DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2008/76

On the Paleogene plateau basalts and their Ni-potential, NE Greenland (73°-75°30'N)

Per Kalvig & Simun D. Olsen

(1 CD-Rom included)

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2008/76

On the Paleogene plateau basalts and their Ni-potential, NE Greenland (73°-75°30'N)

Per Kalvig & Simun D. Olsen

(1 CD-Rom included)

Released 01.06.2009

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE END ENERGY

G E U S

Summary

The present report is a data compilation study on the Paleogene plateau basalts from Hold with Hope (c. 73º N) to Shannon Ø (75º30' N), East Greenland focussing the Ni-potential. The report is prepared on the request of NunaMinerals A/S.

Hold with Hope and Wollaston Foreland are the major outcrop areas of Paleogene volcanic rocks in the focus area and the majority of the data stems from these areas. During the Paleogene the final break-up of the North Atlantic occurred to the east of the existing basin and significant volumes of tholeiitic basalts were extruded to form the up to 1 km thick succession of plateau basalts in the focus area. The Hold with Hope lava plateau is subdivided into the Upper Plateau Lava Series (UPLS) (max. 350 m) and the Lower Plateau Lava Series (LPLS) (max. 450 m) , and rests mainly on a hyaloclastic breccia (max. 300 m) which in turn rests on Mesozoic to Paleogene sediments to the north and south, and Caledonian and Precambrian gneisses to the west. Major sill-complexes occurs in the Mesozoic and basal Paleogene sediments and basalts. NE-SW to N-S dyke swarm intruded all the units. The LPLS are typically K-poor oversaturated tholeiitic basalts, with a low contents of incompatible elements and a depleted mantle source signature. The UPLS consists predominantly of pahoehoe-type lava, originated for discrete crustal magma chambers, and erupted close to their present locations; the UPLS are K-rich, and relative to LPLS they are richer in incompatible elements and are suggested to be crustally contaminated. Compositionally the sills are predominantly either olivine- or quartz tholeiites and compare with the LPLS.

In terms of tectonics, the dominant NNE-SSW and N-S trending faults are mainly related to reactivation of Mesozoic faults. Only minor mineralisations have been observed in relations to these faults.

The assessment of the Ni-potential is based on the available petrographic and geochemical data, as a consequence of scarcity of exploration data and observed Ni-mineralisations. The focus area meets the following criteria, normally regarded as positive indicators for the presence of Ni-mineralisations:

- The continental flood basalts of the East Greenland volcanic rifted margin were extruded during continental break-up related to the ancestral Iceland plume at 55 Ma, from which it follows that a hot spot gave rise to vast amounts of continental-scale rifting and hot spot development.
- Major faults, reactivated during rifting and serving as the conduits for volcanic eruptions and magma intrusions.

- Geochemical signatures indicates that – in particular – the UPLS have been crustally contaminated.
- Only few data indicate loss of Ni to a sulphide melt. However, this may be a scale phenomenon.

The available information does not point to any clear exploration targets. However, the following localities on Hold with Hope warrants further investigation:

- Tobias Dal, north: picrites
- Kap Franklin: dykes with poikilitic globules and disseminated sulphides
- Ladderbjerg: sill of intermediate composition with ore minerals and apatite
- Myggbukta magmas: lava rich in sulphides.

LIST OF CONTENT

Page

1 Introduction

The present report is the result of a data compilation study on the plateau basalts in East Greenland focussed on the Ni-potential. The report is prepared on the request of NunaMinerals A/S. The scope of work is defined in correspondence between NunaMinerals A/S and GEUS (J. nr. GEUS 439-00007). The region covered by the contract stretches from Hold with Hope in the south (c. 73º N) to Shannon Ø (75º30' N) in the north; to the west the area is defined by longitude 22º 30' W (fig. 1) and to the east by the North Atlantic Ocean.

The main effort has been to identify and organise data and information. Due to the scarce exploration activities and the type of data available the compilation focuses on the petrography and geochemistry of the basalt and their implications for the Ni-potential of the region.

2 Geological activities - overview

Since the discovery of the region in the 1820's the search for mineral occurrences has been conducted alongside a range of expeditions. However, only limited mineral exploration per say has been undertaken in the region. The vast majority of the efforts focussed on geological mapping and petrographic aspects. A brief summary of the activities is given below. Some of the previously investigated areas are indicated in fig. 2.

- 1823-1907: Early expeditions. The finds were scattered and of little significance (Jameson 1823, Bay 1896 and Nordenskjold 1907). Most notable were calcareous quartzites with thin veinlets of chalcocite, cuprite, and malachite in Pingel Dal, Flemming Fjord (Nordenskjold,1907). Rosenkrantz (1970), Haller (1971) and Bøggild (1905, 1953) list the earliest findings.
- 1930-1934: Systematic exploration was initiated in 1930 to 1934 with the "Danske Treårsekspedition til Østgrønland" (Eklund 1944, Koch 1955).
- 1927-1938: Scattered observations; except for Clavering Ø, which was explored in detail by Koch (1955, see fig. 2).
- 1947-1958: Scattered observations; except for the investigations of the Blyklippen deposit (Harpøth et al 1986).

Figure 1. *Geological map showing the areas of plateau basalts in the investigated region in NE Greenland (map on DVD). Based on Henriksen (1997) and Esher (2001).* ***Dette bliver en A3 figur***

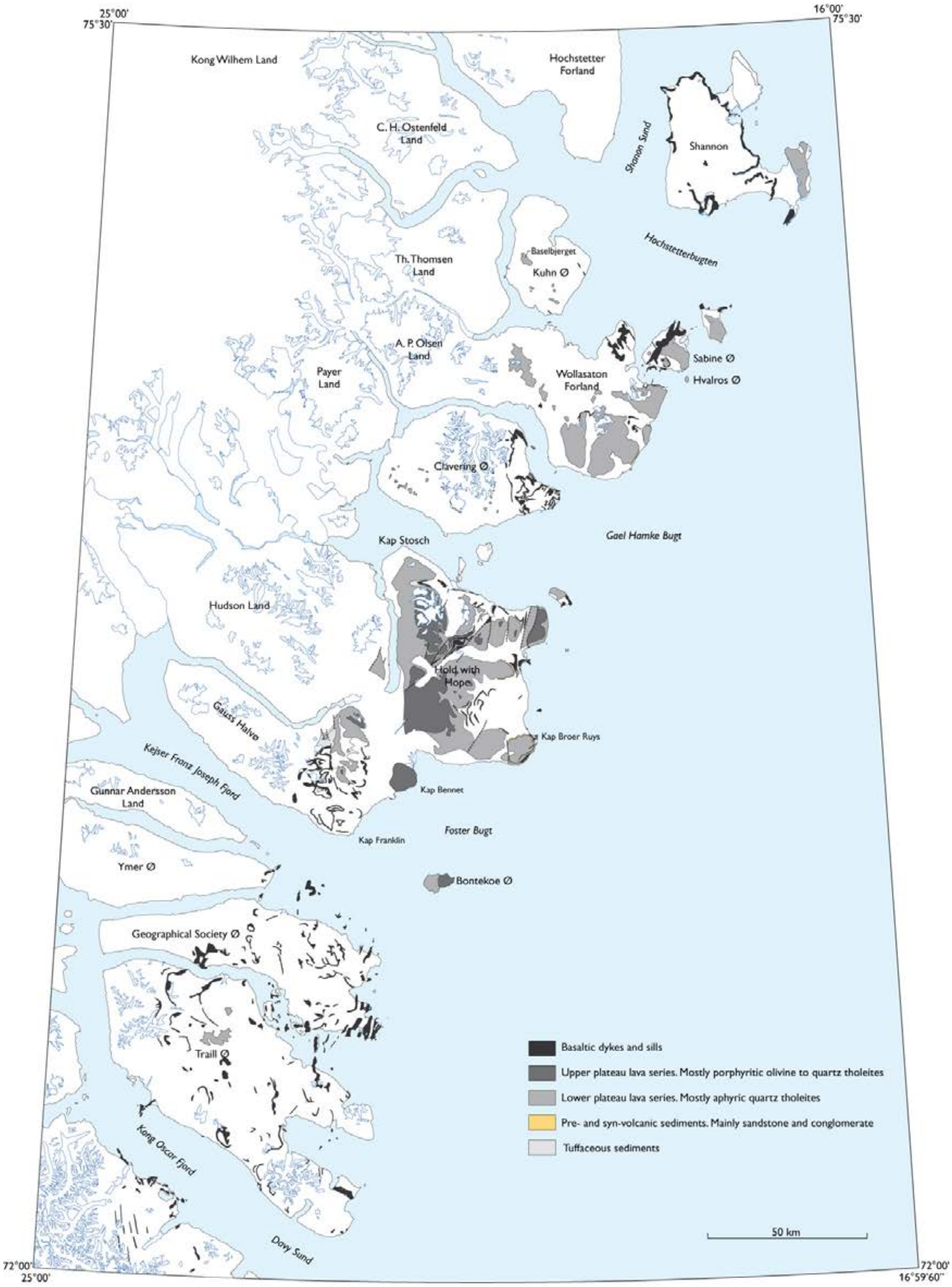
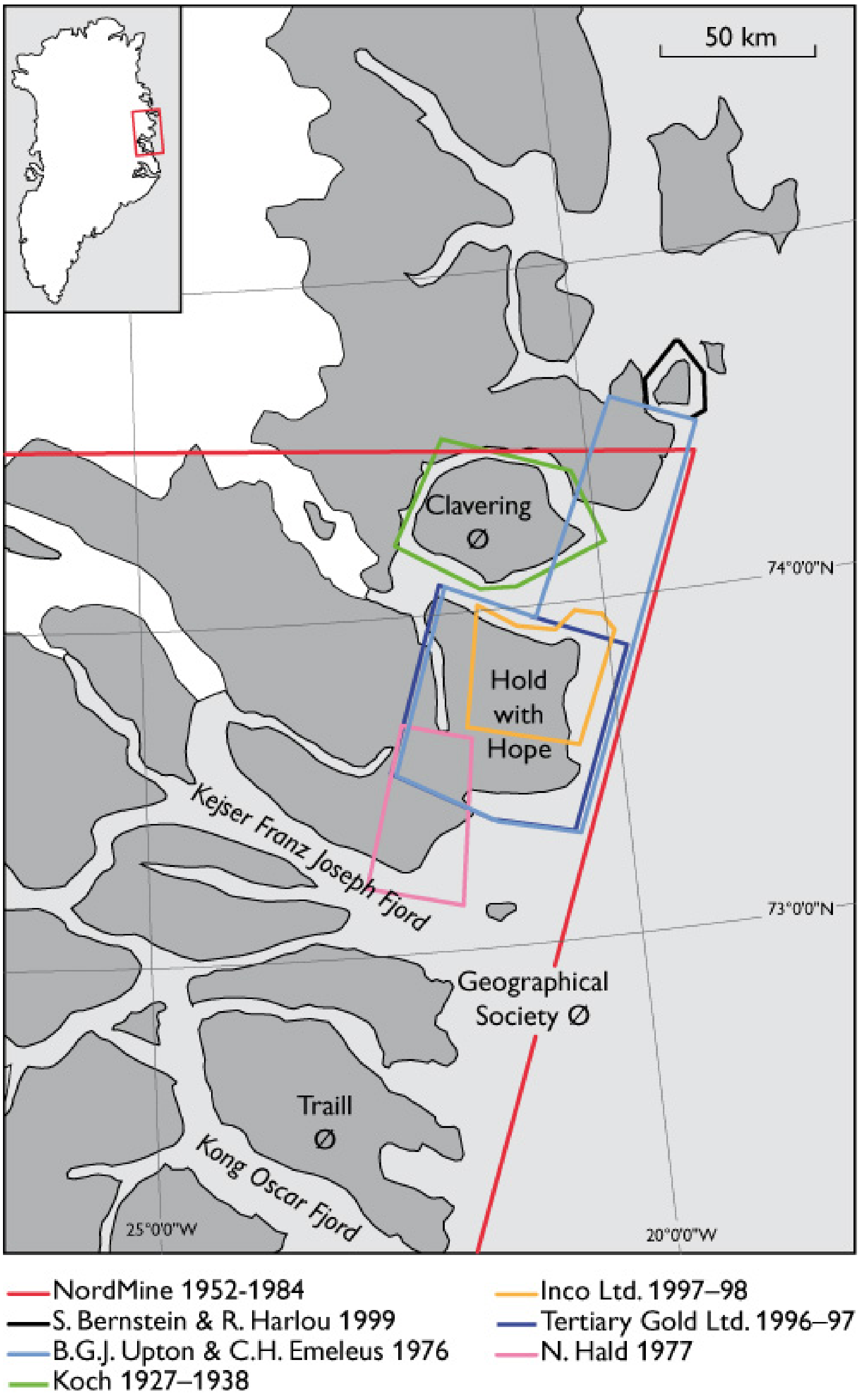


Figure 2. *The most important areas of earlier investigation and exploration*



- 1952-1984: Exploration by Nordisk Mineselskab A/S in NE Greenland from 70°N to 74°30'N (see fig. 2) . The exploration was conducted under one exclusive concession. The results are presented in Harpøth et al. (1986).
  - 1952-1954: Deposit investigation at Blyklippen and Sortebjerg.
  - 1956-1962: Reconnaissance exploration
  - 1956-1975: Arktisk Minekompagni A/S: Exploration and deposit investigation at Malmbjerg.
  - 1963-1984: Exploration mainly for base metals.
  - 1979-1984: Nordmine and Commission of the European Communities, tungsten-antimony exploration. Porphyry-type mineralizations (Geyti, 1982).
- 1973-1977: The Geological Survey of Greenland (GGU) exploration for uranium between 72º and 76ºN (Steenfelt, 1982, 1987).
- 1974-1975: International Geology Correlation Programme, University of Copenhagen. Reconnaissance investigations between 72º and 74ºN (Ghisler et al. 1980).
- 1976: Upton and Emeleus, investigations of sedimentary and magmatic successions and update of geological map covering Hold with Hope and Wollaston Forland (Upton and Emeleus, 1977; see fig. 2)
- 1977: Investigations, mainly of volcanics in Giescke Bjerge, Gauss Halvø (Hald, 1978a,b; see fig. 2).
- 1979-1984: Commission of European Communities supported NordMine in their exploration for tungsten, Central East Greenland (see Harpøth et al. 1986).
- 1979-1982: The Technical University of Denmark and Commission of European Communities launched and finished a geochemical mapping using stream sediment samples in an area covering the East Greenland Caledonides (Steenfelt, 1987).
- 1983-1986: University of Aarhus and Commission of the European Communities studied and modelled molybdenum-bearing quartz and feldspar porphyries (Harpøth et al. 1986).
- 1989: 2900 m of basalt profile sampled on Wollaston Forland and adjacent islands (Watt, 1994).
- 1996-1997: Exploration licence given to Tertiary Gold Ltd. covering Hold with Hope including the intrusive centres at Myggbukta and Kap Broer Ruys (Brown, 1996, see fig. 2).
- 1997-1998: Inco Ltd. Nickel prospecting on Hold with Hope (Rose et al. 1998, see fig. 2).

- 1999: Bernstein and Harlou investigating the Paleogene igneous province of East Greenland.

3 Introduction to the Paleogene plateau basalts of NE Greenland

The early Paleogene basalt province in East Greenland represents major eruptions at the margin of the continent. The volcanic products were formed during the continental break-up and the initiation of sea-floor spreading in the early Paleogene. The lavas spilled in over Mesozoic-early Paleocene sedimentary successions and lapped onto the Precambrian basement.

Paleogene igneous rocks are known from two main regions of East Greenland: The southern region extending from Scoresby Sund (70°N) to Kap Gustav Holm (66°N), and the northern region extending from Scoresby Sund (70°N) to Shannon Ø (75°30'N). By the Client's instructions this study focuses on the NE Greenland magmatic province, only, and covers most of the ice-free land from Kejser Franz Josephs Fjord (73°N) to Shannon Ø (75°N). The plateau basalts of the nunatak area East of André Land (West of 25 W) have not been included. The focus area is shown in fig. 1.

The geological formations included in this study are confined to the Paleogene plateau basalts and volcanics, including hyaloclastites and ash deposits, sills and dykes. Acidic and felsic volcanics have not been included, e.g., the Kap Broer Ruys complex, has not been included.

The Upper Palaeozoic and Mesozoic rifting in Jameson Land basin did not lead to active separation and sea-floor spreading in East Greenland (Surlyk et al. 1981). However, during the Paleogene the final break-up of the North Atlantic occurred slightly to the east of the existing basin and significant volumes of tholeiitic basalts were extruded to form the up to 1 km thick plateau basalts in NE Greenland. In the southern part of the province as much as 10 km of flood basalts were deposited (Pedersen et al. 1997).

The Hold with Hope peninsula, between 73°N25' and 74°N05' and Wollaston Foreland are the major outcrop areas of Paleogene volcanic rocks in the focus area and appear to be the areas of the most prolonged magmatic activity. These areas have been investigated by a number of groups (Koch & Haller 1971; Noe-Nygaard & Pedersen 1974; Upton & Emeleus, 1977; Hald, 1978a). A brief description of the type localities at Hope with Hope and Wollaston Foreland – in essence a summary of Upton et al. (1980, 1984a, 1984b) - is given below, in order to provide a geological and petrographic framework for the subsequent data presentation and discussion.

3.1 The Hold with Hope area

The initial activity, from presumed fissure volcanism to the east of the present coastline gave rise to the accumulation of c. 1 km thickness of predominantly subaerial basalt lavas. In addition to the extrusion of these quasi-horizontal and essentially conformable lavas a major sill-complex developed in the underlying Mesozoic and basal Paleogene sediments and in the lowermost parts of the plateau basalt succession. Following these events a NE-SW to N-S dyke swarm – associated with the Myggbukta Complex - intruded across Hold with Hope and Gauss Halvø.

The Hold with Hope lava plateau can be subdivided – on field and geochemical criteria – into a lower and an upper series – the Lower Plateau Lava Series (LPLS) and the Upper Plateau Lava Series (UPLS), respectively. The UPLS is not known from areas north of Hold with Hope. A schematic stratigraphy is given in fig.3.

The pre-volcanic basement

The plateau basalts of the focus area rest mainly on Mesozoic to Paleogene sediments in the north and south and on Caledonian and Precambrian gneiss in the west. The Mesozoic sediments are dominated by siltstone, sandstone and conglomerate; and the Paleozoic successions are mainly sandstone, siltstone intercalated with coal and evaporites (Upton & Emeleus, 1977).

Basal hyaloclastic breccias

Hald (1978) describes a more than 300 m thick succession of volcanic breccias, interpreted as hyaloclastite breccia, with subordinate lava flows in northern and western part of Giesicke Bjerge. The fragments in the breccias are angular to subangular (<2cm). Microphenocrysts of plagioclase, augite and olivine are common, showing various degrees of devitrification and alteration. Fragments include dolerite and occasionally sandstone. A close relationship is suggested between the hyaloclastite breccias and the overlying plateau basalts

The plateau basalts

The plateau basalts are on the basis of flow morphology, petrography and geochemistry, divided into the Lower Plateau Basalt Series (LPLS) and the Upper Plateau Basalt Series (UPLS). Both series are c. 47-55 Ma. old (Upton et al. 1984b).

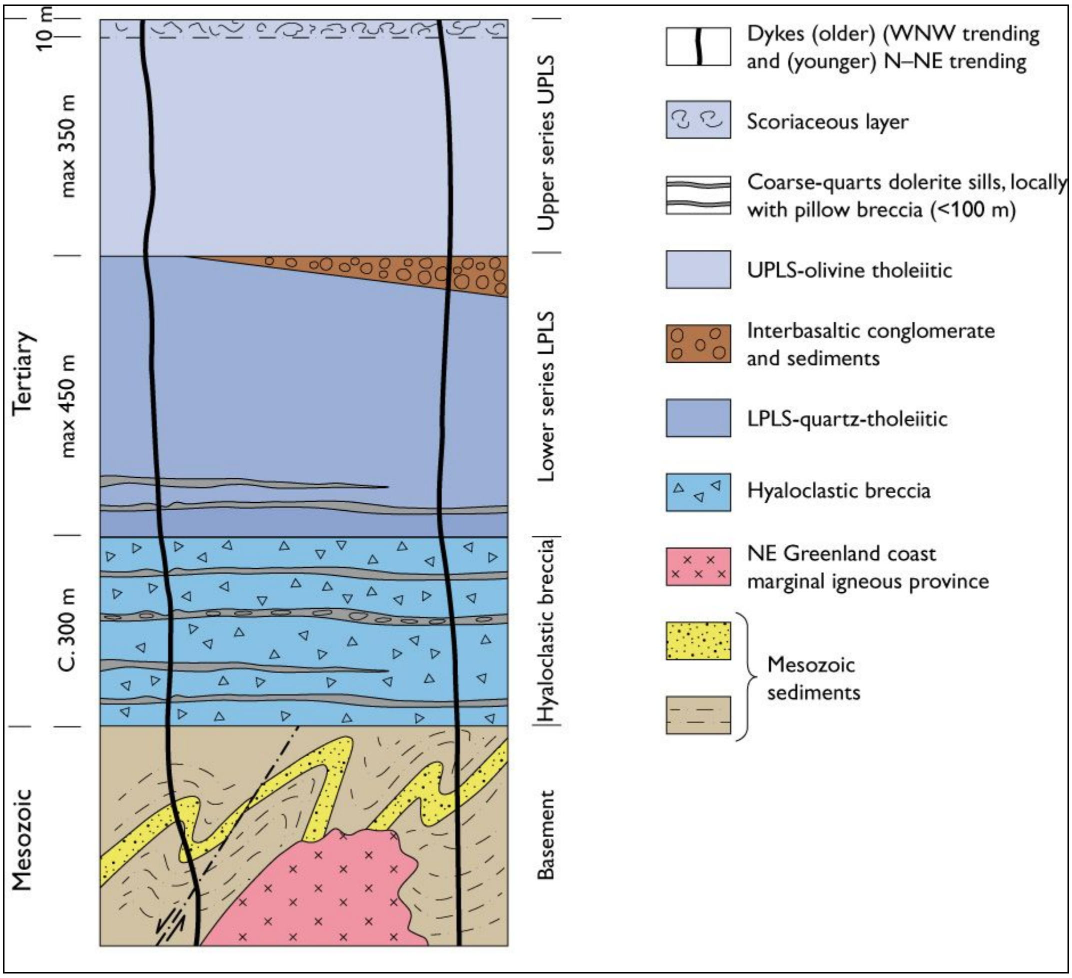


Figure 3. *Schematic stratigraphy of the Paleogene basalt in the study area.*

The Lower Plateau Lava Series (LPLS). The grey-green, aphyric pahoehoe LPLS basalt succession is between 400-450 m thick across Hold with Hope. In the topmost 50 m of the LPLS the flows have brick-red oxidised tops. The flows range in thickness from a few meters to c. 40 m, and show considerable lateral continuity. Columnar jointing is well developed in some of the thicker flows. The predominant part of the series erupted sub-aerially, but hyaloclastites and pillow lavas structures are observed on Kap Stosch, only, suggesting a marine environment within a minor part of the region. The LPLS rocks are typically K-poor oversaturated tholeiitic basalts and have a limited compositional range representing large degrees of partial melting, density filtering, and tapping from large crustal magma reservoir(s). The lavas have low contents of incompatible elements and a depleted mantle source signature. The lavas are homogeneous. Lavas with the same characteristics predominate in the Wollaston Foreland lava plateau.

The Upper Plateau Lava Series (UPLS). The UPLS lavas conformably overly the LPLS in the Hold with Hope area. A ca. 350 m succession of these lavas is preserved mainly in the southern part of the study area, in particular on Hold with Hope, Kap Bennet, and in Giesecke Bjerge on Gauss Halvø. The UPLS consists predominantly of pahoehoe-type lava, and are assumed to have originated from discrete crustal magma chambers and erupted close to their present locations. The average flow-thickness is ~4 m, and columnar jointing is poorly developed, except in the thicker flows. The UPLS is characterised by oxidized flow-tops and a large variability from nearly aphyric to densely porphyritic basalts. Olivine- and pyroxene-phyric, olivine-phyric, and fedspar-phyric basalts (up to c. 30 vol.% phenocrysts) are common in the central part of Hold with Hope, the latter two petrographic types have only been observed at Hold with Hope. The UPLS lavas include picrite, oceanite, alkaline basalt and nephelinite. The UPLS lavas are K-rich, and relative to LPLS lavas, richer in incompatible elements, and as suggested by Upton et al. (1984a) and Thirlwall et al. (1993) they also tend to be crustally contaminated (see section 4).

No unconformity is observed at the transition from LPLS to UPLS, but interbasaltic conglomerates and sediments are reported. As mapping criteria, the first lavas containing phenocrysts of olivine or augite define the base of the UPLS. However, UPLS compositional characteristics may be seen below the first porphyritic lavas and the transition between LPLS and UPLS is not easily mapped in the field. Due to the variability and more impersistent character of the flows, as well as occasional presence of cognate accumulitic xenoliths it has been suggested that the lavas have erupted from shallow magma chambers forming central-vent type shield volcanos (Upton et al. 1980). All the plateau lavas have been hydrothermally altered to a greater or lesser extent.

The magnitude of volcanic activity in the northerly area is reduced compared to the region south of Scoresby Sund. The northern part was peripheral to the main volcanic activity in the East Greenland Paleogene volcanic province and the centre of the Paleogene Iceland Plume at 68°N (Brooks, 1973).

The LPLS have higher abundance of transitional metals than the UPLS, which as also suggested by both Upton et al (1984),Thirlwall et al (1995) and Hansen and Nielsen (1998) is interpreted to indicate that the parental melts to the UPLS were crustally contaminated.

Sill and dyke swarms

Upton & Emeleus (1977), Hald (1978) and Upton et al. (1980) describe the sills and dyke on Hold with Hope. Scattered WNW-trending, mostly aphyric dykes of basaltic composition occur in the Giesecke Bjerge region, and a NNE-trending swarm – also predominantly aphyric and basaltic occurs at Kap Franklin on the southern tip of Gauss Halvø. However, some of the latter dykes north of Kap Franklin are microporphyritic and ankaramitic. Hald (1978a) observed one case where a WNW trending dyke is cut by a NNE trending dyke. Hald (1978b) noted that many of the Kap Franklin dykes contain 'poikilitic globules and disseminated groundmass sulphides'. Harpøth et al. (1986) report low nickel values from Kap Franklin.

Table 1. *Comparative features of the sills from Giesecke Bjerge, Hold with Hope and Wollaston Foreland.*

	Giesecke Bjerge	**Hold with Hope**	**Wollaston Foreland**
Sills	Mesozoic and Paleogene sediments intruded by sills (up to c.100 m thick). Mafic clinopyroxene-amphibole-olivine porphyritic sills intruded into granites and Mesozoic sediments on Ladderbjerg.	Sills intruded into sedimentary series (especially in the Cretaceous) below the LPLS. Thicknesses range from dm up to 100 m. Chilled at margins and coarsely ophitic in the centres, rarely pegmatitic. Picirites occur in Tobias Dal. The sills are compositionally similar to the LPLS	A major sill-complex developed in the Mesozoic sediments and LPLS.

From central Hold with Hope to Badlanddal is a 25 km wide and NE trending dyke swarm exposed. The dykes are mostly aphyric, but slightly porphyritic feldspar basalt. Oceanitic lithologies are also recognized.

Dykes are also exposed on the northern tip of Wollaston Forland, but no new information has been added since the description in Noe-Nygaard and Pedersen (1976).
The dykes dip up to 50º, and rarely reach >3 m in width (most range from 0.5 to 2.5 m). There is no general orientation in the dip except locally, either NW or SE.

Sills are quite common in the sub-basaltic lithologies, from Giescke Bjerge in the south to Sabine Ø in the north. On Gauss Halvø the sediments and hyaloclastites are intruded by sills. The thickness of the sills may be more than 100 m and the total accumulated thickness is >200 m. Petrographically the sills are doleritic with plagioclase porphyritic chilled margins; the grain size is < 5 mm, except for pegmatitic schlieren. Xenoliths of the wall-rocks up to several meters size are observed at two locations in Giescke Bjerge. Compositionally the sills are either olivine- or quartz tholeiites and they compare compositionally with the LPLS. On the eastern slopes of Ladderbjerg, a few mafic sills with clinpyroxene, amphibole, and olivine phenocrysts intrude basement granite and Mesozoic sediments.

On Hold with Hope the sills also intrude the tuffs and basal flows of the LPLS. As on Giesecke Bjerge they are homogeneous and doleritic with predominantly slightly feldspar phyric chilled margins. The range is doleritic to picritic; with occasional felsic segregations. In Tobias Dal a more than 10 m thick sill has a picritic basal layer.

Table 2. *Summary of the Paleogene basaltic rocks in the focus area, listed approx. from south to north. All localities are cited by Koch & Haller (1971), and Noe-Nygaard (1976); additional references are given in the table. All localities are shown in figure 1.*

Area		***References***	***Dominating Paleogene geology and features***
Bontekoe Ø		Noe-Nygaard & Pedersen (1983)	Basaltic lavas and dykes. Lavas are part of LPLS and UPLS.
Gauss Halvø/Giesecke Bjerge		Hald (1978a,b)	Basalts are widespread; mainly LPLS; sills occur in the basalts and in the underlying sediments.
Hudson Land		Backlund & Malmqvist (1932)	LPLS (olivine trachy basalt) (*).
		Stern (1964)	Two NW-SE trending dykes: potential feeders to sills or lava flows
Hold with Hope		Noe-Nyegaard & Pedersen (1974); Hald (1978a), Upton et al. (1980; 1984a).	The largest area of plateau basalts (LPLS, UPLS, sills and dykes). Pre-basaltic sediments outcrop on the floor of the large valleys.
	Myggbukta	Upton et al (1984b) Emeleus and Upton (field diaries 1977)	Sparsely porphyritic hypabyssal or extrusive with fine-grained matrices. Picritic dykes with up to 30 % olivine. Possible separation of a Cu-rich sulphide liquid.
	Tobias Dal	Rose et al. (1998)	Picritic to olivine gabbroic intrusive rocks concentrated at the head of Tobias Dal . More voluminous than previously suggested, and ranging from 10 to 50 meters in thickness, exceptionally they reach 100 meters.
		Tyrrell (1932)	LPLS and coarse grained intrusive dolerite
Jackson Ø		Backlund & Malmqvist (1932)	Sills dominate in the eastern part. Noe-Nyegaard (1976) argues against the suggested emplacement of concentric sheets.
Clavering Ø		Vischer (1943)	LPLS (up to 700 m thickness), sills and dykes.

			Two topmost flows may be part of UPLS. Visicular and scorieaceous tops common. The rocks are weathered in shades of blue, green, yellow and red.
Wollaston Forland		Upton et al (1984b)	Resembles the Hold with Hope basalts in being relatively uniform tholeiites, but chemically more primitive.
Kap Berlin		Vischer (1943)	LPLS as small remnants in the western part. Basalt dykes cut sediments in the eastern part.
Kuhn Ø		Vischer (1943); Elvevold & Gilotti (1999).	Basalts (LPLS?) overlie Mesozoic deposits on the higher mountains and dykes cross-cut all other rocks; basalts are ~100 m thick, dykes 2-10 m, strike NNE-SSW.
Pendulum Øer	Sabine Ø	Tyrrell (1932) Bernstein & Harlou (1999)	Basaltic flows (LPLS) occur only at highest topographic portions, The dominanting igneous rocks on Sabine Ø are medium-grained and most likely intrusive (sills?).
	Hvalros Ø	Noe-Nygaard (1976)	LBLS; light coloured and low augite content.
	Bass Rock	Noe-Nyegaard (1976)	Small island dominated by basaltic dykes and sills.
Shannon	Kap Pansch	Noe-Nyegaard (1976)	LPLS and basaltic sills and dykes are widespread in the coastal areas.

Table 3. *Comparative features within the NE Greenland magmatic province. References: Hald 1978a,b; Upton & Emeleus 1977; Upton et al. 1984a,b; Bojesen-Koefoed et al. 1997.*

Volcanic rocks	**Giesecke Bjerge**	**Hold with Hope**	**Wollaston Foreland**
Ash/hyaloclastite	Hyaloclastite breccias (xenoliths: dolerite and rare sandstone)	Poorly bedded ash	
The lava series	Basalts ~ 800 m LPLS: Thickness unknown, pahoehoe laveas in 10 m sequences; locally pillow breccias. Thin vesicular flows are common. Phenocrysts assemblages: plagioclase-olivine and plagioclase-olivine-clinopyroxene. Olivine may be replaced by sheet silicates or carbonates. Xenoliths of quartzitic sandstone. UPLS: thickness not reported. Ankaramites to pyroxene-olvine porphyritic trachybasalts and trachyandesites. Xenoliths of wehrlite,	Basalts > 600 m LPLS, 400-450 m. Maximum thickness of flows is 40 m whith an average of 9 m. One horizon contains hyaloclastite and pillow lavas. Dominantly, the eruptions were subaerial and on low-relief landscape. UPLS, 200 m. Base of UPLS defined by the appearance of clinopyroxene/olivine phenocrysts. Most lavas are mafic and	Basalts ~ 450 m LPLS; thickness unknown. Aphyric to sparsely porphyritic (<10 vol.% modal) tholeiitic basalts. Marginally more Mg-rich than Hold with Hope and Giesecke Bjerge equivalents. UPLS not observed

	olivne-clinopyroxenite and olivine-clinopyroxene gabbro are observed. Flows have 10 m thick scoraceous tops	range from picrite to oceanite and an-karamite. The aver-age flow thickness is c. 4 m. Dark mica is a groundmass phase. Rich in K,	
	MgO 4-12wt.%	MgO 5-26wt.%	MgO 3-19wt.%
Dykes	Two trends, WNW and NNE (younger). Both are basaltic. Phenocrysts are pla-gioclase, olivine and occasionally clinopy-roxene. The N-S to NE-SW dykes carry sulphide as poikilitic globules and as dis-seminated phases in the groundmass.	NE oriented, they reach max. intensity at Ravnebjerg; they are clearly related to Myggbukta complex.	Dykes on northern tip.

Tectonics

Post-basaltic tectonism is mainly related to reactivation of Mesozoic faults.
A summary on a compilation of lineaments and geological settings in the study area is presented by Stendal (1999) and selected parts are cited below:

Lineaments in the focus area are dominantly oriented NNE-SSW, parallel to the Caledonian orogen. The lineaments can be divided into structures formed during the main Caledonian collisional orogeny and post-Caldonian extentional structures formed from Devonian to Paleogene. The Caledonian and post-Caledonian structural ‘domains’ are separated by the Western Faults Zone (WFZ), which most likely seems be a reactivated Caledonian structure. The WFZ seems to have been the western boundary of the present day outcrop of Devonian Sediments. High-angle faults relative to the main faults developed into valleys were important as feeder channels for the basin fills. The high angle faults also acted as channel-ways for hydrothermal solutions.

During the Late Devonian the Eastern Fault Zone (EFZ) became the prominent active tectonic feature in the region, defining the western margin of post-Devonian sedimentary basin. Concurrently, the activity along the WFZ slowed down. Intense extensional block-faulting characterised the Carboniferous–Early Permian and created a 400 km long and 80 km wide N-S oriented basin of tilted half-grabens.

The N-S and NNE-SSW trending lineaments form part of the post-Devonian main fault system (EFZ) which runs through the central parts of Hudson Land and Gauss Halvø, probably belonging to the same system. The post-Devonian fault structures continue southwards to the Scoresby Sund region, and have a total extent of more than 400 km.

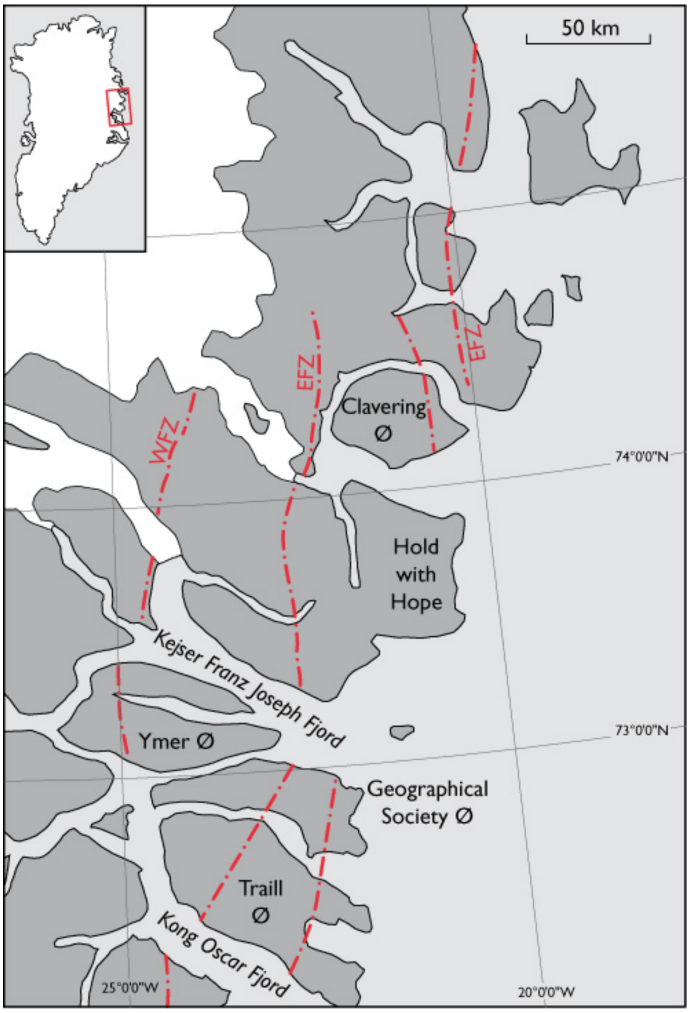


Figure 4. *The main lineaments of the Western Fault Zone (WFZ) and the post-Devonian, Eastern Fault Zone (EFZ) (based on Stendal, 1999 and Nielsen and Bernstein, 2004).*

The post-Devonian main fault zone, cutting Hudson Land and Gauss Halvø has been investigated with respect to mineralisation (Stendal, 1999). A summary of the investigations are shown in table 4.

Table 4. *Mineralisation related to the main post-Devonian fault zones on Hudson Land and Gauss Halvø (based on Stendal, 1999).*

Area	**Mineralisation**	**Type**	**Occurrence**
Western side of EFZ	Fluorite, carbonate		Limited to a few shear/breccia zones
Near the EFZ	Pyrite, galena, chalcopyrite, sphalerite, bornite, aresenopyrite. Elevated Au and As	In breccia zones and quartz veins.	Normally well below 1 vol%
Eastern side of EFZ	Pyrite	In joints, faults, and shear zones striking NE—SW to E-W.	Copper contents slightly elevated

The on land magnetic anomalies form a natural continuation of the initial North Atlantic spreading ridge north of Kong Oscar Fjord and is suggested (Harpøth et al. 1986) to represent a continuation of an oceanic spreading ridge in the East Greenland continental crust.

There is no evidence of faulting or tilting during the formation of the lava piles. Around Giesecke Bjerge the ‘post-Devonian main fault’ and the ‘Giesecke Fault’ have probably been reactivated, at the onset of volcanism (Watt, 1994), with downthrows to the east. A major N-S trending fault is bisecting Giesecke Bjerge, and is also downthrown to the east, separating WNW-dipping lavas to the east and E-dipping lavas to the west.

The WNW trend shown by the dykes is assumed by Hald (1978a) to reflect zones of weakness parallel to Kejser Franz Josephs Fjord. No faulting parallel to this direction has, however, been noted.

The final phase of the Paleogene activity is marked by differential vertical movements of the continental margin starting in Oligocene-Miocene. The coastal area was uplifted 1.5-2 km to its present position, while subsidence in the order of 3-6 km occurred off-shore (Surlyk et al. 1981)

Geochronology

Attempts to date the early lavas and sills in the northern province have so far been unsuccessful. Selected K-Ar geochron data for younger formations are given in Tab. 5.

Table 5. *Selected K-Ar geochron data (Upton et al.1984b).*

Locality	**Rock type**	**Methodology**	**Geochron data**
Myggbukta	Picrite Olivine dolerite	K-Ar K-Ar	28.0 ±0.6 Ma 34.4 ±1.3 Ma
Hold with Hope	UPLS basalt	K-Ar	55.1±1.8 Ma 47.2 ±1 Ma
Hold with Hope	Dyke rock	K-Ar	47.8 ±1.1 Ma 48.8 ±1.1Ma
Kap Broer Ruys	Felsite	K-Ar	47.9 ±1 Ma 45.9 ±1 Ma

4. Ni-potential assessment

The assessment of the Ni-potential is based on the available petrographic and geochemical data, as a consequence of scarcity of exploration data and obvious Ni-mineralisations. An overview of the geochemical data is presented in the figures 5-11. Each of the figures show Mg# (=100xMg/(Mg+Fe), FeO*= FeO + Fe_2O_3x0,8998) at the abscissa, as a measure of the degree of fractionation; interpretations are based on Nielsen and Bernstein (2004).

- Cu versus Mg# and Pd versus Mg# show the degree of incompatibility of these elements with fractionation.
- 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 versus Mg# is indicative of crustal contamination, because most mantle derived mafic melts will have Nb/La at about unity or higher; crustal materials are usually characterised by very low Nb/La ratios.

- Primary, Paleogene astenosperic melts will have $^{87}Sr/^{86}Sr$ ratios between 0.7025 -0.7045, while crustal material, depending of age and lithology, will have Sr isotopic ratios >0.7045.
- εNd[1] is a strong measure of contamination, since all old material in the crust will have strongly negative εNd. Astenosphere-derived melts will have εNd values in the range of 4 -12 in the Paleogene (Nielsen & Bernstein 2004).

Flood basalt provinces are regarded favourably environments for Ni-sulphide mineralisation, a conclusion largely inspired by the size and richness of the Noril'sk deposits. The key metallogenic features identified in the Noril'sk region are here used as a guide for the development of an exploration strategy for Ni in NE Greenland. Seven key metallogenic features for Noril'sk type deposits have been outlined by Naldrett (1992, 2004). In the following, the focus area is tested for these seven key features to established similarities and differences between the magmatism and regional setting between the East Greenland plateau basalts and the Noril´sk environment. A summary of the test is shown in Table 6.

1. A hot spot in the mantle giving rise to vast amounts of flood basalt, and
2. Continental-scale rifting following hot spot development
The continental flood basalts of the East Greenland volcanic rifted margin were extruded during continental break-up above the ancestral Iceland plume at 55 Ma. Thus the criteria 1 and 2 are both met in the area under investigation.

3. Major faults, penetrating to the mantle, activated or reactivated during rifting and serving as the conduits for volcanic eruptions and magma intrusions
It is well established that the continental flood basalts were part of a rifted margin and were extruded during a continental break-up. The continuation of the initial North Atlantic spreading ridge north of Kong Oscar Fjord is suggested by Harpøth et al. (1986) based on magnetic anomalies representing a continuation of an oceanic spreading ridge into the East Greenland continental crust.

4. Crustal contamination of some of the magmas

Indications of basalts subjected to crustal contamination can be obtained from i.e. corre-

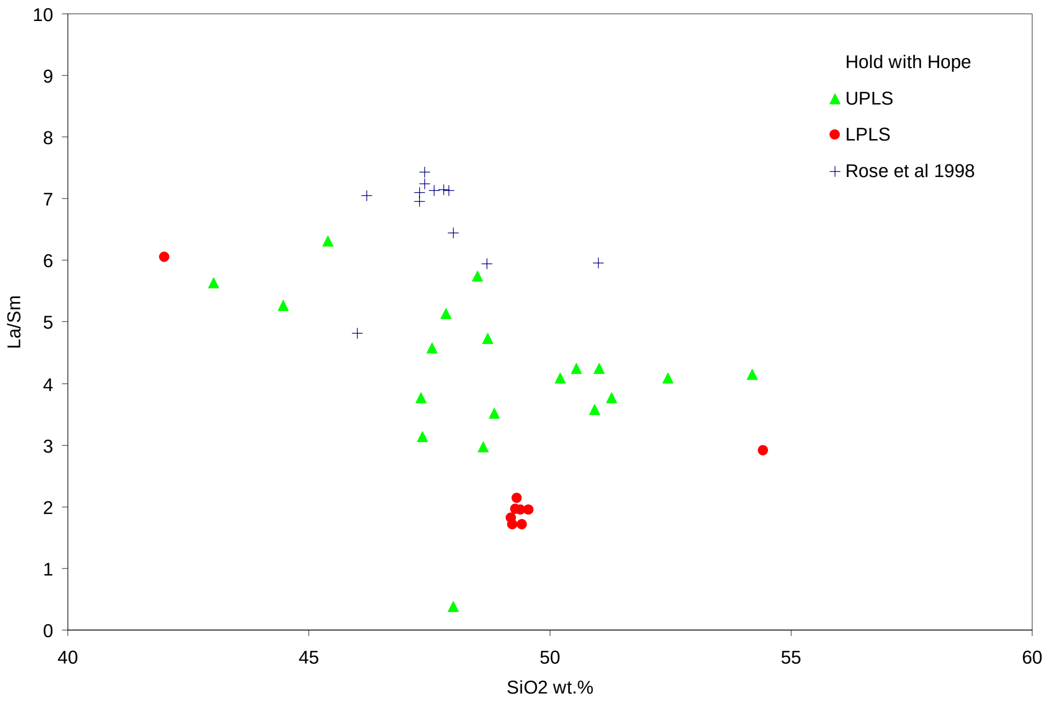


Figure 5. *Plot illustrating the relationship between La/Sm and SiO_2 for rocks from Hold with Hope. The LPLS show a close cluster (except for one evolved composition) and no evidence of contamination. The UPLS show in general the expected inverse ratio of La/Sm with decreasing SiO_2 in increasingly alkaline melts. The Rose et al. samples show comparatively high La/Sm, probably a result of contamination (see below).*

lated high La/Sm and high SiO_2, plots of Nb/La versus Mg#, and plots of εNd versus Mg#. Fig. 5 shows that the Upper Series displays inverse relations between La/Sm and SiO_2, and the Lower Series magma form a tight group with about 49% SiO_2 and a La/Sm ratio of about 2, except for one early nephelinite. The plot suggests that the LPSL were not subjected to contamination, The UPLS show range from low to high SiO2 (43-54 wt% SiO2 and a significant variability in the La/Sm ratio. The εNd versus Mg# plot (fig. 6), shows that

---

[1] $$\varepsilon Nd(t) = \left[\frac{\left(\frac{^{143}Nd}{^{144}Nd} \right)_{sample(t)}}{\left(\frac{^{143}Nd}{^{144}Nd} \right)_{CHUR(t)}} - 1 \right] \cdot 10000$$

c. half of the samples have εNd-values < 4, and thus appear to have been contaminated, which is the case for the vast majority of the UPLS; those above 4 – which are mainly the LPLS - are likely to have been uncontaminated. Plot of Nb/La versus Mg# (fig. 7), shows random data, except for the samples by Rose et al. 1998, which all appears crustally contaminated.

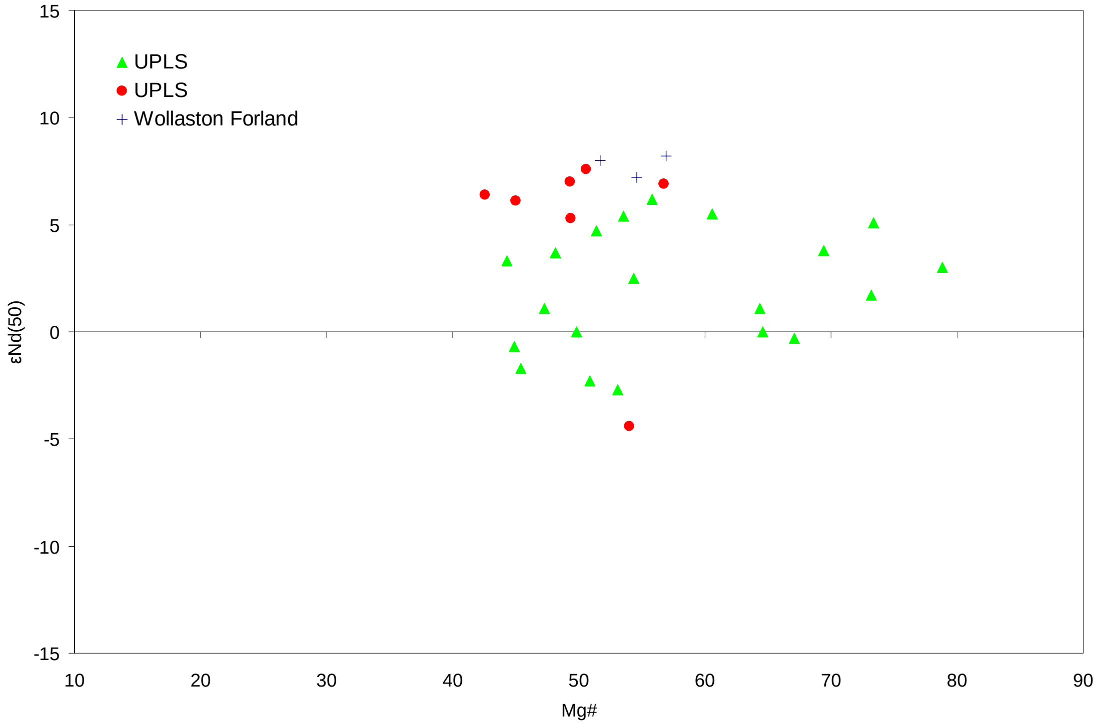


Figure 6. *Plot of εNd versus Mg#. Approx. half of the samples have εNd < 4, and thus appear to have been contaminated. Those above 4 may have been derived from the Asthenosphere.*

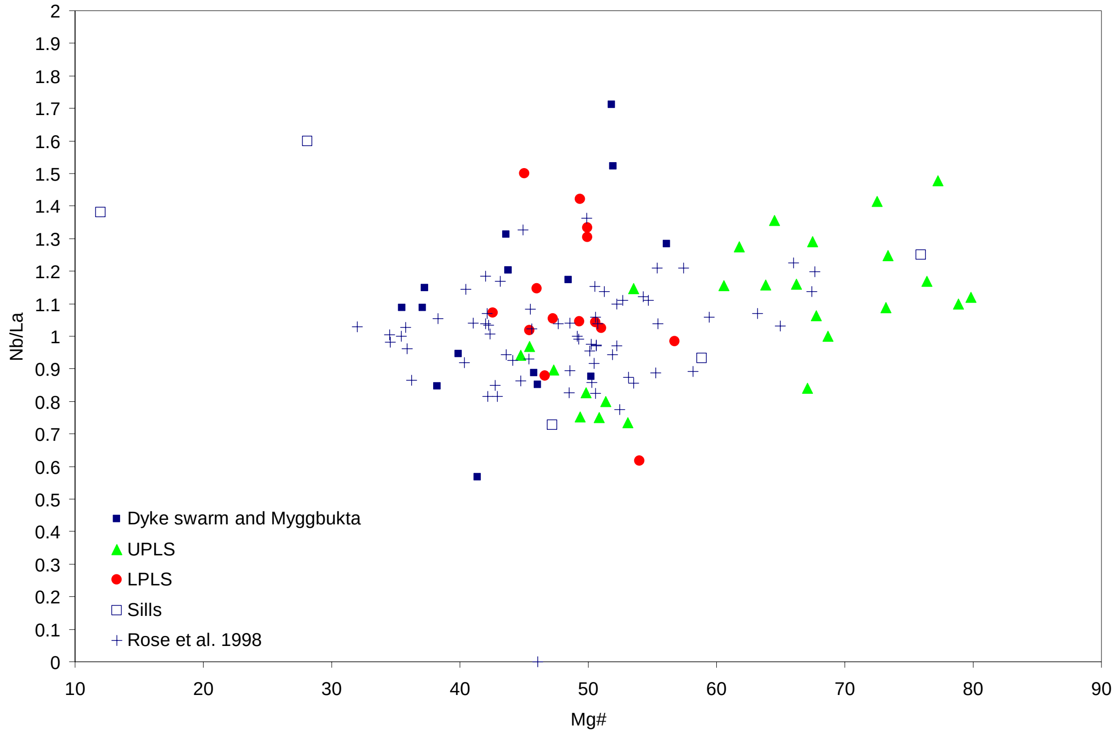


Figure 7. *Plot of Nb/La versus Mg#. The data has a random distribution, except for some of the samples by Rose et al. 1998, that appear crustally contaminated (Nielsen & Bernstein, 2004).*

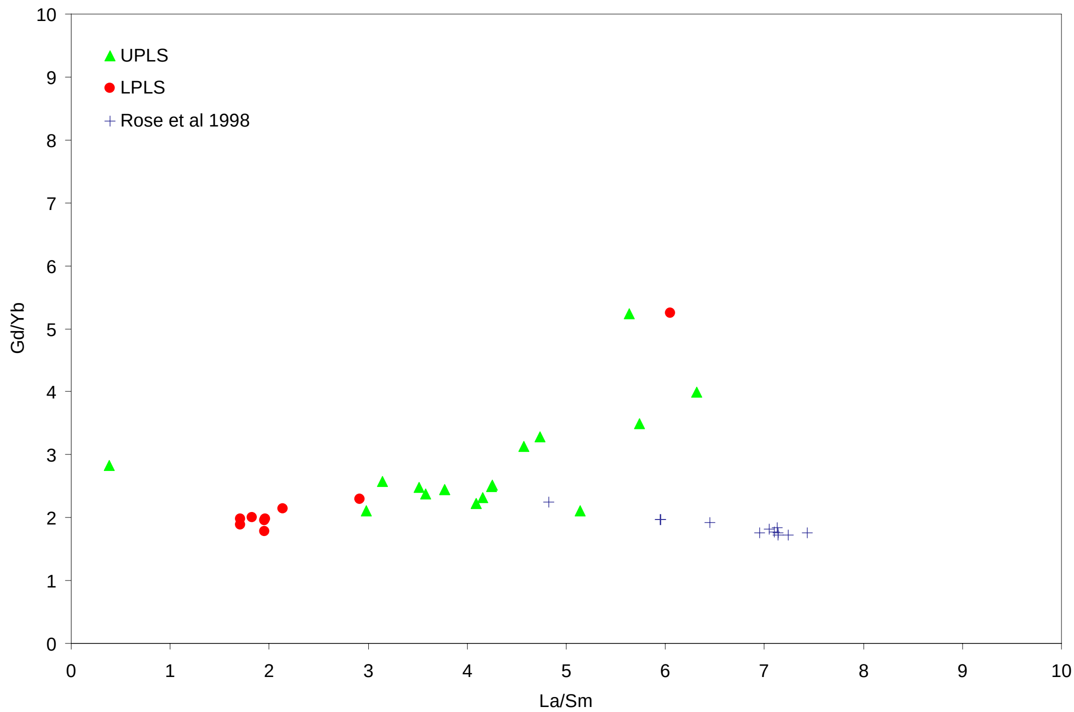


Figure 8. *Plot of Gd/Yb versus La/Sm. LPLS are clustered, except for one, in the low Gd/Yb:La/Sm ratio area. The UPLS show a trend in increasing La/Sm, which may indicate crustal contamination (Lightfoot et al. 1990).*

5. Chalcophile element depletion of contaminated magma, due to sulphide segregation

Chalcophile element depletion is tested in figures 9 and 10. Figure 9 shows Ni/Mg versus Mg#, where relative depletion in Ni is used as a proxy for chalcophile element depletion. In general, Ni decreases rapidly with differentiation in high Mg melts, since Ni is removed from a mafic magma and concentrated in early forming olivine.

The approach is mainly applicable on a regional scale. From fig. 9 it appears that the UPLS have a more varied composition compared to the LPLS, forming a cluster around Mg# 40-60 and Ni/Mgx10,000 10-15, except for one sample appearing to have lost Ni. The plot of Cu versus Mg# (fig. 10), shows that the LPLS tholeiitic samples are undersaturated in sulphur and thus Cu is incompatible and consequently the most fractionated samples have the highest Cu-content. Fig. 10, also shows that the UPLS melt was relatively more saturated in S. The Rose et al. (1998) data form two main groups, (i) one around the LPLS and (ii) one with relatively higher Mg#, but same Cu, indicating that the latter group represents sills with olivine accumulations.

Figure 11a shows a normal depletion trend in Ni with olivine crystallisation. The data from Rose et al (1998) (fig. 11b and 12) appears to represent sills mainly, however the data forms two clusters, resembling a LPLS- and UPLS plot. Two samples in fig. 11b are situated below the trend line and may have lost Ni to a sulphide melt.

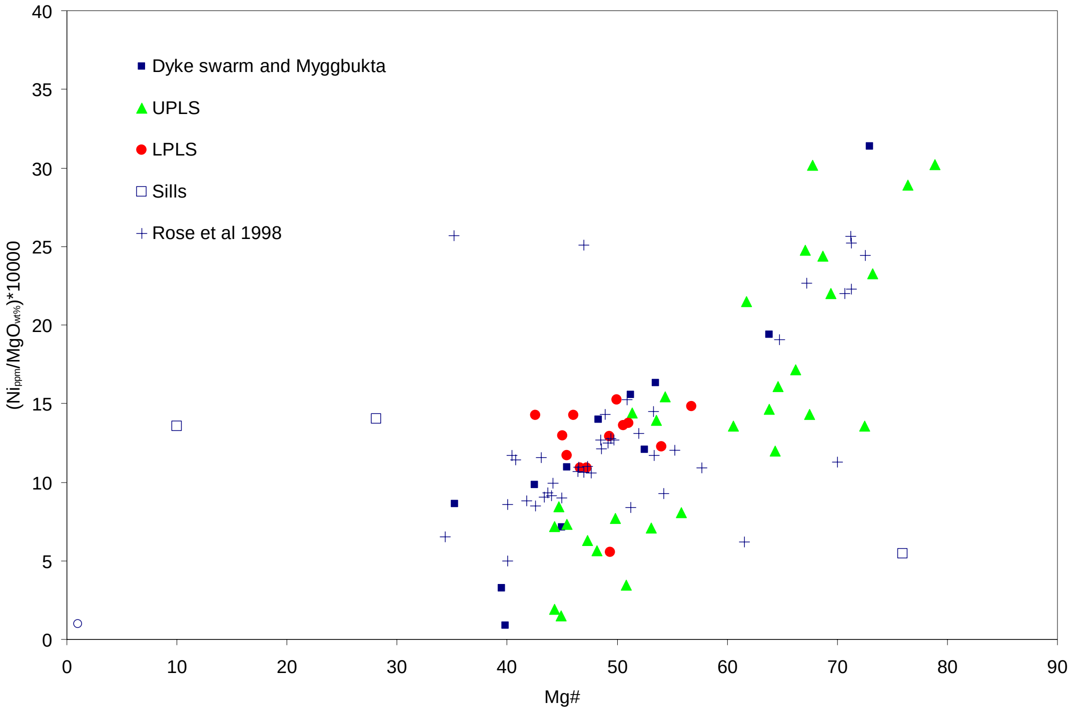


Figure 9. *Plot of Ni/MgO versus Mg# for samples from Hold with Hope, Upper and Lower Series. One sill and two of the Rose et al. samples have comparatively low Ni/Mg at high Mg# and may have suffered Ni loss due to sulphide formation.*

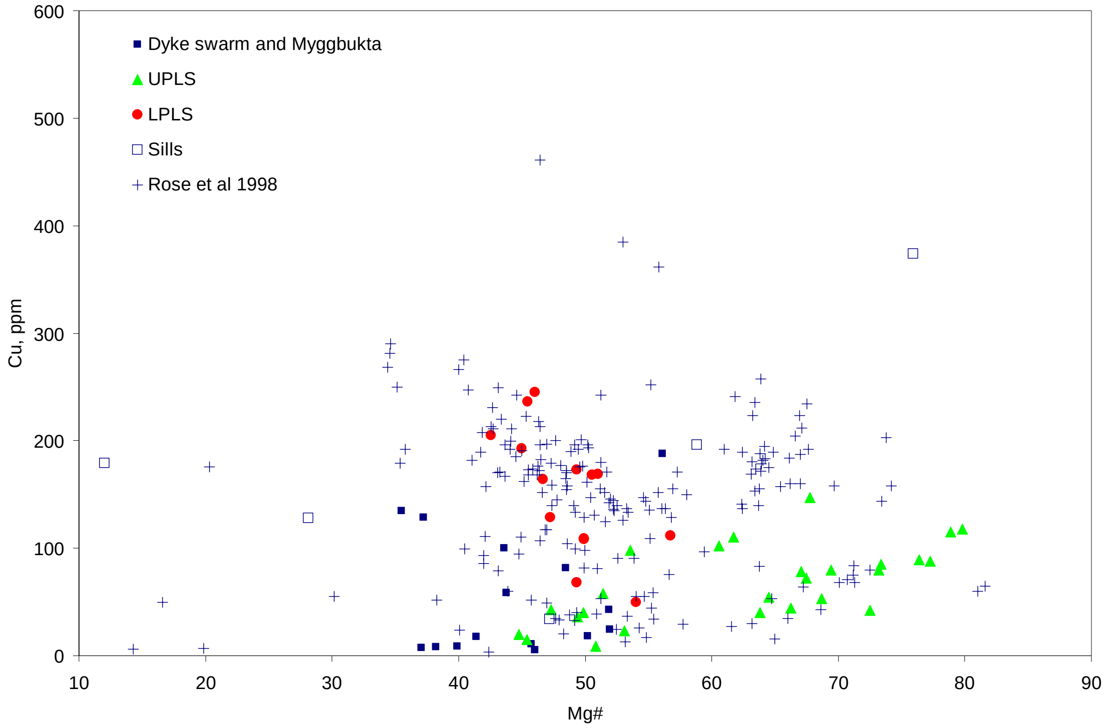


Figure 10. *Plot of Cu versus Mg#. The data from Rose at al. 1998 are predominantly sill samples. UPLS and some of the Rose et al. samples show S-saturated evolutions, whereas LPLS and the majority of the Rose et al. samples show S-undersaturated evolutions.*

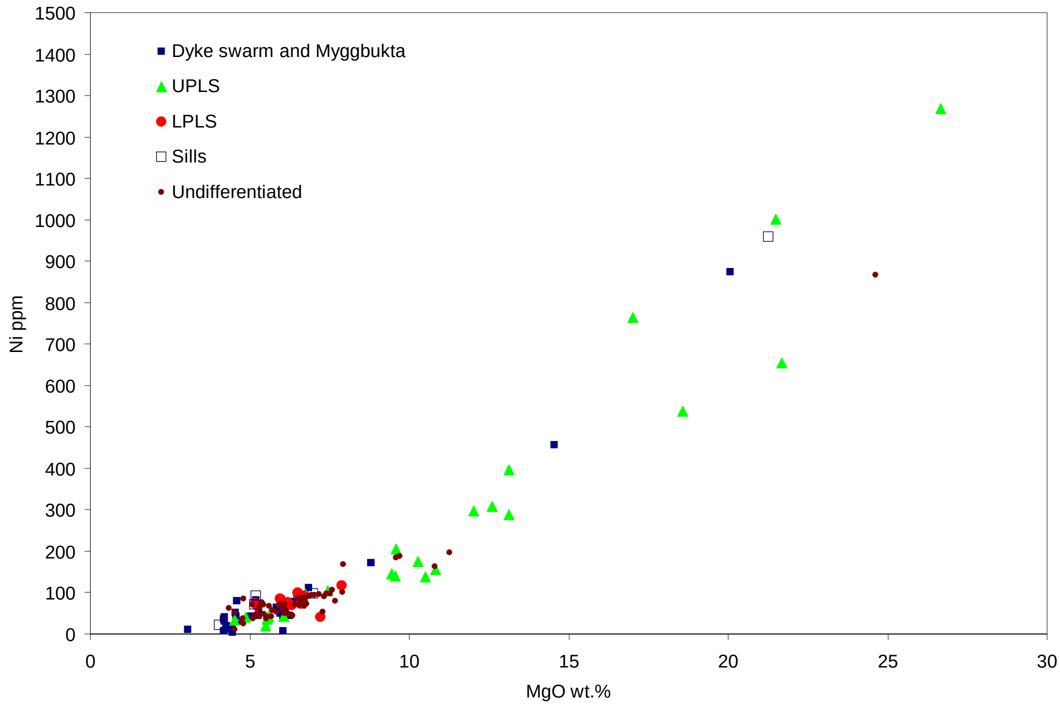


Figure 11a. *Plot of Ni versus MgO. The UPLS data suggests normal depletion in Ni with olivine crystallisation. Rose et al. data in figure 11b.*

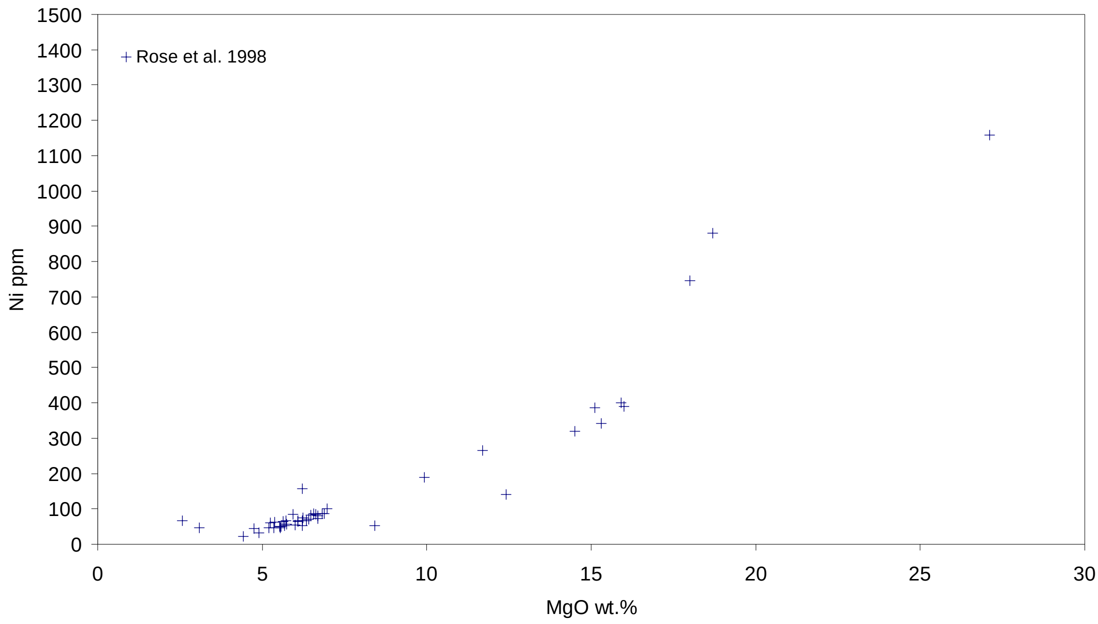


Figure 11b. *Plot of Ni versus MgO of Rose et al. 1998 data. The localities of the of data are not known, but shows general depletion in Ni with decreasing MgO. A few samples seem to be depleted relative to the general trend.*

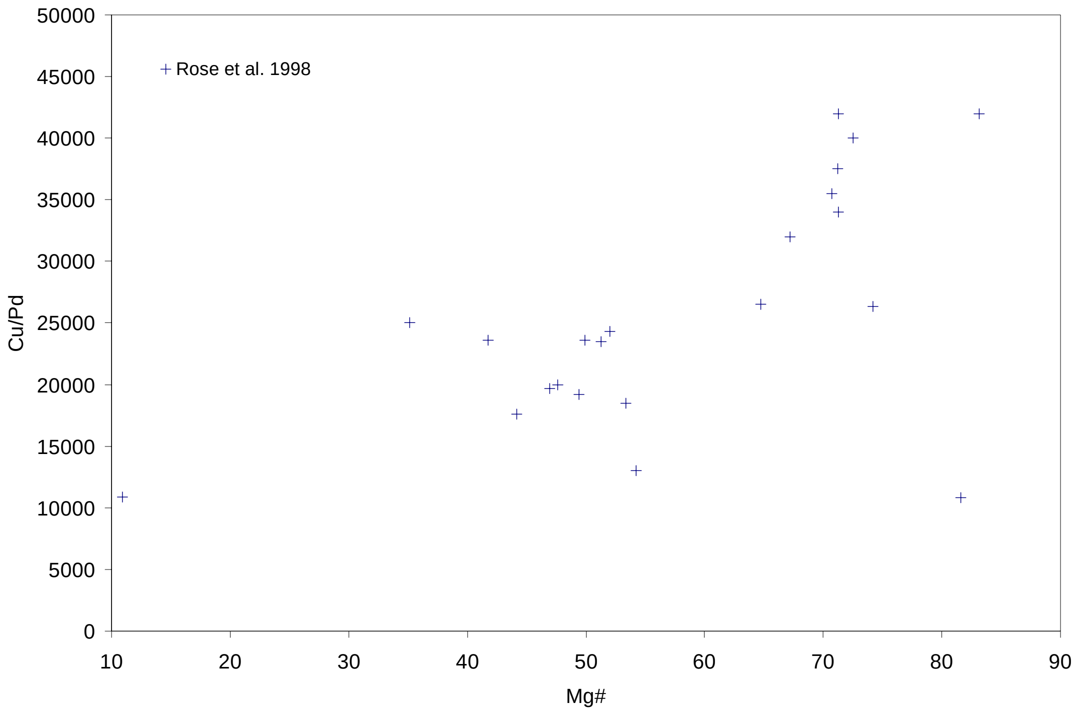


Figure 12. *Plot of Cu/Pd versus Mg# based on Rose et al. 1998 data. The data plot in two clusters, of which the low Mg# cluster resembles the LPLS samples and the other the UPLS, but supporting info is not available.*

Naldrett (1992) points to the fact that chalcophile element depletion is very important as a guide to regions where sulphides have formed from mafic magma, but also states that on the smaller scale – selecting individual targets within a region for exploration - a thorough understanding of the geological evolution should rather be applied. This may well be the case for Hold with Hope.

6. Intrusion of magma that has inherited sulphide

Intrusions of a magma that have inherited and/or concentrated sulphide, and therefore are enriched in chalcophile elements, are not known in the area.

7. Presence of sulphate-bearing evaporites

Based on theoretical calculations of the concentration of sulphur carried in solution in the Lower Nadezhdinsky formation, Noril'sk, Naldrett (1992) suggests that there may have been some addition of crustal sulphur to the melt during crustal contamination. In the focus area, gypsum (calcium sulphate) is known mainly from the Upper Permian in the northwest part of Hold with Hope and Giesecke Bjerge, but may have been more widespread during Paleogene.

Table 6 provides a brief comparison of the key components for the Noril'sk Ni-deposit and the Paleogene basalts in the focus area.

5. Conclusions and recommendations

The formations in northern part of the Paleogene basalt province in East Greenland includes Lower Plateau Basalt Series, Upper Plateau Basalt Series, sills, and dykes, all post-dated by the Myggbukta and Kap Broer Ruys complexes. The LPLS Basalt Series have higher content of transitional metals (Cu, Ni, Cr, V etc.) than the UPLS, while the UPLS based on geochemical data, isotopic data, and petrographical observations appear to be a much more varied group that is commonly crustally contaminated.

Table 6. *Key components for the Noril'sk Ni-deposit compared with the flood basalt provinces in NE Greenland.*

Key component for the Noril'sk Ni-deposit	**Observations in the focus area**
A large volume of relatively primitive (Mg# ~0.55) magma including olivine-phyric magma.	The Mg# of the UPLS is in general > 0.55, and olivine porphyric rocks are widespread in this section.
Evidence of crustal contamination.	The UPLS seem to be crustally contaminated.
Evidence of chalcophile depletion in some of the magma.	Samples of the UPLS from Hold with Hope show some Cu depletion.
A source of sulphur in the country rocks.	Gypsum evaporites are known from Giesecke Bjerge and northern Hold with Hope.

A structural setting which exposes intrusions feeding the lavas. Deposits will not be found in the lavas themselves.	Substantial uplift and erosion that post dates the flood basalts.
An intrusive environment in which the magma has had the opportunity to thermally erode and react with the country rocks	Possible, but not identified
Flow of magma that has already developed immiscible sulphides	Not identified
Conduits used by several batches of sulphide depositing magmas.	Not identified

Naldrett (2004) listed key factors for Ni-mineralisation, and Andersen et al (2002) listed significant factors for PGE mineralization's which also have a bearing on the nickel potential. Some of these key factors are listed in table 6.

The available information does not point to any clear exploration targets in the focus area. However, on Hold with Hope the following localities warrants further investigation:

- Tobias Dal, North: picrites rich in olivine (Upton et al. 1984a, Rose et al. 1998).
- Kap Franklin: Many dykes have sulphides as poikilitic globules (1 cm) and disseminated sulphides (Hald 1978b and field diary).
- East side of Ladderbjerg: “Pale grey sill of intermediate composition w. plagioclase phenocrysts, unidentified ore minerals, altered olivine and pyroxene, set in a groundmass of plagioclase, alkali feldspar, quartz, dark mica, ore minerals and apatite” (Hald field diary).
- Myggbukta magmas: Upton and Emeleus (field diaries) noted that the magmas around this Myggbukta complex were rich in sulphides. The Cu contents rises to c. 200 ppm at 7wt% MgO, it decreases drastically at lower MgO values, possibly a reflection of S-saturation.

6. References and background literature

Andersen, J.C.Ø., Power, M.R. & Momme, P. 2002: Platinum-group elements in the Paleogene North Atlantic Igneous Province. In: Cabri, l.J., (Ed.). Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume, **54**, p637-667.

Backlund , H.G. & Malmqvist, D. 1932: Zur Geologie und Petrographie der nordostgrönländischen Basaltformation.1. Die basische Reihe. *Meddelelser om Grønland* **87**, 5, 61.

Bay, E. 1896: Den østgrønlandske Ekspedition, udført i Aarene 1891-1892 under Ledelse af C. Ryder, 3. Del. Geologi. *Meddelelser om Grønland*, **19**, 6, 147-187.

Bernstein, S. & Harlou, R. 1998: Field work in the Tertiary igneous province of East Greenland. In: Higgins, A.K. & Frederiksen, K.S. (eds.), Geology of East Greenland 72-75 N mainly Caledonian: preliminary reports from the 1998 expedition. Danmarks og Grønlands Geologiske Undersøgelse, Rapport **1999/19**, 217-220.

Bernstein, S., Leslie, A.G., Higgins, A.K. & Brooks, C.K., 2000: Tertiary alkaline volcanics in the Nunatak Region, Northeast Greenland: new observations and comparison with Siberian Maymechites. *Lithos*, **53**, 1-20.

Bojesen-Koefoed, J.A., Petersen, H.I., Surlyk, F. & Vosgerau, H. 1997: Organic petrography and geochemistry of inertinite-rich mudstones, Jakobsstigen Formation, Upper Jurassic, Northeast Greenland: Indications of forest fires and variations in relative sea-level. *International Journal of Coal Geology*, **34**, 345-370.

Brooks, C.K., Pedersen, A.K., Rex, D.C., 1979: The petrology and age of alkaline mafic lavas from the nunatak zone of central East Greenland. *Bulletin of the Grønlands Geologiske Undersøgelse*, **133**, 1–28.

Bøggild, O.B. 1905: Mineralogia Groenlandica. *Meddelelser om Grønland*, **32,** 642p.

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

Eklund, O.1944: Malmgeologisk forskning på Nordostgrønland. *Teknisk Tidsskrift*, **14**: 393-401.

Elvevold, S. & Gilotti, J.A., 1999: The geology of Kuhn Ø, East Greenland, Caledonides. In: Higgins, A.K. & Frederisksen, K.S. (eds.), Geology of East Greenland 72^{o}-75^{o} N maimly Caledonian: preliminary reports from the 1998 expedition. Danmarks of Grønlands Geologiske Undersøgelse, Rapport **1999/19**, 121-126.

Ghisler, M., Jensen, Aa,. Stendal, H. & Urban, H. 1980: Stratabound scheelite, arsenopyrite and copper sulphide mineralization in the late Precambrian sediments succession of the East Greenland Caledonides. *Geological Survey of Irland, Special Paper* **5,** 19-24.

Hald, N. 1978a: Field investigation of Tertiary basic igneous rocks between 72º and 73º 30'N, northern East Greenland. *Grønlands Geologiske Undersøgelse*, Rapport, **90**, 109-113.

Hald, N. 1978b: Tertiary igneous activity at Giesecke Bjerge, northern East Greenland. *Bulleting of the Geological Society of Denmark*, **27** (special issue), 107-115.

Haller, J. 1971: Geology of East Greenland Caledonides. Interscience Publishers. New York: 413p.

Hansen, H. & Nielsen, T.F.D. 1999: Crustal contamination in Palaeogene East Greenland flood basalts: plumbing system evolution during continental rifting. *Chemical Geology*, **157**, 89-118

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

Henriksen, N., Higgins, A.K., Kalsbeek, F. & Pulvertaft, T.C.R. 2000: Greenland from Archaean to Quaternary. Descriptive text to the Geological Map of Greenland; 1:2.500.000. *Geology of Greenland Survey Bulletin*, **185**, 93p.

Eklund, O.1944: Malmgeologisk forskning på Nordostgrønland. *Teknisk Tidsskrift*, **14**: 393-401.

Koch, L. 1955: Report on the expeditions to central East Greenland 1926-39 conducted by Lauge Koch. *Meddelelser om Grønland*, **143, 2,** 642p.

Koch, L. & Haller. J.: (1971): Geological Map of East Greenland 72º-76º N. Lat. (1:250,000). *Meddelelser om Grønland*, **183**, 26p.

Larsen, H.C. 1984. Project NAD – East Greenland. An integrated aeromagnetic and marine geophysical project off the east coast of Greenland. Pre-final report no. **7**. Geological Survey of Greenland, Copenhagen: 44pp

Lightfood, P.C., Naldrett, A.J., Gorbachev, N.S., Doherty, W. and Fedorenko, V.A. (1990): Geochemistry of the Siberian Trap of the Noril'sk area, USSR, with implications for the relative contributions of crust and mantle to flood basalt magmatism. *Contributions to Mineralogy and Petrology, **104**, 631-644.*

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.

Momme, P., Tegner, C., Brooks, C.K. & Keays, R.R. 2006: Two melting regimes during Paleogene flood basalt generation in East Greenland: combined REE and PGE modelling. *Contributions to Mineralogy Petrology*, **151**, 88-100.

Naldrett, A.J. 1992: A model for the Ni-Cu-PGE ores of the Noril'sk region and its application to other areas of flood basalts. *Economical Geology* **87**, 8, 1945-1962

Naldrett, A.J. 2004: Magmatic sulphide deposits. Springer. Heidelberg. 727p.

Nielsen, T.F.D. & Bernstein, S. 2004: Maturation of areas in the Paleogene of East Greenland for PGE-Ni-Cu exploration. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2004/6**, 59 pp. (CD-ROM included).

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.

Noe-Nygaard, A. & Pedersen, A.K. 1974: Progressive chemical variation in a tholeiitic lava sequence at Kap Stoch, northern east Greenland. *Bulletin of the geological Society of Denmark*, **23**, 175-90.

Noe-Nygaard, A. & Pedersen, A.K., 1983: Tertiary volcanic rocks from Bontekoe Ø, East Greenland. *Rapport, Grønlands Geologiske Undersøgelsen*, **116**, 13p.

Nordenskjold, O. 1907: On the geology and physical geography of East Greenland. *Meddelelser om Grønland,* **28**, 5, 151-284.

Pauly, H. 1958: Igdlukúnguaq nickeliferous pyrrhotite. Texture and composition. A contribution to the genesis of the ore type. *Meddelelser om Grønland,* **157, 3**,167 pp.

Pedersen, A. K., Watt, M., Watt, W. S. & Larsen, L. M. 1997: Structure and stratigraphy of the Early Tertiary basalts of the Blosseville Kyst, East Greenland. *Journal of the Geological Society, London*, **154**, 565-570

Rose, N.M., Lightfoot, P.C., Golightly, J.P. & Makela, E.F. 1998: Inco Ltd – Northeast Greenland Project Report on 1997 Exploration Activities at Hold with Hope, 16pp. (GEUS File no: 21554).

Rosenkrantz, A. 1970: Træk af den geologiske udforskningshistorie. In: Nielsen, N., Skautrup. P. & Vibe, C. (Eds.), J.P. Trap DANMARK, 5. udg., Grønland, **14**. København: 43-51.

Stern, P. 1964: Zur Petrographie von Nordhoeks Bjerg und Nörlunds Alper Hudson Land. *Meddelelser om Grønland* **168**, 5, 112 pp.

Stendal, H. (ed.) 2000: Exploration in Greenland: discoveries of the 1990s. Transactions of the Institution of Mining and Metallurgy, section B, Applied Earth Science 109, B1B66.

Steenfelt, A. 1982: Uranium and selected elements in granite from Caledonides of East Greenland. *Mineralogical Magazine*, **46**, 201-210.

Steenfelt, A. 1987. Geochemical mapping and prospecting in Greenland – a review of results and experience. *Journal of Geochemical Exploration*, **29**, 183-205.

Surlyk, F., Clemmensen, L.B. & Larsen, H.C. 1981: Post-Paleozoic evolution of the East Greenland continental margin. In: Kerr, J.W. & Ferguson, A.J. (Eds.), Geology of the Northatlantic Borderlands. Mem. Can. Soc. Petrol. Geol.**7**, 611-645.

Thirlwall, M.F., Upton B.G.J. & Jenkins, C. 1994: Interaction between continental lithosphere and the Iceland plume Sr-Nd-Pb isotope geochemistry of Tertiary basalts, NE Greenland. *Journal of Petrology*, **35**, 839-879.

Tyrrell, G. W. 1932: The petrography of some Kainozoic igneous rocks, and of the Cape Parry alkaline complex, East Greenland. *Geological Magazine,* **69**, 520-527.

Upton, B.G.J., Emeleus, C.H. & Hald, N.: 1980. Tertiary volcanism in northern E. Greenland: Gauss Halvø and Hold with Hope. *Journal of the Geological Society London*, **137**, 491-508.

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., & 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.

Upton, B.G.J., Emeleus, C.H., & Mackintyre, E.M. 1984b: Myggbukta and Kap Broer Ruys: the most northerly of East Greenland Centre. *Mineralogical Magazine*, **48**, 323-343.

Vischer, A. 1943: Die postdevonische Tektonik von Ostgrönland zwischen 74º und 75ºN. Br. *Meddelelser om Grønland*, **133**, 1, 194 pp.

Watt, S.W., 1994: Stratigraphy and correlation of the Tertiary plateau basalts in North-East Greenland. In: Higgins, A.K. (Ed.), Geology of North-East Greenland, **162**, 185-194.

7 Company reports

Brown, M.A.: 1996: Geological field work, infra-red spectral assay results from the Kap Simpson, Kap Perry, Myggbukta and Kap Broer Ruys igneous complexes in East Central Greenland, 50pp. Internal report. Tertiary Gold Ltd. (in archive of the Geological Survey of Denmark and Greenland, GRF no. 21465).

Geyti, A., 1982: Geological reconnaissance for porphyry-type mineralization 1981: Hudson Land, Hold with Hope, Bontokoe Ø, Scoresby Land, and Traill Ø. Nordisk Mineselskab, København, 26p (GEUS File no: 20724)

Rose, N.M., Lightfoot, P.C., Golightly, J.P. & Makela, E.F. 1998: Inco Ltd – Northeast Greenland Project Report on 1997 Exploration Activities at Hold with Hope, 16pp. (GEUS File no: 21554).

8 GGU/GEUS reports

Bernstein, S. & Harlou, R. 1998: Field work in the Tertiary igneous province of East Greenland. In: Higgins, A.K. & Frederisksen, K.S. (eds.), Geology of East Greenland 72^o-75^o N maimly Caledonian: preliminary reports from the 1998 expedition. Danmarks of Grønlands Geologiske Undersøgelse, Rapport **1999/19**. p217-220.

Elvevold, S. & Gilotti, J.A., 1999: The geology of Kuhn Ø, East Greenland, Caledonides. In: Higgins, A.K. & Frederisksen, K.S. (eds.), Geology of East Greenland 72^o-75^o N mainly Caledonian: preliminary reports from the 1998 expedition. Danmarks of Grønlands Geologiske Undersøgelse, Rapport **1999/19**. p121-126.

Emeleus, C.H., 1976: Field Notes 1976. 69p. Unpublished. In archive of Geological Survey of Denmark and Greenland.

Hald, N., 1977: Dagbog. 64p. Unpublished. In archive of Geological Survey of Denmark and Greenland.

Hald, N., 1977: Undersøgelse af tertiære magmatiske bjergarter i Østgrønland mellem 72^o N og 74^o N: Giesecke Bjerge, Loch Fyne, Geologfjord, Geographical Society Ø og Traill Ø. 30p. Unpublished. In archive of Geological Survey of Denmark and Greenland.

Henriksen, N., Higgins, A.K., Kalsbeek, F. & Pulvertaft, T.C.R., 2000: Greenland Archean to Quarternary: Descriptiptive text to the geological Map of Greenland 1:2500000. Geology of Greenland Survey Bulletin, **185**, 93p.

Nielsen B.L. & Johansson, R. 1977: Field report 1977, North East Greenland, Rapport Grønlands Geologiske Undersøgelse

Nielsen, T.F.D. 2002: Paleogene intrusions and magmatic complexes in East Greenland, 66^o to 75^o N. Danmarks og Grønlandske Undersøgelse Rapport **2002/113**, 249p.

Nielsen, T.F.D. & Bernstein, S. 2004: Maturation of areas in the Paleogene of East Greenland for PGE-Ni-Cu exploration. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2004/6**, 59 pp. (CD-ROM included).

Upton, B.G.J., 1976: Field Notes. 1976. 100p. Unpublished. In archive of Geological Survey of Denmark and Greenland.

Upton, B.G.J. & Emeleus, C.H. 1976: The Tertiary geology of Hold with Hope, East Greenland. 48p. Unpublished. In archive of the Geological Survey of Denmark and Greenland.

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

Watt, S.W., 1994: Stratigraphy and correlation of the Tertiary plateau basalts in North-East Greenland. In: Higgins, A.K. (Ed.), Geology of North-East Greenland, **162**, 185-194.

9 Geological maps

- Koch, L. & Haller, J. 1971: Geological map of East Greenland 72°-76°N Lat. (1: 250 000). Meddelelser om Grønland 183, 26pp.
- Escher, J.C. 2001: Geological map of Greenland, 1:500,000, Kong Oscar Fjord, Sheet 11. Copenhagen: Geological Survey of Denmark and Greenland
- Henriksen, N. 1997: Geological map of Greenland, 1:500,000, Dove Bugt, Sheet 10. Copenhagen: Geological Survey Denmark and Greenland.
- Gilotti, J.A. & Elvevold, S. 1998: Geological map of Kuhn Ø, 74°40' -75°00' N and 19°40'-20°40'W (1:100 000). Unpublished. Geological Survey of Denmark and Greenland.
- Upton, B.G.J. & Emelus, C.H., 1976: Geological map of Hold with Hope, East Greenland (1: 160 000). 73Ø1, 4a. Brought in on request of L.M. Larsen 2008.
- Watt, W.S., 1997: Trail Ø (1: 100 000). Built on previous studies by Koch and Haller 1971. Unpublished. Geological Survey of Denmark and Greenland.
- Hjort, C., 1976: Shannon: Geological sketch map (1: 250 000). Built on Koch & Haller 1971, flight recognisance 1974 and field work 1976. Unpublished.
- Escher, J.C., 1999: Clavering Ø (1: 150 000). 74Ø2, 008. Compilation based on reconnaissance- and local detailed mapping by K.A. Jones & J.C. Escher, August 1998 and interpretation from vertical maps. Unpublished. Geological Survey of Denmark and Greenland.
- Watt, W.S., 1989: Geological map of Kuhn Ø and Wollaston Forland (1: 100 000). 74Ø2, 006. Based on J. Haller 1965 and field work by W.S. Watt 1989. Unpublished. Geological Survey of Denmark and Greenland.
- Watt, W.S., 1999: Geological map of Wollaston Forland (1: 100 000). 74Ø1, 006. Unpublished. Geological Survey of Denmark and Greenland.
- Watt, W.S., 1999: Geological map of Wollaston Forland (1: 100 000). 74Ø1, 005. Unpublished. Geological Survey of Denmark and Greenland.
- Watt, W.S. & Bernstein, S., 1998: Geological map of Hochstetterbugten (1: 100 000). 74Ø1, 004. Unpublished. Geological Survey of Denmark and Greenland.
- Emeleus C.H. & Upton, B.G.J., 1976: Sample map of Hochstetterbugten and Hold with Hope. 74Ø1, 3. Unpublished. Geological Survey of Denmark and Greenland.
- Watt, W.S. 1999: Geological map of Home Forland and Kap Broer Ruys (1: 100 000). 73Ø1, 016. Based on C.H. Emeleus & B.G.J. Upton's field work 1976. Unpublished. Geological Survey of Denmark and Greenland.

- Watt, W.S., 1999: Geological map of Loch Fyne, Badlanddal and Hudson Land (1: 100 000). 73Ø1, 014. Unpublished. Geological Survey of Denmark and Greenland.
- Watt, W.S., 2000: Bonteko Ø (1: 100 000). 73Ø1, 013. Compiled from Noe-Nygaard & Pedersen (1983). Geological Survey of Denmark and Greenland.
- Watt, W.S., 1999: Geological map of Kap Bennet (1: 100 000). 73Ø1, 012. Map based on C.H. Emeleus & B.G.J. Upton 1976 field maps. Unpublished. Geological Survey of Denmark and Greenland.
- Upton, B.G.J. & Emeleus, C.H., 1976: Sample map of Hold with Hope, East Greenland (1: 100 000). 73Ø1, 4b. Unpublished. Geological Survey of Denmark and Greenland.
- Thyrsted, T.H. 1975: Randbøldalen, profile. (1: 10 000). 73Ø1, 6. Unpublished. Geological Survey of Denmark and Greenland.
- Bengaard, H.-J. 1991: Geological map (1: 100 000) of Hudson Land. Photo interpretation. 73Ø1, 2. Unpublished. Geological Survey of Denmark and Greenland.
- Thyrsted, T.H. 1975: Geologisk kort over Randbøldalen. (1: 10 000). 73Ø1, 5. Unpublished. Geological Survey of Denmark and Greenland.

10 Overview of geochemical samples

About 490 geochemical samples are obtained from the focus area. Coordinates do not exist for any of them, but Upton & Emeleus' (1976) samples are identified in field maps and exploration reports. The samples are collected by Upton & Emeleus in 1976 and Hald in 1977 and Rose et al. in 1997. The samples from Rose et al. are not divided between the upper and lower series and/or sill and dyke. What is noted is that 36 of their 129 are sediment samples, the rest are hand samples. Rose et al.'s only listed names for about 44 samples of the 93 hand samples and one is shale. In addition there are 85 samples from the Nunatak region, ~200 km to the west of the focus area, these are Paleogene volcanics (Brooks et al. 1979; Bernstein et al. 2000). The samples collected by N. Hald were not analyzed for trace elements. However, they were analyzed by the in-house laboratory, thus relics do still exist and can be analyzed upon request.

Hald (1978a) and Upton & Emeleus (field diary and personal comments) noted that some of their samples were rich in sulphur. However, these samples were not analyzed due to difficulties in analyzing sulphur.

The data are not included in the database of the Geological Survey of Denmark and Greenland. Rather, they have been uploaded from the GEOROC database found Under Precompiled Files (URL http://georoc.mpch-mainz.gwdg.de/georoc/Entry.html)=> Continental Flood Basalts the North Atlantic Province is listed. This file contains 4210 lines that can be sorted after latitude, only latitude higher than 72.5 (corresponding to 72ºN30') are extracted. This procedure brings the number of lines down to ~134.

The additional data that have been obtained have been received from L.M. Larsen (Geological Survey of Denmark and Greenland) on request from C.H. Emeleus and data that she has typed in from N. Hald. These samples include not published results, some are published. The samples obtained from N. Hald are only major elements. Other data are typed in by the authors from Noe-Nygaard & Pedersen (1983) and Rose et al. (1998).

List of figures

Figure 11a: Plot of Ni versus MgO. The UPLS data suggests normal depletion in Ni with olivine crystallisation. Rose et al. data in figure 11b.

Figure 11b: Plot of Ni versus MgO of Rose et al. 1998 data. The sample localities are not known, but shows general depletion in Ni with decreasing MgO. A few samples seem to be depleted relative to the general trend.

Figure 12: Plot of Cu/Pd versus Mg# based on Rose et al. 1998 data. The data plot in two clusters, of which the low Mg# cluster resembles the LPLS samples and the other the UPLS, but supporting info is not available.

List of tables

APPENDIX

Geochemical data (on CD only)

Figure 1: Geological map showing the areas of plateau basalts in the investigated region in NE Greenland (map on DVD). Based on Henriksen (1997) and Esher (2001).