kangerlussuaq Basin (Fig. 1) developed from Early Cretaceous or earlier and sedimentation continued until and during the onset of the magmatism related to the continental breakup in the Palaeocene (Larsen *et* al., 2001). The structure of the Kangerlussuaq basin is not well understood. Large parts are hidden below the Palaeogene lava successions and faulting and differential uplift and subsidence during continental breakup has fragmented the pre-existing basin structure. The total thickness of Early Cretaceous to Eocene sediment reaches in some areas c. 1 km. The geology of the basin is reviewed by Larsen *et* al. (2001). Dam al. (1998) relates the development of the sedimentary basin to plume impact beneath East Greenland.

Following Larsen *et* al. (2001), the unconformity between the oldest sediments and the Precambrian basement is nowhere to be observed. Sediments older than Lower Cretaceous (Aptian) may exist at depth. The oldest deposits (Aptian) comprise lacustrine shale, fluviatile conglomerate, marine sandstone and calcareous mudstone. They form the lower part of the Cretaceous Sorgenfri Formation otherwise dominated by marine shales with submarine channel turbidites. A hiatus follows and the Upper Cretaceous Ryberg Formation is also composed of marine shale and submarine channel turbidite. It is capped by marine sandstone. An unconformity separates the Ryberg Formation from the overlying Palaeocene Vandfaldsdalen Formation, that is dominated by the earliest volcanics (the Lower Basalts of the Kangerlussuaq area). A succession of fluviatile conglomerates (the Schelderup Member) forms the base of the Vandfaldsdalen Formation. The earliest volcanics are interbedded with marine and lacustrine shales. Some of the shales are rich in pyrite.

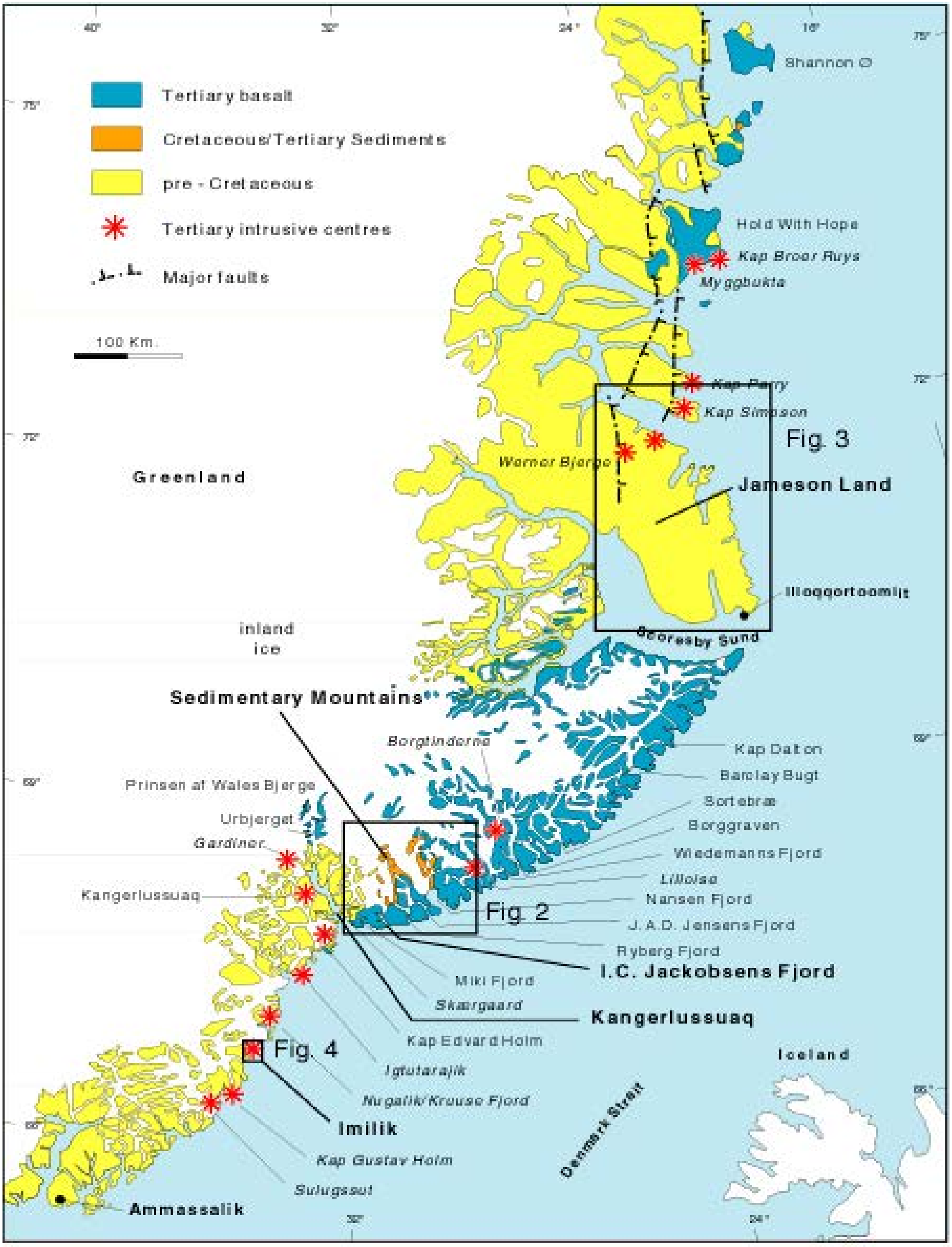

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Figure 1. *Geological map of the east coast of Greenland with the main geological units and the location of maps shown in figure 2-4.*

The Jameson Land – Traill Ø region

In the Jameson land – Traill Ø region (Fig. 1) the Mesozoic basin and the Late Permian to Cretaceous succession is well preserved as the result of a rather continuous subsidence. The basin is bowl-shaped with a centre in Jameson land. Following Larsen and Marcussen (1992) up to 10 km of sediments have been deposited in the deepest part of the basin in Jameson Land. Larsen and Marcussen (1992) review the results of extensive seismological investigations of the basin.

Basin development began after the formation of the Caledonides of East Greenland. Reviews of the Jameson Land – Traill Ø region can be found in, e. g., Birkelund and Perch-Nielsen (1976) and Surlyk *et* al. (1981).

The exposed Late Permian marine sediments are less than 300 m thick. They are dominated by clastic sediments including shales, sandstones, arkoses and conglomerates, but include minor thicknesses of limestones, dolostones and locally developed evaporites (e. g., Karstryggen).

The exposed Triassic succession is up to 1700 meters thick. Most of the succession is composed of marine as well as non-marine shales, sandstones and arkoses with intercalated conglomerates. The upper part of the Triassic succession is characterised by carbonates and evaporites. It includes limestones, dolostones and gypsum formations. The carbonates and evaporites have a maximum, exposed, thickness in the order of 500 m.

The exposed marine Jurassic successions are in the Jameson Land – Traill Ø region up to 1400 m thick. All the sediments are clastic and range from silty shales to conglomerates. The exposed marine Cretaceous sediments are >1000 m thick. As in the Jurassic, the sediments are clastic and range from silty shales to conglomerates.

The continental rift and Lower Basalts

The Kangerlussuaq basin is a precursor for the Palaeogene rifting of the continent along the east coast of Greenland. The rift basin is suggested to follow the trend of the East Greenland coast from Ammassalik to Kangerlussusaq and to extend below the preserved flood basalts of the Blosseville Kyst (Fig. 1).

The sedimentary record shows subsidence throughout Cretaceous, and an early Palaeogene uplift, that is apparently related to onset of magmatism (Dam *et* al., 1998). The Lower Basalts comprise a varied group of picritic to evolved tholeiitic basalts characterised by variable degrees of contamination with continental crust and burial metamorphism (Hansen and Nielsen, 1999). They are divided into several suites characterised by very different levels of enrichment in incompatible elements. Bulk rock chemistry (Hansen & Nielsen, 1999 and unpublished melt inclusion data (Nielsen *et* al., 2001) suggests at least three quite different types of magmas to coexist and mix to form the observed geochemical range. Age determination have mostly failed due to intense post-magmatic alteration of the lavas, but correlated lavas inland have given ages up to 61 Ma (Hansen *et* al., 2002) and the Lower Basalts and time-correlated formations below the main flood basalts are suggested to have formed between 61 and 57 Ma (Storey *et* al., 1996; Hansen *et* al., 2002).

The magmas of the Lower Basalts extruded into a basin with significant topography. In parts of the area of the Lower Basalts, up to 500 m thick sequences of hyaloclastites and pillow lavas were deposited. In other areas the lavas are all subaerial. A topographic height seems to have existed near the Kangerlussuaq fjord.

The Lower Basalts record a decreasing chemical variability with time and more uniform basaltic compositions dominate the upper part of the up to 1.6 km thick sequence of Lower Basalts. Reviews are published by Nielsen *et* al. (1981), Brooks and Nielsen (1982), Fram and Lesher (1997), Fram *et* al. (1998) and Hansen and Nielsen (1999).

The Lower Basalts of the Kangerlussuaq region are overlain by basaltic tuffs. The are mostly waterlain sandstones and grits of basaltic provenance, but include in the Nansen Fjord area a succession of primary basaltic tuffs (Peate *et* al., 2003) deposited from vent systems located on the headland between J.A.D. Jensen and Nansen Fjord (Fig. 1).

The Flood basalts

The main flood basalt formations overlying the Lower Basalts of the Kangerlussuaq region and time-correlated Nansen Fjord and Magga Dan Formations (see, e. g., Pedersen *et* al., and 1997). The flood basalts are described in detail from the northern part of the Blosseville Kyst (Larsen *et* al., 1989). Pedersen *et* al. (1997) show that the stratigraphy of the volcanic successions described from the Scoresby Sund region are readily correlated to the areas to the N and E of Kangerlussuaq.

The main flood basalts are divided into two cycles; each comprising a lower and more variable succession of lavas including picritic to evolved tholeiitic compositions and an upper rather uniform sequence of FeTi-basalts. The 1st cycle includes the Milne Land and the Giekie Plateau Formations and the 2nd cycle the Rømer Fjord and Skrænterne Formations (Larsen *et* al., 1989; Tegner *et* al., 1998a). A 3rd and younger cycle comprises the Igtertiva Formation. It is preserved in a small down faulted area on Kap Dalton on the northern part of the Blosseville Kyst (Fig. 1). The main plateau basalts are suggested formed between 57 and 54 Ma (Storey *et* al., 1996).

A suite of much younger basalts, the Vindtop Formation, occurs inland on the central part of the Blosseville Kyst. They are app. 13 Ma old (Storey *et* al., 2004). The magmatism related to the opening of the North Atlantic accordingly occurred over a time span of nearly 50 Ma.

Tectonics

The structural framework of the Palaeogene igneous province is dominated by: (1) a series of sedimentary-volcanic basins, on shore and offshore; (2) a coast parallel flexure; (3) doming in the Kangerlussuaq area and (4) subsidence of the Blosseville Kyst block.

Sedimentary-volcanic basins

Onshore

Mesozoic-Palaeogene sediments are preserved on land from ca. 66°N to 76°N. Small exposures of silty shales, arkoses and sandstones are preserved in the coast parallel flexure from 66 to 68°N (e.g., Myers *et* al., 1993). Many of these are located adjacent to later intrusions and are highly contact metamorphosed. It is suggested that these isolated occurrences of sediments are the remnants sediments deposited in an early coast parallel rift basin or series of basins.

The sediment exposures inland from the Blosseville Kyst in the Kangerlussuaq Basin appear to be deposited into a NNE-SSW trending rift basin along the trend of the coast south of Kangerlussuaq (Fig. 1). The basin is fragmented by later block-faulting and the primary structure of the basin is not clear. Larsen *et* al. (2001) suggest that shelf sediments in the Faeroe Island region originate from East Greenland. This would suggest that the Kangerlussuaq Basin may be quite wide and not a simple two-sided relatively narrow rift basin.

It is not known how far the sediments can be followed beneath the flood basalts of the Blosseville Kyst. Traces of hydrocarbons in the flood basalts near Scoreby Sund suggest the presence of sediments under parts of the flood basalt terrain.

The relationship between the Kangerlussuaq Basin and the Mesozoic deposits in the Jameson Land basin is not known. This large basin and its northern continuation started to develop in Upper Permian. It is an intercratonic basin that does not seem to have any direct relationship to the Palaeogene rifting along the east coast of Greenland. This may be supported by the fact that the basin did not develop into a rift.

Offshore

Geophysical investigations of the shelf areas, in part in connection with ODP drilling operations, have located pre-basalt, fault controlled, sedimentary basins south of Ammassalik township (65°N).

The coast parallel flexure

The coast parallel flexure of East Greenland (Wager and Deer, 1938) is a major coast parallel flexure caused by seaward rotation of a large number of small fault blocks in a structure reminiscent of the rift margins of, e.g., the Rhine Graben. It is most strongly developed in the area over the supposed plume head in the Kangerlussuaq region. The flexure is by Nielsen and Brooks (1981) described as a collapse structure. More recent descriptions can be found in Klausen and Larsen (2002). The occurrence of pseudotachylytes in shear zones related to the faulting is described by (Karson *et* al., 1998)

Pedersen *et* al. (1997) describe seaward subsidence of large fault block in flood basalts of the Blosseville Kyst. Time constraints suggest that this was a later development. The very steep seaward dip of basaltic successions in the Kangerdlussuaq area was the result of an early flexure followed by large-scale seaward subsidence of large fault blocks (see below).

Doming in the Kangerlussuaq area

Brooks (1980) describes a large, several kilometres, high and tens of kilometres wide domal structure in the Kangerlussuaq area. It is suggested to have developed over the head of the proto-Icelandic mantle plume. It is not entirely clear when the domal structure developed, but the strong flexing in the coast parallel flexure in the Kangerlussuaq area seem dynamically related to the doming. Pre-basaltic sediments and flood basalts are all affected by the doming and an extended period of doming is therefore inferred. The time constraints suggest that doming started around 55 Ma.

Subsidence of the Blosseville Kyst block.

The main exposures of the East Greenland flood basalts are found along the Blosseville Kyst. Only small exposures of pre-basaltic sediments and lavas are preserved south of Kangerdlussuaq fjord and in areas much further north. The preservation of the Palaeogene flood basalts along the Blosseville Kyst may be due to a significant subsidence of the coastal areas in the sector between Kangerlussuaq fjord and Scoresby Sund. The main structural elements of this post plateau basalt tectonism are described in Pedersen *et* al. (1997).

Sills provinces

Sills are common in the sediments below the flood basalts and in the lower part of the volcanic succession. Sills are commonly observed in the Kangerlussuaq Basin sediments and Lower Basalts N and NE of the Kangerlussuaq Fjord (Fig. 2) and in the Mesozoic Jameson Land Basin (Fig. 3) and the Mesozoic terrains to the north, from Traill Ø (72^{o}N) to Hold with Hope (76^{o}N).

Kangerlussuaq Basin

In a study of the sills of the Kangerlussuaq Basin, Gisselø (2000) record a total accumulated thickness of sills up to 1000 meters. On the assumption that such sills underlie much of the plateau basalt province, as much as 20% of the total volume of basaltic magma that reached upper crustal levels could be contained in sills (Gisselø, 2000).

The individual sills are very variable in thickness. In the lower part of the plateau basalts the sills are mostly thin from a few meters to tenth of meter, except from rare sills more than 100 m thick. Inland, within the Cretaceous sediments and deeper in the stratigraphic section, the sills may be several hundred meters thick. They can be quite irregular and step up or down trough the stratigraphy. Damming of sill magma at fault zones are observed in several localities (see Gisselø, 2000; Nielsen in press).

The sills are dominantly tholeiitic in composition. Many of the sills are fine-grained basalts and chocolate brown to rusty red in surface exposures. Picritic sills are clearly subordinate. Some sills are plagioclase phyric. The thicker sills commonly have late and coarse-grained pegmatitic segregations. Some sills are multiple, as the sill complex on "Sill Point" in I.C. Jakobsen Fjord, where a picritic sill is emplaced into the centre of a basaltic sill (Nielsen, pers. comm, 2004).

Late felsic and alkaline sills are common in the Kangerlussuaq Basin, and may explain an occurrence of erratic sodalite syenite blocks on the north shore of I.C. Jakobsen Fjord.

The samples used in the geochemical investigations have been selected from collections build up over the last 30 years, mainly by research groups from University of Copenhagen and more recent investigations by P. Gisselø, Danish Lithosphere Centre and GEUS (Gisselø, 2000). Nielsen (2002) has summarised the available information on the sills in the Kangerlussuaq area (Appendix 1).

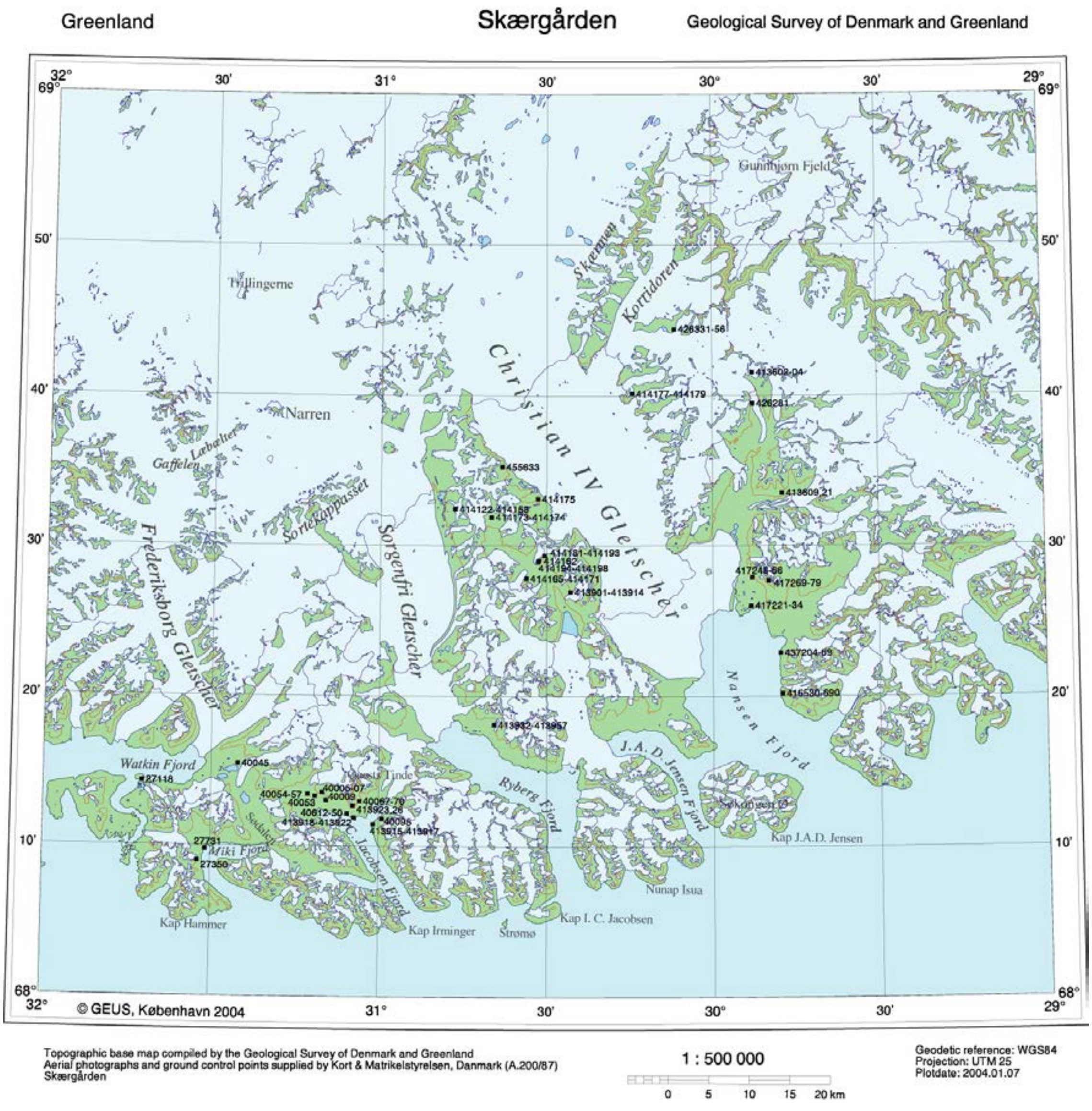

Figure 2. *Topographic map of the Kangerlussuaq region including Skaergaarden. Sample locations are indicated. A digital version can be found on the CD-ROM (Appendix 7).*

Jameson Land –Traill Ø region

Jameson Land and Scoresby Land

In their interpretation of geophysical data acquired during petroleum exploration Larsen and Marcussen (1992) identify a number of marked reflectors deep in the sedimentary basin. They argue that these represent sill complexes. The sill exposures on Jameson Land are representatives of a major suite of sills emplaced into the up to 10 km deep basin. The sills seem to be continues throughout the basin and volumes of individual sills may be as high as 1000 km^3.

Following Larsen & Marcussen (1992) the mid-crustal sills of the basin may be up to 300 m thick and thin towards the margins of the basin. The sills appear to step up through the stratigraphy towards the margins of the basin.

Hald & Tegner (2000) give a detailed description of the exposed sills. The sills are basaltic and commonly 10-20 m thick, but may reach 75 m in thickness in the axial part of the basin. Hald and Tegner (2000) estimate the sill volume to 100 km^3 in the Ørsted Dal area (Scoresby Land) (Fig. 3). In Ørsted Dal the lower of three sills (#1) is up to 50 m thick. The overlying sills (#2 and #3) are app. 30 m thick. The sills show internal differentiation. The sills are c. 52 Ma old and younger than the main flood basalts exposed on the Blosseville Kyst (Hald & Tegner, 2000).

Part of the sill province in the Jameson Land – Scoresby Land area is covered by a series of geophysical maps, including AEM (Stemp, 1999). A number of anomalies have been identified, some directly related to the sills. Later field investigations have shown the occurrence of magnetite-rich skarn deposits in the contact zones of the sills (Perdersen & Stendal, 1999).

The samples used for the geochemical investigation have been selected from the collections of N. Hald, Geological Museum Copenhagen (Hald & Tegner, 2000). Nielsen (2002) has summarised the available information on the sills of Jameson Land and Scoresby Land (Appendix 2).

Traill Ø

Price *et* al. (1997) give the most recent description of the sills of Traill Ø and Geographical Society Ø. Older descriptions are found in Schaub (1938 &1942).

On Traill Ø, the sills are emplaced into the Cretaceous sediments. The sills are very prominent and form steep walls in large part of the island and the island of Mountnorris Fjord on the eastern side of the island. The sills are basaltic and tholeiitic. They reach thicknesses of more than 300 meters and the thicker sills show internal differentiation.

Greenland Jameson Land GEUS

Base map compiled by the Geological Survey of Denmark and Greenland
Aerial photographs and ground control points supplied by
Kort & Matrikelstyrelsen, Danmark (A.200/87)
Jameson Land

1 : 750 000

Geodetic reference: WGS84
Projection: UTM 26
Plotdate: 2004.01.07

Figure 3. *Topographic map of the Jameson land – Traill Ø region with sample locations. A digital version of the map can be found in the CD-ROM (Appendix 7).*

The samples used for the geochemical investigation of sills from the Jameson Land – Traill Ø region were collected by P. Gisselø (Gisselø, 1998 & 2000) and N. Hald (Hald & Tegner, 2000). Nielsen (2002) has summarised the available information on the sills in Central East Greenland (Appendix 3).

Intrusions

The intrusions of the Palaeogene East Greenland magma Province are reviewed in Nielsen (2002). They cover a very wide age span (ca. 55 to 25 Ma) and range from ultramafic to highly evolved subalkaline to alkaline intrusions, including quartz-porphyry type complexes and ultramafic alkaline and carbonatite-bearing complexes with peralkaline syenites. Of specific interest is the common occurrence of ultramafic to gabbroic complexes. They occur along large parts of the East Coast (Fig. 1) from the Imilik gabbro complex in the south to the many gabbroic bodies in the Kangerlussuaq area, including the Skaergaard intrusion, and the ultramafic to mafic complexes of the Blosseville Kyst. A more northerly concentration of plutonic complexes is located in the Mestervig - Traill Ø region, including the large Werner Bjerge and Kap Simpson complexes. More than 60 intrusive complexes are recorded (Nielsen, 2002).

Tegner *et* al. (1998b) suggest that a bimodal age distribution of the gabbro complexes (55 and 50 Ma) represents gabbro complexes related to the continental rift setting and complexes emplaced during the passage of the Icelandic mantle plume beneath the initial rift and continental margin

Most of these complexes are tholeiitic. The classic Skaergaard intrusion (Wager & Deer, 1939) represents one batch of magma emplaced into a fault controlled magma chamber on the continental side of the cratonic edge (see also Nielsen, in press). Other complexes, e.g., the Kap Edvard Holm complex (Bernstein *et* al. 1992 & 1996) and the Imilik complex (Bernstein *et* al., 1998) represent replenished magma chamber systems, more akin to ocean floor type gabbro complexes.

The Skaergaard intrusion contains a large, low grade PGE deposit, including an intrusion-wide, 5 meter thick, Pd-rich horizon with Pd grade up to 5 g/t and an average grade of 2 g/t in >300 million tons. Other parts of the mineralisation are Au-rich, with up to 4 g/t Au. Sub-economic PGE mineralisations are recorded in many of the mafic complexes in Kangerlussuaq region and in areas to the south.

Introductions, short descriptions and selected references including a complete record of company reports (exploration reports) can be found in Nielsen (2002).

The Imilik gabbro complex

The Imilik Complex at app. 66°48'N covers about 60km^2, but is strongly dissected by fjords and glaciers (Fig. 4). The complex mainly comprises layered olivine gabbros with subordinate leucogabbros and anorthosites and intrusive peridotites (Bernstein *et* al., 1998 and Nielsen, 2002; appendix 6). Basaltic dykes are common everywhere in the intrusion, with a strong increase in abundance from a few volume percent in the western portions to about 60% in the eastern portions at the coast. Fieldwork in 1994 and 1995 shows that the complex can be divided into at least three mappable units, which are interpreted to represent major episodes of magma injection. The youngest of these units resides in the centre of the complex and has an age of about 49 my while the older units are older than 56 my (Tegner *et* al., 1998a). In comparison to the Skaergaard Intrusion, the Imilik complex show only moderate development in mineral chemistry, which suggests that each unit further developed through multiple replenishment episodes. Details in Appendix 4.

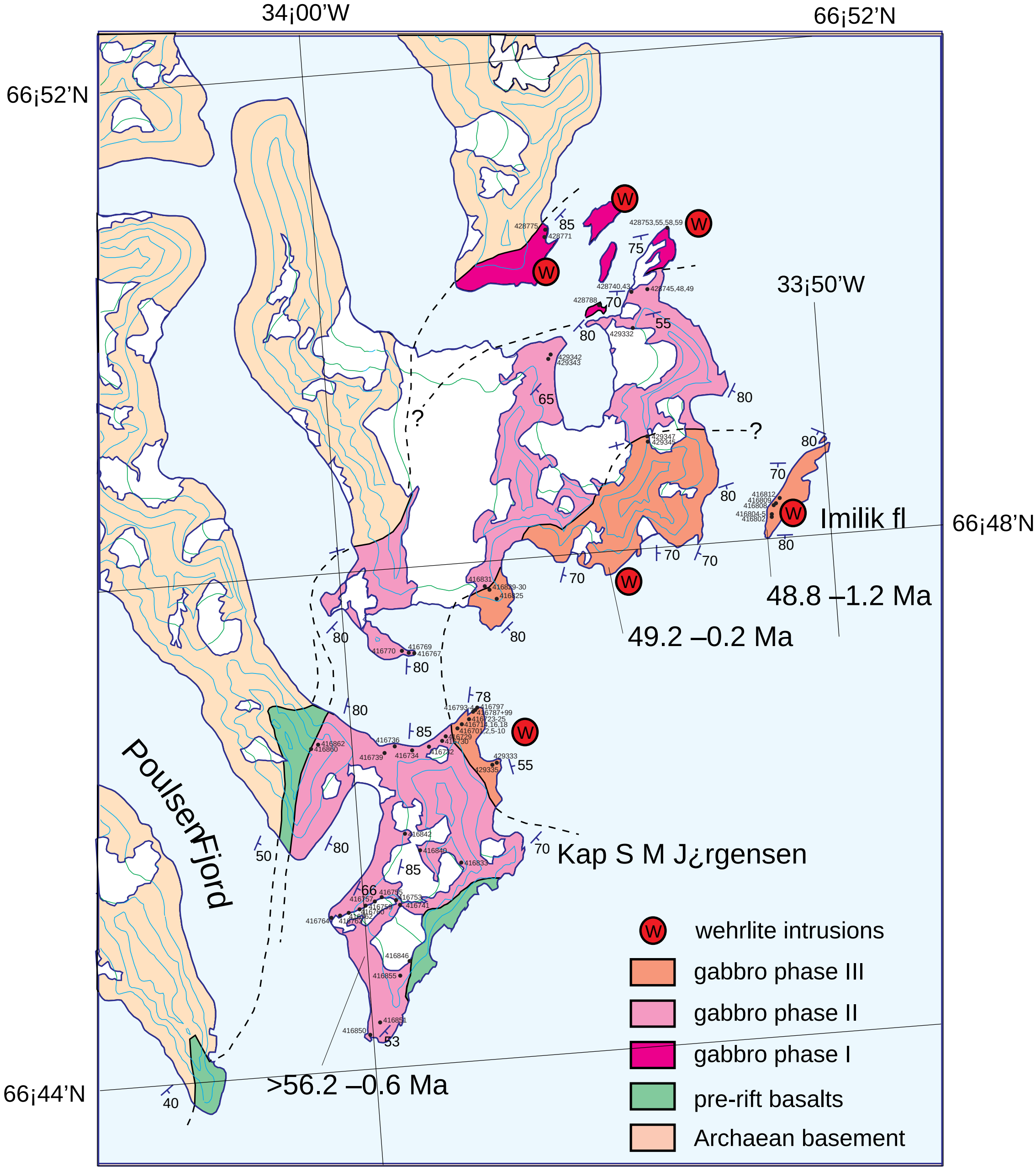

Figure 4. *Geological map of the Imilik gabbro intrusion and surroundings with sample locations. A digital version of the map can be found on the CD-ROM (Appendix 7).*

Macrodykes

A special group of gabbroic intrusions comprises macodykes. Macrodykes are up to 500 m wide and several to tens of kilometres long gabbroic intrusions. The three most important macrodykes, the Mikis Fjord, the Vandfaldsdalen and the Kraemer Ø macrodykes are all described in Nielsen (2002).

The Mikis Fjord Macrodyke (Blickert-Toft *et* al., 1992) can be followed for several tens of kilometres. It shows significant interaction with host rocks, including extensive melting of host gneisses and hybridisation. Inclusions of host rocks are in parts of the dyke quite common. Some contact rocks are enriched in sulphides and have elevated PGE contents (ppm level) and have been subjected to some exploration. Minor contact mineralisations with PGE concentrations in the ppm level have been observed. Platinova A/S has identified a geophysical target.

The samples used for the geochemical investigation were collected in the southern end of the macrodyke in 1974 by a research group from University of Copenhagen (C.K. Brooks). The samples are curated in the Geological Museum in Copenhagen. The data sheet for the Mikis Fjord Macrodyke in Nielsen (2002) is reproduced in Appendix 5.

Ultramafic and mafic plugs

A number of ultramafic to mafic plugs are exposed along the Kangerlussuaq fjord. The most prominent ultramafic plug is the poorly exposed Watkins Fjord peridotite plug located only a few kilometres north of the Skaergaard intrusion. The field information is limited, but it appears composed of a rather uniform mass of peridotite.

One sample has been included in the geochemical investigation. The available information is summarised in Nielsen (2002, see Appendix 6).

Exploration history

The exploration history of the Palaeogene magmatic province in East Greenland can be summarised as follows:

Period	Company	target
1952 - 1984	Nordisk Mineselskab A/S and patners.	Exploration between 70 and 74^{o}30 degrees North and in minor area further south in 1970-1971. Details in Harpøth *et* al. (1986). The main Paleaogene targets were the molybdenum deposits in the Werner Bjerge complex and alkaline intrusions of the Palaeogene intrusive centres. Gabbro intrusions were investigated superficially.
1961 - 1984	Arktisk Minekompani A/S and partners	The Malmbjerg molybdenum deposit and other molybdenum prospects in Werner Bjerge and on Traill Ø.
1986-2000	Platinova Resources Ltd and later Platinova A/S	The Palaeogene gabbro intrusions in the Kangerlussuaq region and area to the north and south of Kangerlussuaq fjord. Regional reconnaissance in the Kangerlussuaq region for PGE and AU.
1997	INCO	Sills in the Hold with Hope region and in Jameson land.
1993-1995	Quadrant Resources	The Kruuse Fjord complex for PGE.
2002-2002	Gryphon Metals Corporation	The Skaergaard intrusion for PGE and Au.
2002 -	Shambhala Gold Corp.; Skaergaard Minerals; Galahad Gold Corp.	The Skaergaard intrusion for PGE and Au.

Details of the exploration activities by Nordisk Mineselskab A/S and Arktisk Minekompani A/S and partners are reviewed in Harpøth *et* al. (1986). Besides this exploration Nordisk Mineselskab conducted reconnaissance exploration in the Kangerlussuaq fjord area (68^{o}N), in Nualik (67^{o}N) and Kialineq (66^{o}N) from 1970 to 1971.

A description of the exploration in the Palaeogene intrusions can be found in Nielsen (2002). This report also contains references to all non-confidential company reports.

The Geochemical Investigation

From diaries, reports and the literature was initially searched for a total of c. 500 samples. Approximately 400 were identified to be of possible interest. On further examination many were found not to be available. Some had been lost, others did not meet the required standard and in some cases the remaining amount of sample was insufficient for the analytical programme.

The data sheet attached to this report contains all the available information for the selected samples (see description of the data sheet below). Previously acquired geochemical data is included and only in a few cases have samples been re-analysed. The analytical programme includes major- and trace element analysis using a variety of analytical methods, analyses for Pt, Pd and Au for all samples, and Sr and Nd isotope determinations for a subset of 50 samples.

In summary, the geochemical information includes:

- 279 major elements analyses by XRF on glass discs.
- 252 trace elements analyses by XRF on glass discs or powder pellets.
- 210 trace element analyses by ICPMS.
- 277 analyses for Au, Pd and Pt by ACTLABS.
- 50 Sr and Nd isotope determinations by the Geological Institute, Geocenter Copenhagen.

Analytical methods

Major elements by XRF at GEUS:	method described in Kystol & Larsen (1999).
Trace element by XRF at GEUS:	method described in *Kystol & Larsen (1999).*
Trace elements by XRF:	*f*ollowing Norrish & Chappell (1977).
ICP-MS at GEUS:	method described in Larsen *et* al. (2003).
ICP-MS at UCDavis:	method described in Lassen *et* al. (*2004).*
ICP-MS at OSU:	method described in Tegner *et* al. (1998b).
Au, Pd and Pt at ACTLABS:	Pb fire assay with ICP-MS finish (code 1C research) with detection limits of 0.1 ppb for Pt and Pd and 1 ppb for Au.
Sr and Nd isotopes at Geocenter Copenhagen:	methods described in Frei *et* al. (1999). All samples were leached in 2.5N HCl for 1 hour, prior to dissolution.

The structure of the data sheet

The data for all the samples have been compiled in a single data sheet. The columns contain the available information. It should be noted that the selected samples originate from many different collections and that the amount of available information varies.

The samples are given in the following order:

Sills from the Kangerlussuaq Basin.
Sills in the I.C.Jakobsen Fjord area.
Sills from profiles in the plateau basalts
Sills and dykes in the Jameson Land Basin
Sills from southern Traill Ø
Pateau basalts from the Nansen Fjord area
Gabbros from the Imilik complex
Gabbros and other rocks from the Mikis Fjord macrodyke
Shale from the Kangerlussuaq Basin. Potential contaminant. Data for other potential contaminants of the basement gneisses can be found in Blichert-Toft *et* al., 1992)

Comment to individual columns

Column A: Reference

The samples were collected by a large number of investigators over a period of 30 years. The collections are housed in the Geological Museum in Copenhagen (GM), in the Geological Institute of University of Copenhagen (GI) or in the Geological Survey of Denmark and Greenland. The Geological Museum and the Geological Institute use the same registration system and the prefix to the five digit numbers is (GM/GI). The Geological Survey of Denmark and Greenland use the Geological Survey of Greenland registration system (GGU). Danish Lithosphere Center (DLC) uses the GEUS registration system.

Column B: Sample number

Each sample has a unique registration number. It may be a (GM/GI) number (five digits) or a GGU number (six digits).

Column C: Sub number

Some collectors have given several samples the same registration number. A sub-number then identifies the individual sample. Sub-numbers may be: A, B, C, .1, .2, .3 or an altitude, e. g., 180m.

Column D. Divide

Column E and F: Latitude and longitude

Many samples were collected before the introduction of GPS technology. Samples collected before 1995 were plotted on sample maps (Geodætic Institute map sheets in the scale 1: 250 000). The latitude and longitude for those samples are to be treated with caution. They can be off by several hundred meters compared to GPS positions.

Samples collected later than 1995 are mostly located by GPS. Plateau basalts samples originate from profiles. All samples in a given profile have the latitude and longitude of the base point of the profile. Individual samples in profiles are identified by elevation. Further details for plateau basalts samples can be supplied on request.

Column G: elevation
The elevation is in most cases subjected to some uncertainty. Elevation for old samples are mostly read from the topographic map sheets (1:250 000 sheets) or measured using small altimeters with considerable uncertainty (+/- 50 m). The elevation of samples collected later than 1995 were positioned by GPS, but due to the northern latitude the uncertainty on the elevation is probably in the order of +/- 25m.

Column H: Collector
Name of collector or group. DLC refers to groups from Danish Lithosphere Centre.

Column I: Year
The year the sample was collected. The information can be used in a search for diaries and expedition report, e. g. in the Report of Activities in the report series of GGU or GEUS.

Columns J, K, L and M zoom in on the locality.

Column J: Area.
Refers to sectors of the East Greenland coast. Conventionally used subdivisions.

Column K: Locality 1.
For all samples, excluding plateau basalts, a locality name from the topographic map sheets, e. g. a fjord or glacier. For plateau basalts the profile number and the flow numbers are given (DLC records).

Column L: Locality 2.
Official or field name of locality. The name is used in reports and diaries.

Column M: Further comments.
Comments extracted from field notes or other sources for a limited number of samples.

Column N: Divide

Column O: Type.
Type of occurrence from which the sample has been collected.

Column P: Description/petrographic name.
Available field description.

Column Q. Comments
Further, mostly petrographic information and comments.

Column R: ol:cpx:plag:ox

Estimated proportions of olivine, clinopyroxene, plagioclase and FeTi-oxides for a limited number of samples. Data from Gisselø (1998 & 2000).

Column S: Divide

Columns T to AI: Major element compositions

Column T: Laboratory

Column AF: Volatiles recorded as loss on ignition

Column AH: FeO15:
Calculated FeO at Fe_2O_3/FeO = 0.15.

Column AJ: Divide

Columns AK to BF:
Trace elements by XRF.

Column BG: Divide.

Columns BH to CR :
Trace elements by ICP-MS.

Column CS: Divide.

Columns CT to DA:
Pt, Pd and Au and varies precious metal ratios.

Column DB: *Divide.*

Column DC:
Geochemical classification.

Column DF:
Alkaline index according to Wright 1969: atomic (Na+K+Ca+Al)/(Ca+Al).

Column DG: divide

Columns DH to DN
Sr and Nd isotope ratios corrected to initial ratios 55 Ma ago.

Results

Introduction to geochemical plots

An overview of the geochemical data is presented in the figures 5-13. The data is presented for Kangerlussuaq sills (Fig. 5), Jameson Land sills and dykes (Fig. 6), Plateau lavas (Fig. 6), Imilik complex (Fig. 8) and the Miki Fjord macrodyke (Fig. 9).

Each of these figures show Mg# (=100xMg/(Mg+Fe)) at the x-axis, as a measure of the degree of fractionation in six diagrams. Cu versus Mg# and Pd versus Mg# show the degree of incompatibility of these elements with fractionation.

The Cu/Pd versus Mg# is a measure of possible sulphide melt fractionation, since Pd is considerably more compatible in a sulphide melt than Cu. Nb/La is indicative of crustal contamination, because most mantle derived mafic melts will have Nb/La at about unity or higher. Crustal materials (gneisses and sediments) are usually characterised by very low Nb/La ratios.

The Sr and Nb isotopic ratios give a further indication possible of crustal contamination. Primary, Palaeogene, astenospheric melts will have 87Sr/86Sr ratios between 0.7025 and 0.7045, while crustal material, depending on their age and lithology, will have Sr isotopic ratios > 0.7045, except for granulite facies gneisses which can have low, mantle-like ratios.

eNd is a strong measure of contamination, since all old material in the crust will have strongly negative eNd, including gneisses in granulite facies. Asthenosphere-derived melts will have eNd of +4-+12 in the Palaeogene.

In order to ease the comparison between the various provinces, Cu, Pd, 87Sr/86Sr, and eNd are plotted against Mg# for the provinces in Fig. 10-13. Note that the x and y-axes have been expanded in order to encompass all analysed samples.

Geochemical plots

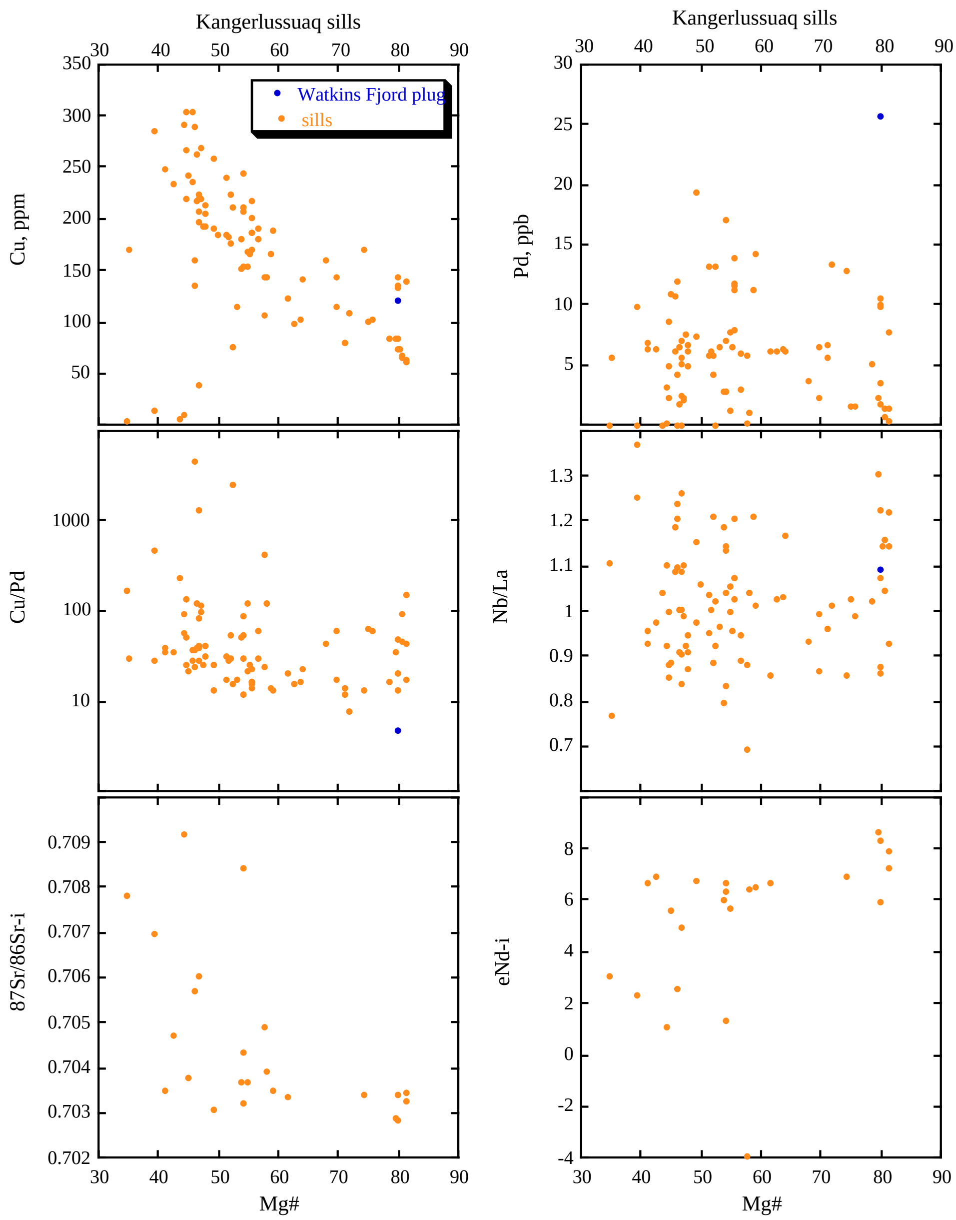

Figure 5. *Plot of Cu, Pd, Cu/Pd, Nb/La, initial 87Sr/86Sr and initial eNd for sills from the Kangerlussuaq Basin.*

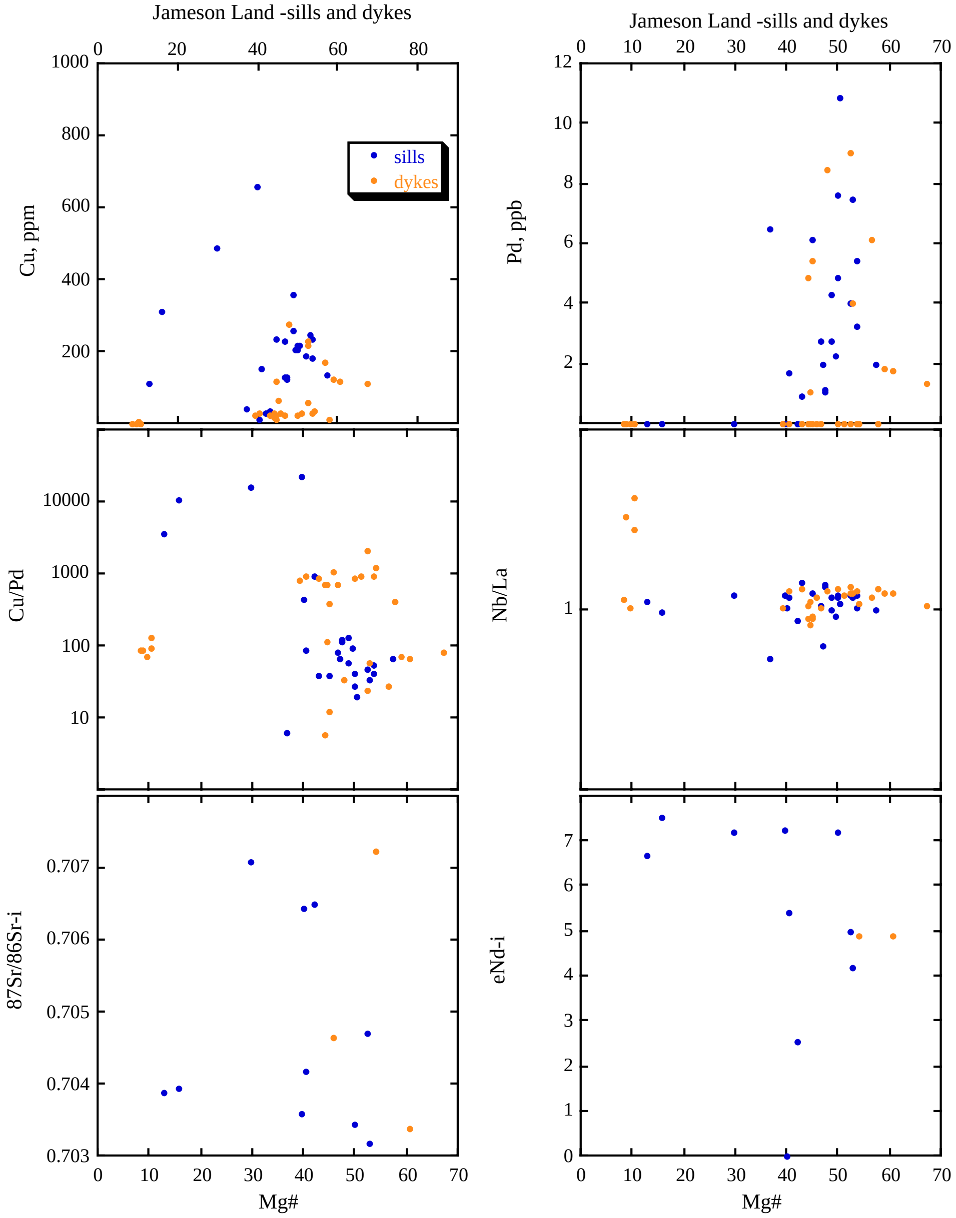

Figure 6. *Plot of Cu, Pd, Cu/Pd, Nb/La, initial 87Sr/86Sr and initial eNd for sills and dykes from the Jameson Land-Traill Ø region.*

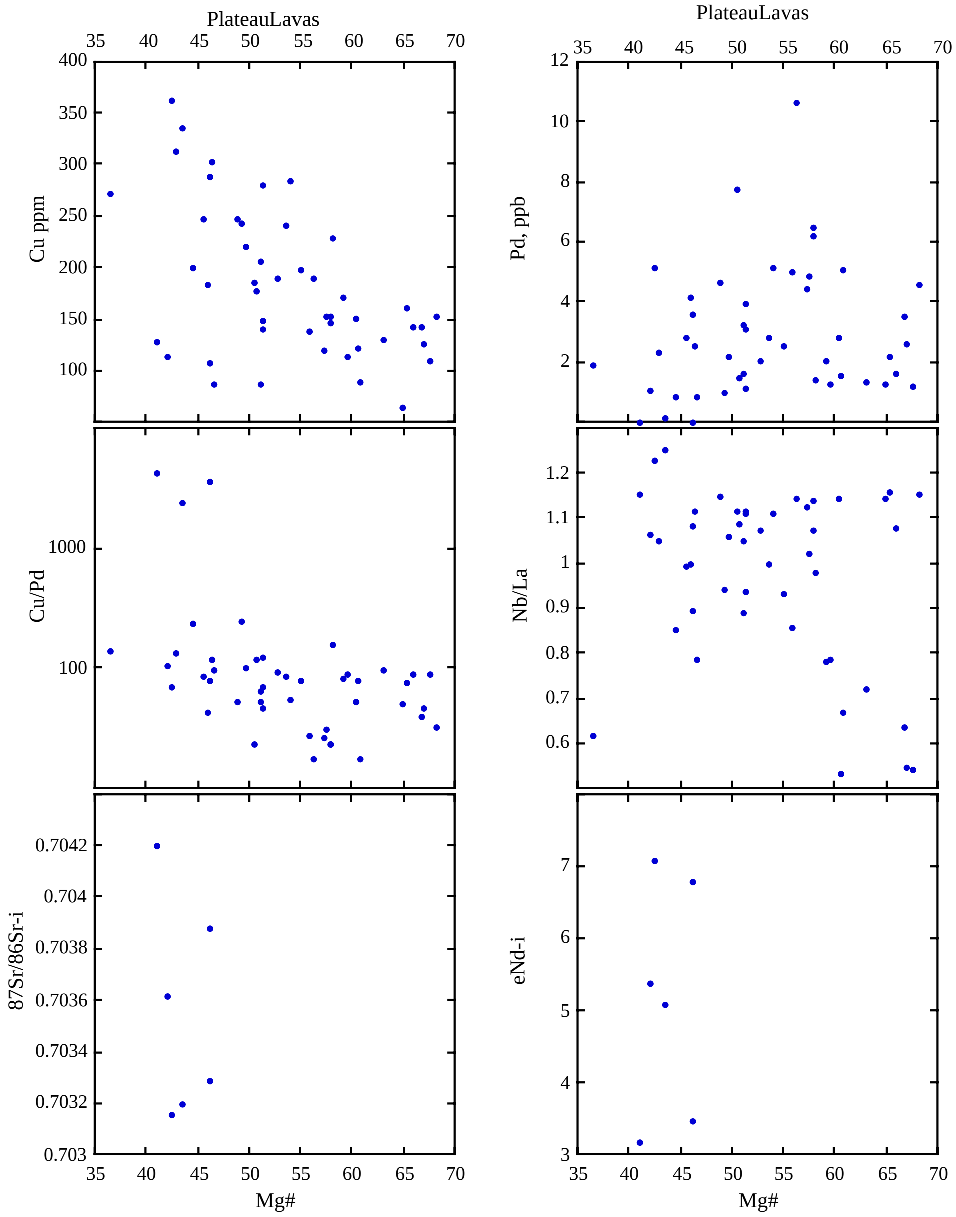

Figure 7. *Plot of Cu, Pd, Cu/Pd, Nb/La, initial 87Sr/86Sr and initial eNd for plateau basalts from the Nansen Fjord area.*

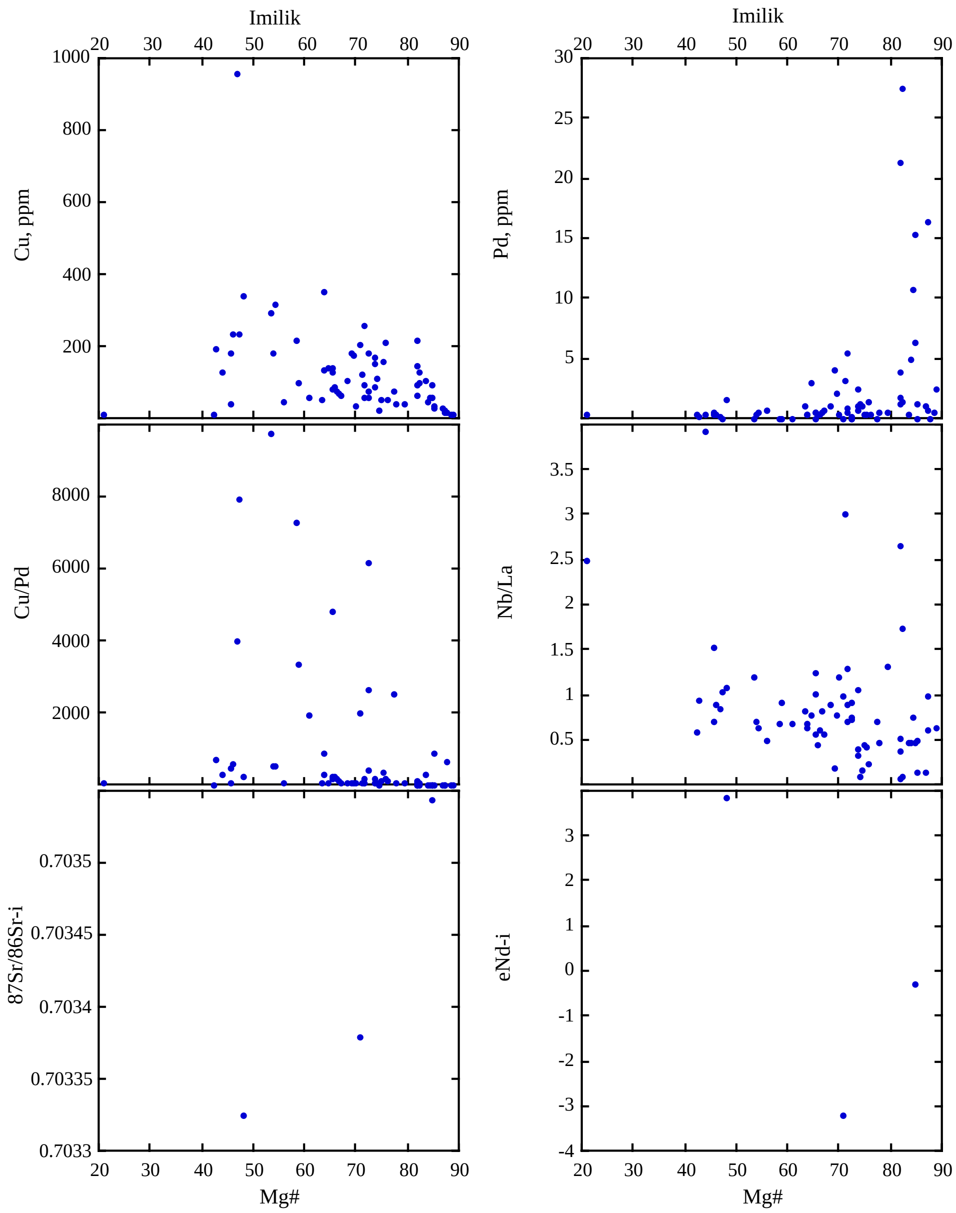

Figure 8. *Plot of Cu, Pd, Cu/Pd, Nb/La, initial 87Sr/86Sr and initial eNd for the Imilik gabbro complex.*

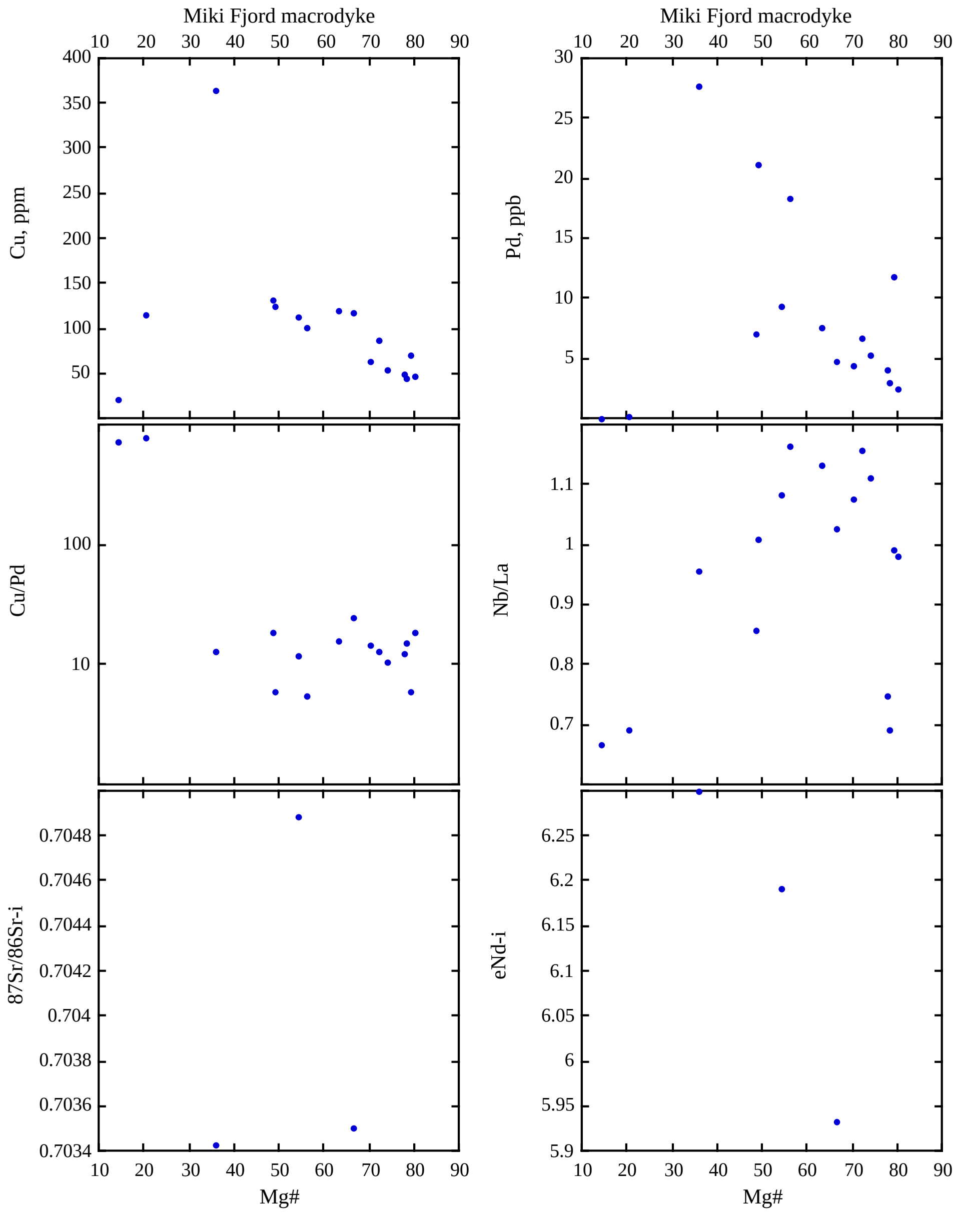

Figure 9. *Plot of Cu, Pd, Cu/Pd, Nb/La, initial 87Sr/86Sr and initial eNd for the Mikis Fjord Macrodyke.*

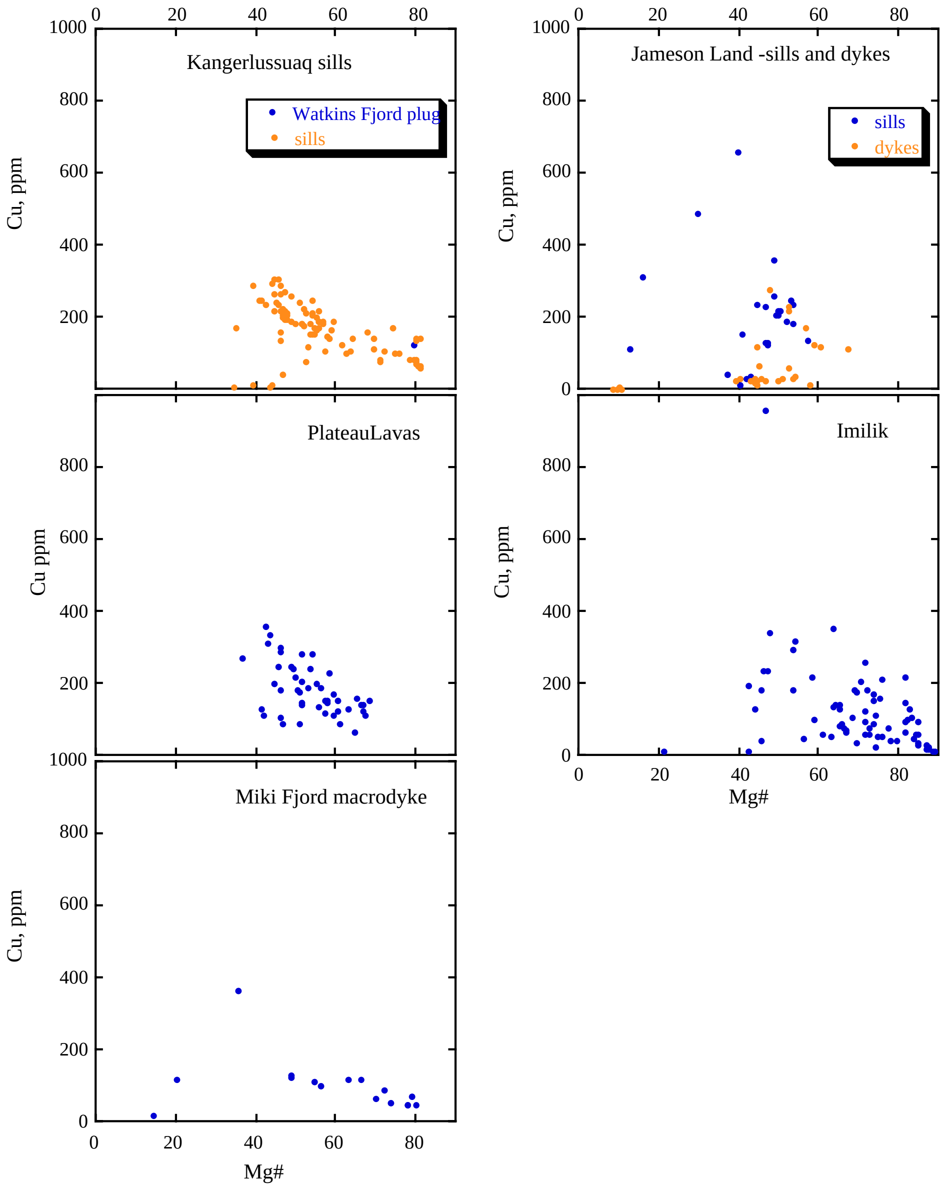

Figure 10. *Cu variation in all suites. From Figs. 5-9.*

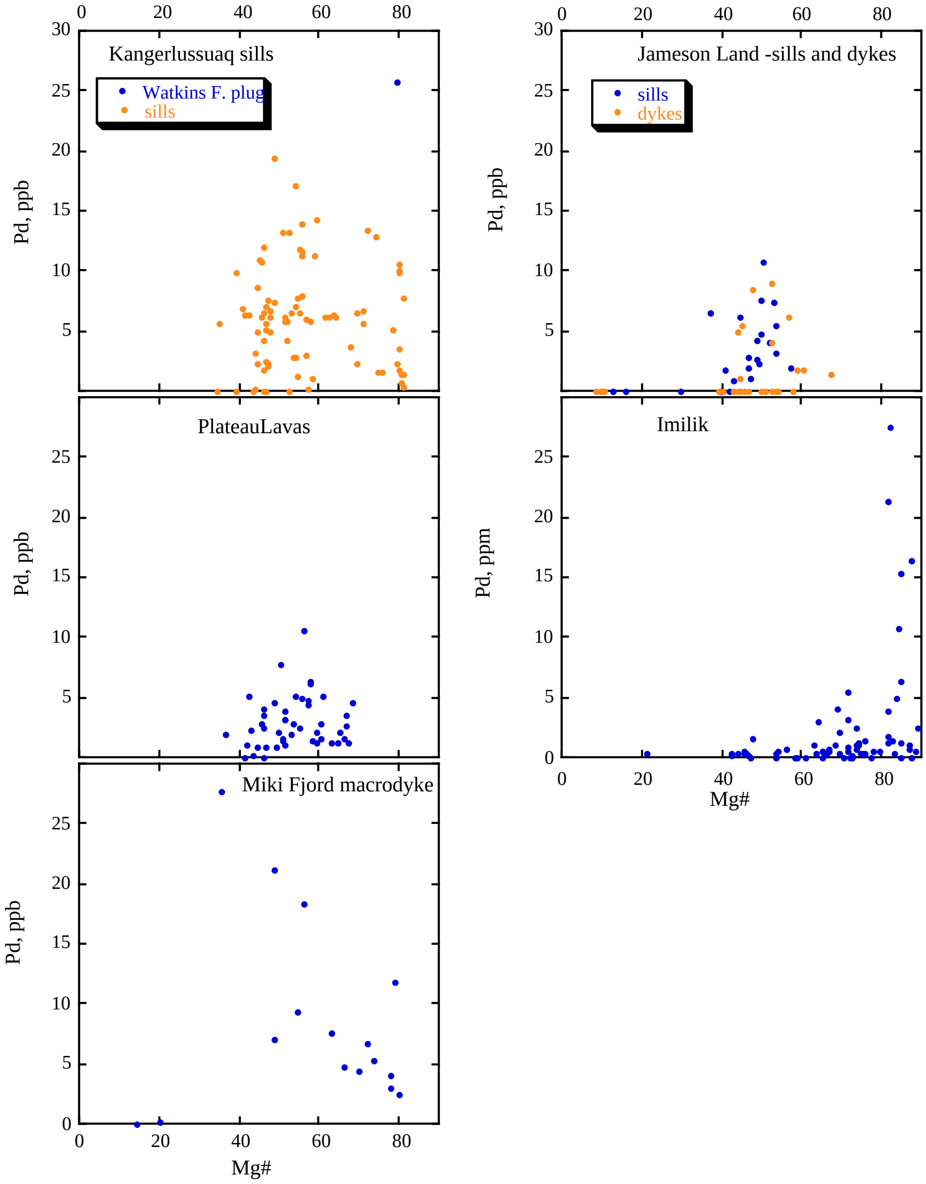

Figure 11. *Pd variation in all suites. From Figs. 5-9.*

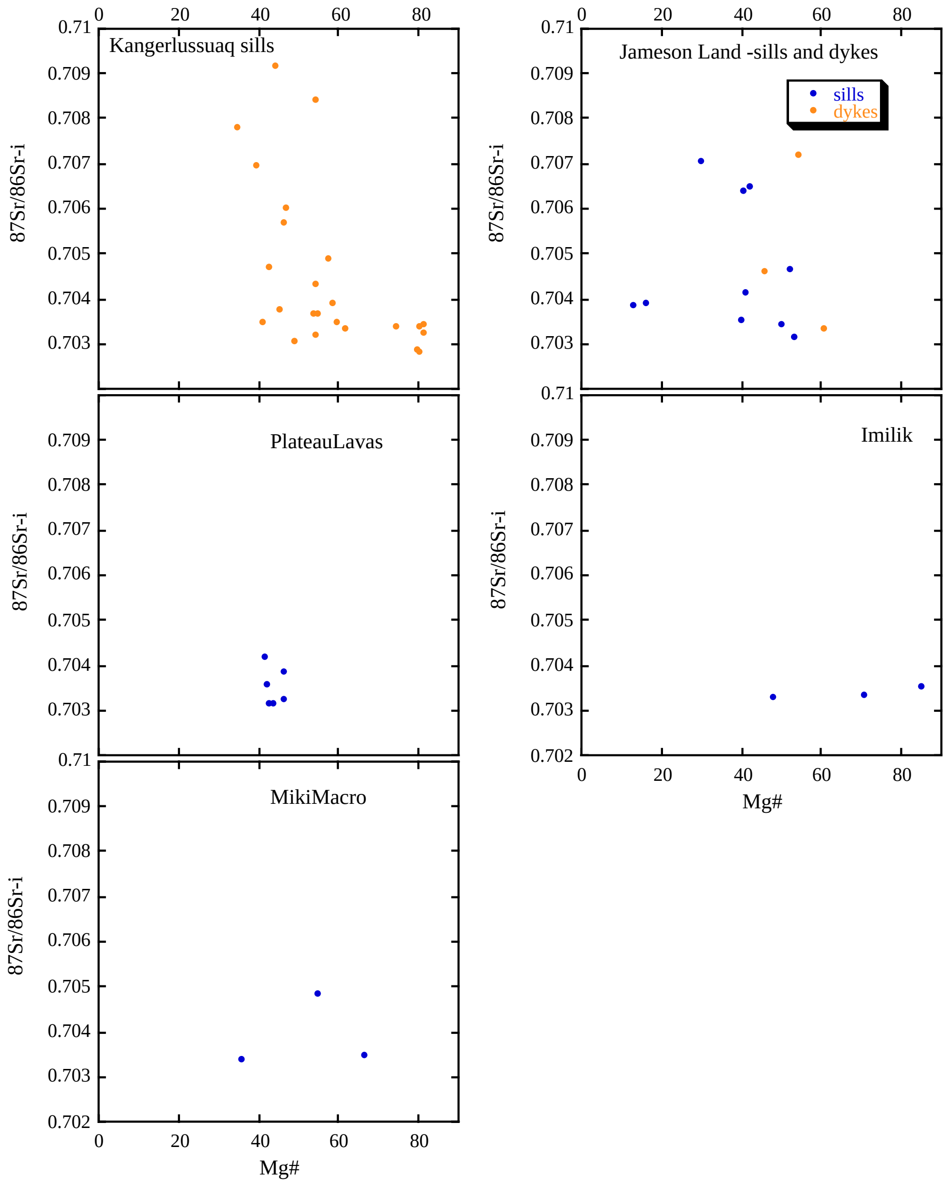

Figure 12. *Variation in initial Sr-isotope ratio in all suites. From Figs. 5-9.*

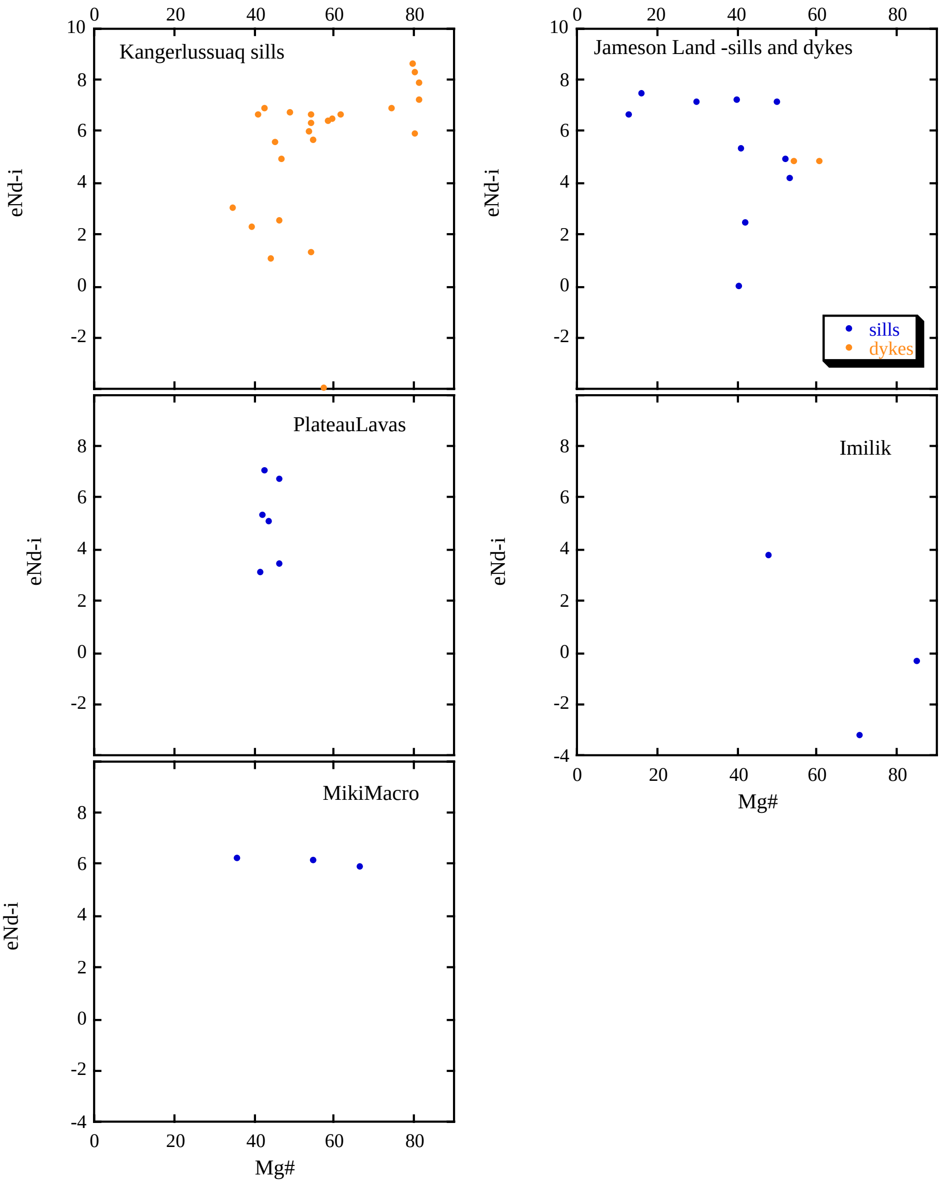

Figure 13. *Variation in initial eNd in all suites from figures 5-9*

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Appendixes

Appendix 1 to 6 contains reproductions from Nielsen (2002) of the introductions to:

(1) The sills in the Kangerlussuaq basin,
(2) Regional sills in Jameson Land and Scoresby Land,
(3) Sills in Central East Greenland,
(4) Imilik gabbro complex,
(5) Mikis Fjord macrodyke,
(6) Watkins Fjord Peridotite plug,
(7) CD-ROM containing a spreadsheet with sample information and analytical data and files for all illustrations.

Appendix 1

Sills in Kangerlussuaq basin

Picritic, basaltic and syenitic sills in sediments and lavas.
No mineralisations are reported.

Location: 68°30N: 30°45'N (centre of circle with 30 km radius).

Main references: Wager (1947), Brooks & Nielsen (1982) and Gisselø (2001).

Topographic maps:
1:250 000
KMS: 68Ø2 Kap Garde and 68Ø3 Kangerdlugssuaq.

1:100 000
GEUS: digital maps in 1:100 000 and compilations in 1:250 000, 1:500 000 and 1:1 000 000 and other scales on request.

Landsat TM image: Not available from GEUS.

Aerial photographs:
1:150 000
KMS flight line 878E, nos 911-925.
KMS flight line 878F, nos 1843-1857.
KMS flight line 878G, nos 397-409.
KMS flight line 878H, nos 767-773.

Geological maps:
Regional map: 1:500 000, Geological map of Greenland, Sheet 13 Kangerdlugssuaq (Geological Survey of Greenland, 1988).
Publication maps: In Gisselø (2000, for the Sorgenfri Gletscher area) and Nielsen *et* al. (1981, for the Miki Fjord and I.C.Jacobsen Fjord area

Geophysical maps: None.

Geochemical maps: None, except for minor investigations in the fjord region east of the Skaergaard intrusion (Kap Irminger concession) by Della Valle (1992).

Short description: Major province of picritic, basaltic and syenitic sills. The sills are in part concordant with bedding in Kangerdlugssuaq series sediments and the lower formations in the regional lavas.

The sills are often irregular and step up or down through the host rocks. The sills vary from <1m to >200m in thickness. Gisselø (2000) evaluates that up to 20% of the volume of basalt in the Paleaogene magmatic province in East Greenland can be hosted in sill complexes.

Thick sills show internal differentiation whereas most sills show chemical variations due internal redistribution of intercumulus melt.

The tholeiitic sills are assumed and known to becontemporaneous with the flood basalt magmatism along the Blosseville Kyst. No age information has yet been published (see *"Further information"*).

Petrography: Tholeiitic picrite, tholeiitic basalt and syenite sills occur. Basalt sills predominate. The picrite sills are mostly accumulative. Thick basaltic sills are doleritic or gabbroic, often with pegmatitic schlieren. For details: see Gisselø (2000).

Geochemistry: Gisselø (2000) and for PGE Momme (2000) and Momme *et* al. (2002).

Exploration activity: Search for sulphide anomalies in the I.C. Jacobsen Fjord region by Platinova Resources Ltd. 1990 (see report by Della Valle, 1992 and GEUS GRF no. 21087).

Exploration results: Minor geochemical anomalies in the I.C. Jacobsen Fjord region. Elevated Ni values in sediments probably due to the common occurrence of picritic lavas with elevated Ni concentrations. No traces of massive sulphide mineralisations have been observed.

Comments and company Recommendations: GEUS (T.F.D. Nielsen): A potential for PGE-rich massive sulphide mineralisation can not be excluded. The generally high PGE content of the mafic sills and the possibility for reaction with sediments (bithumen-rich and sulphide bearing shales and silisic sediments) could favour formation of PGE-rich massive sulphide deposits. Airborne geophysical investigations, geochemical mapping and systematic boulder search in moraines are suggested

Further information: GEUS: T.F.D. Nielsen.
Århus Universitet: C. Tegner (unpublished Ar-Ar age determinations).

References:

Research papers and descriptions:

Brooks, C.K. & Nielsen, T.F.D. 1982: The Phanerozoic development of the Kangerdlugssuaq area, East Greenland. Meddelelser om Grønland, Geoscience **9**, 30 pp.

Deer, W.A. 1976: Tertiary igneous rocks between Scoresby Sund and Kap Gustav Holm, East Greenland. In: Escher, A. & Watt, W.S. (eds): Geology of Greenland, 404-429. Copenhagen: Grønlands Geologiske Undersøgelse.

Gisselø, P. 2000: Sorgenfri Gletscher Sill Complex, East Greenland. Solidification mechanisms of sheet-like bodies and the role of sill complexes in large igneous provinces. Aarhus Geoscience – Ph.D. Thesis **10**, 100 pp.

Momme, P. 2000: Flood basalt generation and differentiation: PGE-geochemistry of East Greenland flood basalts, comagmatic intrusions and comparison with Siberian flood basalts. Unpublished PhD Thesis, Geological Institute, Aarhus University, Denmark. 154 pp.

Momme, P., Tegner, C., Brooks, C.K. & Keays, R.R. 2002: The behaviour of platinum group elements in basalts from the East Greenland rifted margin. Contributions to Mineralogy and Petrology **143**, 133-153.

Nielsen, T.F.D. 1987: Tertiary alkaline magmatism in East Greenland: a review. In: Fitton, J.G. & Upton, B.G.J. (eds): Alkaline igneous rocks. Special Publication Geological Society of London **30**, 489-515.

Nielsen, T.F.D., Soper, N.J., Brooks, C.K., Faller, A.M., Higgins, A.C. & MatthewsKangerdlugssuaq, East Greenland: their stratigraphy, lithology, palaeomagnetism and petrology. Meddelelser om Grønland, Geoscience **6**, 25 pp.

Wager, L.R. 1947: Geological investigations in East Greenland. Part IV. The stratigraphy and tectonics of Knud Rasmussens Land and the Kangerdlugssuaq region, D.W. 1981: The pre-basaltic sediments and the Lower Basalts at. Meddelelser om Grønland **134** (5), 64 pp.

Company reports:

Della Valle, G. 1992: Geological report on the 1991 Kap Irminger exploration project central east Greenland. Internal report, Platinova Resources Ltd. & RTZ ltd., 35 pp. (in achives of Danmarks og Grønlands Geologiske Undersøgelse, GRF no. 21087).

Compiler: T.F.D. Nielsen.

Date: 2002-11-20.

Appendix 2

Regional sills in Jameson Land and Scoresby Land

Mainly tholeiitic sills, some with significant volumes
Contact magnetite skarn mineralisation.

Location:	East Coast of Greenland between 70°15' and 72°N.
Main references:	Larsen & Marcussen (1992) and Hald & Tegner (2000).
Topographic maps:	1:250 000 KMS: 70Ø1 Scorebysund and 71Ø1 Carlsberg Fjord. 1:100 000 GEUS archive: All of Jameson Land is covered by maps produced by GEUS around 1980.
Landsat image:	TM path-row 226-010.
Aerial photographs:	1:150 000 KMS flight line 888M, nos 1215–1239. KMS flight line 888N, nos 345–376. KMS flight line 888P, nos 1340–1364. KMS flight line 888Q, nos 534–553. 1:50 000 and other scales Special search in GEUS archive.
Geological maps:	Regional map: GEUS 1:500 000, sheet 12 Scoresby Sund (Geological Survey of Denmark and Greenland, 1982). GEUS 1:100 000: 70Ø1 Syd Kap Brewster; 70Ø1 Nord Hurry Inlet; 70Ø2 Syd Vikinge Bugt; 70Ø2 Nord Kap Leslie; 71Ø1 Syd Carlsberg Fjord; 71Ø1 Nord Fleming Fjord; 71Ø2 Syd Gurreholm and 71Ø2 Nord Sydlige Stauning Alper. Publication map: Larsen & Marcussen (1992). Unpublished field maps: Special search for exploration related maps in GEUS archive.

Geophysical maps: GEUS: Aeromagnetic Map of Greenland, sheet 4 (69° - 74°N, 19° - 27°W); 1:1 000 000 (Geological Survey of Greenland, 1988).

GEUS: Magnetic and AEM maps and data. Standard dataset area G (Stemp, 1998).

Special search in GEUS archives for geophysical investigations related to exploration for hydrocarbons.

Geochemical maps: Geochemistry of heavy mineral samples in Harpøth et al. (1986).

Short description: Three regionally exposed sills have been mapped through large areas in the Jameson Land sedimentary basin. The three sills belong to a suite of very voluminous sills emplaced into the deep sedimentary basin (Larsen & Marcussen, 1992). The sills have the shape of lopoliths and reach across the entire basin. They may be up to 300 m thick in the centre of the basin. They thin and step up through the stratigraphy toward the margins of the basin. The age of dated sill samples is 52-53 Ma. The sill complex post-dates the main tholeiitic plateau basalt magmatism in East Greenland (Hald & Tegner, 2000).

Petrography: The sills are tholeiitic in composition and vary from aphyric to strongly plagioclase-phyric with phenocrysts up to 7 cm in length.

Geochemistry: Hald & Tegner (2000) gives major and trace element analyses, age information and petrogenetic models.

PGE concentrations are given by Momme (2000). They indicate that the sill magmas are not depleted in PGE.

Exploration activity: Based on AEM investigations (Stemp, 1998) a number of magnetic anomalies related to exposed sills have been investigated by GEUS (Pedersen & Stendal, 1999).

Exploration results: The results of the investigations of AEM anomalies related to the Palaeogene sills of the Jameson Land basin are described in Pedersen & Stendal (1999). The anomalies are caused by magnetite-rich skarns in the sediments at the contacts to one out of three regionally occurring sills in the sedimentary basin. The sulphide content is low. Further details in Pedersen & Stendal (1999).

Comments and company recommendations: No further exploration is suggested.

Further information: GEUS: H. Stendal and B. M. Nielsen.
Geological Museum, Copenhagen: N. Hald.
Århus Universitet: C. Tegner.

References: Research papers and descriptions:

Hald, N. & Tegner, C. 2000: Composition and age of tertiary sills and dykes, Jameson Land Basin, East Greenland: relation to regional flood volcanism. Lithos **54**, 207-233.

Larsen, H.C. & Marcussen, C. 1992: Sill-intrusion, flood basalt emplacement and the deep structure of the Scoresby Sund region, East Greenland. In: Storey, B.C., Alabaster, T & Pankhurst, R.J. (eds): Magmatism and the causes of continental break-up. Geological Society of London, Special Publication **68**, 365-386.

Momme, P. 2000: Flood basalt generation and differentiation: PGE-geochemistry of East Greenland flood basalts, co-magmatic intrusions and comparison with Siberian flood basalts. Ph.D. thesis, Geological Institute, Aarhus Universitet, Århus, Danmark, 154 pp.

Pedersen, M. & Stendal, H. (1999) Ground check of airborne geophysical anomalies in northern Jameson Land, central East Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1999/38**, 74 pp.

Stemp, R.W. 1998: Airborne electromagnetic and magnetic survey of the northern Jameson Land area, central East Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1998/18**, 30 pp.

Compiler: T.F.D. Nielsen.

Date: 2002-07-25.

Appendix 3

Sills in central East Greenland

Subalkaline and alkaline basaltic sills.
***No mineralisation is reported*.**

Location:	East coast of Greenland between 72 and 74^{o}N.
Main references:	Noe-Nygaard (1976), Hald (1996) and Price *et* al. (1997).
Topographic maps:	1:250 000 KMS: 72Ø1 Kap Parry, 72Ø2 Kong Oscars Fjord, 73Ø1 Hold with Hope and 73Ø2 Ymers Ø. 1:100 000 GEUS: digital maps in 1:100 000 and compilations in 1:250 000, 1:500 000 and 1:1 000 000 and other scales on request.
Landsat image:	TM path rows: 227-009 and 229-010.
Aerial photographs:	1:150 000 KMS flight line 888N, nos 380–395. KMS flight line 888P, nos 1318–1334. KMS flight line 888Q, nos 507–524. KMS flight line 888R, nos 980–983.
Geological maps:	Regional map:1:500 000, sheet 11 Kong Oscar Fjord (Geological Survey of Denmark and Greenland, 2001). Publication map: Koch & Haller (1971), Upton & Emeleus (1977), Upton *et* al. (1980) and Upton *et* al. (1984a).
Geophysical maps:	Aeromagnetic Map of Greenland, sheet 4 (69^{o} - 74^{o}N, 19^{o} - 27^{o}W); 1:1 000 000 (Geological Survey of Greenland, 1988).
Hyperspectral data:	
Geochemical maps:	Geochemistry of heavy mineral samples in Harpøth et al. (1986).
Short description:	The coastal regions between 72 and 73^{o}N are characterised by very significant volumes of basaltic melt emplaced as sills. The most useful overview is given by Noe-Nygaard (1976)

and Hald (1996). The sills are in general hosted by and sub-concordant with the Mesozoic sediment of the East Greenland Basin on the eastern tip of Ymers Ø, the eastern parts of Geographical Society Island and Traill Ø.

The sills vary in thickness from less than 1 m to 250 m, but thicknesses between 20 and 30 m are common. Aphyric to plagioclase phyric tholeiitic varieties dominate. Alkaline mafic sills occur as a subordinate type throughout the region and include ankaramite and nepheline tephrite (Noe-Nygaard, 1976).

Age determinations in Price *et* al. (1997) suggest the main suite of tholeiite intrusions to be *c.* 54 Ma old. Alkaline intrusions have been dated to *c.* 36 Ma.

Petrography: Noe-Nygaard (1976), Hald (1996) and Price *et* al. (1997).

Geochemistry: Noe-Nygaard (1976), Hald (1996) and Price *et* al. (1997).

Exploration activity: No exploration activity has been directed towards the sills of the coastal region between 72 and 74^{o}N.

Exploration results: None

Comments and company recommendations: All basaltic magmas in East Greenland investigated to date show no depletion in PGE and have the capability to form sulphide related PGE deposits. No systematic investigations for sulphide mineralisations with PGE have been conducted in the sill regions in central East Greenland between 72^{o} and 74^{o}N.

Further information: Geologisk Museum, Copenhagen: N. Hald.

References: <u>Research papers and descriptions:</u>

Hald, N. 1996: Early Tertiary lavas and sills on Traill Ø and Geographical Society Island, northern East Greenland: petrography and geochemistry. Bulletin of the Geological Survey of Greenland 171, 29-43.

Harpøth, O., Pedersen, J.L., Schønwandt, H.K. & Thomassen, B. 1986: The mineral occurrences of central East Greenland. Meddelelser om Grønland, Geoscience 17, 139 pp.

Koch, L. & Haller, J. 1971: Geological map of East Greenland 72^{o} – 76^{o}N. Lat. (1:250 000). Meddelelser om Grønland **183**, 26 pp.

Noe-Nygaard, A. 1976: Tertiary igneous rocks between Shannon and Scoresby Sund, East Greenland. In: Escher A. &Watt, W.S. (eds): Geology of Greenland, 386-402. Copenhagen: Grønlands Geologiske Undersøgelse.

Upton, B.G.J. & Emeleus, C.H. 1977: The Tertiary geology of Hold with Hope, northern east Greenland. Rapport Grønlands Geologiske Undersøgelse **85**, 115-121.

Upton, B.G.J.; Emeleus, C.H. & Hald, N. 1980: Tertiary volcanism in northern East Greenland: Gauss Halvø and Hold with Hope. Journal of the Geological Society of London **109**, 21-49.

Upton, B.G.J, Emeleus, C.H. & Beckinsale, R.D. 1984a:Petrology of the northern East Greenland Tertiary flood basalts: evidence from Hold with Hope and Wollaston Forland. Journal of Petrology **25**, 151-184.

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Date: 2002-01-08.

Appendix 4

Imilik gabbro complex

Large, replenished, layered tholeiitic gabbro complex.
No mineralisations are reported.

Location:	66°48'N; 33°55'W.
Main references:	Brown & Farmer (1972), Brown *et* al. (1977), Myers (1980) and Bernstein *et* al. (1998).
Topographic maps:	1:250 000 KMS: 66Ø1 Steenstrups Bræer.
Landsat image:	TM path row 231-013 and MSS250-013.
Aerial photographs:	1:150 000 KMS flight line 878D, nos 208-214. 1:50 000 KMS flight line 861R, nos 7417-7421. KMS flight line 861S, nos 7383-7493. 1:40 000 KMS flight line A32C, nos 51-53. KMS flight line A32E, nos 82-86. KMS flight line A34F, nos 107-111 and 113-115.
Geological maps:	Regional map: 1:500 000, Sheet 13, Kangerdlugssuaq (Geological Survey of Greenland, 1988). Publication maps: Brown & Farmer (1972).
Geophysical maps:.	Aeromagnetic Map of Greenland, sheet 3 (63°30' 68°30'N, 23°00' - 41°00'W); 1:1 000 000 (Geological Survey of Greenland, 1988).
Hyperspectral data:	None.
Geochemical maps:	None.

Short description:	The Imilik gabbro complex has been known for several decades, but nevertheless only quite limited information has been published. The gabbers are believed to represent 3 individual pulses of relatively It-poor, tholeiitic magma that produced three overlying successions of cumulates separated by unconformities (Myers, 1980). The Imilik gabbros are exposed on headlands and islands from Nûgtuaq, over Imilik island and the larger unnamed island to the west and possibly to the island Lille Tindholm about 16 km to the northeast. Tegner at al. (1998) refer to the three units in the Imilik Gabbro complex as Imilik Intrusions I-III. Imilik II has given an Ar-Ar age of 56.2 +/- 0.2 Ma, whereas Imilik intrusion III gives ages of 49-52 Ma. No age is available for the oldest unit, Imilik Intrusion I.
Petrography:	Limited data in Brown & Farmer (1972) and Brown *et* al. (1977).
Geochemistry:	Deer (1976), Bernstein *et* al. (1998) and unpublished GEUS analyses (J.S. Myers).
Exploration activity:	None.
Exploration results:	None.
Comments and company recommendations:	None.
Further information:	GEUS: S. Bernstein Københavns Universitet: C.K. Brooks.
References:	Research papers and descriptions:

Bernstein, S., Kelemen, P.B., Tegner, C., Kurz, M.D., Blusztajn, J. & Brooks, C.K. 1998: Post-breakup basaltic magmatism along the East Greenland Tertiary rifted margin. Earth and Planetary Science Letters **160**, 845-862.

Brown, P.E. & Farmer, D.G. 1972: Size-graded layering in the Imilik gabbro, East Greenland. Geological Magazine **108**, 465-476.

Brown, P.E., van Breeman, O., Noble, R.H. & Macintyre, R.M. 1977: Mid-Tertiary igneous activity in East Greenland - the Kialineq complex. Contributions to Mineralogy and Petrology **64**, 109-122.

Deer, W.A. 1976: Tertiary igneous rocks between Scoresby Sund and Kap Gustav Holm, East Greenland. In: Escher, A. & Watt, W.S. (eds): Geology of Greenland, 404-429. Copenhagen: Grønlands Geologiske Undersøgelse.

Myers, J.S. 1980: Structure of the coastal dyke swarm and associated plutonic intrusions of East Greenland. Earth and Planetary Science Letters **47**, 407-418.

Tegner, C., Duncan, R.A., Bernstein, S., Brooks, C.K., Bird, D.K. & Storey, M. 1998: 40Ar-39Ar geochronomlogy of Tertiary mafic intrusions along the East Greenland rifted margin: Relation to flood basalts and the Icelandic hot-spot track. Earth and Planetary Science Letters **156**, 75-88.

Compiler: T.F.D. Nielsen.

Date: 2002-11-05.

Appendix 5

Mikis Fjord Macrodyke

Layered gabbro dyke.
PGE-bearing sulphide mineralisation along contacts.

Location:	68°10'30''N; 31°30'W.
Main references:	Deer (1976) and Blickert-Toft *et* al. (1992).
Topographic maps:	<u>1:250 000</u> KMS 68Ø3 Kangerdlugssuaq. <u>1:100 000</u> GEUS: digital maps in 1:100 000 and compilations in 1:250 000, 1:500 000 and 1:1 000 000 and other scales on request. <u>1:25 000</u> GEUS: Orthophoto map produced by Geodætisk Institut (KMS) in 1982. The map covers the northern part of the Macrodyke. <u>1:21 350</u> Transparency of the area between Skaergaard intusion and I.C. Jacobsen Fjord and Miki Fjord and Watkins Fjord. Base for geological map in 1:40 000 in Nielsen *et* al. (1981).
Landsat TM image:	Not available from GEUS.
Aerial photographs:	<u>1:150 000</u> KMS flight line 878F, nos 1842-1846. <u>1:27 000 Colour</u> GEUS: McBirney series, nos 3227-3231 and 3241-3246
Geological maps:	<u>Regional map</u>: 1:500 000, sheet 13 Kangerdlugssuaq (Geological Survey of Greenland, 1988). <u>Publication maps</u>: Nielsen *et* al. (1981) and Blickert-Toft *et* al. (1992).

Geophysical maps:	Exploration geophysics, See Williams (1988) and Andersen (1997).
Hyperspectral data:	None.
Geochemical maps:	None.
Short description:	NE-trending up to 500m wide tholeiitic gabbro dyke. The dyke can be followed >50km inland (Deer, 1976). Part of the roof is preserved in the high country between Miki Fjord and the Issøerne area. The dike thins to a few tenths of meters or less NE of the head of Watkins Fjord. The lower parts as exposed at the mouth of Vandfaldsdalen are composed of non-layered fairly homogeneous gabbro. In the high country to the NE the dyke becomes strongly layered and very rich in large rafts of hornfelsed lava. Spectacular layering, also due to anorthosite melt layers formed during anatectic melting of altered basalt inclusions (Blichert-Toft *et* al., 1992). Based on the field relations and the similarities to the Skaergaard intrusion the Mikis Fjord Macrodyke is believed to be *c.* 55 Ma old.
Petrography:	Deer (1976) and Blichert-Toft *et* al. (1992).
Geochemistry:	Deer (1976) and Blichert-Toft *et* al. (1992).
Exploration activity:	***1986:*** Reconnaissance investigations by Platinova Resources Ltd. (Waters, 1987). ***1987***: Systematic sampling by Platinova Resources Ltd. (Goodwin and Turner, 1988) and geophysical investigations reported by Williams (1988). **1996**: Geophysical investigations (Andersen, 1997).
Exploration results:	PGE-bearing sulphide mineralisations in contact zones. Assays have given up to 40 ppb Pt, 615 ppb Pd and 76 ppb Au (Goodwin & Turner, 1988). Geophysical investigations suggests drilling target for massive sulphide mineralisation in the Issøerne area (Andersen, 1997).
Comments and company recommendations:	Platinova A/S suggest drilling of geophysical anomaly and further exploration.

Further information: GEUS: T.F.D. Nielsen.
University of Copenhagen: C.K. Brooks.
University of California Davis: C.E. Lesher.

References: Research papers and descriptions:

Blichert-Toft, J., Lesher, C.E. & Rosing, M.T. 1992: Selectively contaminated magmas of the Tertiary East Greenland macrodike complex. Contributions to Mineralogy and Petrology **110**, 154-172.

Deer, W.A. 1976: Tertiary igneous rocks between Scoresby Sund and Kap Gustav Holm, East Greenland. In: Escher, A. & Watt, W.S. (eds): Geology of Greenland, 404-429. Copenhagen: Grønlands Geologiske Undersøgelse.

Company reports:

Andersen, E.O 1997: Report on geophysical surveying. Time domain electromagnetics and magnetics. Macrodyke project. East Greenland. Mineral licence 08/92, 5 pp. Internal report. Toronto: Platinova A/S (in archive of Danmarks og Grønland Geologiske Undersøgelse, GRF. no. 21509).

Goodwin, J.A. & Turner, P.A. 1988: East Greenland Kangerdlugssuaq Concession, Summary report of 1987 program, 43 pp. Toronto: Platinova Resources Ltd. (in archives of Danmarks og Grønlands Geologiske Undersøgelse, GRF no. 20844).

Waters, B.C. 1987: Geological report, Platinova Resources Ltd. Kangerdlugssuaq concession, East Greenland, 43 pp. Company report. Toronto: Platinova Resources Ltd. (in archive of Danmarks og Grønlands Geologiske Undersøgelse, GRF no. 20838).

Williams, B.S. 1988: Report on geophysical surveys in the Skaergaard area, eastern Greenland - for Platinova Resources – July 1987, 5 pp.. Dublin: Williams Geophysics (in archive of Danmarks and Grønlands Geologiske Undersøgelse, GRF. no. 20839).

Compiler: T.F.D. Nielsen.

Date: 2002-08-01.

Appendix 6

Watkins Fjord Peridotite plug.

Ultramafic intrusion on the shore of Watkins Fjord.
No mineralisation is reported.

Location:	68^{o} 14''N; 31^{o}42'W.
Main references:	Kays & McBirney, (1982).
Topographic maps:	1:250 000 KMS: 68Ø3 Kangerdlugssuaq. 1:100 000 GEUS: digital maps in 1:100 000 and compilations in 1:250 000, 1:500 000 and 1:1 000 000 and other scales on request. 1:20 000 KMS: Skærgården.
Landsat TM image:	Path row: 231-012
Aerial photographs:	1:150 000 KMS flight line 878F, nos 1843-1844. 1:27 000 Colour GEUS: McBirney series, nos 3273-3275 and 3289-3291.
Geological maps:	Regional map: 1:500 000, Sheet 13, Kangerdlugssuaq (Geological Survey of Greenland, 1988). Publication maps: 1:20 000 (McBirney, 1989b and 1996b).
Geophysical maps:	None.
Hyperspectral data:	None.
Geochemical maps:	None.

Short description: Exposures in heavily moraine-covered low area on the south shore of Watkins Fjord. Very few details are available (Kays & McBirney, 1982) and Brooks & Nielsen (1982). In some references this intrusion has been named the Watkins Fjord picrite. In this report it is re-named to Watkins Fjord Peridotite.

The known exposures only show a rather homogenous body of peridotite. The contacts have not been found.

Petrography: Some information in Kays & McBirney (1982).

Geochemistry: Some information in Kays & McBirney (1982). Unpublished chemical analyses by C.K. Brooks.

Exploration activity: None.

Exploration results: None.

Comments and company recommendations: None.

Further information: GEUS: T.F.D. Nielsen.
University of Copenhagen: C.K. Brooks.

References: Research papers and descriptions:

Brooks, C.K. & Nielsen, T.F.D. 1982: The Phanerozoic development of the Kangerdlugssuaq area, East Greenland. Meddelelser om Grønland, Geoscience **9**, 30 pp.

Kays, M.A. & McBirney, A.R. 1982: Origin of picritic blocks in the Marginal Border Group of the Skaergaard intrusion, East Greenland. Geochimica et Cosmochimica Acta 46, 23-30. (Watkins Fjord plug).

McBirney 1989b: Geological map of the Skaergaard intrusion, East Greenland. Eugene: University of Oregon.

McBirney, A. R. 1996b: Geological map of the Skaergaard intrusion, East Greenland. In: Cawthorn, R. G. (ed.): Layered Intrusions. Amsterdam: Elsevier.

Compiler: T.F.D. Nielsen.

Date: 2002-08-29.

Appendix 7

CD-ROM

In pocket: CD-ROM with sample information, and analytical data in excel spreadsheet and Illustrations in digital format (word files).