DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/104

Quantitative mineral resource assessment: Sedimentary-hosted copper in Greenland

Reporting the copper assessment workshop, GEUS, Copenhagen, March 2009

Bo Møller Stensgaard, Per Kalvig & Henrik Stendal

(1 CD-Rom included)

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Frontispice: *Chip sampling profile in Revett Copper type mineralised conglomerates of the Upper Permian Huledal Formation is being prepared by geologist Bjørn Thomassen during fieldwork for Nordisk Mineselskab A/S (Nordmine) in 1980 at Ladder Bjerg, Gauss Halvø, central East Greenland. Photo from workshop presentation by Bjørn Thomassen.*

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Executive summary

Quantitative information on mineral resources is needed among decision makers from governmental agencies and in the private mining sector, and in response to this, the United States Geological Survey (USGS) initiated the project ‘Global Mineral Resource Assessment Project‘ (GMRAP) in 2002. The objective of the project is to, globally, identify principal areas with a potential for undiscovered mineral resources, in the top one kilometre, based on available information and modern quantitative statistical models. The assessments are being conducted on a regional-multinational basis for selected deposit models and commodities, and on a global scale, coordinated by the USGS, by compiling information from the regional assessments. The Greenland Bureau of Minerals and Petroleum (BMP) and the Geological Survey of Denmark and Greenland (GEUS) are participants in the GMRAP-project, and in this capacity organised a workshop (27th–29th of March 2009 at GEUS, Copenhagen) to assess the potential for non-discovered sedimentary copper deposits in Greenland.

The workshop applied the standardized methodology, defined and adapted for the GMRAP assessments involving the ‗Three-Part Form‘ assessment approach, including, (i) delineation of tracts of land where the geology is permissive for sedimentary copper deposits to form; (ii) selection of grade and tonnage models appropriate for estimating grades and tonnages of undiscovered sedimentary copper deposits in each tract; and (iii) estimation of the number of undiscovered sedimentary copper deposits in each tract consistent with the grade and tonnage model.

At the workshop, the members of the assessment team provided individual estimates on how many deposits of a certain size and a certain grade would be possible to find, *under the best possible circumstances*. Subsequently, all estimates were used as inputs to a Monte Carlo simulation computer program (EMINERS devolved by the USGS), combining the probability distributions of the estimated number of undiscovered deposits, the grades, and the tonnages of the selected model to obtain the probability distributions for undiscovered metals in each tract. The assessment procedure applied is in strict accordance with the guidelines provided by USGS, but differs from some other assessments in the fact that only very scarce information is available for most of the tracts, due to logistical and economic constraints of undertaking mineral exploration in Greenland.

Sedimentary basin environments constitute approximately 40% of Greenland‘s 410,000 km^2 ice-free land, and several of the basins host known copper mineralization. The workshop considered three sub-groups of mineralizations, (i) Revett Copper type, (ii) Reduced Facies Copper type, and (iii) Redbed Copper type, for which statistical models exist for the quantitative resource assessments. Additionally, the Basaltic Copper type was applied on tracts in North-East and North-West Greenland to assess the probability of finding this type of copper deposits; however, no quantitative assessment was done, due to the absence of a statistical model for this type of mineralization.

In the course of the workshop a total of ninety-three tracts were assessed for their potential of hosting undiscovered sedimentary copper deposits. The total mean of undiscovered copper resources, for Reduced-facies, Revett and Redbed Copper types, is estimated to 3.68 million tons Cu; in addition to this is a potential undiscovered copper resource of the Basaltic Copper Type. The assessment also reveals that around forty thousand km^2 are considered permissive to host undiscovered sedimentary copper deposits. However, it should be noted that the figures are statistical estimates reflecting the present – fairly low – level of knowledge of the tracts assessed; thus any new information within a tract could impact this figure greatly, in either direction. The bids on undiscovered copper deposits made by the assessment team at different confidence levels are likely to be more relevant if used in combination with the resulting statistical estimated number of undiscovered copper deposits as a decision-making tool in future exploration campaigns. Details on the assessments are summarized below.

Mineral deposit model / type	Region in Greenland	Permissive area extent (Km^2)	Estimated tonnage (tons Cu)	Number of undiscovered Cu deposits estimated at different confidence levels*		
				N10	N05	N01
Reduced facies	Central East	2,250	240,000	0	0	2
		2,000	830,000	0	2	4
		1,000	300,000	0	0	2
	North East	2,111	730,000	0	1	4
		1,000	810,000	0	2	4
Revett	Central East	436	95,000	0	1	2
		882	130,000	0	1	3
		449	190,000	0	2	4
		361	130,000	0	1	3
		165	23,000	0	0	1
Redbed facies	Central East	2,310	10,000	0	2	4
		1,150	28,000	0	0	2
	North West	5,740	41,000	0	2	5
		5,680	79,000	1	2	5
		320	9,300	0	0	2
		1,230	31,000	0	2	4
Basaltic	North West	3,000	N.A.	0	1	2
		290	N.A.	0	1	2
	Northeastern	15,000	N.A.	2	3	6
		5,810	N.A.	0	1	3

* N10, N05, N01 = confidence levels; a measure of how reliable a statistical result l, expressed as a percentage that indicates the probability of the results being correct. A confidence level of 10% (N10) means that there is a probability of at least 10% that the result is reliable. That means that the the assessment team was 10% sure (consensus opinion) that there would be 2 undiscovered Basaltic Cu type deposits in the Northeastern part of Greenland.

The overall assessment indicates that the Reduced Facies and the Basaltic Copper types might be the most prospective types of targets in Greenland. The greatest potential for large-grade tonnage deposits of the Reduced-facies Copper Type is in the Neoproterozoic Eleonore Bay Supergroup in North-East Greenland and the Upper Triassic Pingel Dal Bed of the Fleming Fjord Formation in Central East Greenland. The Hagen Fjord Group in Northeastern Greenland has a large potential for hosting Basaltic Copper Type deposits. Only very limited exploration has been undertaken in these areas.

The possibility of finding large tonnage/high grade Revett and Redbed Copper deposits cannot be ruled out; the best potential for Revett Copper Type mineralizations is considered to be in Central East Greenland. Redbed Copper Type mineralizations are known from several different sedimentary basins in Greenland, and in particular areas in Central East and Northeastern Greenland are potential areas for this type of mineralization.

Introduction

Quantitative information about the general locations and amounts of undiscovered mineral resources is important to exploration managers, land-use and environmental planners, economists, and policymakers. On this background, in 2002, the United States Geological Survey (USGS) initiated the project 'Global Mineral Resource Assessment Project' (GMRAP; Briskey and Schulz, 2002; 2003). The objective of the project is to, globally, identify principal areas with a potential for undiscovered mineral resources, in the top one kilometre, based on available information and modern quantitative statistical models. The assessments are being conducted on a regional-multinational basis for selected deposit models and commodities, and on a global scale, coordinated by the USGS, by compiling information from the regional assessments. The Greenland Bureau of Minerals and Petroleum (BMP) and the Geological Survey of Denmark and Greenland (GEUS) are participants in the GMRAP-project, and, in this capacity, organized a workshop to assess the potential for non-discovered sedimentary copper deposits in Greenland. The workshop was held 27-29 March 2009 at GEUS, Copenhagen.

A standardized methodology has been defined for the GMRAP assessments based on a ‗Three-Part Form' assessment approach, which includes, (i) delineation of tracts of land where the geology is permissive for sedimentary copper deposits to form; (ii) selection of grade and tonnage models appropriate for estimating grades and tonnages of the undiscovered sedimentary copper deposits in each tract; and (iii) estimation of the number of undiscovered sedimentary copper deposits in each tract consistent with the grade and tonnage model. The assessment team for the workshop consisted of thirteen geologists from research institutions, BMP, GEUS, and private exploration companies, each of whom have knowledge on relevant aspects of Greenlandic geology and/or expertise in sedimentary copper deposits.

The initial tracts with potential of hosting non-discovered sedimentary copper deposits were defined and delineated by GEUS and BMP prior to the workshop. At the workshop, individual members of the assessment team provided estimates of how many deposits of a certain size and a certain grade could be possible in the individual 'tracts' in the uppermost kilometre of the crust, and under the best possible circumstances. Subsequently, the estimates from the team members were used as inputs to a Monte Carlo simulation computer program (EMINERS), combining the probability distributions of the estimated number of undiscovered deposits, the grades, and the tonnages of the selected models to obtain the probability distributions for undiscovered metals in each tract.

Acknowledgments

The authors would like to thank the numerous individuals from industry, academia, USGS, BMP and GEUS that have been involved in the assessment workshop of sedimentary-hosted copper in Greenland. Especially Cliff Taylor (from USGS) is thanked for his willigness to share his knowledge and ability to comprehend Greenlandic geology. Also a special thanks to all presenters at the workshop; without their valuable input the assessment workshop would be impossible. Karen Hanghøj and Leif Thorning are also acknowledged for their support to the project and their editorial suggestions and reviews of the report.

Deposit models covered

For each tract the assessment team has considered the following types of deposit models for which tonnage of ore and tons of copper has been estimated:

- ***Reduced-facies Copper***
    - USGS deposit model 30b.2;
    - Synonyms: Copper-shale, stratiform copper hosted by low-energy sediments, marine paralic, Kupferschiefer type, Central African type
- ***Redbed Copper***
    - USGS deposit model 30b.3;
    - Synonyms: Redbed hosted copper, sandstone-hosted copper, continental redbed
- ***Revett Copper***
    - USGS deposit model 30b.4;
    - Synonyms: None

The above deposit models are described in detail in USGS Open-File Report 03-107 by Cox et al. (2007).

For the type ***Basaltic Copper***, the models described in Cox and Singer (1986) and Kirkham (1984) were used. However, no grade and tonnage model is available for this model, and thus no quantitative estimation of tonnage of ore and tons copper within tracts have been undertaken.

Characteristics of sedimentary hosted copper deposits

Sedimentary hosted copper deposits account for approximately 23 percent of the world‘s copper production and known reserves. They also are important sources of Ag and Co, and some deposits produce other metals such as Pb, Zn, U, Au and PGE.

Sedimentary hosted copper deposits are stratabound epigenetic and digenetic deposits formed independently of igneous processes. They are formed after the host sediment is deposited, but in most cases, prior to citification of the hosts. Genetically, they form in permeable sedimentary and (more rarely) volcanic rocks, from mixing of two fluids, an oxidizing brine that carry copper and a reduced fluid, commonly formed in the presence of anaerobic sulphate-reducing bacteria. Mineralization in the sedimentary copper systems occurs from early digenesis to basin inversion and metamorphism. They occur most commonly in sedimentary basins that contain marine or large-scale lacustrine sediments containing evaporates that immediately overlie continental redbeds and in isolated non-red units within the redbed successions themselves. Generally, they occur within 30° of the palaeoequator in arid environments, and are formed in sedimentary successions associated with intracratonic, long-lived rift or passive margin settings.

Overall, to form a sediment-hosted copper deposit four conditions are required:

1. Oxidized source rocks where hematite is stable that contain ferromagnesian minerals or mafic rock fragments from which the copper can be leached.
2. A source of basinal brine that mobilizes the copper.
3. A source of a reduced fluid to precipitate the copper and (in many cases) supplies the sulphur.
4. A structural and stratigraphic setting favourable for fluid mixing between the Cu-bearing brine and the reduced fluid and subsequent sulphide deposition.

According to Cox et al. (2007) sedimentary-hosted copper can be divided into three descriptive mineral deposit models; Reduced-facies Copper, Redbed Copper and Revett Copper deposit model. The three models differ in the strength and efficiency of the reductant at the site of deposition. Furthermore, a genetically related fourth type, Basaltic Copper, is included in the assessment. A summary of the overall characteristics of each type of model is given in Table 1.

Occurrences of sedimentary-hosted copper are relative frequent within sedimentary successions that can be regarded as being fertile for this type of mineralization. However, the vast majority of sedimentary-hosted copper mineralising systems produce small, mostly sub-economic occurrences. Nevertheless, large tonnage-grade deposits are found in all of the copper mineral deposit types. Especially the Reduced-facies Copper type can form very large mineralising systems as illustrated by the Kupferschiefer copper deposits in the Permian Zechstein basin of Europe and the African Copper Belt deposits in the Neoproterozoic Katangan basin. Also the Basaltic Copper type can produce large deposits.

In general, some of the principal observations and important factors for the formation of sedimentary-hosted Copper are:

1. All ages from Lower Proterozoic are possible (Fig. 1). Reduced-facies Copper deposits are restricted to periods in which the atmosphere was oxygenated. Especially Meso- and Neoproterozoic basins are permissive. However, Permian rocks host major deposits in Germany, and Permian and Early Mesozoic deposits are present in Eastern Europe and USA.

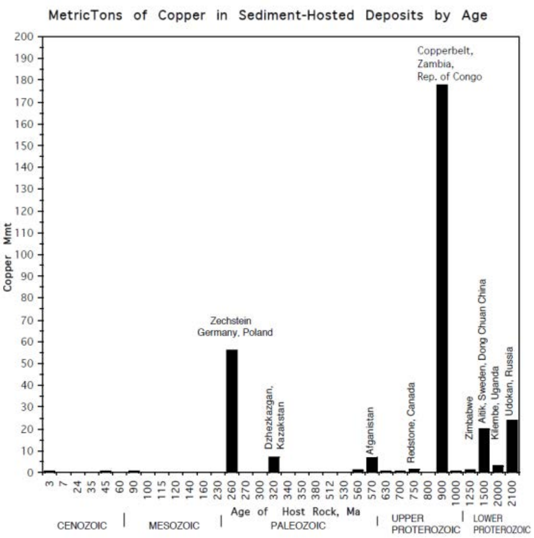

Figure 1. *Distribution of copper (million metric tons) in sedimentary-hosted copper deposits of different ages (from Cox et al. 2007).*

2. A common association of sedimentary-hosted copper deposits with a rift basin setting is observed, which translates to an extensional tectonic setting, particularly intracratonic/intracontinental rifts, failed arms of triple junctions, and passive continental margins.

3. Red beds and evaporates formed in highly permeable shallow-marine basins at low palaeolatitudes (20–30° off palaeoequator positions) with low evaporation rates are considered especially permissive for sedimentary-hosted copper mineralization.

4. The rift basin should be well-developed and contain thick oxidized strata (e.g. sequences of red beds or, alternatively, shale, conglomerate, and subaerial volcanic rocks). This sequence acts as the source of the copper. The oxidized strata should be overlain or intercalated with reducing units of at least mineable thickness and lateral continuous extend.

5. A source of brine that can mobilize copper must have been present. Evaporates, commonly interbedded with red beds, can act as brine source; however, any sedimentary environment in which evaporation exceeds rainfall will produce brines.

6. A source of a reduced fluid to precipitate the copper must has been present. Such a fluid can be derived from organic-rich shales (pyritic “black shale”/reducing siltstone) and carbonate rocks (e.g. Sabkha- and marginal-basin carbonate), from pockets of liquid or gaseous hydrocarbons. Reducing rock units with abundant original sulphides and organic constituents may provide the most favourable host.

7. A mineralization is typical located in the basal parts of the reducing units above or laterally adjacent to boundary between the reduced and oxidized environment – the redoxcline.

8. Faulting or folding may produce a hydraulic head that causes the two fluids to mix. Major graben and growth faults are commonly contemporaneous with mineralization.

Table 1. *General characteristics of sedimentary hosted copper deposits*

Mineral deposit type	Synonyms	General description	Mineralization	Depositional environment	Ore control	Host rock types	Ore tonnage and grade	Global examples
Reduced-facies Cu	Copper-shale, stratiform copper hosted by low-energy sediments, marine paralic, Kupferschiefer type, Central African type.	Stratabound, disseminated copper sulphide deposits in reduced-facies sedimentary rocks overlying or interbedded with redbed sequences or sub aerial basalt flows.	Copper mobilized by oxidized brines; the reducing sulphide-bearing fluids are derived from reduction of sulphate in marine or lacustrine, organic-rich, fine-grained sediments. Sabkhas, evaporates, or other sources of brines are important.	Formed in continental clastic sedimentary basins succeeded by epicontinental shallow-marine or lacustrine basin within 30° of palaeoequator.	Pyritic shales, algal mats or reef colonies are important as reducing environments. Late orogenic development of fracture-permeability and hydrologic head to drive the process of fluid mixing is important.	Shale, siltstone, mudstone, clay (reduced facies marine or lacustrine rocks) Organic carbon and disseminated pyrite common constituents.	Median ore tonnage of 33 million tons and a median copper grade of 2.3 %.	Kupfershiefer (Poland), Zambia deposits (African Copperbelt, Zambia).
Redbed Cu	Redbed hosted Cu, sandstone-hosted Cu, continental redbed.	Stratabound disseminated copper and copper sulphides occurring in reduced zones of redbed sequences.	Copper mobilized by oxidized brines; the reductant is formed by the present of plant debris. In some cases local evaporate beds are present.	Found within host rocks deposited by alluvial systems ranging from fans to meandering streams entering closed-basin playas or coastal environments, shallow seas and evaporate basins. Within 30° of the palaeoequator.	Permeable sandstone beds are a controlling factor. Pyrite can be a significant local reductant if present. Redox fronts (roll fronts) in ore-forming fluids and disequilibrium conditions are important chemical controls.	Redbed sequence containing white or grey bleached zones in sandstone and/or black, grey or green reduced beds of shale and siltstone.	Median ore tonnage of 2 million tons and a median copper grade of 1.6 %.	Corocoro (Bolivia), Nacimiento and Stauber (New Mexico, USA).
Revett Cu	None.	Stratabound disseminated copper and lead-zinc sulphides occurring on broad redox boundaries.	Copper mobilized by oxidized brines; the reductant is a broadly distributed and diffuse fluid, typically a hydrocarbon liquid or gas, or sulphide-rich sour gas.	Deposited as fan deltas entering closed-basin playas or coastal environments, shallow seas and evaporate basins. Within 30° of the palaeoequator.	Permeable beds are important. Redox front (roll front) control copper deposition. Nearby marine basins with deposits of hydrocarbon are sources for the formation of reducing fluids.	Sandstone, quartzite, arkose and conglomerate.	Median ore tonnage of 14 million tons and a median copper grade of 0.8 %.	Spar Lake and Montanore-Rock Creek (Montana, USA), Cashin Mine (Colorado, USA), Dzhekazgan (Kazakhstan).
Volcanic Redbed Cu	Basaltic Cu, Andean manto Cu.	Disseminated native copper and copper sulphides veins and infilling amygdules, fractures and flowtop breccias in the upper parts of thick sequences of subaerial basalt, and copper sulphides in overlying sedimentary beds.	Copper mobilized from volcanic rocks during diagenesis or early-stage metamorphism; precipitation in permeable locations under favourable chemical, pressure, and temperature conditions.	Copper-rich continental to shallow-marine basalt interlayered with redbeds in arid to semi-arid environments formed near palaeoequator.	Flow-top breccias, amygdules, fractures in basalt; organic shale, limestone in overlying sequence. Associated reduced, carbonaceous sedimentary rocks may play a role. Synsedimentary faulting may be important.	Shallow marine basalt flows, breccias and tuffs, red-bed sandstone, tuffaceous sandstone, conglomerate.	Not applicable (USGS grade tonnage-curves have not been established). Kirkham (1996): 28 deposits with an ore tonnage ranging from 0.85 to 220 million tons and a copper grade from 0.8% to 12.8% Cu.	Keweenaw and Calumet (Michigan, USA), Kennicott and Denali (Alska, USA), Boleo (Mexico), Buena Esperanza (Chile), Redstone and Sustut (Canada).

Geological provinces and permissive tracts

In order to undertake the quantitative mineral resource assessment, tracts of land permissive for the occurrence of undiscovered mineral deposits, have been delineated, in accordance with the following rules: (i) All tracts of land where the geology is permissive for the occurrence of the undiscovered mineral deposits are delineated such that the probability of a deposit being outside of a tract is negligible; and (ii) The tracts are subdivided where reasons exist to suspect spatial differences in the density or probability of occurrence of undiscovered deposits within the tracts.

The tract proposals, defined by Bo Møller Stensgaard (GEUS) and Henrik Stendal (BMP) prior to the workshop, served as the basis for the discussions. In the course of the workshop the tract proposals were modified according to the consensus view of the assessment team, and in some cases, additional tracts were added. All tracts were defined in a GIS environment and digitally accessible data relevant for the assessment was compiled and made available. A list of the permissive tracts is given in Table 2.

The tract proposals are based on the geological provinces:

- *Peary Land – Kronprins Christians Land region, North Greenland*
- *Neoproterozoic Elenore Bay Supergroup, Central East Greenland*
- *Upper Permian, Central East Greenland*
- *Triassic, Central East Greenland*
- *Meso-Neoproterozoic Thule Supergroup, North-West Greenland*

Statistical treatment of data

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper, Revett Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Revett Copper, model 30b.4‘ using the EMINERS program (Root et al. 1991; Duval 2004).

The statistical procedure applied: Nxx - Estimated number of deposits associated with the xxth percentile, N_{und} – expected number of undiscovered deposits, s – standard deviation, Cv% - coefficient of variance, N_{known} – number of known deposits in the tract that are included in the grade and tonnage model, N_{total} – total of expected number of deposits plus known deposits, area – area of permissive tract in square kilometres, density – deposit density reported as the total number of deposits per km^2. N_{und},S, and Cv% are calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied in addition to the consensus estimate, individual estimates are listed.

Data sharing in advance of the workshop

Papers describing the assessment process and the initial tract proposals were forwarded to the team members prior to the workshop, along with a selection of the relevant literature regarding regional and basin/sedimentary geology, mineralization and copper deposits in Greenland, as well as key literature on the deposit models covered at the workshop.

The assessment team

The following were part of the assessment team:

- Cliff Taylor (USGS, responsible for the USGS GMRAP on copper)
- Henrik Stendal (Workshop leader, BMP)
- Bo Møller Stensgaard (Workshop leader, GEUS)
- Martin Ghisler (GEUS)
- Per Kalvig (GEUS)
- Anders Lie (NunaMinerals A/S)
- Mogens Lind (Nalunaq Gold Mine A/S)
- Jesper K. Nielsen (SINTEF, Norway)
- Símun D. Olsen (GEUS, data/GIS responsible)
- Mikael Pedersen (GEUS)
- Nicholas Rose (Avannaa Resources Ltd.)
- Bjørn Thomassen (GEUS)
- Tapani Tukiainen (GEUS)

Presenters at the workshop

Presentations about the regional geology and sedimentary/basin geology in the selected provinces were given during the workshop by invited speakers, along with presentations about mineralization patterns and known occurrences, prospects or deposits. The lectures are listed in Table 3. All presentations are given on the CD-ROM accompanying the report (Appendix D).

List of permissive tracts and discovered deposits

Table 2. *List of all permissive tracts for non-discovered and discovered sedimentary copper deposits, discussed at the workshop*

Tract no.	Region	Locality	type	Comments*
CE 2 Huledal Fm	Central E Greenland	Wegner Halvø	Revett Copper	
CE 4-7 Huledal Fm		Jameson Land, West	Revett Copper	
CE 8-12 Huledal Fm		Trail Ø and Geographical Society Ø	Revett Copper	
CE 13-14 Huledal Fm		Gauss Halvø	Revett Copper	
CE15 Huledal Fm		Hold with Hope	Revett Copper	
CE 1 Ravnefjeld Fm		Jameson Land South to Hold with Hope	Reduced Facies Copper	Excluded
CE 2 Ravnefjeld Fm		Jameson Land South to Hold with Hope	Reduced Facies Copper	
CE 3 Ravnefjeld Fm		Jameson Land South to Hold with Hope	Reduced Facies Copper	Excluded
CE 4 – 15 Ravnefjeld Fm		Jameson Land South to Hold with Hope	Reduced Facies Copper	
CE 16 Ravnefjeld Fm		Jameson Land South to Hold with Hope	Reduced Facies Copper	Excluded
CE 17 Ravnefjeld Fm		Jameson Land South to Hold with Hope	Reduced Facies Copper	Excluded
CE 1A Malmros Klint and Ørsted Dal Mb		Jameson Land to Kong Oscars Fjord	Redbed Copper	
CE 1B Malmros Klint and Ørsted Dal Mb		Werner Bjerge	Redbed Copper	
CE2 -10 Malmros Klint / Ørsted Dal Mb.		Jameson Land	Redbed Copper	Excluded
CE 1A –Pingel Dal Bed		Jameson Land E	Reduced Facies Copper	
CE 1A –Pingel Dal Bed		Jameson Land E	Redbed Copper	
CE 1B –Pingel Dal Bed		Jameson Land E	Redbed Copper	
CE 1B –Pingel Dal Bed		Jameson Land E	Reduced Facies Copper	
CE 1-6 EBS	North-East Greenland	Kong Oscar Fjord to Ardencaple Fjord	Reduced Facies Copper	
CE 7-8 EBS		Kong Oscar Fjord to Ardencaple Fjord	Reduced Facies Copper	
CE 9-16 EBS		Strindberg Land and Andrée Land	Reduced Facies Copper	

(Table 2 continued)

Tract no.	Region	Locality	type	Comments*
NW 3-4 Narssârssuk Group	North-East Greenland	Blot Sund	Redbed Copper	
NW 5-10 Baffin Bay Group			Redbed Copper	
NW 3-4 Narssarssuk Group		Saunders Ø and Bylot Sund	Redbed Copper	
NW 11-13 Smith Sound Group		Kap Alexander and Rensselaer Bay	Redbed Copper	
NE 1-9 Hagen Fjord Group	Norhteastern Greenland	Independence Fjord and Hekla Sund	Basaltic Copper	No estimations made
NE 10-11 Independence Fjord Group		Independence Fjord and Hekla Sund	Basaltic Copper	No estimations made
NW 5, 8, 9, 10 Nares Strait	NW Greenland	Thule Basin	Basaltic Copper	No estimations made

* When the assessment team found, that a tract was not permissive for sedimentary hosted copper or the team evaluated the available information inadequate for the assessment, the tract was excluded from the assessment. No tonnage-grade curve exists for the Basaltic Copper type mineralization, and thus for tracts assessed for this sub-type estimation of undiscovered deposits could not be made. However, the tracts were still assessed for their potential.

Table 3. *Workshop presentations.*

Presenter	Title	**Presentation number** (on accompanying CD-ROM)
Cliff Taylor	Overview of Threee-Part quantitative Mineral Resource Assessment Method	1
Cliff Taylor	Progress towards a global estimate of undiscovered sediment-hosted copper resources: Progress in Europe and elsewhere as of March 2009	2
Cliff Taylor	A review of the USGS sediment-hosted copper deposit model	3
Henrik Stendal	Sedimentary copper models – prospective regions in Greenland	4
Bjørn Thomassen	Upper Permian–Triassic sediments, central East Greenland: Overview of copper localities and exploration history.	5
Jesper K. Nielsen & Mikael Pedersen	Permian and Triassic sedimentary environments of the East Greenland Basin.	6
Bjørn Thomassen	Overview of Cu localities and exploration history in the Thule Supergroup, North-West Greenland.	7
Peter Dawes	The Proterozoic thule basin: an intracratonic sedimentary-volcanic depocentre across Baffin Bay.	8
Tapani Tukiainen & Mogens Lind	North-East Greenland: Overview of copper localities and exploration history.	9
Henrik Stendal	Elenore Bay Supergroup and sedimentary copper.	10
Martin Sønderholm	Neoproterozoic sedimentary basins fof eastern Greenland.	12

Assessment of Sediment-hosted copper deposit for Permian central East Greenland - Revett Copper type

Scattered stratabound copper showings are known from the Upper Permian Huledal Formation in central East Greenland. Two of these (CE9 Bulbjerg Knude, CE14 Ladderbjerg Copper deposit) are large enough to have been associated with estimates (based on chip-sample profiles) of tonnage and grade and are included in the grade-tonnage curves defined by USGS for Revett Copper type (Cox et al. 2007). The assessment team agreed, based on the description of the showings and the geological setting, to classify them as Revett Copper type. Fig. 2 shows the distribution of tracts being treated by the assessment team for Permian hosted Revett Copper type during the workshop.

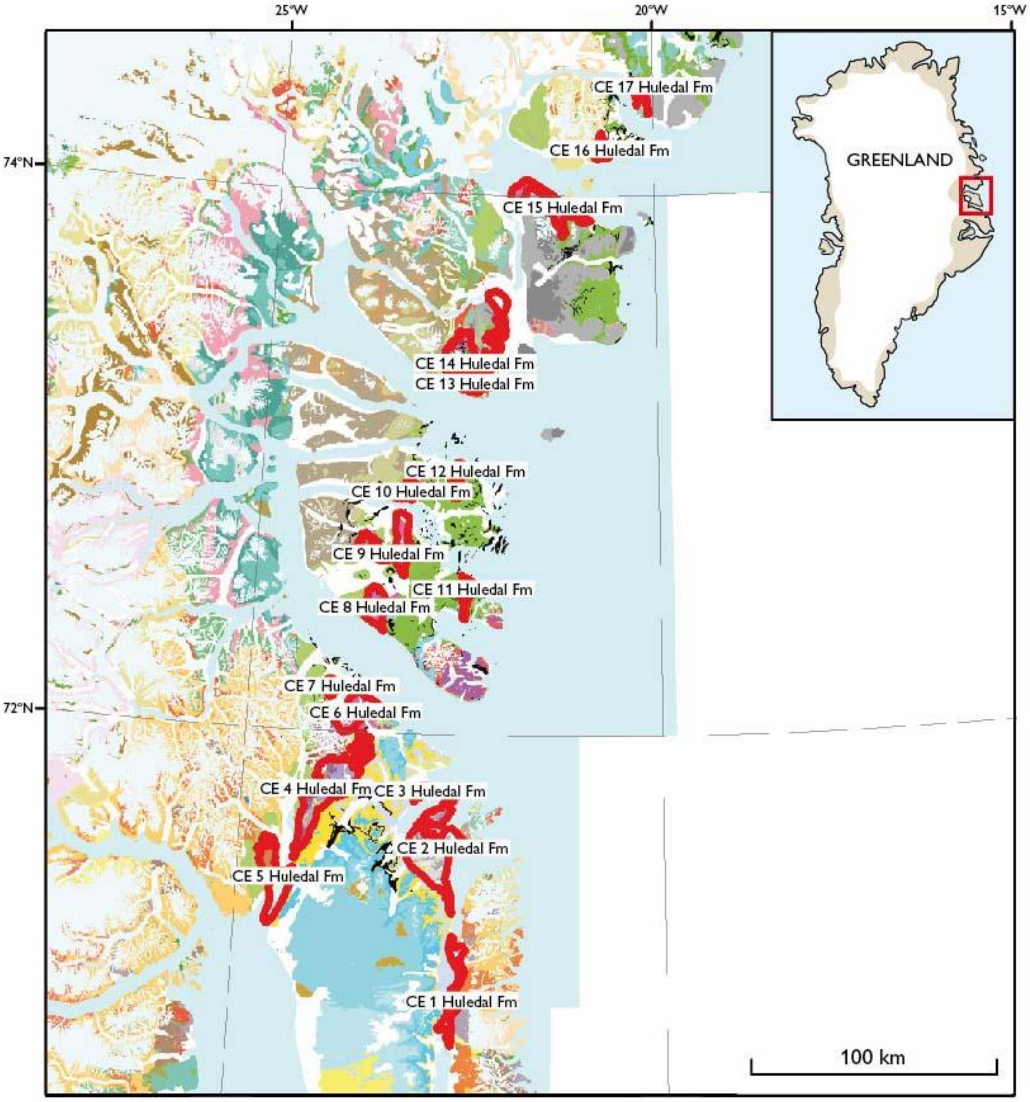

Figure 2. *Tracts for Upper Permian hosted Revett Copper type (Tracts CE1-17 Huledal Formation). Tracts CE 1, CE 3, CE16 and CE 17 Huledal Formation were excluded.*

Deposit type assessed

Deposit type: Sediment-hosted Copper.

Descriptive model: Sediment-hosted Copper, Revett Copper type (Cox et al. 2007).

Grade and tonnage model: Sediment-hosted Copper, Revett Copper type (Cox et al. 2003).

Sources of information

The principal sources of information used for the assessment of the tracts in the Permian of central East Greenland for the Revett Copper type are given in Appendix A.

Tracts excluded from estimations – Permian tracts CE 1, CE 3, CE16 and CE 17 Huledal Formation – Revett Copper type

The tracts CE 1, -3, -16 and -17 Huledal Formation, which are shown in Fig. 2, were excluded from the assessment. It was found, that there was insufficient information to carry out a proper assessment of tract CE 1, -3 and -17 Huledal and furthermore, tract CE 3 occupies a small area only. Based on description of the Upper Permian sedimentary succession in tract CE 16 and CE 17 Permian it was concluded that the Huledal Formation probably is not present.

Tract CE 2 Huledal Formation – Revett Copper type

Location

The tract CE 2 Huledal Formation is located at Wegener Halvø at the eastern margin of the Jameson Land sedimentary basin, central East Greenland at 71°30‘N and 22°30‘W (Fig. 3).

Table 4. *Summary of selected resource assessment results for the tract CE 2 Huledal Formation, Wegener Halvø*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	436	0	95,000

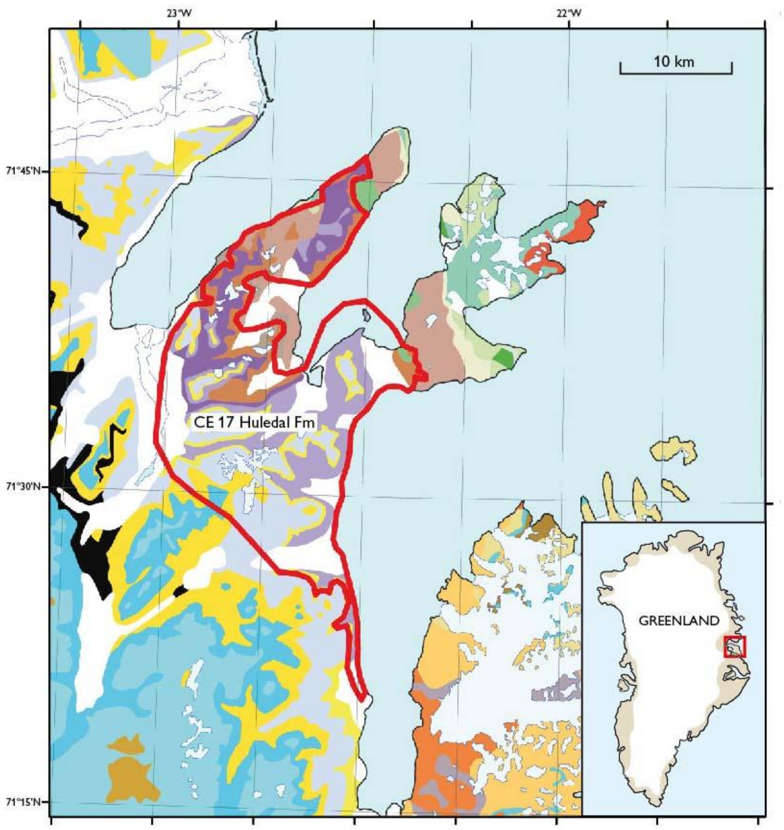

Figure 3. *Tract CE 2 Huledal Formation, Permian on Wegener Halvø, central East Greenland. The Permian Foldvik Creek Group, comprising the Huledal Formation is shown in brown. For geological legend see Appendix B.*

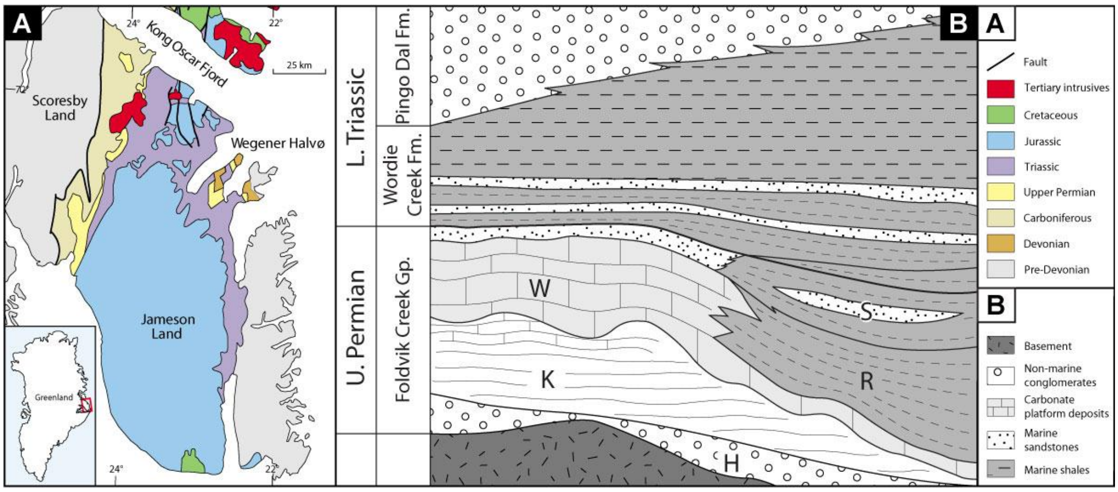

Figure 4. *A. Simplified geological map of central East Greenland. B. Simplified geological cross section from Upper Permian to Lower Triassic sedimentary succession in Jameson Land Basin. H = Huledal Formation, K = Karstryggen Formation, W = Wegner Halvø Formation, R = Ravnefjeld Formation, S = Schuchert Dal Formation. Figure from workshop presentation by J.K. Nielsen and M. Pedersen.*

Geological feature assessed

Tract CE 2 Huledal Formation consists of marine basal, fluviomarine, sandy conglomerates. The Huledal Formation belongs to the marine Upper Permian Foldvik Creek Group which was deposited, mostly unconformably, on a very flat Carboniferous – Lower Permian peneplain (Harpøth et al. 1986). The Huledal Formation is up to 120 metres thick with great thickness variation. At Wegener Halvø the Huledal Formation is relatively thin with normal thickness from 5–10 m. The Huledal Formation consists of poorly sorted, immature fluvial conglomerate bed, sandstone sheet deposits and some mudstones. The youngest sediments interfinger with deposit of the Karstryggen Formation reflecting invasion of the sea.

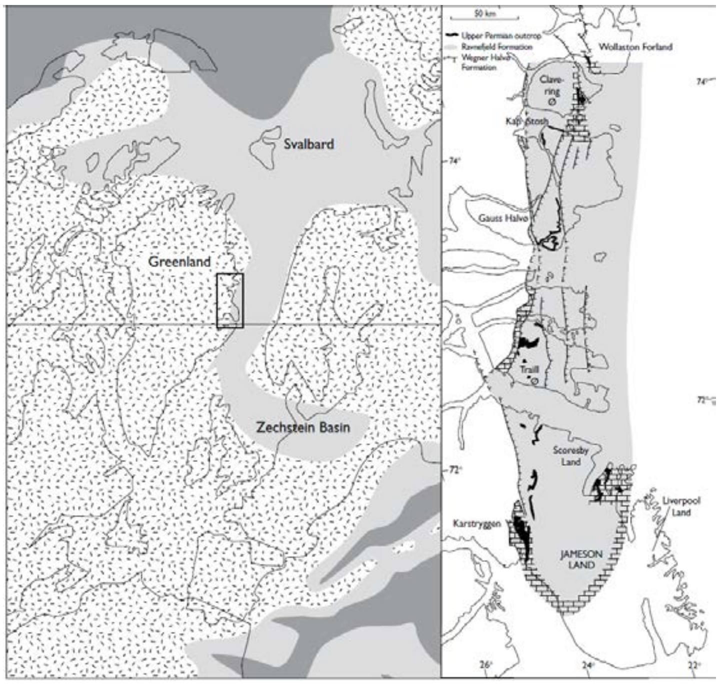

Figure 5. *Reconstruction of the Upper Permian North Atlantic showing the position of East Greenland. The East Greenland map shows the outline of the Upper Permian depositional basin with distribution of exposed Upper Permian stratum shown in black. Figure from Sørensen et al. 2008.*

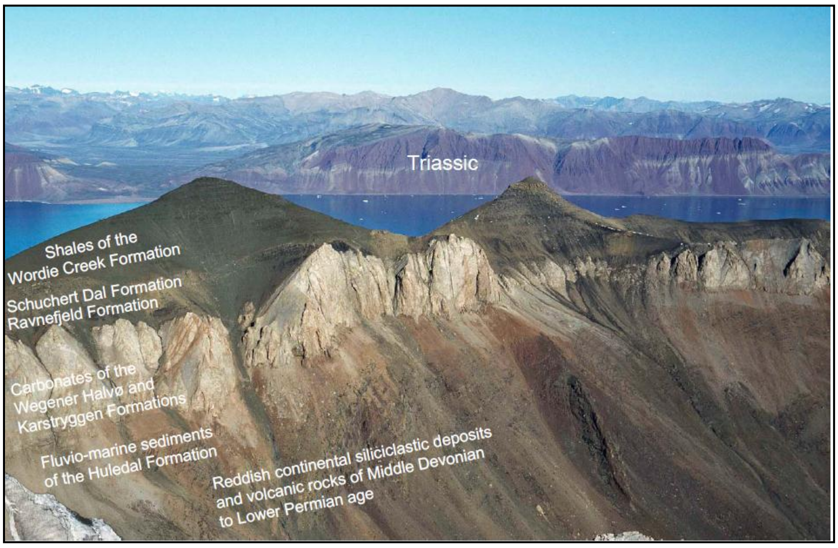

Figure 6. *Upper Permian sedimentary succession, looking E from Wegner Halvø. Figure from workshop presentation by Nielsen and Pedersen.*

Figure 7. *The Huledal Formation at Ladderbjerg, central East Greenland. Figure from workshop presentation by B. Thomassen.*

Figure 8. *Malachite stained conglomerate of the Huledal Formation at Ladderbjerg, central East Greenland. Figure from workshop presentation by B. Thomassen.*

Delineation of the permissive tract

The CE 2 Huledal Formation tract contains the distribution of the Huledal Formation down to an estimated depth of 1 km below the surface. The extent of the tract is based on geological maps of the Huledal Formation.

Geological criteria

The Upper Permian sequence of Wegener Halvø is approximately 300 m thick and rests with an angular unconformity on continental Middle Devonian to Lower Permian sediments. It is dominated by an up to 250 m thick carbonate sequence (Karstryggen and Wegener Halvø Formation with local black shale basins (Ravnefjeld Formation)). These sediments are under- and overlain by coarse clastic sediments (Huledal and Schuchert Dal Formations). The peninsula is dissected by numerous Upper Palaeozoic and post-Triassic, mainly N-S-trending, faults. Base metal mineralization is known in the shales of the Ravnefjeld formation and in the carbonates of the Wegener Halvø Formation. No copper observations have been made in the Huledal Formation at Wegener Halvø. However, the Huledal Formation at Wegener Halvø is mainly exposed in steep, inaccessible slopes. The black shales of the Ravnefjeld Formation are bituminous and micaceous. Stratiform fine-grained Zn- and Pb-sulfide occurs throughout the Ravnefjeld Formation.

Known deposits

No known deposits are known in this tract.

Prospects, mineral occurrences, and related deposit types

No known prospects or mineral occurrences are known in this tract. However, the Ladderbjerg and Rubjerg Knude Copper deposit, which is hosted by the Huledal Formation, is located in tracts north of the CE 2 Huledal Formation tract.

Exploration history

Nordisk Mineselskab A/S has carried out exploration for base metals from 1968–1982 in the region. The Wegener Halvø has been one of the focus areas by several campaigns.

Grade and tonnage model selection

Based on the characteristics of the settings of the Huledal Formation (the conglomerate sediments, the position of the formation in the Upper Permian succession and the characteristics of the copper occurrences/prospects found in other tracts containing the Huledal

Formation) the assessment team found it justified to use the Sediment-hosted Copper, Revett Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

Even though the assessment team acknowledge that no copper occurrences have been found in the Huledal Formation within the CE 2 Huledal Formation tract and even though the Wegener Halvø has been investigated in details, the team found that the tract carries a potential for undiscovered Revett Copper type deposits and it deemed it appropriate to carry out an estimation for this tract, on the following grounds: i) although no drilling has been carried out (a great part of the Huledal Formation has never been investigated), the general setting is good; (ii), the Huledal Formation constitutes a high pre-ore permeable bed in a sedimentary succession; (iii) bituminous-bearing parts of the Upper Permian succession are present, which may play a role in mineralization (this has not been investigated); (iv) redox fronts (roll fronts) reflecting fluids are seen; and (v) other parts of the Upper Permian succession (the Ravnefjeld and the Wegener Halvø Formations) carry several base metal occurrences.

Table 5. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for CE 2 Huledal Formation*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	0	1	2	0.11	0.44	420	0	0.11	436	0.000252

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	1	2
Individual 2	0	0	0	0	2
Individual 3	0	0	0	0	1
Individual 4	0	0	0	1	2
Individual 5	0	0	0	0	2
Individual 6	0	0	0	1	3
Individual 7	0	0	0	1	2
Individual 8	0	0	0	1	1
Individual 9	0	0	0	0	1
Individual 10	0	0	0	0	1
Consensus	0	0	0	1	2

Quantitative assessment simulation results

Selected simulation results are reported in Table 6. Results of the Monte Carlo simulation are presented as cumulative frequency plots in Fig. 9. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 6. *Results of Monte Carlo simulations of undiscovered resources in the tract CE 2 Huledal Formation. [t = metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of mean or greater	Probability of zero [none]
	0.95	0.90	0.50	0.10	0.05	Mean		
Cu (t)	0	0	0	0	140,000	95,000	0.05	0.93
Ag (t)	0	0	0	0	160	230	0.05	0.94
Rock (t)	0	0	0	0	17,000,00	9,900,00	0.06	0.93

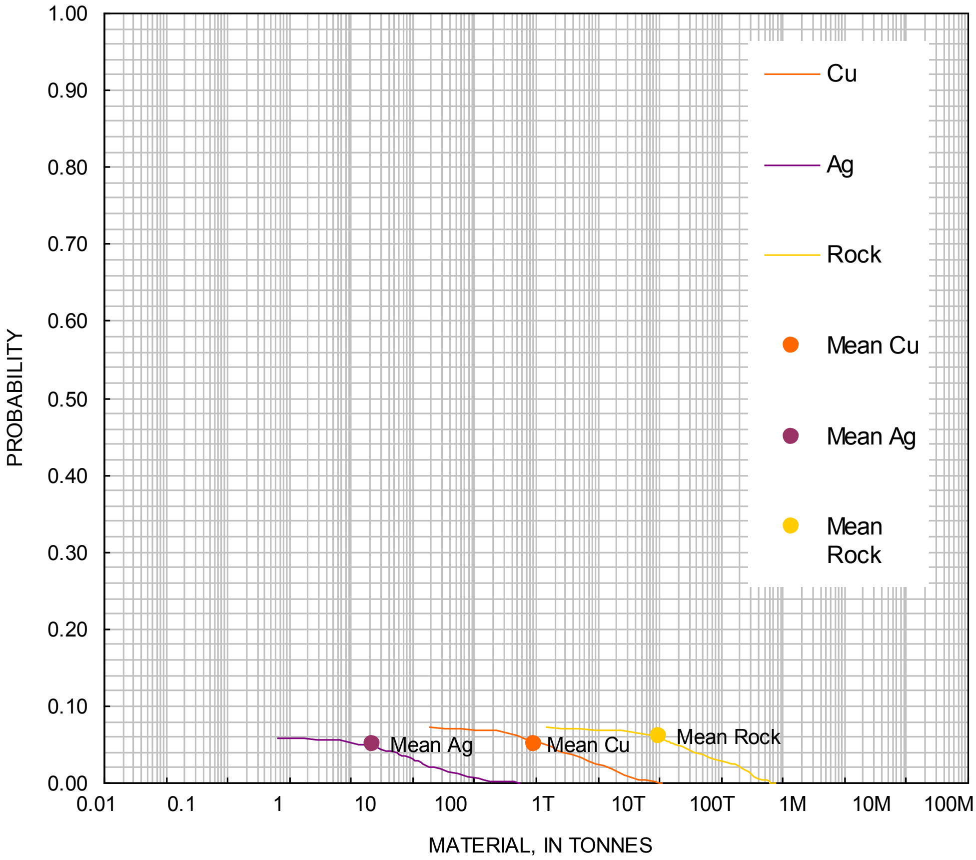

Figure 9. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the tract CE 2 Huledal Formation. T=thousands, M=millions.*

Tract CE 4–7 Huledal Formation – Revett Copper type

Location

The tracts CE 4–7 Huledal Formation were treated jointly by the assessment team.

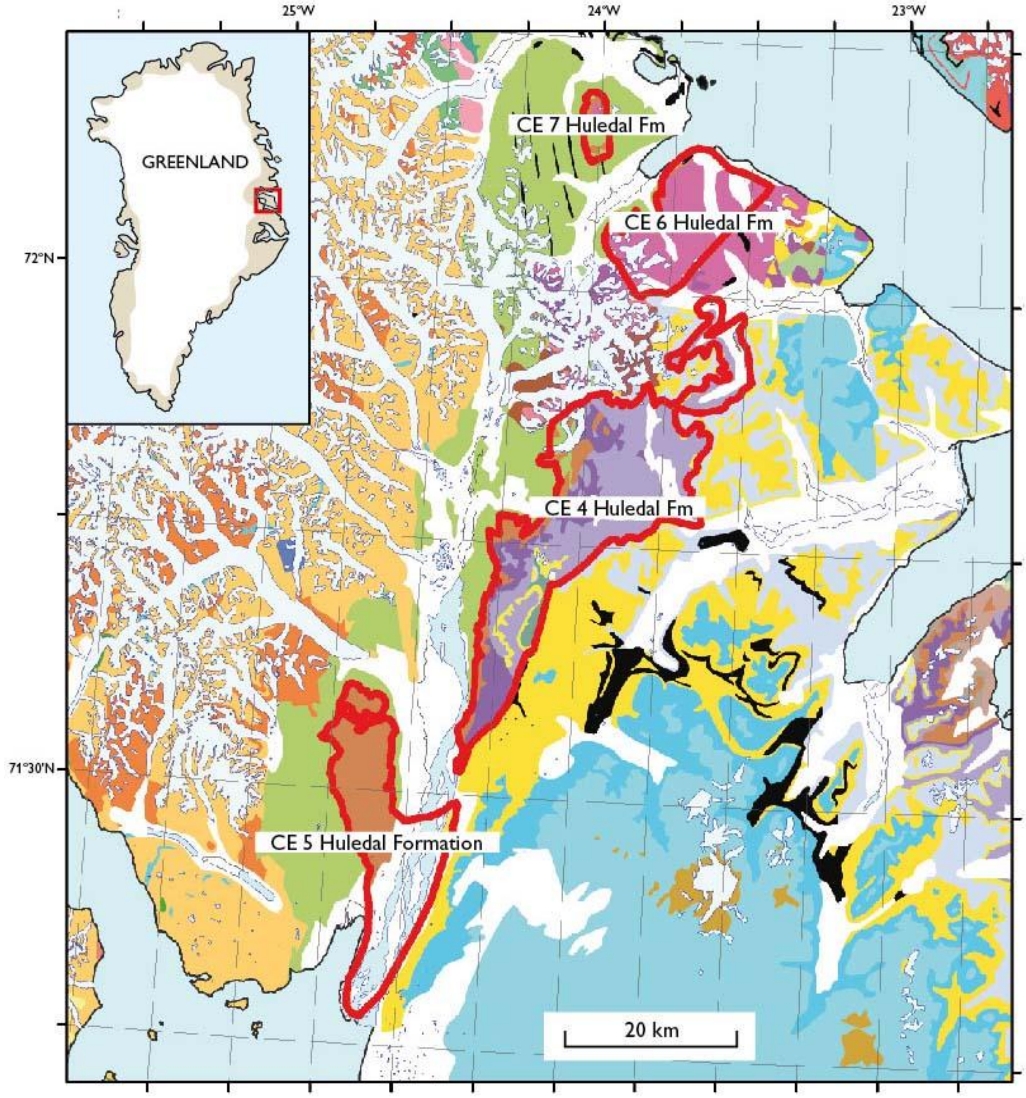

Figure 10. *Tracts CE 4-7 Huledal Formation in the western part of the Jameson Land sedimentary basin; the Huledal Formation is shown in brown. See Appendix B for a geological legend.*

Tract CE 4 Huledal Formation is located at Gurreholm Bjerge at the western margin of the northern part of the Jameson Land basin. Tract CE 5 Huledal Formation is located at Schuchert Dal–Karstryggen at the western margin of the southern part of the Jameson Land basin. Tract CE 6 Huledal Formation is situated around Oksedal southeast Mestersvig in the northern part of Jameson Land. Tract CE 7 Huledal is located northwest of Mestersvig at the mountain Domkirken (Fig. 10).

Table 7. *Summary of selected resource assessment results for the tract CE 4–7 Huledal Formation*

Date of assessment	Assessment depth (km)	Tract area (km2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	827	0	130,000

Geological feature assessed

Tract CE 4–7 Huledal Formation contains the Huledal Formation, which consists of marine basal, fluviomarine, sandy conglomerates. The Huledal Formation belongs to the marine Upper Permian Foldvik Creek Group deposited unconformably on a flat Carboniferous – Lower Permian peneplain (Harpøth et al. 1986). The Huledal Formation is up to 120 m thick with great thickness variation. The Huledal Formation within the CE 4–7 Huledal Formation tract has general normal thickness of 10–30 m. The Huledal Formation consists of poorly sorted, immature fluvial conglomerate bed, sandstone sheet deposits and some mudstones. The youngest sediments interfinger with the deposit of the Karstryggen Formation reflecting invasion of the sea.

Delineation of the permissive tract

The CE 4–7 Huledal Formation tract contains the distribution of this formation down to an estimated depth of 1 km below the surface. The extent of the tract is based on the mapped distribution of the Huledal Formation. The tracts CE 4 -, CE 5 -, CE 6 - and CE 7 Huledal Formation were treated jointly because they represent the same geological settings and same level of investigation and exploration, and similar observations with respect to geology and mineralization have been made in all four tracts.

Geological criteria

The Upper Permian sequence at the western margin of the Jameson Land basin comprises the basal fluvio-marine sandy conglomerate unit, the Huledal Formation, overlain by marginal marine carbonate and evaporates rocks of the Karstryggen Formation with the more open marine carbonate unit of the Wegener Halvø on top. The tract is bounded by basin-margin faults to the west. Hydrocarbon fluids in the Jameson Land basin have been found in the central part of the Jameson Land basin and could have migrated towards the margins of the basin.

Known deposits

The tract does not contain any known mineral deposits.

Prospects, mineral occurrences, and related deposit types

No known prospects or mineral occurrences are known in these tracts. However, numerous minor copper observations within the Huledal Formation have been made within all tracts of the joint CE 4–7 Huledal Formation. The Ladderbjerg and Rubjerg Knude Copper deposit, which is hosted by the Huledal Formation, is located north of the CE 4–7 Huledal Formation tracts.

Stratabound lead-zinc mineralization is present within the carbonates of the Wegener Halvø Formation and in the karst breccia of the Karstryggen Formation. Also a large (more than 80 km^2, 3–10 m thick) stratabound celestite ($SrSO_4$) occurrence is known from the Karstryggen Formation.

Exploration history

Nordisk Mineselskab A/S has carried out exploration for base metals in the period 1968–1982. The Karstryggen area, with focus on the Karstryggen and Wegener Halvø Formations were targeted in 1980–81. The Karstryggen Formation at Oksedal was the focus for exploration campaigns in 1971–72 1975 and 1979–82.

Grade and tonnage model selection

Based on the characteristics of the settings of the Huledal Formation (the conglomerate sediments, the position of the formation in the Upper Permian succession and the characteristics of the copper occurrences/prospects found in other tracts containing the Huledal Formation) the assessment team found it justified to use the Sediment-hosted Copper, Revett Copper type (Cox et al. 2003) as the appropriate grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

The assessment team appreciated that copper observations have been made only in the Huledal Formation within the CE 4–7 Huledal Formation tracts (though numerous observations), however, it was the view of the team the tract had a potential for undiscovered Revett Copper type deposits. No focused exploration for copper has been undertaken on that part of the Huledal Formation situated inside the tracts, where it is poorly exposed. The Huledal Formation at the western margin of the Jameson Land basin is greater than at the eastern margin of the basin (at the CE 2 Huledal Formation tract).

Although a large part of the Huledal Formation has never been investigated, and no exploration drilling has been undertaken, the general geological settings for the development of Revett Copper type mineralizations are thought to be good, since the Huledal Formation constitute a high pre-ore permeable bed in a sedimentary succession. Bituminous-bearing parts of the Upper Permian succession is present, which may have played a role in the mineralization; this has not been investigated. Redox fronts reflecting fluid movement have been observed. Other parts of the Upper Permian succession, such as the Ravnefjeld and the Wegener Halvø Formations carry several base metal occurrences.

It was noted that the areal extent of the joint CE 4–7 Huledal Formation tract is large given the areal footprint of a mean Revett Copper deposit (size of 14 Mt ore).

Table 8. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for CE 4–7 Huledal Formation*

Consensus undiscovered deposit estimates					Summary statistics					Tract Area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	0	1	3	0.14	0.56	420	0	0.14	827	0.000017

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	1	3
Individual 2	0	0	0	1	4
Individual 3	0	0	0	0	1
Individual 4	0	0	1	2	4
Individual 5	0	0	0	1	4
Individual 6	0	0	0	1	1
Individual 7	0	0	0	1	5
Individual 8	0	0	0	1	2
Individual 9	0	0	0	2	3
Individual 10	0	0	0	0	3
Consensus	0	0	0	1	3

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper, Revett Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Revett Copper, model 30b.4' using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 9, and the results of the Monte Carlo simulation as cumulative frequency plots are shown in Fig. 11. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 9. *Results of Monte Carlo simulations of undiscovered resources in the Permian tract CE 4–7 Huledal Formation [t = metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	250,000	130,000	0.06	0.93
Ag (t)	0	0	0	0	490	350	0.05	0.94
Rock (t)	0	0	0	0	29,000,000	13,000,000	0.06	0.93

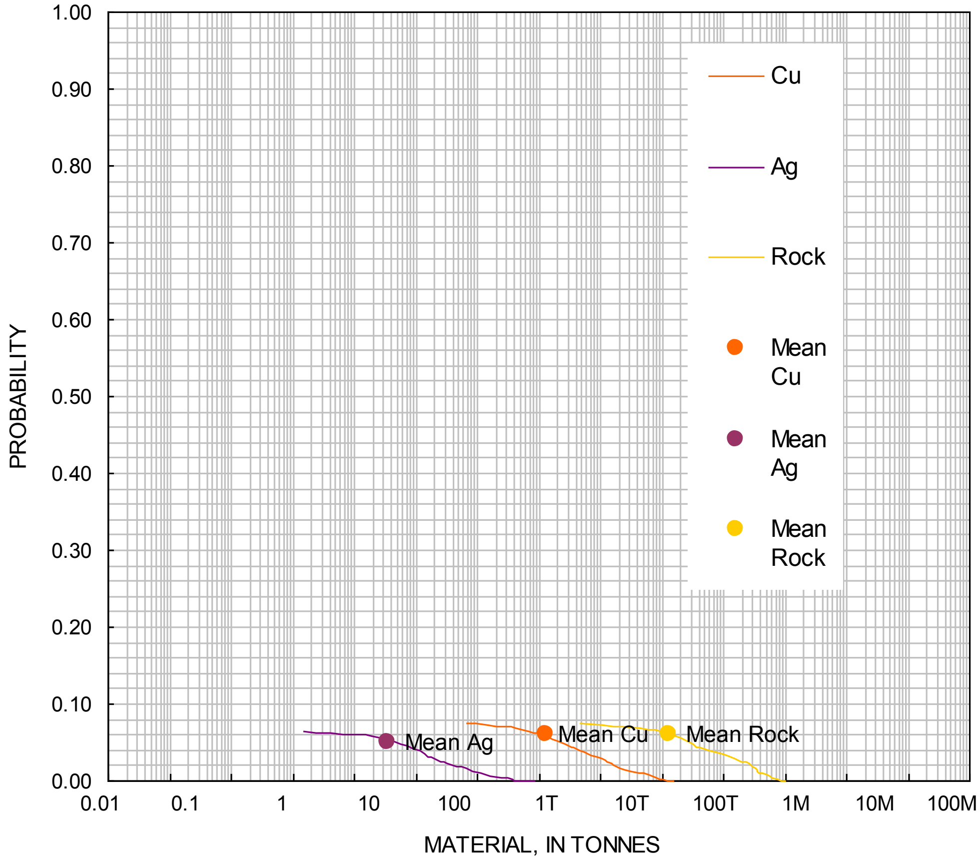

Figure 11. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the tract CE4–7 Huledal Formation. T=thousands, M=millions.*

Tract CE 8–12 Huledal Formation – Revett Copper type

Location

The Permian Tract CE 8–12 Huledal Formation is located on Trail Ø and Geographical Society Ø.

The initially proposed Permian tracts CE 8 Huledal Formation, CE 9 Huledal Formation, CE 10 Huledal Formation, CE 11 Huledal Formation, and CE 12 Huledal Formation were treated jointly by the assessment team under the tract named CE 8–12 Huledal Formation (Fig. 12).

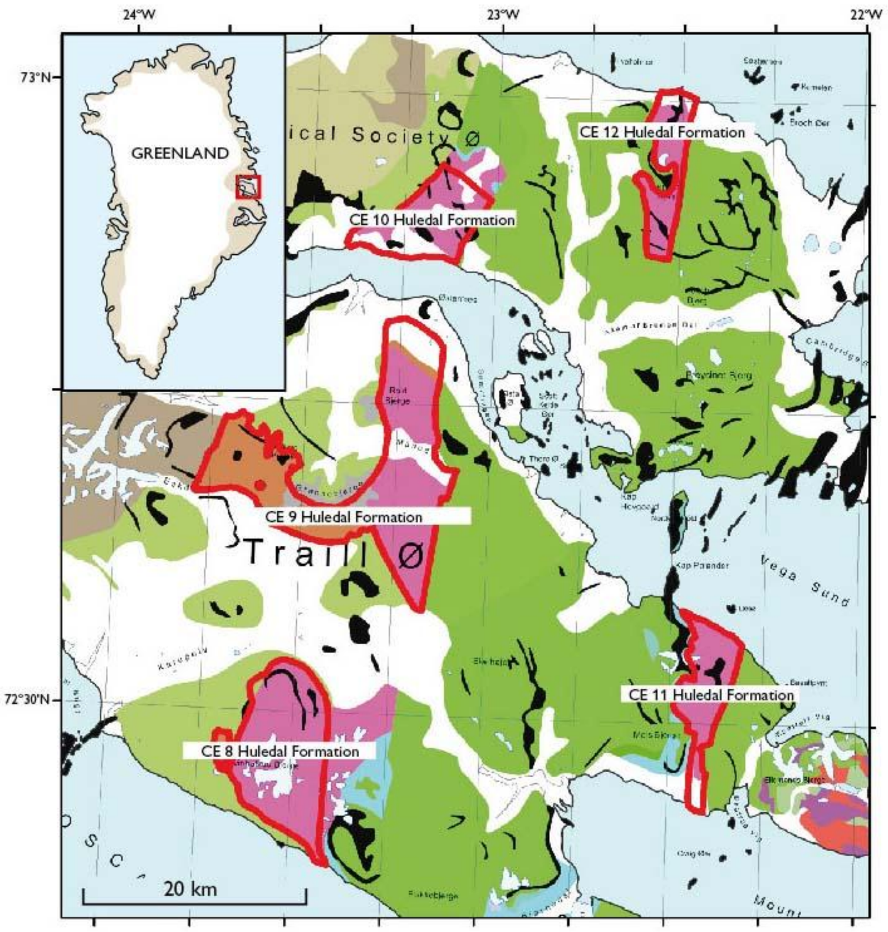

Figure 12. *The Permian Tract CE 8-12 Huledal Formation on Trail Ø and Geographical Society Ø. Rubjerg Knude Copper deposit is indicated by a red dot. The Huledal Formation is shown in brown and the Triassic units are in pink. See Appendix B for a geological legend.*

Table 10. *Summary of selected resource assessment results for the Permian tract CE 8–12 Huledal Formation*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	452	15,000	190,000

Geological feature assessed

The Permian Tract CE 8–12 Huledal Formation contains the Huledal Formation, which consists of marine basal, fluviomarine, sandy conglomerates. The Huledal Formation belongs to the marine Upper Permian Foldvik Creek Group which was deposited unconformably on a flat Carboniferous – Lower Permian peneplain (Figs 4 and 5) (Harpøth et al. 1986). The Huledal Formation is up to 120 m thick with great thickness variation.

The Huledal Formation reaches its greatest thickness on central Trail Ø (between 80–110 m) within the CE 8–9 Huledal Formation tracts. In the tracts CE 11–12 on Geographical Society Ø, only Triassic rocks are exposed, however, the Permian Huledal Formation is considered to be present in the stratigraphic column in the uppermost kilometre. The Huledal Formation on Trail Ø consists of a 30–60 m thick conglomerate unit with a high proportion of quart and quartzitic pebbles and cobbles, and abundant limestone/dolomite and granite pebbles. Locally, thin sandstone layers are interfingering with the conglomeratic beds. All the sediments are of braided alluvial plain origin with NNE transport direction (Harpøth et al. 1986). In the Huledal Formation, bitumen has been reported from thin sections between sand grains and grains are often surrounded by fine grained organic material.

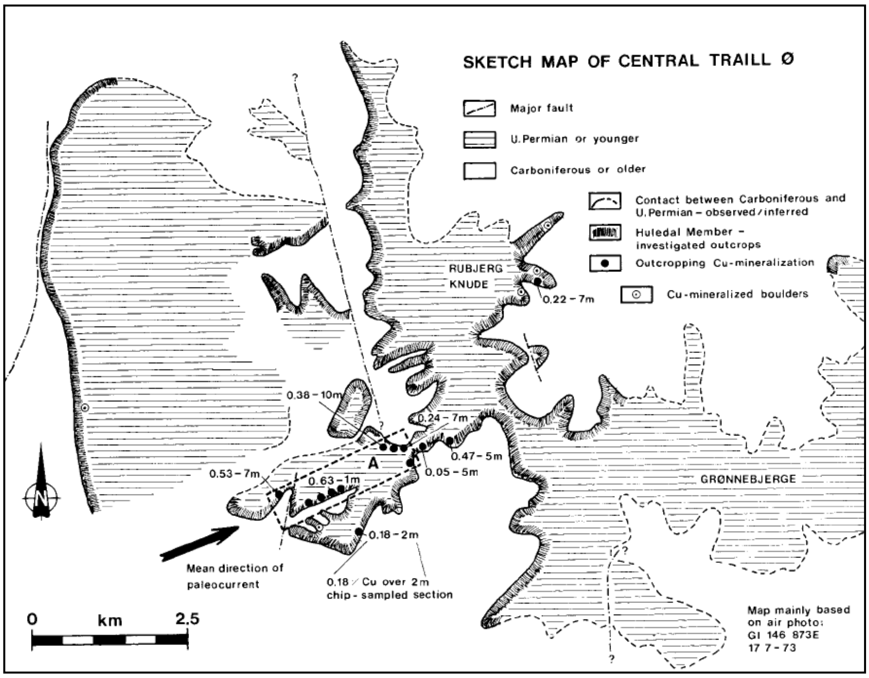

Figure 13. *Sketch map of central Trail Ø with copper occurrences in the Upper Permian Huledal Formation (Harpøth et al. 1986).*

Delineation of the permissive tract

The Permian CE 8–12 Huledal Formation tract contains the Huledal formation at depths down to 1 km below the surface. The extent of the tract is based on the mapped out distribution of Foldvik Creek Group, comprising the Huledal Formation, and the overlying Triassic units. The tracts CE 8, CE 9, CE 10, CE 11 and CE 12 Huledal Formation were treated jointly because they represent the same geological settings and characteristics. However, it was discussed to split the tracts into two groups, treating the tracts on Trail Ø and on Geographical Society Ø separately. However, the assessment team decided on merging the five tracts following the assumption that the characteristics of the Huledal Formation on Trail Ø can be extrapolated to Geographical Society Ø, even if it is not exposed here.

Geological criteria

As no exposures of the Huledal Formation are known from Geographical Society Ø the following description is based on the geological settings at Trails Ø. Harpøth (1982) provides the following detailed description of the geological setting: „Central Trail Ø is dominated by major NNE-SSW to N-S trending block faulting (Fig. 11) resulting in exposure of progressively younger rocks going from west towards east. Around Rubjerg Knude (tract CE 9), Carboniferous deltaic-sedimentary rocks, mainly arkoses and conglomerates are unconformably overlain by Upper Permian to Lower Triassic deposits. The Upper Permian sequence, which is the main target for sedimentary copper (Revett Copper type) mineralization, is divided into four sedimentary units by Harpøth (1982) (Fig. 12). The Conglomerate Unit (the Huledal Formation) is about 30–60 m thick and overlies unconformably the Upper Carboniferous sediments (Fig. 13). The Conglomerate Unit is overlain by a Sandstone Unit. This unit is approximately 50 m thick and comprises yellowish-weathering medium to fine-grained sandstones. Individual beds range in thickness from a few cm up to about one metre and are often crossbedded. The Sandstone Unit is overlain by the Sabkha and Complex Units. The Sandstone Unit gradually grades into the Sabkha Unit. The Sabkha Unit mainly comprises fine-grained gypsiferous sandstone, occasionally with nodular bedding, and various gypsum beds (Fig. 14). The approximate thickness of the unit is 10 m. The upper Complex Unit constitutes the erosional plateau of most of the area, and thus the thickness of the sequence is somewhat uncertain, but it is estimated to be in the range of 10–20 m. The unit comprises alternating fine-grained sandstones, siltstones, shales, marls and various carbonate rocks such as skeletal limestone, interformational limestone breccias etc. In summary, the Upper Permian of central Trail Ø comprises a 100–125 m transgressive fining-upward sequence.

Known deposits

Tract CE 9 Huledal Formation on central Trail Ø hosts the Rubjerg Knude Copper deposit (Figs 15-19) where scattered low-grade copper-silver and lead mineralization occurs in the conglomerates of the Huledal Formation in a 6 by 2 km ENE-WSW-striking belt. The deposit was investigated and reported in Harpøth (1982) and a summary of its characteristics is given by Harpøth et al. 1986. The mineralization at Rubjerg Knude is confined to yellowish weathering conglomerate beds (representing reducing conditions), which dominate in the mineralised belt. Outside this belt brownish red colours (representing oxidizing conditions) dominate the conglomerate unit. In general mineralization is associated with palaeochannels in the central part of the unit. At some localities, a vertical thickness of up to 20 m is mineralised, but on the average the outcropping thickness is 5–10 m. Continuous mineralization has been observed laterally for 200–300 m. The ore minerals are chalcocite with minor bornite, chalcopyrite and galena disseminated within the cement and in the coarser beds typically as encrustations on the pebbles and cobbles. In more fine-grained sandstone beds the sulfide occurs as disseminated and as blebs. Secondary malachite and azurite occurs only in minor amounts. Vertical zonation is observed as copper-mineral zoning. In the easternmost mineralised outcrops of the belt chalcopyrite is the dominant ore mineral, whereas chalcocite/bornite) is only primary mineral elsewhere. Microscopically, the primary ore minerals chalcocite, bornite, chalcopyrite, galena and pyrite occur as cementing phases together with quartz and rutile/anatase. The cementing sulfide aggregates are often surrounded by fine-grained organic matter. Authigenic quartz overgrowths on clastic grains often contain minor sulfide-phase inclusions. Secondary ore minerals comprise blaubleibender covellite, covellite, chalcopyrite, native copper, malachite, azurite and cerussite (Harpøth et al. 1986).

Based on 13 chip-sampled sections from a 1,300 by 2,500 m area with the highest mineralization intensity a tonnage-grade of approximately 5 Mt with 0.3% Cu and minor Ag (approximately 5 ppm), Pb and Zn is estimated (Harpøth 1982: 50 000 m^2 mineralised area (200 by 2,500 m), a 5 m mineralised section, with 75% of the volume being mineralised).

Harpøth et al. (1986) suggest on the basis of microscopic observations of authigenic quartz overgrowths with sulfide inclusions, an early diagenetic precipitation of copper and lead sulphides from silica-saturated mineralising ground water, and explain the sulfide precipitation by reducing conditions provided by the observed organic matter. However, based on the description of the deposit and especially the observed bitumen content between mineral grains the assessment team classified the deposit as a Revett Copper type.

Prospects, mineral occurrences, and related deposit types

Beside the Rubjerg Knude Copper deposit several other outcropping copper mineralization and copper-mineralised boulders have been located within the CE 9 Huledal Formation Tract.

Within the northern part of a major NNE-SSW fault zone extensive low-grade hydrothermal baryte mineralization (as barite veins ranging from mm to dm in thickness) have been observed over 3–4 km along strike in a 50–100 m wide zone cutting Upper Carboniferous sediments

Exploration history

Nordisk Mineselskab A/S has carried out exploration for base metals from 1968–1982 in the region, and the Trail Ø area was sporadically investigated by Nordisk Mineselskab A/S in the mid-1970‘s. Detailed investigations on the Rubjerg Knude copper deposit and in the adjacent area were made in the early 1980‘s (Harpøth 1982). This study concluded that the Rubjerg Knude copper deposit was uneconomic due to the lack of any high-grade (4–5% Cu) mineralization, and recommended that more prospecting were carried out along the strike of the mineralised belt towards the ENE and towards the WSW Harpøth (1982). Furthermore, it was recommended, that an area of Svinhufvuds Bjerge (tract CE 8 Huledal Formation) be investigated because of intensive faulting, which could have enriched any pre-existing strata-bound copper-silver mineralization in the Huledal Formation.

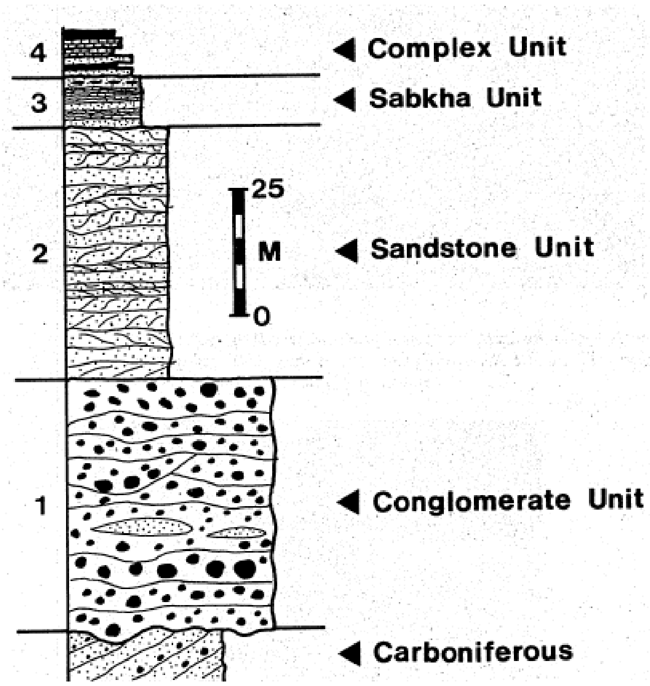

Figure 10. *Generalised Upper Permian sequence of the Rubjerg Knude area, central Trail Ø – tract CE 9 Huledal Formation. From Harpøth (1982).*

Figure 11. *The Huledal Formation, west of Rubjerg Knude, unconformably overlying the Upper Carboniferous sediments. A small erosional channel is seen just right of the hammer. From Harpøth (1982).*

Figure 12. *Sandstone unit (yellowish weathering) overlain by Sabkha Unit (white gypsum nodules) and Complex Unit (top of cliff). South of Rubjerg Knude. From Harpøth (1982).*

Figure 13. *Laminated gypsiferous rocks, south of Rubjerg Knude. From Harpøth (1982).*

Figure 15. *Typical chalcocite-mineralised conglomerate. South of Rubjerg Knude. Photo from Harpøth (1982).*

Figure 16. *Galena-mineralised conglomerate; black galena encrustation just above point of knife. South of Rubjerg Knude. Photo from Harpøth (1982).*

Figure 17. *Chalcocite-mineralised sandstone lens. South of Rubjerg Knude. Photo from Harpøth (1982).*

Figure18. *Black-greenish chalcocite blebs in sandstone, south of Rubjerg Knude. Photo from Harpøth (1982).*

Grade and tonnage model selection

Based on the characteristics of the settings of the Huledal Formation (the conglomerate sediments, the position of the Formation in the Upper Permian succession and the characteristics of the copper occurrences/prospects found in other tracts containing the Huledal Formation) the assessment team found it justified to use the Sediment-hosted Copper, Revett Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Figure 19. *The Upper Permian Huledal Formation at Rubjerg Knude, central Trail Ø – tract CE 9 Permian. Photo: B. Thomassen.*

Estimate of the number of undiscovered deposits

Rationale for the estimate

The Rubjerg Knude copper deposit on Trail Ø is most likely a Revett Copper type deposit. Additionally, the general geological settings and characteristics of the Huledal Formation are permissive for Revett Copper type. Although tract CE 9 has been investigated in some detail, the joint CE 8–12 Huledal Formation tract still has limited systematic work. The tracts on eastern Trail Ø (CE 11 Huledal Formation) and on Geographical Society Ø (CE 10 and CE 12 Huledal Formation) contain non-exposed Permian Huledal Formation in the uppermost kilometre of the stratigrafic column. These tracts, and perhaps especially tract CE 10, may also contain similar (or greater) thickness of the Huledal Formation as reported from central Trail Ø (tract CE 9 Huledal Formation). No drilling has been carried out in any of the sub-tracts. Bituminous-bearing parts of the Upper Permian succession have been observed as have pronounced redox fronts reflecting fluids.

The areal extent of the joint CE 8–12 Huledal Formation tract is quite large considering the footprint of an average sized Revett Copper deposit (size of 14 Mt ore).

Table 11. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for Permian CE 8–12 Huledal Formation tract*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	**N50**	**N10**	**N05**	**N01**	N_{und}	**s**	**Cv%**	N_{known}	N_{total}		
0	0	0	2	4	0.21	0.76	360	1	1.21	452	0.00265

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	1	4
Individual 2	0	0	0	1	3
Individual 3	0	0	0	1	2
Individual 4	0	0	0	1	3
Individual 5	0	0	0	2	4
Individual 6	0	0	1	2	3
Individual 7	0	0	0	2	5
Individual 8	0	0	1	2	3
Individual 9	0	0	1	2	4
Individual 10	0	0	0	2	3
Consensus	0	0	0	2	4

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper, Revett Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Revett Copper, model 30b.4' using he EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 12, and as cumulative frequency plots in Fig. 20. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 12. *Results of Monte Carlo simulations of undiscovered resources in the Permian tract CE 8–12 Huledal Formation. [t = metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	**0.9**	**0.5**	**0.1**	**0.05**	**Mean**	**Mean or greater**	**None**
Cu (t)	0	0	0	0	660,000	190,000	0.07	0.92
Ag (t)	0	0	0	0	1,100	440	0.06	0.92
Rock (t)	0	0	0	0	75,000,000	20,000,000	0.07	0.92

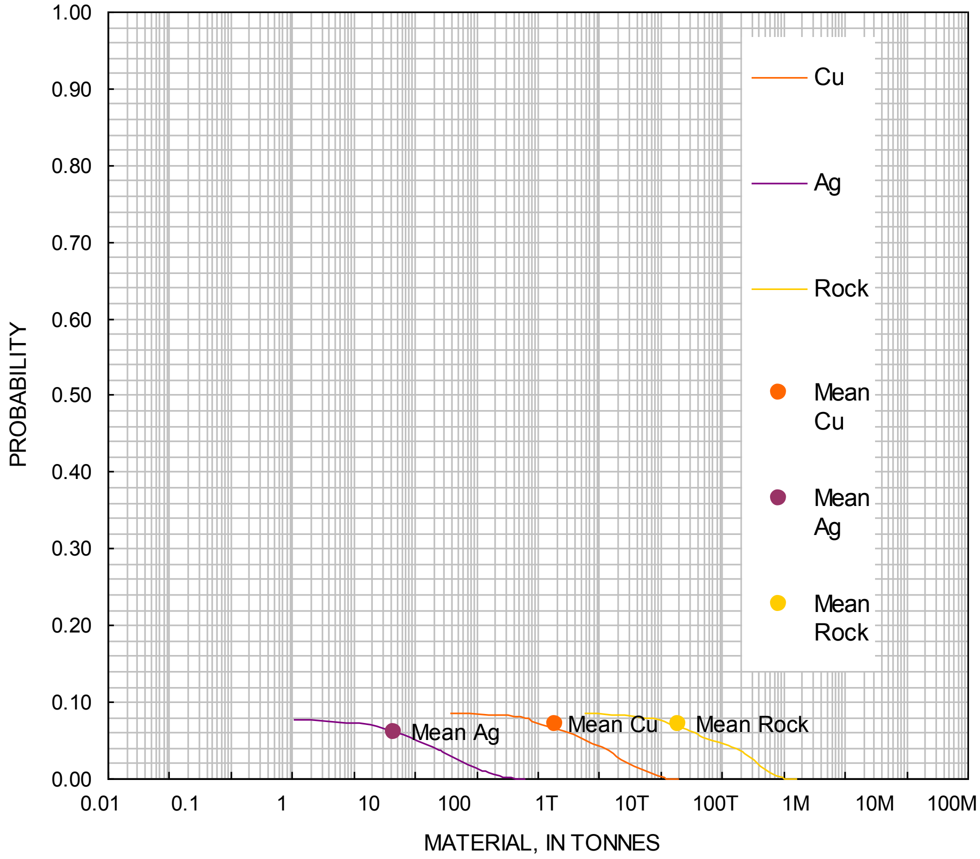

Figure 20. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the Permian tract CE 8–12 Huledal Formation. T=thousands, M=millions.*

Tract CE 13–14 Permian Huledal Formation – Revett Copper type

Location

The initial Permian tracts CE 13 Huledal Formation and CE 14 Huledal Formation are treated jointly by the assessment team under the tract named CE 13–14 Huledal Formation.

Tract CE 13–14 Huledal Formation is located at the eastern extension of Gauss Halvø north of Kejser Franz Joseph Fjord in central East Greenland (Fig. 21).

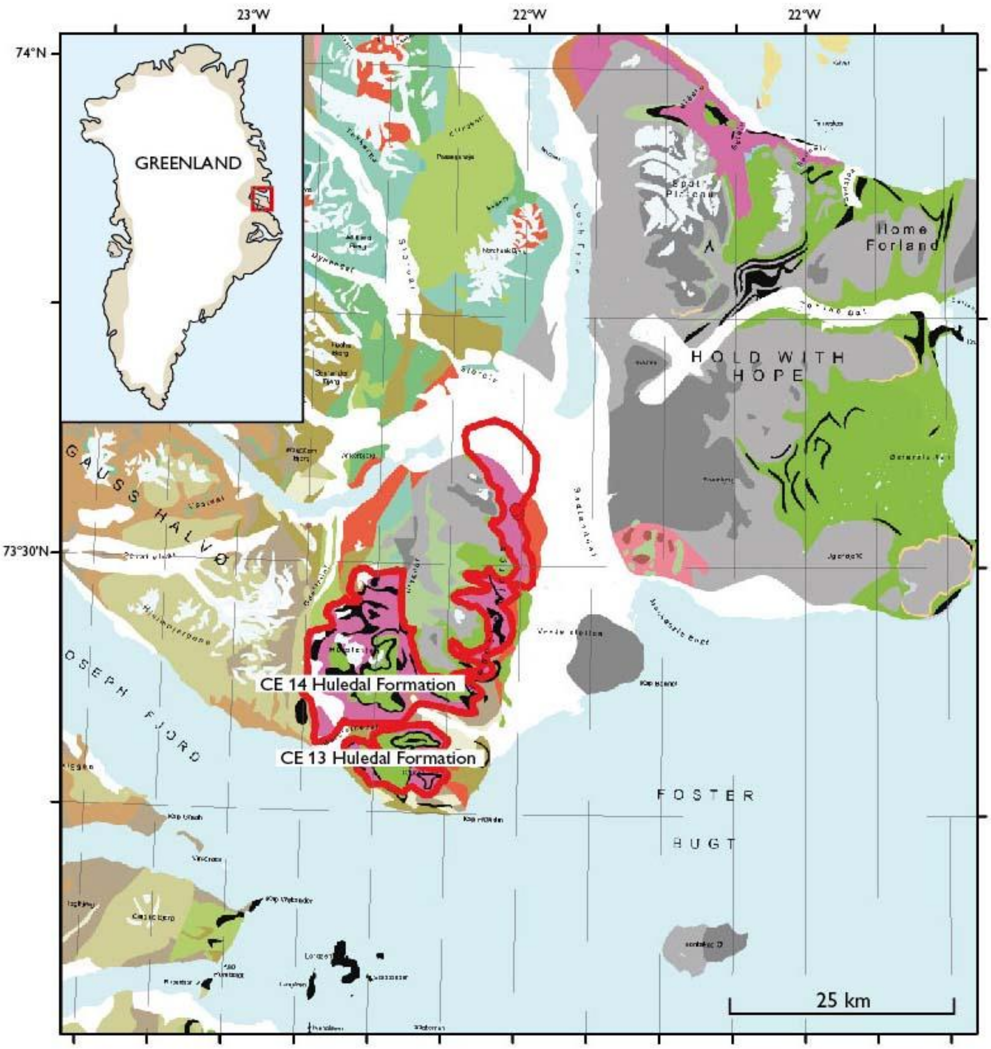

Figure 21. *Outline of the Permian tracts CE 13 and CE 14 Huledal Formation at Gauss Halvø. Location of the Ladderbjerg Copper deposit is indicated by red dot. The Huledal Formation is shown in brown; Triassic units are shown in pink. See* Appendix B *for the geological legend.*

Table 13. *Summary of selected resource assessment results for the tract Permian CE 13–14 Huledal Formation*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	345	37,500	130,000

Geological feature assessed

The Permian Tract CE 13–14 Huledal Formation contains the Huledal Formation, which consists of marine basal, fluviomarine, sandy conglomerates. The Huledal Formation belonging to the marine Upper Permian Foldvik Creek Group, was deposited unconformably on a flat Carboniferous – Lower Permian peneplain (Harpøth et al. 1986) (Figs 4 and 5). The Huledal Formation is up to 120 m thick with great thickness variation. The Foldvik Creek Group is exposed in both subtracts CE 13 and CE 14 Huledal Formation, although large parts are covered by younger sediments.

Delineation of the permissive tract

The Permian CE 13–14 Huledal Formation tract contains the Huledal formation in the uppermost kilometre. The extent of the tract is based on the mapped distribution of the Foldvik Creek Group, comprising the Huledal Formation and overlying Triassic units. No information on exploration in CE 13 is available, whereas exploration programs have been carried out in CE 14, and it was agreed by the assessment team to assess CE 13 and CE 14 jointly, given the close proximity and the likelihood that the two tracts represent similar geological settings.

Geological criteria

The fluviatile-deltaic conglomerate of the Huledal Formation is described from the central-northern part of Giesecke Bjerge as being rather thin (<50 m, with an average around 10 m) and the braided alluvial plain conglomerates consists of well-rounded, grey quartzite pebbles/boulders (< 20 cm) with a sandy matrix and carbonate cement. The conglomerate is overlain by various black shales, gypsum and grey limestone followed by Triassic and Cretaceous clastic sediments and/or Tertiary basalts. The conglomerates unconformably overlie Caledonian/Devonian granites, Devonian acidic volcanics or Devonian-Carboniferous clastic sediments. The Giesecke Bjerge is bounded by N–S trending faults to the east and west. Along the so-called ‗post-Devonian Main Fault' to the west, the Gastisdal forms a narrow graben structure (Thomassen & Nilsson 1982).

Known deposits

No copper deposits are known from subtract CE 13 Huledal Formation, but in the subtract CE 14 Huledal Formation, the Ladderbjerg Copper deposit is found in the Huledal Formation in the central part of Giesecke Bjerge (1,000 by 400 m in an area SE of Ladderbjerg) (Fig. 21). A pronounced lateral metal zonation is observed with enrichment in copper in the south eastern part and lead in the north-western part. The transition zone is characterised by having copper in the lower part and lead in the upper part of the formation. The copper mineralization is observed as irregular malachite and subordinate azurite stained on larger clasts and forms the cement together with goethite and chalcopyrite. The lead mineralization is barely noticeable with scattered mm-sized galena spots. Preliminary tonnage-grade estimates are based on eight chip-sample sections throughout the area. Assuming a thickness of 10 m, the copper mineralization, is estimated to contain a minimum of 2.5 Mt with a grade of 0.15 % Cu and minor Ag (8 ppm), Pb and Zn; and assuming an average 8 m thickness of lead mineralization, it is estimated to contain at least 2.5 Mt with a grade of 0.1 % Pb (Harpøth et al. 1986).

Prospects, mineral occurrences, and related deposit types

Scattered stratabound copper mineralizations are known throughout the central Giesecke Bjerge area.

Exploration history

Nordisk Mineselskab A/S has carried out exploration for base metals from 1968–1982 in the region. Trail Ø area was sporadic investigated by Nordisk Mineselskab A/S in the mid-1970ies. Detailed investigations on the Ladderbjerg copper deposit and the adjacent area were made in the early 1980's (Thomassen & Nilsson 1982).

Grade and tonnage model selection

Based on the characteristics of the Huledal Formation (the conglomerate sediments, the position of the Formation in the Upper Permian succession and the characteristics of the copper occurrences/prospects found in other tracts containing the Huledal Formation) the assessment team found it justified to used the Sediment-hosted Copper, Revett Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

With respect to Gauss Halvø and north and central Giesecke Bjerge, the Ladderbjerg copper deposit as well as the general geological settings and characteristics of the Huledal Formation reported from the tracts make it permissive for Revett Copper type. No drilling has been carried out in any of the tracts.

Table 14. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for the Permian CE 13–14 Huledal Formation tract*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	0	1	3	0.14	0.56	420	1	1.14	452	0.00252

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	1	3
Individual 2	0	0	0	1	4
Individual 3	0	0	0	1	3
Individual 4	0	0	0	1	4
Individual 5	0	0	0	1	3
Individual 6	0	0	1	1	2
Individual 7	0	0	0	1	4
Individual 8	0	0	0	1	3
Individual 9	0	0	0	0	3
Consensus	0	0	0	1	3

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 14), Revett Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Revett Copper, model 30b.4' using the EMINERS program (Root et al 1991; Duval 2004).

Selected simulation results are reported in Table 15 and as cumulative frequency plots in Fig. 22. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 15. *Results of Monte Carlo simulations of undiscovered resources in the Permian tracts CE 13–14 Huledal Formation [t = metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	250,000	130,000	0.06	0.92
Ag (t)	0	0	0	0	490	310	0.06	0.93
Rock (t)	0	0	0	0	31,000,000	14,000,000	0.07	0.92

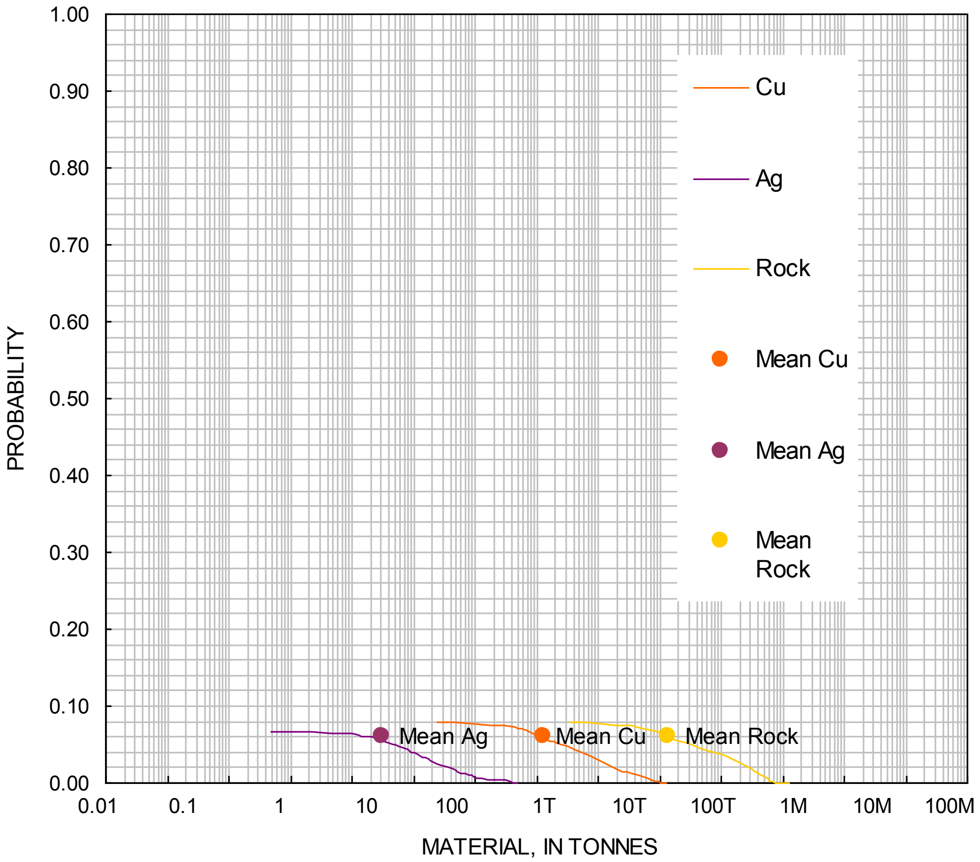

Figure 22. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the Permian tract CE13–14 Huledal Formation. T=thousands, M=millions.*

The Permian tract CE 15 Huledal Formation – Revett Copper type

Location

The Permian tract CE 15 Huledal Formation is located in the northernmost part of Hold With Hope, at Kap Stosch (Fig. 23).

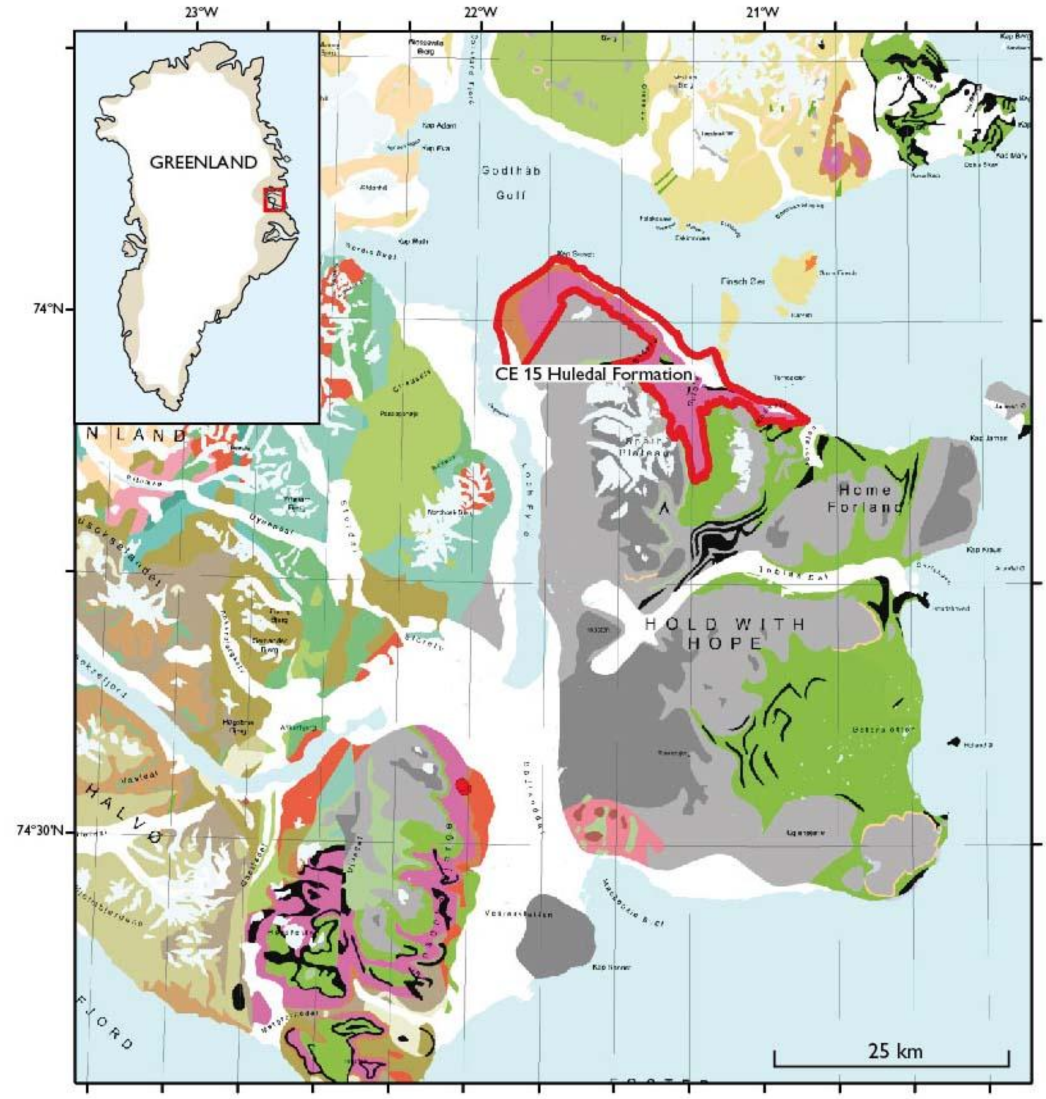

Figure 23. *Outline of the Permian tract CE 15 Huledal Formation, Hold With Hope. The Huledal Formation, is shown in brown; Triassic units are shown in pink. See Appendix B for a geological legend.*

Table 16. *Summary of selected resource assessment results for the Permian tract CE 15 Huledal Formation*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	208	0	23,000

Geological feature assessed

The Permian tract CE 15 Huledal Formation contains the marine Upper Permian Foldvik Creek Group which was deposited unconformably on a flat Carboniferous – Lower Permian peneplain (Harpøth et al. 1986) (Figs 4 and 5).

The Huledal Formation is part of the Foldvik Creek Group and the formation is well exposed in the lower part of the relatively steep 1,300 m high cliff-face at Kap Stosch (Fig. 24). However, the remaining part of the Huledal Formation in the CE 15 Huledal Formation tract is covered by younger rocks.

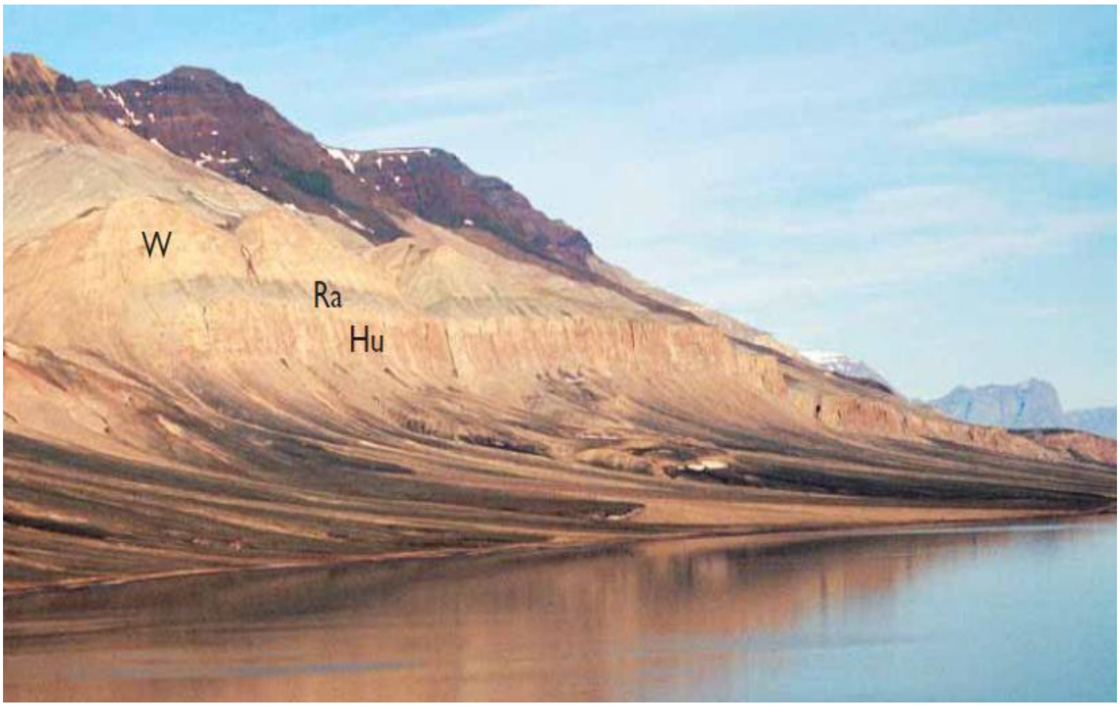

Figure 24. *The Permian-Triassic boundary at Kap Stosch. The dark Upper Permian Ravnefjeld Formation (Ra) is directly overlain by the Wordie Creek Formation (W) which is unconformably overlain by Tertiary basalts forming the top of the approximately 1300 m high mountains; (Hu) is Huledal Formation. Photo from Stemmerik et al. (2001).*

Delineation of the permissive tract

The Permian CE 15 Huledal Formation tract contains the Huledal formation in the uppermost kilometre. The extent of the tract is based on the mapped distribution of Foldvik Creek

Group (which comprises the Huledal Formation) and the overlying Triassic and Tertiary units.

Geological criteria

No detailed description of the Huledal Formation at Hold With Hope is available.

Known deposits

There are no known deposits within the tract.

Prospects, mineral occurrences, and related deposit types

There are no known prospects or mineral occurrences known within the tract.

Exploration history

Nordisk Mineselskab A/S has carried out regional exploration in the region 70°N to 74°30‘N for mineralization in the period from 1952–1984. The activities and discoveries made during this period together with pervious known occurrences from this area is summarised in a review by Harpøth et al. (1986). No known occurrences are reported from the central and northern part of Hold With Hope. However, Permian units in the tract, have been explored only little. The Palaeogene flood basalts that cover the sedimentary units have been explored for magmatic Cu-Ni-PGE massive sulfide deposits but no encouraging results were reported from this work (Rose et al. 1998 , GRF 51554).

Grade and tonnage model selection

Based on the characteristics of the settings of the Huledal Formation (the conglomerate sediments, the position of the Formation in the Upper Permian succession and the characteristics of the copper occurrences/prospects found in other tracts containing the Huledal Formation) the assessment team found it justified to use the Sediment-hosted Copper, Revett Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

Approximately 40–50 km southeast of tract CE 15 Huledal Formation, the Huledal Formation hosts two significant copper deposits and numerous scattered copper showings, at Giesecke Bjerge, situated within tract CE 13–14 Huledal Formation. Given, (i) the relative short distance; (ii) geological setting similarities of the Huledal Formation at Hold With

Hope; (iii) the little exploration activity within the Permian strata; and (iv) the fact that most of the Permian strata is covered by younger rocks (but still within the uppermost 1 km of the crust) tract CE 15 Huledal Formation was thought to be permissive for Revett Copper type mineralization.

Table 17. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for Permian tract CE 15 Huledal Formation*

Consensus undiscovered deposit estimate					**Summary statistics**					**Area (km^2)**	**Deposit density (N/km^2)**
N90	**N50**	**N10**	**N05**	**N01**	**N_{und}**	**s**	**Cv%**	**N_{known}**	**N_{total}**		
0	0	0	0	1	0.03	0.24	810	0	0.03	208	0.00014

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	0	1
Individual 2	0	0	0	0	1
Individual 3	0	0	0	0	1
Individual 4	0	0	0	1	2
Individual 5	0	0	0	0	1
Individual 6	0	0	1	0	1
Individual 7	0	0	0	0	1
Individual 8	0	0	0	0	1
Individual 9	0	0	0	0	1
Consensus	0	0	0	0	1

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 17), Revett Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Revett Copper, model 30b.4' using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 18 and as cumulative frequency plots (Fig. 25). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 18. *Results of Monte Carlo simulations of undiscovered resources in the Permian tracts CE 15 Huledal Formation [t = metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	0	23,000	0.03	0.97
Ag (t)	0	0	0	0	0	60	0.02	0.98
Rock (t)	0	0	0	0	0	2,600,000	0.03	0.97

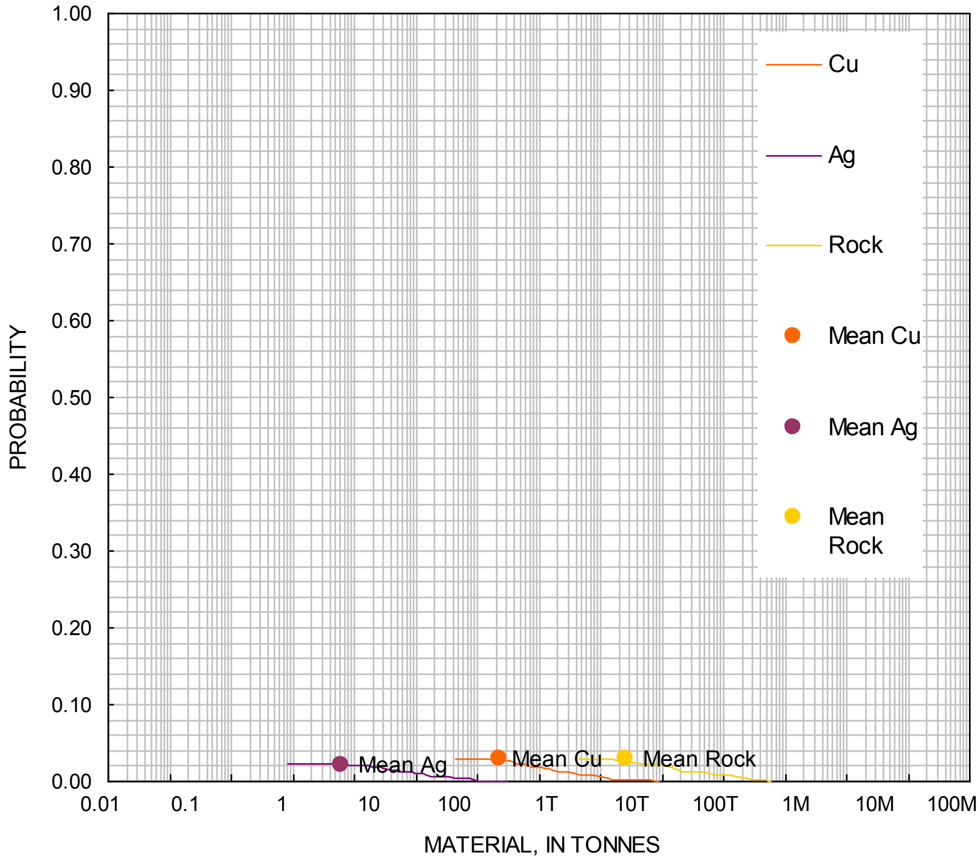

Figure 25. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the tract CE 15 Huledal Formation. T=thousands, M=millions.*

Assessment of Sediment-hosted Copper deposit for Permian central East Greenland – Reduced Facies Copper type

Stratiform fine-grained base metal mineralization occurs in the black shales of the Upper Permian Ravnefjeld Formation at Wegener Halvø, carrying similarities with the European Kupferschiefer, except that the metal grades in the Ravnefjeld Formation are relatively low and not copper dominated. Despite the low grades reported, the assessment team found it justified to assess the tracts with Upper Permian Ravnefjeld Formation as permissive areas for Reduced Facies Copper type mineralization. Given that the distribution of the Upper Permian Huledal Formation and Ravnefjeld Formation (both of the Foldvik Creek Group) coincide, the assessment team found it reasonable to use the Upper Permian tracts defined for the distribution of the Huledal Formation for the assessment of Reduced Facies Copper type deposits within the Ravnefjeld Formation.

Deposit type assessed

Deposit type: Sediment-hosted Copper.

Descriptive model: Sediment-hosted Copper, Reduced Facies Copper type (Cox et al. 2003).

Grade and tonnage model: Sediment-hosted Copper, Reduced Facies Copper type (Cox et al. 2003).

Sources of information

The principal sources of information used for the assessment of the tracts in the Permian of central East Greenland for the Reduced Facies Copper type are given Appendix A.

Permian tracts excluded from estimations – Tract CE 1, CE 3, CE 16, and CE 17 Ravnefjeld Formation – Reduced Facies Copper type

The assessment team decided to exclude the Permian tracts CE 1, CE 3, CE 16, and CE 17 Ravnefjeld Formation, due to lack of data i combined with the view, that there was no potential for finding undiscovered Reduced Facies Copper deposits within the tracts. The Ravnefjeld Formation is not present in tract CE 16 and CE 17 (Fig. 26).

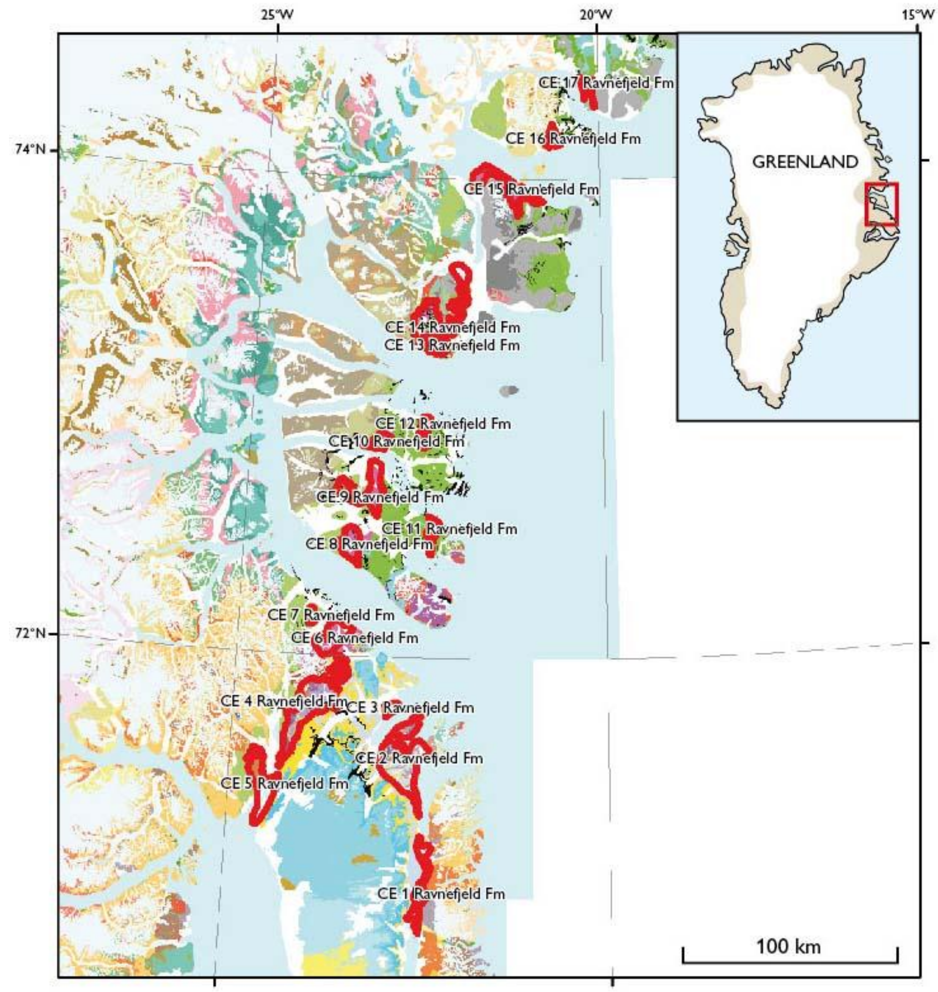

Figure 26. *Tracts for Upper Permian hosted Reduced Facies Copper type, tracts CE 1 – 17 Ravnefjeld Formation.*

The Permian tracts CE 2 and CE 4-15 Ravnefjeld Formation – Reduced Facies Copper type

Location

The Permian tracts CE 2 and CE 4–15 Ravnefjeld Formation are located within a corridor stretching from the south eastern part of the Jameson Land Basin in the south to Hold With Hope in the north (Fig. 26). Because of the similar level of information within the subtracts and similar geological settings/conditions the assessment team decided that the above tracts should be treated as a combined tract, which is named CE 2 and CE 4–15 Ravnefjeld Formation.

Table 19. *Summary of selected resource assessment results for the Permian tracts CE 2 and CE 4–15 Ravnefjeld Formation*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	208	0	130,000

Geological feature assessed

The Permian tract CE 2 and CE 4–15 Ravnefjeld Formation contain the marine Upper Permian Ravnefjeld Formation, which consists of bituminous black shales, deposited in the subsiding East Greenland basin. The shale can be traced throughout the entire East Greenland basin over a N-S distance of more than 400 km, and has been located in offshore mid-Norway drill holes as well. The shales have attracted considerable attention because of their high potential as hydrocarbon source rock (Nielsen & Pedersen 1998). The formation is part of the Upper Permian Foldvik Creek Group, marking the first transgression in the East Greenland basin deposited unconformably on a flat Carboniferous – Lower Permian peneplain (Harpøth et al. 1986) (Figs 4 and 5).

The following is a modified summary of the description of the Ravnefjeld Formation given in Nielsen & Pedersen (1998). Mineralization of lead, zinc and copper is found at several locations within the formation. The most significant occurrences, and the most investigated, are on Wegener Halvø. This mineralization was originally assumed to be of primary or early diagenetic origin due to similarities with the central European Kupferschiefer (Harpøth et al. 1986). However, later studies have shown that base metal mineralizations in the underlying carbonate reefs of the Wegener Halvø Formation are Palaeogene (Stemmerik 1991). Due to the geographical coincidence between the two mineralizations a common history has been suggested by Nielsen & Pedersen (1998), however, the timing and genesis of the base metal enrichment in the Ravnefjeld Formation on Wegener Halvø is still ambiguous. The Ravnefjeld Formation is up to 60 m thick and is divided into three bioturbated and two laminated units. Along the eastern basin margin, the formation is dominated by bituminous siltstones, which in inter-reef depressions are interlayered with numerous packstone and grainstone layers. More sandy lithologies are found in some areas along the western basin margin.

Delineation of the permissive tract

The CE 2 and CE 4–15 Ravnefjeld Formation tract contains the Ravnefjeld Formation down to an estimated depth of 1 km below surface. The extent of the tract is based on the mapped distribution of the Foldvik Creek Group, including the Ravnefjeld Formation.

Geological criteria

At Wegener Halvø (tract CE 2 Ravnefjeld Formation), base metal enrichment is widespread, and in an area of almost 50 km^2, ore minerals can be found at nearly all localities (Pedersen 1997). The base metal enrichment is present in the lowermost few metres of the shale formation only, except for a locality on Lille Ravnefjeld, at Vimmelskaftet, where abundant sphalerite and galena is found over a stratigraphic thickness of 15 m (Thomassen & Svensson 1979). Base metal sulphides in the mineralised horizons occur as disseminated, anhedral to subhedral grains or aggregates, variable in size from a few hundred microns to several centimetres. Continuous massive sulfide layers (2–3 cm in thickness) are found in the highly mineralised zone around Vimmelskaftet. Sphalerite and galena are by far the most abundant base metal sulphides in the Ravnefjeld Formation with chalcopyrite becoming increasingly important towards the NW. In general, four types of mineralised lithologies are seen: (i) Packstone layers, (ii) Concretionary shale layers (cemented by calcite or quartz, or both), (iii) concretionary shale lenses (cemented by calcite), and (iv) Non-lithified shales.

The most significant base metal mineralization in the Ravnefjeld Formation is known from the Wegener Halvø, but scattered base metal sulphides are found throughout all subtracts, e.g. primary sulphides have been found in drill cores from the Schuchert Dal area in the western part of the Jameson Land basin where the shale are thermally immature and no signs of secondary metal enrichment exist. Pyrite is found to be the main sulfide phase in this area.

Known deposits

There are no known deposits within the tracts.

Prospects, mineral occurrences, and related deposit types

The bituminous black shale of the Ravnefjeld Formation at Wegener Halvø and Devondal are found to host stratiform fine-grained mineralization throughout. The mineralizations in the Ravnefjeld Formation at these localities have been sampled systematically and in detail. The following is a modified version of the description for this occurrence given by

Harpøth et al. (1986). The sulphides exhibit colloform textures and replacement of fossils is widespread. The main ore minerals are sphalerite and galena with minor chalcopyrite, pyrite and marcasite; rare sulphides on joints indicate minor remobilization.

Channel samples collected southwest of Vimmelskaftet through the lowermost 15 m of the formation average 0.13 % Pb, 350 ppm Zn, 200 ppm Cu, 79 ppm V, 72 ppm Ni, 30 ppm Co, 11 ppm Th, 7 ppm U and contain up to 80 ppm Mo and 30 ppm Ag. Chip samples (n=39) from a 20 m long trench run 1,300–7,000 ppm Pb, 350–1,260 ppm Zn and 200–830 ppm Cu.

A 2.5 m black shale chip sample in Devondal returned 200 ppm Pb, 200 ppm Cu, <500 ppm Zn, 350 ppm V, 70 ppm Ni, 50 ppm Co, 50 ppm Mo and 4 ppm Ag. The thin, richly mineralised massive sulfide layers from south of Vimmelskaftet contain ca 10 % combined zinc and lead. The beds may grade laterally into barren, silicified horizons. The mineralization has a syn-genetic signature.

Exploration history

Nordisk Mineselskab A/S has carried out regional exploration in the region from 70°N to 74°30'N in the period from 1952–1984. Harpøth et al. (1986) reviews the activities and discoveries made during this period; and the following is from Harpøth et al. (1986): ‗The first reports of base-metal mineralization in the upper part of the Wegener Halvø were made by members of ―De Danske Treårsekspeditioner 1931–34". During a Nordmine reconnaissance in 1968 mineralization were also found in the Ravnefjeld Formation and the following year a 20 m long trench was blasted and sampled. Later, based on air observations of malachite staining of the limestone of Quensel Bjerg on south Wegener Halvø, a reconnaissance of this area was carried out in 1971–72. Further observations were made here during Nordmine investigations of the Triassic in 1973–76. In 1979 the Upper Permian of the entire Wegener Halvø peninsula was traversed and mapped at scale 1:10 000'. Since the Nordisk Mineselskab work, The Ravnefjeld Formation and its sulfide mineralization has been investigated in two Ph.D. projects (Pedersen 1997; Nielsen 2001).

Grade and tonnage model selection

Based on the characteristics of the mineralization in the Ravnefjeld Formation, and the previously established similarity with the European Kupferschiefer, the assessment team found it justifiable to use the Sediment-hosted Copper, Reduced Facies Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

The known base metal occurrences in the Ravnefjeld Formation are dominated by lead and zinc, and none yield economic copper grades. Despite these facts the assessment team found that the occurrences are evidence for potential reduced facies mineralization, and that the formation can be considered as being permissive for such mineralizations. Except for subtract CE 2 Ravnefjeld Formation, only little exploration has been focused on the Ravnefjeld Formation, and given the lateral extent of the combined tracts (2,250 km^2) a potential for undiscovered Reduced Facies Copper type were considered possible. It was discussed if the mineralization in the Ravnefjeld Formation were more likely SEDEX type mineralizations (e.g. similar to the Rammelsberg Pb-Zn deposit in Germany), however, it was concluded that more investigations would be required to support this and that the present data pointed towards a Reduced Facies mineralization model.

Table 20. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for CE 2 and CE 4-15 Ravnefjeld Formation*

Consensus undiscovered deposit estimate					**Summary statistics**					**Area (km^2)**	**Deposit density (N/km^2)**
N90	**N50**	**N10**	**N05**	**N01**	**N_{und}**	**s**	**Cv%**	**N_{known}**	**N_{total}**		
0	0	0	0	2	0.06	0.37	610	0	0.06	2,250	0.000027

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	0	1
Individual 2	0	0	0	0	2
Individual 3	0	0	0	0	1
Individual 4	0	0	0	0	1
Individual 5	0	0	0	0	1
Individual 6	0	0	1	1	1
Individual 7	0	0	0	0	1
Individual 8	0	0	0	0	1
Individual 9	0	0	0	0	1
Individual 9	0	0	0	0	1
Consensus	0	0	0	0	2

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 20), Facies Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Reduced Facies Copper, model 30b.2' using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 21, and the results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 27). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 21. *Results of Monte Carlo simulations of undiscovered resources in the Permian tracts CE 8–12 Huledal Formation [t = metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	0	240,000	0.03	0.97
Ag (t)	0	0	0	0	0	140	0.01	0.99
Co (t)	0	0	0	0	0	10,000	0.01	0.99
Rock (mt)	0	0	0	0	0	11	0.03	0.97

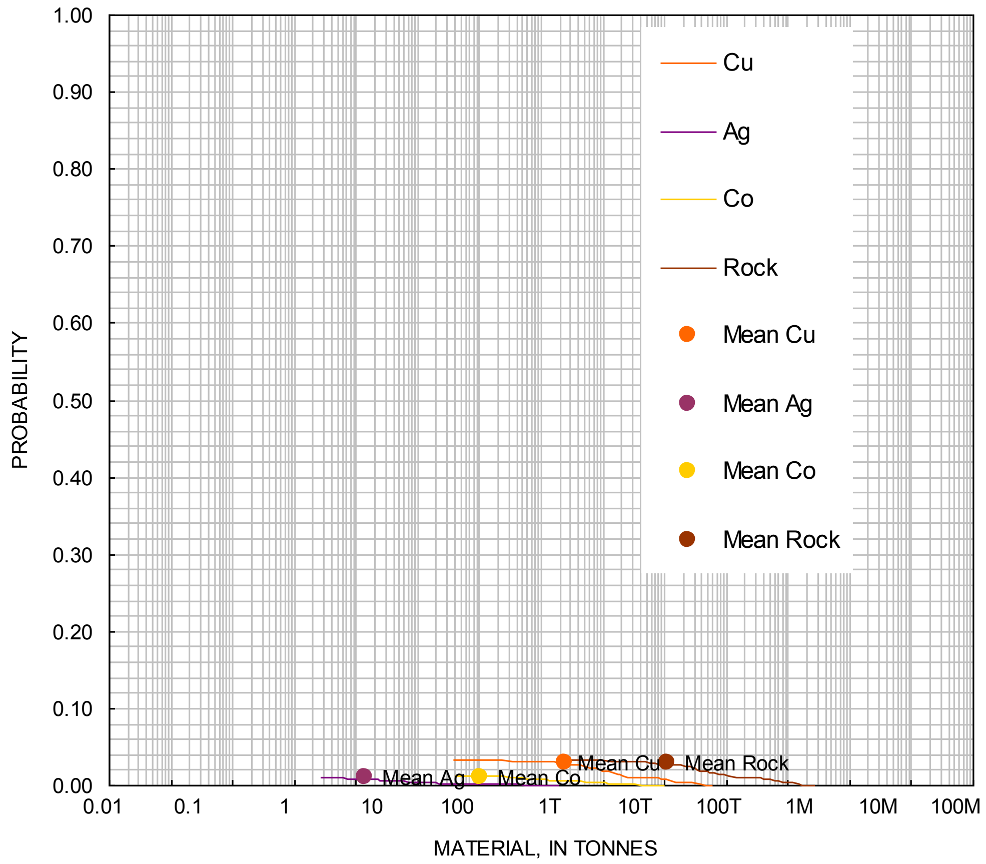

Figure 27. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the tracts CE 2 and CE 4-15 Ravnefjeld Formation. T=thousands, M=millions.*

Assessment of Sediment-hosted Copper deposit for Upper Triassic central East Greenland – Redbed Copper type

Copper mineralization is found throughout the Triassic stratum in the East Greenland basin (Table 21). Especially the Malmros Klint Member and Ørsted Dal Member of the Upper Triassic Fleming Fjord Formation and the Klitdal and Paradigmabjerg Member of the Lower Triassic Pingo Dal Formation host significant copper mineralizations. The Malmros Klint Member is host to Redbed Copper type mineralizations, whereas Klitdal and Paradigmabjerg Member host Reduced Facies Copper type mineralization. The latter type is also found within the Pingel Dal bed of the Upper Triassic Malmros Klint Member.

Table 22. *Triassic lithostratigraphy and mineralizations in the Jameson Land Basin*

Series	Formation	Member	Beds	Max. thickness	Dominant lithology	Mineral-sation	Redbed type
Upper Triassic		Ørsted Dal	Tait Bjerg	70 m	Light-coloured carbonate rocks and variegated mudstones		
				150 m	Red mudstones and light grey sandstones	*Cu*	Redbed Cu
		Malmros Klint		200 m	Red mudstones and fine sandstones	(Cu)	Redbed Cu
			Pingel Dal	35 m	Variegated cyclic-bedded sandstones and mudstones	**Cu**	Reduced-facies Cu
		Edderfugledal	Sporfjeld	35 m	Yellowish cyclic-bedded dolomitic sediments		
Middle Triassic	Gipsdalen	Kap Seaforth		160 m	Variegated cyclic-bedded gypsiferous sediments	*Cu, Pb, Zn*	
		Solfaldsdal		150 m	Red gypsiferous sandstones		
			Gråklint	30 m	Dark grey limestones and mudstones	*Pb, Zn, Cu*	
		Kolledalen		180 m	Yellowish gypsiferous sandstones		
Lower Triassic	Pingo Dal	Klitdal and Paradigmabjerg		>450 m	Pink arkoses and conglomerates	**Cu**, Ag, Pb, (Zn)	
	Wordie Creek	Rødstaken		330 m	Dark red sandstones		
				550 m	Greenish silty shales and sandstones	(Cu), (Pb), (Zn)	

Cu = major mineralisation; *Cu* = minor mineralisation; (Cu) = trace of sulphides

The stratigraphic levels hosting the most pronounced copper mineralizations are indicated by red. Also, the mineral deposit models applied by the assessment team are indicated. Table from Harpøth et al. 1986.

Deposit type assessed

Deposit type: Sediment-hosted Copper.

Descriptive model: Sediment-hosted Copper, Redbed Copper type (Cox et al. 2003).

Grade and tonnage model: Sediment-hosted Copper, Redbed Copper type (Cox et al. 2003).

Sources of information

The principal sources of information used for the assessment of the tracts in the Upper Triassic of central East Greenland for the Redbed Copper type are given in Appendix A.

Excluded from estimations: Upper Triassic, Redbed Copper tracts CE 2-10 Malmros Klint/ Ørsted Dal Member

The assessment team decided to exclude the following Upper Triassic Redbed Copper type tract CE 2 to CE 10 Malmros Klint/ Ørsted Dal Member (Fig. 28) from the assessment due to the following facts: (i) the palaeoenvironment of the tracts were open marine, and (ii) because the Upper Triassic had been eroded away in several of these tracts.

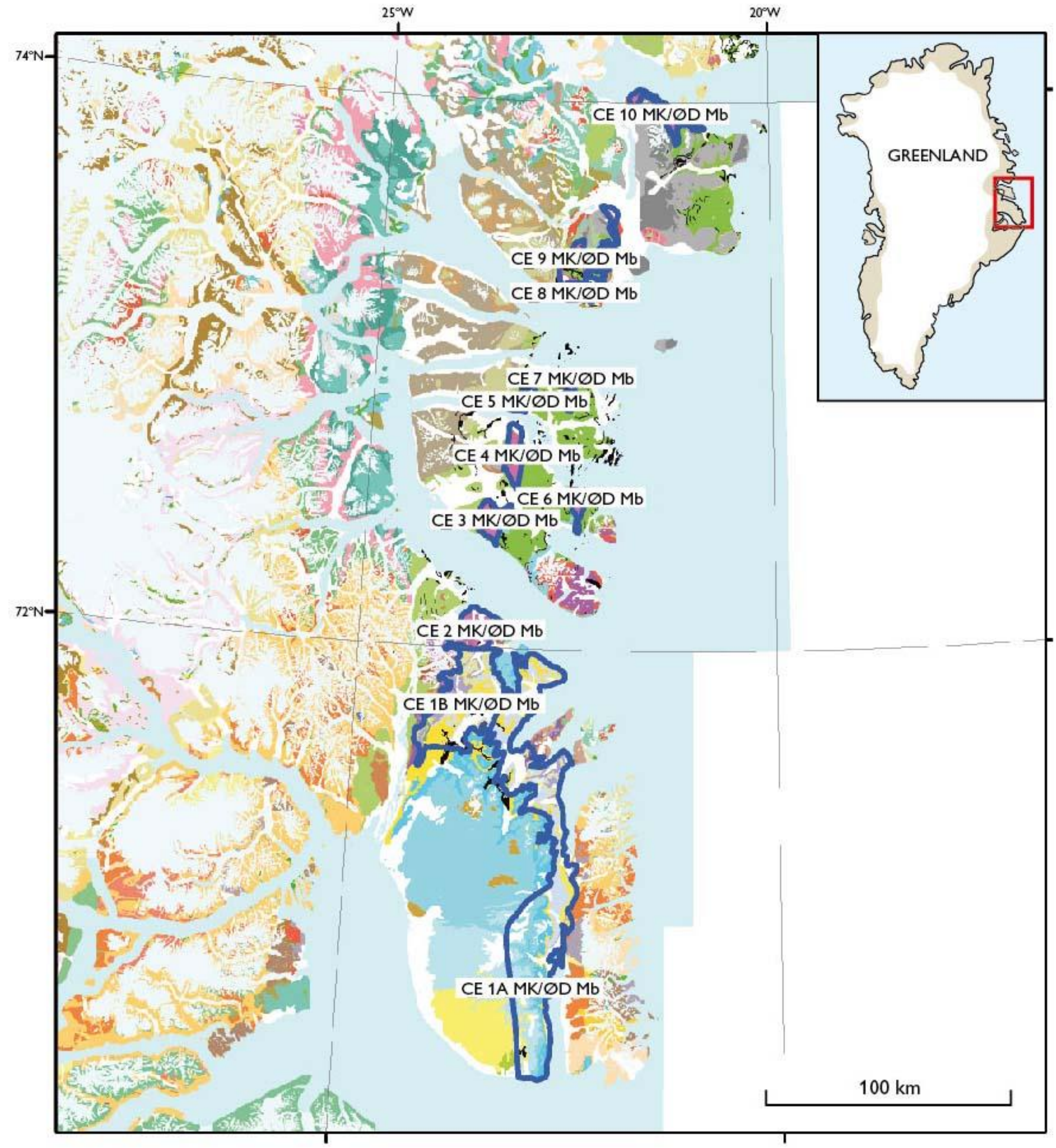

Figure 28. *The tracts for Upper Triassic hosted Redbed Copper type, central East Greenland CE1 –CE10 Malmros Klint/ Ørsted Dal Member (abbreviated to CE1 MK/ØB Mb).*

Upper Triassic tract CE 1A Malmros Klint/ Ørsted Dal Members – Redbed Copper type

Location

The tract CE 1A Malmros Klint/ Ørsted Dal Member, located in the eastern part of the Jameson Land Basin, stretches from the southernmost part at the outer part of Scoresby Sund to the northernmost part of the outer Kong Oscar Fjord (Fig. 29).

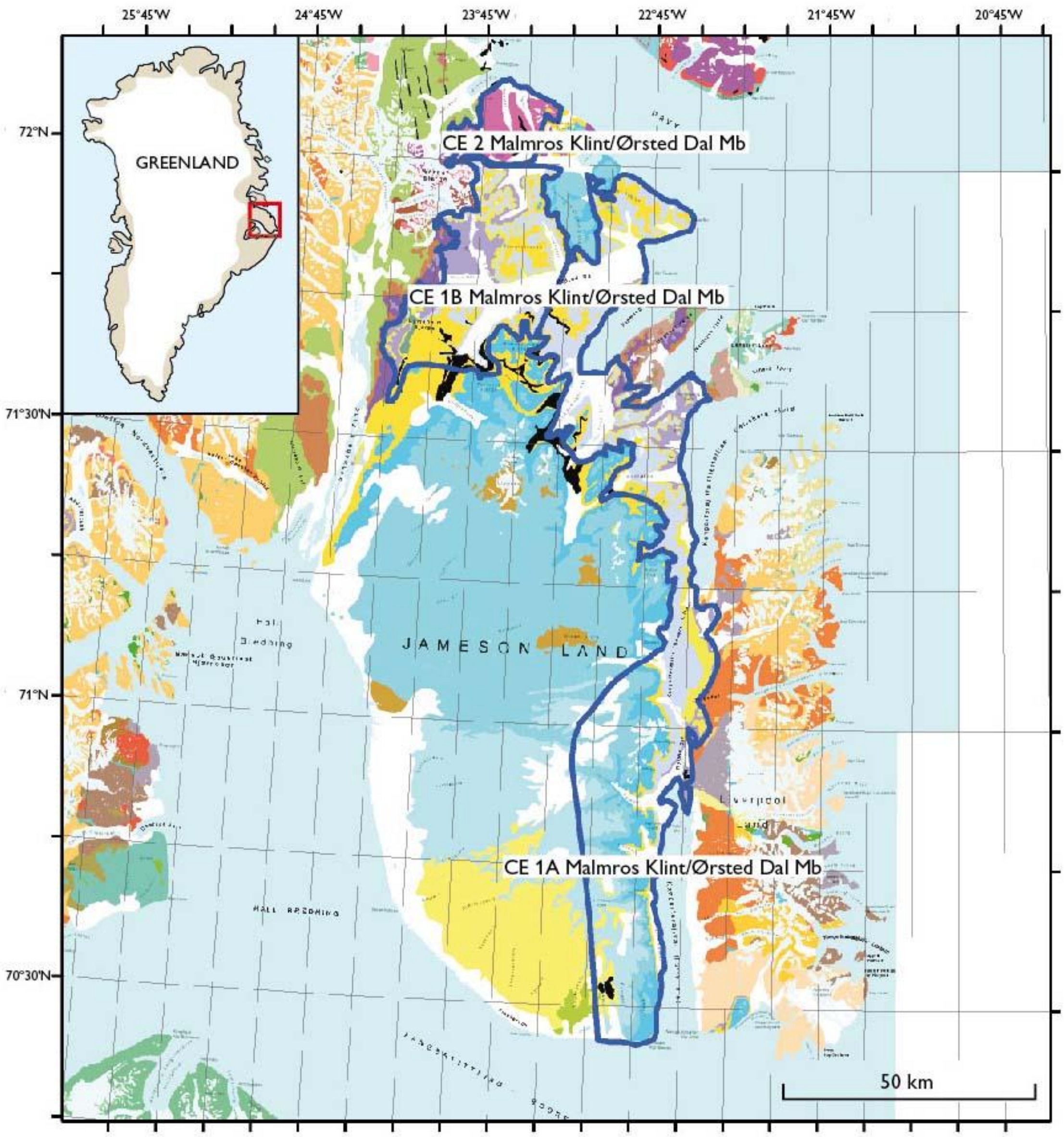

Figure 29. *The Upper Triassic tracts CE 1A, CE 1B, and CE 2 Malmros Klint/ Ørsted Dal Member, in the Jameson Land basin. CE 1 A and CE 1 B Malmros Klint/ Ørsted Dal Member are assessed for undiscovered Redbed Copper type deposit.*

Table 23. *Summary of resource assessment results for the tract CE 1A Malmros Klint /Ørsted Dal Member, Fleming Fjord Formation, assessed for Redbed Copper type deposits*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	2,310	0	28,000

Geological feature assessed

The Triassic of the Jameson Land Basin consists of an approximately 1,700 m thick sequence of shallow marine to continental and lacustrine clastics with intercalations of evaporates and thin carbonates. Mineralization of stratiform to strata-bound character occurs at seven stratigraphic levels (Table 22, Harpøth et al. 1986).

Tract CE 1A Malmros Klint/ Ørsted Dal Member contains the red mudstones of playa flat origin of the Malmros Klint Member grading upwards into the more sandy and distal floodplain fluvial conglomerates and sandstone deposit (Ørsted Dal Member) with an average thickness of 130 m. The Ørsted Dal Member is caped by marine limestone at top. The Malmros Klint consists of lacustrine fine sandstones and siltstones, and ranges in thickness from 30–225 m. Both members are part of the 490 m thick Fleming Fjord Formation.

Delineation of the permissive tract

The Upper Triassic CE 1A Malmros Klint/ Ørsted Dal Member Redbed Copper type tract boundary to the east is defined by the easternmost exposure of Upper Triassic Malmros Klint Member and Ørsted Dal Member of the Fleming Fjord Formation (Fig. 29). The estimated extension of the Upper Triassic stratum (according to dip of the Upper Triassic stratum towards the centre of the basin) to a depth of 1 km defines the western boundary of the tract. The tract is separated from the Upper Triassic tract CE 1B Malmros Klint/ Ørsted Dal Member Redbed Copper type, because significant copper mineralizations have been recorded in the northernmost part of tract CE 1A Malmros Klint/ Ørsted Dal Member (Fig. 30), whereas no copper mineralization has been recorded from Tract CE 1B Malmros Klint/ Ørsted Dal Member.

Geological criteria

The following is a modified description of the copper mineralization hosted within the transition zone between the two members from Harpøth et al. (1986): „Copper mineralization is hosted in two or more 10–100 cm thick, grey, pale-yellowish weathering beds intercalated with red mudstones. The beds consist of fine-grained, muscovite-bearing, carbonate-rich sandstone with cross-lamination. Thin intraformational breccias, septarian nodules and plant fragments up to 30 cm long occur locally. The ore minerals appear partly as up to 10 cm long plates and blebs of native copper and copper arsenides, and partly as more fine-grained disseminations in few cm thick zones. Native copper, often rimmed by secondary cuprite, is the main mineral. Varying amounts of chalcocite, native silver and minerals of the demeykite-algodonite group also occur. A lateral zoning of copper and domeykite-algodonite exists between Fleming Fjord and Passagen.

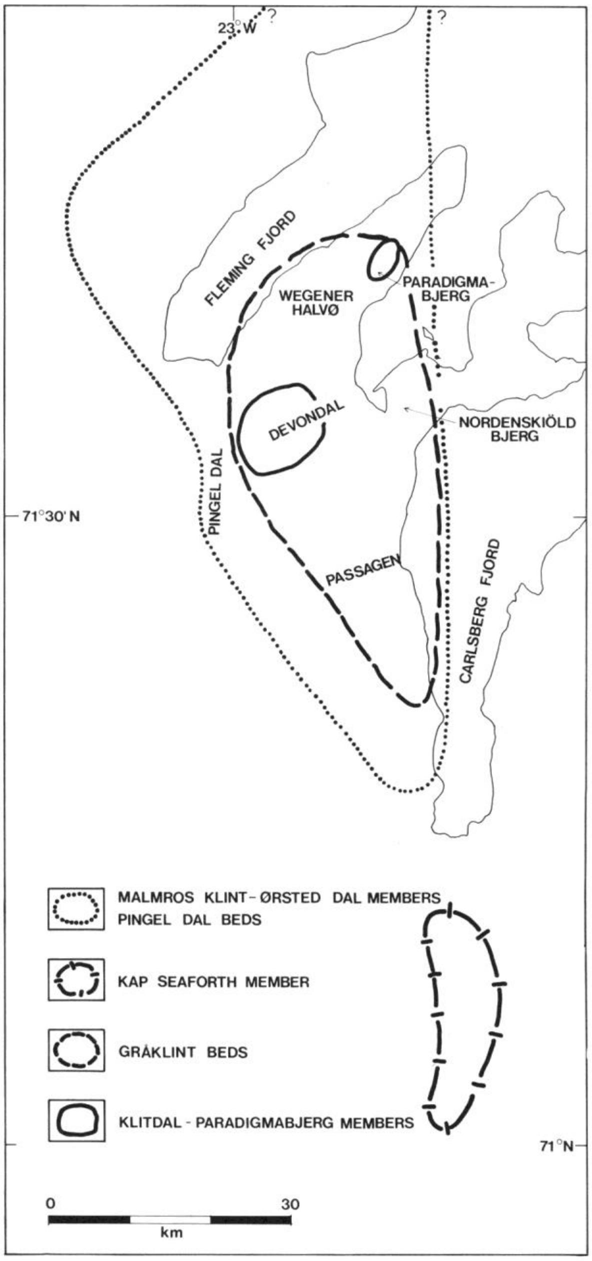

Figure 30. *Distribution of Triassic mineralization in eastern Jameson Land. From Harpøth et al. 1986.*

Known deposits

There are no known deposits within the tracts.

Prospects, mineral occurrences, and related deposit types

Continuous copper mineralizations have been recorded in two or more - 0.1–1 m thick sandstone beds (Fig. 32), and can be followed over an area of about 1,000 km2. Chip samples from 21 sections collected laterally over 650 m in the uppermost mineralised bed at Nordenskjold Bjerg (Figs 30 and 33) have an average content of approximately 500 ppm Cu (range 27–3,500 ppm) and 1.3 ppm Ag (range 0.8–4.8 ppm) over a thickness of 38 cm (range 25–60 cm). Maximum values of silver (787 ppm Ag) and gold (0.5 ppm Au) are in a sample with 27.5% Cu and 5% As. Scattered anomalous vanadium concentrations (< 0.25%) are characteristic (Harpøth et al. 1986). Harpøth et al. (1986) suggest a genesis involving metal precipitation from percolating ground water during diagenesis.

Exploration history

The following text is from Harpøth et al. 1986: "Prior to 1972, mineralization in the Triassic was virtually unknown. Malachite-stained boulders of Triassic sandstone have been observed in Pingel Dal and traces of galena have been noted in Triassic limestone on Wegener Halvø. During reconnaissance work carried out by the exploration company Nordic Mining Company A/S in the Upper Permian limestone in 1972, copper- and lead-bearing boulders were collected in Devondal and in the following year mineralization was found in Lower Triassic arkoses (Thomassen 1974). This find led to a semi-regional reconnaissance of the Triassic of the Jameson Land Basin, as well as detailed investigations of the Devondal area in 1974–76 and 1779–80. The exploration programme comprised stream-, soil- and rock geochemistry, lithostratigraphic mapping of selected areas as well as chip sampling and shallow diamond drilling (4 holes – total 41 drill metres, Thomassen 1982)".

Grade and tonnage model selection

Based on the characteristics of the settings of the mineralization in the transition zone between the Malmros Klint Member and Ørsted Dal Member of the Upper Triassic Fleming Fjord Formation and the geological setting of the host rock and established dispositional palaeoenvironment the assessment team found it justified to use the Sediment-hosted Copper, Redbed Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

The Upper Triassic stratum provide all the ingredients needed for the formation of Redbed Copper mineralizations and the delineated mineralizations in the northern part of the tract are remarkable continuous over a large area (1,000 km^2). However, most of the exploration work carried out in this tract has been focussed on surface anomalies; only limited exploration at depth has been undertaken. Also, the Upper Triassic stratum in the southern part of tract CE 1A has never been explored in detail, for Redbed Copper, even though the stratigraphic levels that carry the known copper occurrences are continuous towards the south.

Table 24. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for Upper Triassic CE 1A Malmros Klint/ Ørsted Dal Member tract Redbed Copper type*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv %	N_{known}	N_{total}		
0	0	0	2	4	0.21	0.76	360	0	0.21	2,000	0.00011

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	2	3
Individual 2	0	0	1	3	5
Individual 3	0	0	0	2	4
Individual 4	0	0	1	2	4
Individual 5	0	0	1	2	3
Individual 6	0	0	0	2	5
Individual 7	0	0	0	2	4
Individual 8	0	0	0	3	5
Individual 9	0	0	0	2	4
Individual 10	0	0	0	1	2
Individual 11	0	0	0	0	2
Consensus	0	0	0	2	4

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 24), Redbed Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Redbed Copper, model 30b.3' using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 25, and results of the Monte Carlo simulation are presented as cumulative frequency plots in Fig. 31. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 25. *Results of Monte Carlo simulations of undiscovered resources in the Upper Triassic tract CE 1A MK/ØD Mb, Redbed Copper type [t = metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	94,000	28,000	0.06	0.92
Ag (t)	0	0	0	0	0	25	0.03	0.95
Co (t)	0	0	0	0	0	360	0.01	0.99
Rock (mt)	0	0	0	0	6	2	0.07	0.92

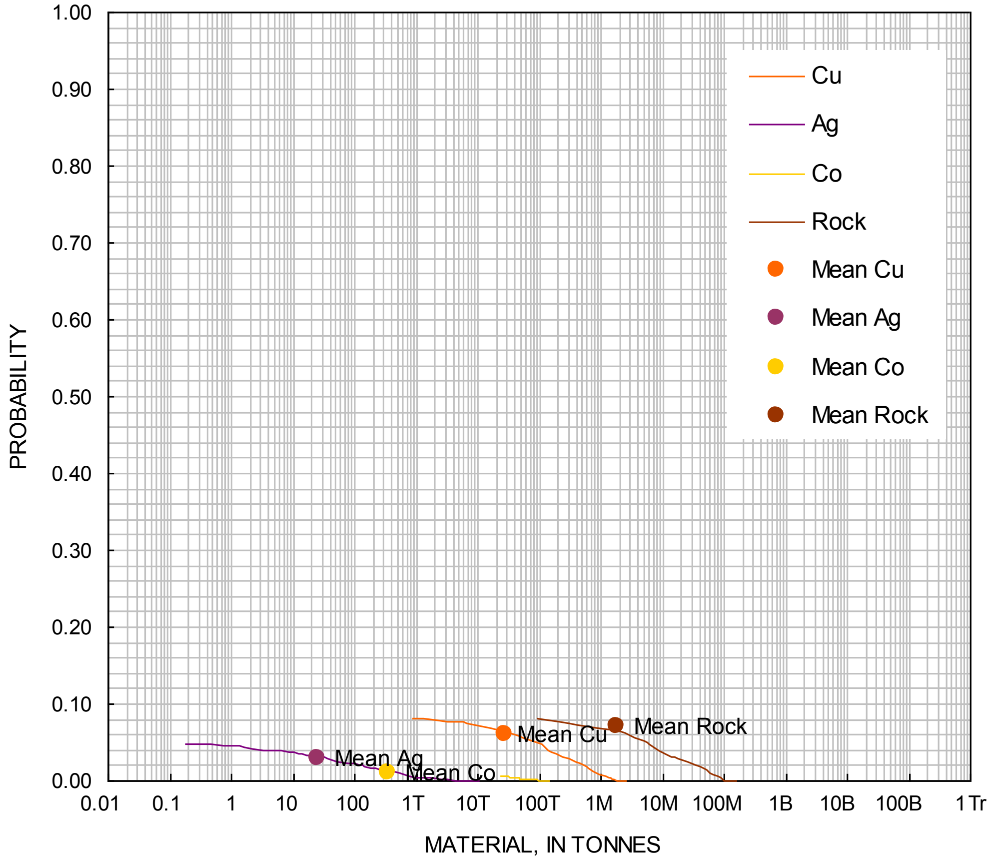

Figure 31. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the Upper Triassic tract CE 1A Malmros Klint/ Ørsted Dal Member, Redbed type. T=thousands, M=millions, B=Billions, Tr=Trillions.*

Figure 32. *The red mudstones and sandstones of the Upper Triassic Ørsted Dal Member; the Ørsted Dal member hosts Redbed Copper type mineralization. Photo from presentation made by B. Thomassen at the workshop.*

Figure 33. *Chip sampling at Nordenskiøld Bjerg of sandstone beds with Redbed Copper type mineralizations. Photo from presentation made by B. Thomassen at the workshop.*

Triassic tract CE 1B Malmros Klint/ Ørsted Dal Members – Red-bed Copper type

Location

The Upper Triassic tract CE 1B Malmros Klint/ Ørsted Dal Member is located in the western part of the Jameson Land Basin, from the southernmost part of Schuchert River valley to the east of Werner Bjerge, south of Kong Oscar Fjord (Fig. 29).

Table 26. *Summary of resource assessment results for the tract CE 1B Malmros Klint/ Ørsted Dal Member, Fleming Fjord Formation, assessed for Redbed Copper type deposits*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	1,150	0	20,000

Geological feature assessed

The Triassic of the Jameson Land Basin consists of an approximately 1,700 m thick sequence of shallow marine to continental and lacustrine clastics with intercalations of evaporates and thin carbonates. Mineralization of stratiform to strata-bound character occurs at seven stratigraphic levels (Table 22, Harpøth et al. 1986).

Tract CE 1B Malmros Klint/ Ørsted Dal Members contains red mudstones of playa flat origin of the Malmros Klint Member grading upwards into the more sandy and distal flood-plain fluvial conglomerates and sandstone deposits of the Ørsted Dal Member, with an average thickness of 130 m. The Ørsted Dal Member is caped by marine limestone at top. The Malmros Klint consists of lacustrine fine sandstones and siltstones, and ranges in thickness from 30–225 m. Both members are part of the 490 m thick Fleming Fjord Formation. The western parts of the Malmros Klint and Ørsted Dal members become richer in fluvial conglomerates and sandstone, whereas the eastern parts of these members are more dominated by fluvial- and lacustrine fine sandstone and mudstone (Clemmensen 1980).

Delineation of the permissive tract

The Upper Triassic CE 1B Malmros Klint/ Ørsted Dal Member Redbed Copper type tract boundary to the west is defined by the easternmost exposure of Upper Triassic Malmros Klint Member and Ørsted Dal Member of the Fleming Fjord Formation. The estimated extension of the Upper Triassic stratum (according to dip of the Upper Triassic stratum towards the centre of the basin) to a depth of 1 km defines the western boundary of the tract. The CE 1B tract is separated from tract CE 1A Redbed Copper type of Upper Triassic stratum in the eastern part of Jameson Land. This is because significant copper mineralizations have been recorded in the northernmost part of tract CE 1A Malmros Klint/ Ørsted Dal Member, whereas no copper mineralization has been recorded from Tract CE 1B Malmros Klint/ Ørsted Dal Member.

Geological criteria

The following is modified from the description of the copper mineralization hosted within the transition zone between the two members from Harpøth et al. (1986). Copper mineralization is hosted in two or more 10–100 cm thick, grey, pale-yellowish weathering beds intercalated with red mudstones. The beds consist of fine-grained, muscovite-bearing, carbonate-rich sandstone with cross-lamination. Thin intraformational breccias, septarian nodules and plant fragments up to 30 cm long occur locally. The ore minerals appear partly as up to 10 cm long plates and blebs of native copper and copper arsenides, and partly as more fine-grained disseminations in few cm thick zones. Native copper, often rimmed by secondary cuprite, is the main mineral. Varying amounts of chalcocite, native silver and minerals of the demeykite-algodonite group also occur. A lateral zoning exists, which copper and domeykite-algodonite between Fleming Fjord and Passagen.

Known deposits

There are no known deposits within the tract.

Prospects, mineral occurrences, and related deposit types

There are no known Redbed Copper occurrences within the tract. No mineralizations are known from the Upper Triassic stratum in the western part of the Jameson Land Basin.

Exploration history

Exploration programs have never been carried out in the Upper Triassic stratum in the western part of the Jameson Land Basin. For the Upper Triassic of the eastern part of Jameson Land Basin (tract CE 1A Malmros Klint/ Ørsted Dal Member) more exploration has been undertaken as summarised above.

Grade and tonnage model selection

Based on the characteristics of the mineralization in the transition zone between the Malmros Klint Member and Ørsted Dal Member of the Upper Triassic Fleming Fjord Formation in the eastern part of the Jameson Land Basin (tract CE 1A Malmros Klint/ Ørsted Dal Member), and the geological setting of the host rock and established dispositional palaeoenvironment the assessment team found it justified to use the Sediment-Hosted Copper, Redbed Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

No detailed exploration have been carried out on the Upper Triassic stratum from the marginal part of the eastern Jameson Land Basin, although is similar to the Upper Triassic stratum of the marginal part of the western Jameson Land Basin. This is probably due to lesser exposure in the western part of the basin. The assessment team considered it highly likely, that the ingredients required for the formation of a Redbed Copper mineralization (as confirmed from the work carried out in the eastern part of the Jameson Land Basin) also are present in the eastern part of the Jameson Land Basin.

Table 27. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for the Upper Triassic CE 1B Malmros Klint/ Ørsted Dal Member, Redbed Copper type deposit*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	0	0	2	0.06	0.37	610	0	0.06	1000	0.00006

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	0	2
Individual 2	0	0	0	1	2
Individual 3	0	0	0	1	2
Individual 4	0	0	0	2	2
Individual 5	0	0	0	1	1
Individual 6	0	0	0	1	3
Individual 7	0	0	0	0	2
Individual 8	0	0	0	0	3
Individual 9	0	0	0	0	1
Individual 10	0	0	0	0	1
Individual 11	0	0	0	0	1
Consensus	0	0	0	0	2

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 27), Redbed Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Redbed Facies Copper, model 30b.3' using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 28 and the results of the Monte Carlo simulation is presented as cumulative frequency plots (Fig. 34). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 28. *Results of Monte Carlo simulations of undiscovered resources in the Upper Triassic tract CE 1B Malmros Klint/ Ørsted Dal Member, Redbed Copper type. [t=metric tons; Mt; mega-tonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	0	10,000	0.04	0.95
Ag (t)	0	0	0	0	0	8	0.02	0.98
Co (t)	0	0	0	0	0	200	0,00	1.00
Rock (mt)	0	0	0	0	0	1	0.04	0.95

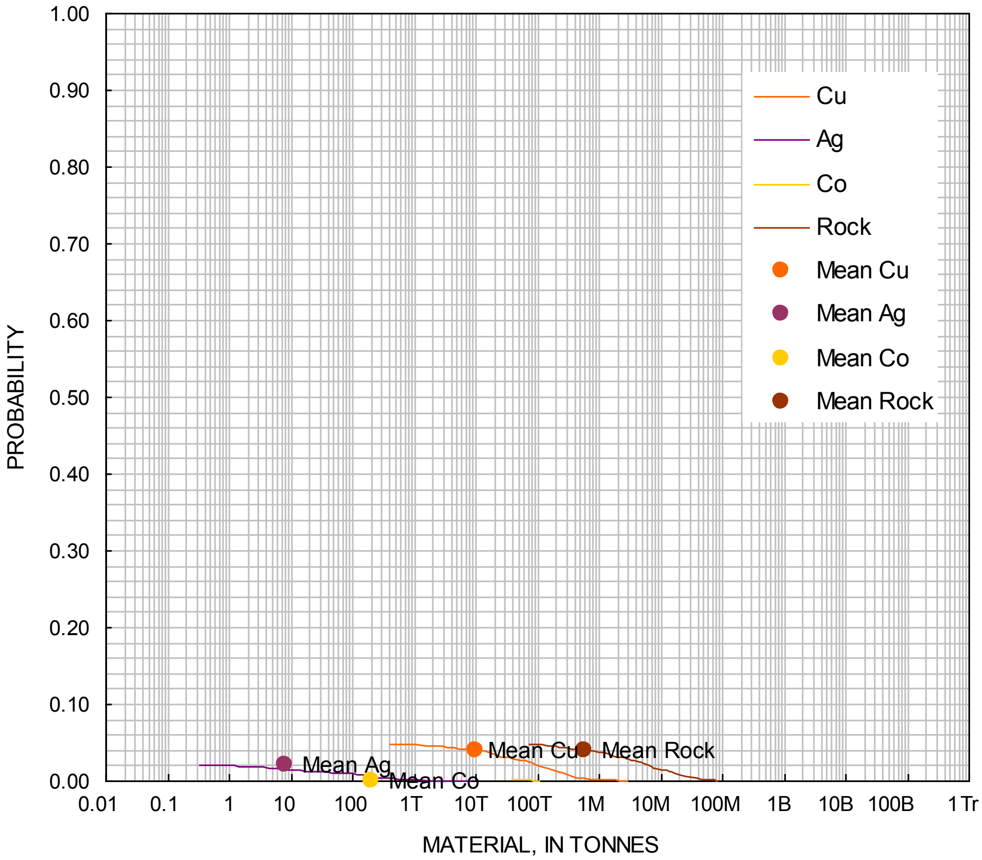

Figure 34. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the Upper Triassic tract CE 1B Malmros Klint/ Ørsted Dal Member, Redbed Copper type. T=thousands, M=millions, B=billions, Tr=trillions.*

Assessment of Sediment-hosted Copper deposit for Upper Triassic central East Greenland – Reduced Facies Copper type

Stratiform, laterally continuous Reduced Facies Copper type mineralization is known from the Pingel Dal Bed of the Edderfugledal Member of the lowermost part of the Upper Triassic Fleming Fjord Formation (Table 29).

Table 29. *Pingel Dal Bed of the Upper Triassic Fleming Fjord Formation (Harpøth et al. 1986)*

Series	Formation	Member	Beds	Max. thick.	Lithology	Cu mineralization
Upper Triassic	Fleming Fjord	Edderfugledal	Pingel Dal	35 m	Red mudstones, dolomitic mudstones, black shales and fine sandstones	Cu in 0.2–2 m thick silty mudstones with plant fragments over approximately 1000 km^2. Copper minerals form stratiform, very fine-grained, disseminations. Mineralised horizons show extreme lateral continuity.

Deposit type assessed

Deposit type: Sediment-hosted Copper.

Descriptive model: Sediment-hosted Copper, Reduced Facies Copper type (Cox et al. 2003).

Grade and tonnage model: Sediment-hosted Copper, Reduced Facies Copper type (Cox et al. 2003).

Sources of information

The principal sources of information used for the assessment of the tracts in the Permian of central East Greenland for the Reduced Facies Copper type are given in Appendix A.

Tracts excluded from estimations – Tract CE 2 to CE 10 Upper Triassic – Reduced Facies Copper type

Tract CE 2 to CE 10 Upper Triassic (Fig. 35) are excluded by the assessment team, due to (i) lack of data from the tracts; and/or (ii) the palaeoenvironment in these tracts were open marine; or (iii) the Upper Triassic had been eroded away in several of these tracts.

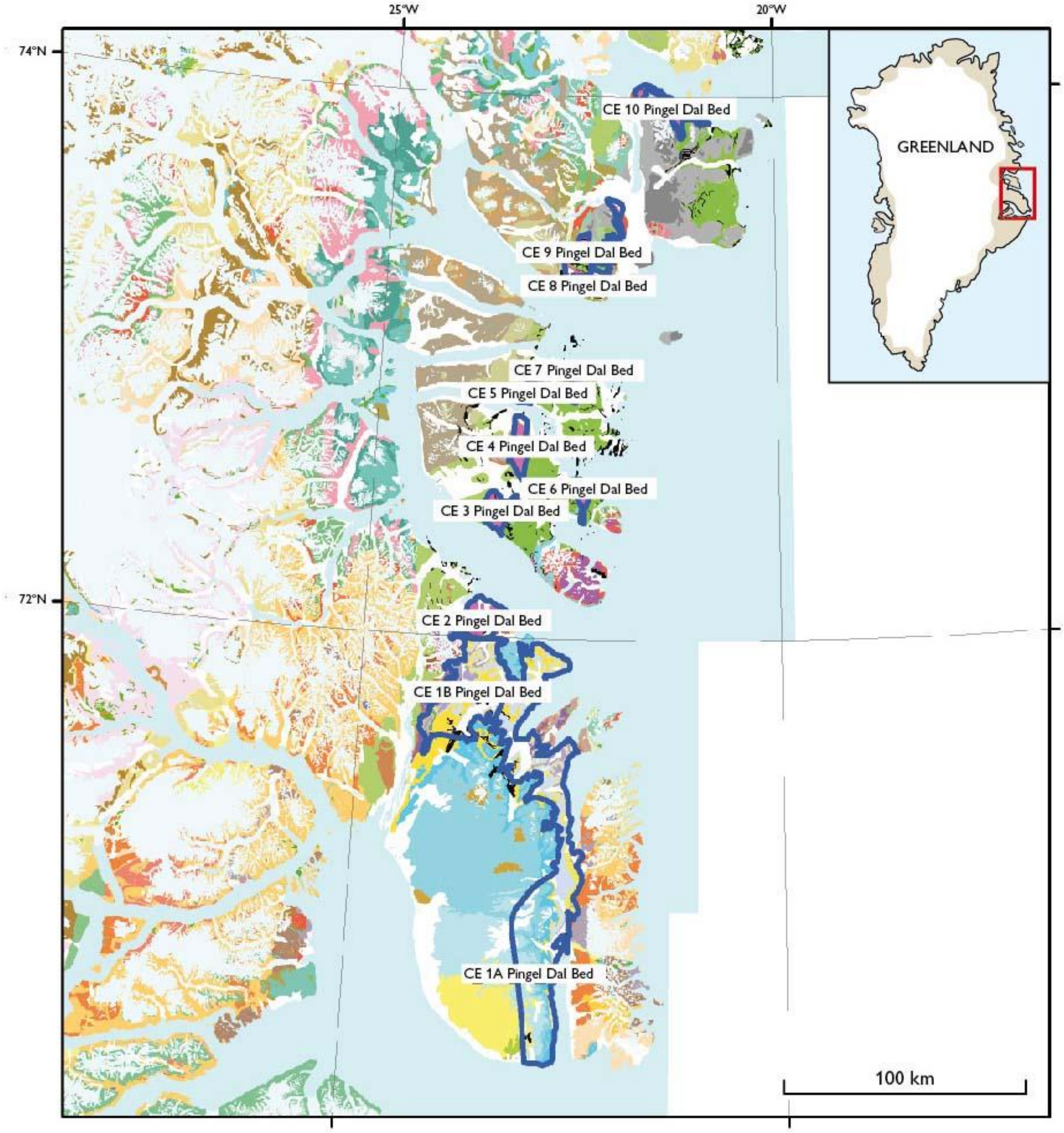

Figure 35. *Tracts for Upper Triassic Pingel Dal Bed hosting Reduced Facies Copper deposit type. Tract CE 2 to CE 10 Upper Triassic are excluded from the assessment.*

Tract CE 1 A Upper Triassic Pingel Dal Bed – Reduced Facies Copper type

Location

The Upper Triassic tract CE 1A Pingel Dal Bed (Fig. 36) is located in the eastern part of the Jameson Land Basin, in an area from the southernmost part at the outer part of Scoresby Sund to the northernmost part of the outer Kong Oscar Fjord.

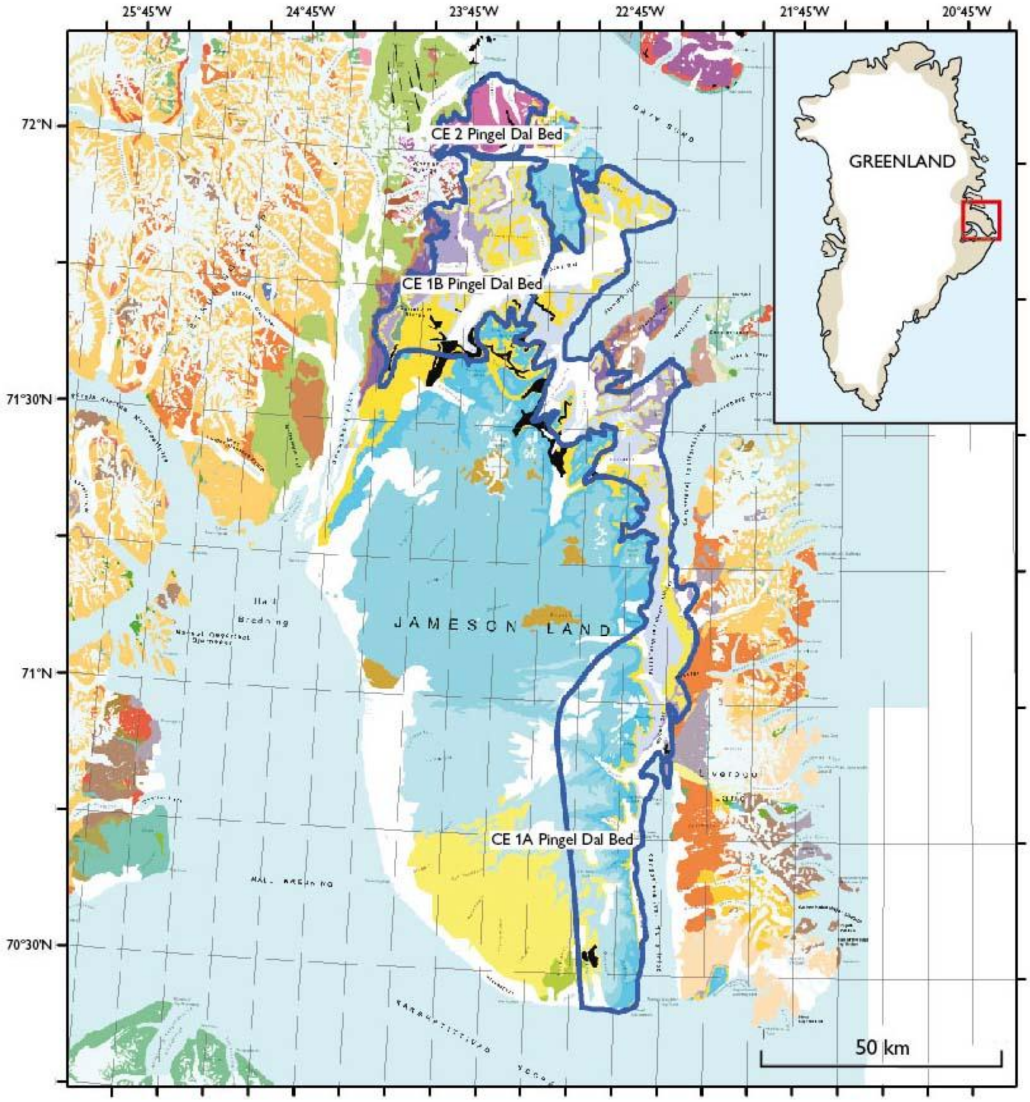

Figure 36. *The Upper Triassic tracts CE 1A-, CE 1B- and CE2 Pingel Dal Bed in the Jameson Land basin. CE 1A and CE 1B Upper Triassic are assesses for undiscovered Reduced Facies Copper type deposits within the Pingel Dal Bed.*

Table 30. *Summary of selected resource assessment results for the Upper Triassic tract CE 1A Pingel Dal Bed assessed for Reduced Facies Copper type deposits*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	2,000	0	830,000

Geological feature assessed

Tract CE 1A Pingel Dal Bed contains the shallow marine lacustrine, cyclically, bedded grey quartz sandstone, red sandstone, and siltstone, yellow dolostone, green mudstone, flat pebble conglomerate and stromatolitic limestone of the Pingel Dal Bed of the Upper Triassic Edderfugledal Member which is the lowermost part of the Upper Triassic Fleming Fjord Formation (Figs. 38-40). The Edderfugledal Member marks the transition to the Middle Jurassic Gipsdalen Formation (Fig. 39). Copper mineralization from this tract is known from different lithofacies at different stratigraphical levels in the Pingel Dal Bed (Harpøth et al. 1986).

Delineation of the permissive tract

The Upper Triassic CE 1A Pingel Dal Bed Reduced Copper type tract boundary to the east is defined by the easternmost exposure of Upper Triassic Fleming Fjord Formation. In the southern and central part of the tract the estimated extension of the Upper Triassic stratum (according to dip of the Upper Triassic stratum towards the centre of the basin) to a depth of 1 km used to define the western boundary of the tract. In the northern part of the tract the approximated extent of known copper mineralization within the Pingel Dal Bed is used to define the western boundary. This, somewhat arbitrary boundary, separates the tract CE 1A Pingel Dal Bed from the tract CE 1B Pingel Dal Bed.

Geological criteria

The following description of the copper mineralization hosted within the Pingel Dal Bed is modified from Harpøth et al. (1986). Persistent copper mineralization is known within the Upper Triassic Pingel Dal Bed. Three lithofacies host the mineralization: (i) a 0.5–1 m thick black, silty mudstone with sand lenses which laterally interfingers with (ii) 1–2 m thick beds of alternating light grey, flaser-bedded sandstone and black, silty shales. The two types occur in the upper part of the Pingel Dal Bed and are overlain by red sandstone. type (iii) is situated 15 m higher in the sequence where it forms two 0.2–1.3 m thick, yellowish weathered dolomitic mudstone horizons interbedded in red mudstones. The copper minerals form stratiform, fine-grained disseminations within the entire thickness of types (i) to (ii) and the mineralised horizons show an extreme lateral persistency. The clay-silt lamina in the mineralised horizons are characterised by relatively abundant microscopic plant fragments.

Known deposits

There are no known deposits within the tract.

Prospects, mineral occurrences, and related deposit types

Copper mineralization of the Pingel Dal Bed is known from silty mudstones with plant fragments, covering approximately 1,000 km^2. The copper mineralization occurs as stratiform, fine-grained disseminations in the entire thickness of three specific lithofacies. The main copper sulfide is chalcocite with minor bornite, blaubleibender covellite, chalcopyrite and pyrite. Results from rock chip samples (n=29) from the mineralization yield an average of 0.2% Cu over 1.1 m with a range of 0.02–0.50% Cu over 0.3–1.9 m (Table 31).

Table 31. *Summary of average chip-sample results of the copper mineralised Pingel Dal Bed. Table modified from Harpøth et al. (1986)*

Lithofacies type (mineralization type)	Locality	Number of sections	Thickness (cm)	Cu (%)	Zn (ppm)	Pb (ppm)	Ag (ppm)
(i) silty mudstone with sand lenses	South of Passagen	10	45 (30–100)	0.22 (0.015 –0.48)	-	-	-
(ii)) alternating light grey, flaser-bedded sandstone and black, silty shales	South-east of Fleming Fjord	13	165 (140–190)	0.12 (0.06 –0.22)	90	30	1.2
(iii) yellowish weathering dolomitic mudstones horizons interbedded in red mudstones	North-west of Fleming Fjord	6	120 (100–130)	0.24 (0.05 –0.52)	100	15	2.4

Exploration history

For the Upper Triassic of the eastern part of Jameson Land Basin (tract CE 1A Pingel Dal Bed) several exploration campaigns have been carried out. The exploration history is summarised by Harpøth et al. (1986) and the following is from this publication. Prior to 1972, mineralization in the Triassic was virtually unknown. Malachite-stained boulder of Triassic sandstone had been observed in Pingel Dal in 1900 and traces of galena had been noted in Triassic limestone on Wegener Halvø. During reconnaissance work carried out by the exploration company Nordic Mining Company in the Upper Permian limestone in 1972, copper- and lead-bearing boulders were collected in Devondal and in 1973 mineralization was found in outcrop in Lower Triassic arkoses (Thomassen 1974). This find led to a semi-regional reconnaissance of the Triassic of the Jameson Land Basin, as well as detailed investigations of the Devondal area in 1974–76 and 1979–80. The exploration programme comprised stream, soil and rock geochemistry, lithostratigraphic mapping of selected areas as well as chip sampling and shallow diamond drilling (4 holes – total 41 drill metres) (Thomassen 1982)).

Grade and tonnage model selection

Based on the characteristics of the mineralization in the Upper Triassic Pingel Dal Bed the assessment team found it justified to use the Sediment-hosted Copper, Reduced Facies Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

The assessment team found that the nature and particularly the persistency of the mineralization over an area of more than 1,000 km^2, together with the very limited work that had been carried out provided the rationale for the estimation.

Table 32. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for the Upper Triassic CE 1A Pingel Dal Bed, Reduced Facies Copper type*

Consensus undiscovered deposit estimate					**Summary statistics**					**Area (km^2)**	**Deposit density (N/km^2)**
N90	**N50**	**N10**	**N05**	**N01**	**N_{und}**	**s**	**Cv%**	**N_{known}**	**N_{total}**		
0	0	0	2	4	0.21	0.76	360	0	0.21	2,000	0.00011

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	1	3	5
Individual 2	0	0	1	2	3
Individual 3	0	0	0	2	3
Individual 4	0	0	0	2	5
Individual 5	0	0	0	1	3
Individual 6	0	0	0	0	2
Individual 7	0	0	0	2	5
Individual 8	0	0	0	2	4
Individual 9	0	0	1	2	4
Individual 10	0	0	0	1	2
Individual 11	0	0	0	1	2
Consensus	0	0	0	2	4

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 32), Reduced Facies Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Reduced Facies Copper, model 30b.2' using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 33, and the results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 37). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 33. *Results of Monte Carlo simulations of undiscovered resources in the Upper Triassic tract CE 1A Pingel Dal Bed, Reduced Facies Copper type deposits [t=metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	2,000,000	830,000	0.07	0.91
Ag (t)	0	0	0	0	0	560	0.02	0.96
Co (t)	0	0	0	0	0	25,000	0.04	0.96
Rock (mt)	0	0	0	0	86	39	0.07	0.91

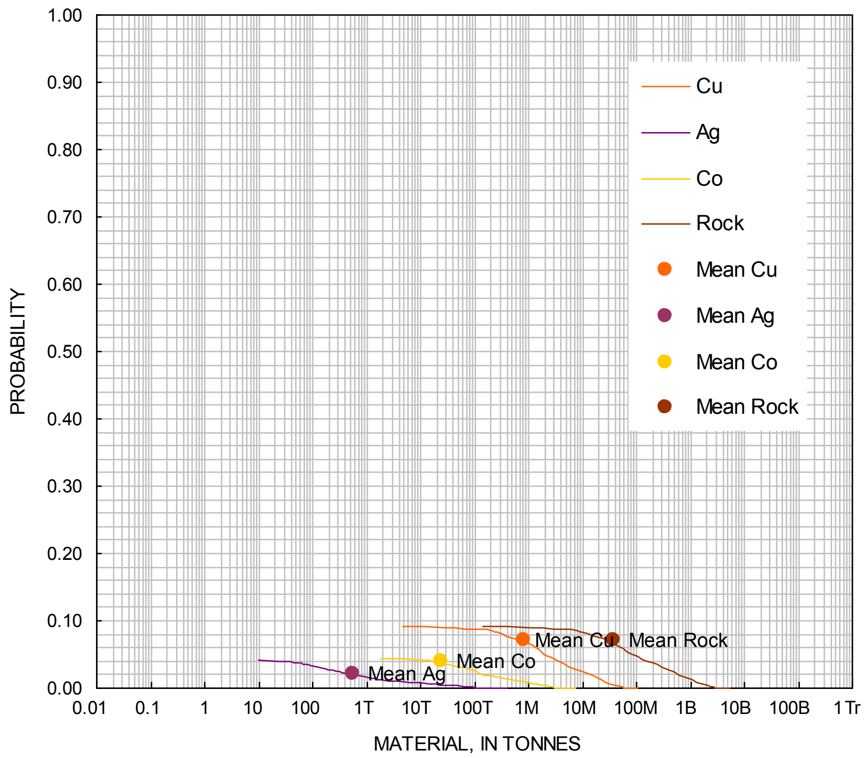

Figure 37. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the Upper Triassic tract CE1A Pingel Dal Bed, Reduced Facies Copper type deposits. T=thousands, M=millions, B=billions, Tr=trillions.*

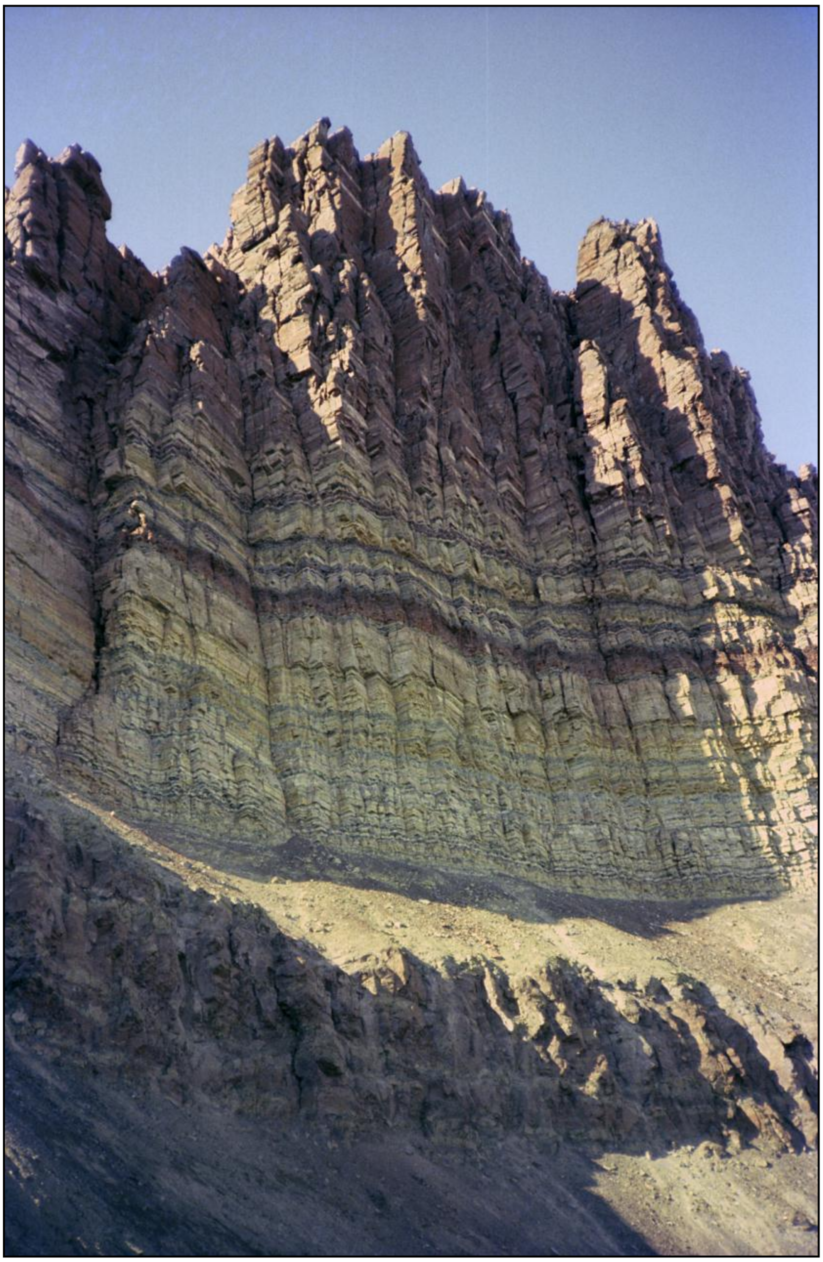

Figure 38. *Multicoloured cyclically bedded sandstones, siltstone, dolostone and mudstone of the Pingel Dal Bed; several of the lithofacies are copper mineralised. Cliff face is c. 60 m high. Photo from presentation by Thomassen.*

Figure 39. *The Edderfugledal Member (yellow strata), hosting the copper mineralised Pingel Dal Bed, resting on the Gipsdalen Formation and overlain by the Malmros Klint Member. Photo from Thomassen & Svensson (1979).*

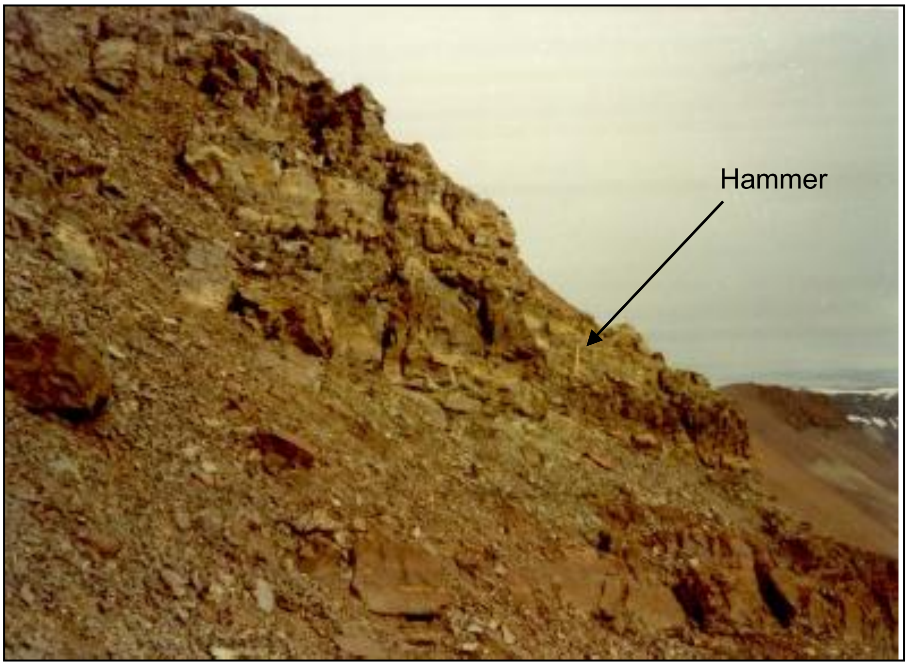

Figure 40. *Pingel Dal Bed at Malmros Klint. Cu-bearing, yellowish beds (hammer 45 cm) underlain by red, unmineralised mudstones. Photo from Thomassen & Svensson (1979).*

The Upper Triassic tract CE 1B Pingel Dal Bed – Reduced Facies Copper type

Location

The Upper Triassic tract CE 1B Pingel Dal Bed is located in the western part of the Jameson Land Basin, stretching from the central part of Schuchert Dal at the western part of the Jameson Land to the central part of Kong Oscar Fjord (Fig. 36).

Table 34. *Summary of selected resource assessment results for the Upper Triassic tract CE 1B Pingel Dal Bed assess for Reduced Facies Copper type deposits*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	1,000	0	300,000

Geological feature assessed

Tract CE 1B Pingel Dal Bed contains the shallow marine-lacustrine cyclically bedded grey quartz sandstone, red sandstone, and siltstone, yellow dolostone, green mudstone, flat pebble conglomerate and stromatolitic limestone of the Pingel Dal Bed of the Edderfugledal Member which is the lowermost part of the Upper Triassic Fleming Fjord Formation (Figs. 38-40). The Edderfugledal Member marks the transition to the Middle Jurassic Gipsdalen Formation (Fig. 39). Copper mineralizations are known from different lithofacies at different stratigraphic levels within the Pingel Dal Bed.

Delineation of the permissive tract

The eastern tract boundary of tract CE 1B Pingel Dal Bed is somewhat arbitrary placed. According to Clemmensen (1980) the Edderfugledal Member, which includes the Pingel Dal Bed, is present in the western part of the Jameson Land Basin. However, compared to the eastern part (tract CE 1A Pingel Dal Bed,) of the basin, the exposed Edderfugledal Member in the western part of the basin is more limited, based on the mapped boundary between Upper Triassic Fleming Fjord and Middle Triassic Gipsdalen Formation, and is also appears less well exposed.

Geological criteria

The following description of the copper mineralization hosted within the Pingel Dal Bed is modified from Harpøth et al. (1986). Persistent copper mineralization is known within the Upper Triassic Pingel Dal Bed. Three lithofacies host the mineralization: (i) a 0.5–1 m thick black, silty mudstone with sand lenses which laterally interfingers with (ii) 1–2 m thick beds of alternating light grey, flaser-bedded sandstone and black, silty shales. The two types occur in the upper part of the Pingel Dal Bed and are overlain by red sandstone. type (iii) is situated 15 m higher in the sequence where it forms two 0.2–1.3 m thick, yellowish weathered dolomitic mudstone horizons interbedded in red mudstones. The copper minerals form stratiform, fine-grained disseminations within the entire thickness of types (i) to (ii) and the mineralised horizons show an extreme lateral persistency. The clay-silt lamina in the mineralised horizons are characterised by relatively abundant microscopic plant fragments.

Known deposits

There are no known deposits within the tract.

Prospects, mineral occurrences, and related deposit types

No copper mineralizations are known in the Edderfugledal Member in the western part of the basin. However, only limited work on the Edderfugledal Member has been carried out. Four stratigraphic profiles have been sampled and, although they include Edderfugledal Member, the profiles and related observations were more focused on the stratigraphic levels above the member. The exposure is limited compared to the exposure in tract CE 1A Pingel Dal Bed, where copper mineralization within the Pingel Dal Bed is known over an area of approximately 1,000 km^2 as discussed above and summarised in Table 31.

Exploration history

For the Upper Triassic of the eastern part of Jameson Land Basin (tract CE 1A Pingel Dal Bed) several exploration campaigns have been carried out. The exploration history is summarized above. As part of the Nordic Mining Company‘s exploration campaign in 1975 one team carried out work on the Upper Triassic successions in the western part of the Jameson Land Basin (tract CE 1B Pingel Dal Bed), but no copper mineralization in the Pingel Dal Bed of the Edderfugledal Member, are reported. However, it appears from the report, that most of the work was focused on Upper Triassic members other than the Edderfugledal Member.

Grade and tonnage model selection

Based on the characteristics of the mineralization in the Upper Triassic Pingel Dal Bed the assessment team found it justified to use the Sediment-hosted Copper, Reduced Facies Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

No copper mineralization has been found within the Pingel Dal Bed in the western part of Jameson Land (tract CE 1B Pingel Dal Bed). However, the assessment team found that an assessment of tract CE 1B Pingel Dal Bed still was justified because; (i) lithofacies hosting the copper mineralization in the eastern part of the basin are also present in the western part; (ii) the limited amount of previous work focused on the Pingel Dal Bed; (iii) Generally less well exposures of the Pingel Dal Bed in the western area; and (iv) the large areal extent of the tract CE 1B Pingel Dal Bed.

Table 35. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for the Upper Triassic CE 1A Pingel Dal Bed, Reduced Facies Copper type*

Consensus undiscovered deposit estimate					**Summary statistics**					**Area (km^2)**	**Deposit density (N/km^2)**
N90	**N50**	**N10**	**N05**	**N01**	**N_{und}**	**s**	**Cv%**	**N_{known}**	**N_{total}**		
0	0	0	0	2	0.06	0.37	610	0	0.06	1,000	0.00006

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	0	2
Individual 2	0	0	0	1	2
Individual 3	0	0	0	1	2
Individual 4	0	0	0	2	2
Individual 5	0	0	0	1	1
Individual 6	0	0	0	1	3
Individual 7	0	0	0	0	2
Individual 8	0	0	0	0	3
Individual 9	0	0	0	0	1
Individual 10	0	0	0	0	1
Individual 11	0	0	0	0	1
Consensus	0	0	0	0	2

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 35), Reduced Facies Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Reduced Facies Copper, model 30b.2' using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 36, and the results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 41). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 36. *Results of Monte Carlo simulations of undiscovered resources in the Upper Triassic tract CE 1B Pingel Dal Bed, Reduced Facies Copper type deposits [t=metric tons; Mt; mega-tonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	0	300,000	0.03	0.96
Ag (t)	0	0	0	0	0	62	0.01	0.99
Co (t)	0	0	0	0	0	9,600	0.01	0.99
Rock (mt)	0	0	0	0	0	13	0.03	0.96

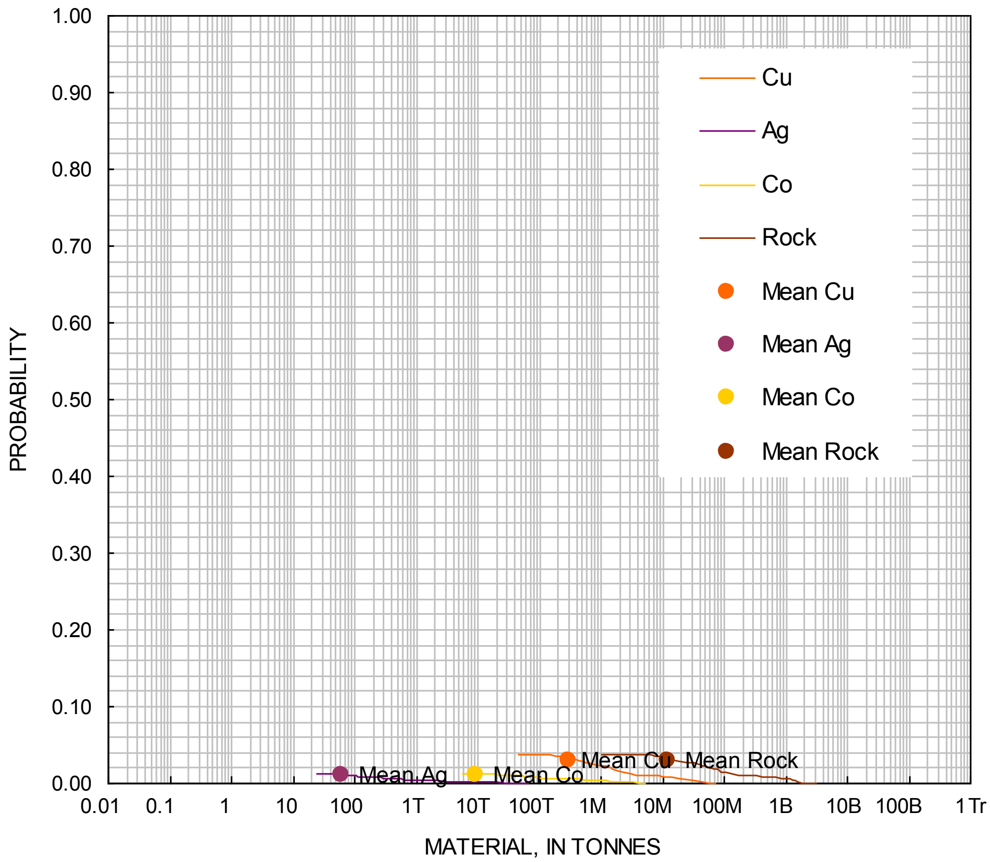

Figure 41. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the Upper Triassic tract CE 1B Pingel Dal Bed, Reduced Facies Copper type deposits. T=thousands, M=millions, B=billions, Tr=trillions.*

Assessment of Sediment-hosted Copper deposit for Neoproterozoic Eleonore Bay Supergroup, central East Greenland – Reduced Facies Copper type

The Neoproterozoic Eleonore Bay Supergroup (EBS) represents an up to 14 km thick, allochtonous sediment sequence. The supergroup has been intruded by numerous S-type late to post-kinematic Caledonian granites.

Stratiform and stratabound copper mineralizations are present at eight levels within a 3 km thick stratigraphic column, representing both the lower and upper part of the EBS. The column comprises thin-bedded quartzites and shales of the Nathorst Land Group Land (formerly referred to as the Argillaceous-Arenaceous Series), well-sorted sandstones (most quartzites), sandy shales and shales of the Lyell Land Group (formerly referred to as the Quartzite Series) and a characteristic sequence of multicoloured alternating beds of shales, mudstones, arenaceous dolomites, limestone dolomitic shales, sandstones and shales (formerly the Multicoloured Series) which makes up the Ymer Ø Group.

Deposit type assessed

Deposit type: Sediment-hosted Copper.

Descriptive model: Sediment-hosted Copper, Reduced Facies Copper type (Cox et al. 2003).

Grade and tonnage model: Sediment-hosted Copper, Reduced Facies Copper type (Cox et al. 2003).

Sources of information

The principal sources of information used for the assessment of the tracts in the Neoproterozoic Eleonore Bay Supergroup in central East Greenland for the Reduced Facies Copper type are given in Appendix A.

The Neoproterozoic tracts CE 1-6 EBS and CE 9-16 EBS, Eleonore Bay Supergroup – Reduced Facies Copper type

Location

The Neoproterozoic tracts, CE 1-6 EBS and CE 9-16 EBS (Fig. 42A and 42B), belong to the Eleonore Bay Supergroup, and consists of areas in central East to Northeast Greenland from Kong Oscar Fjord in the south (72°N) to Ardencaple Fjord in the north (75°N).

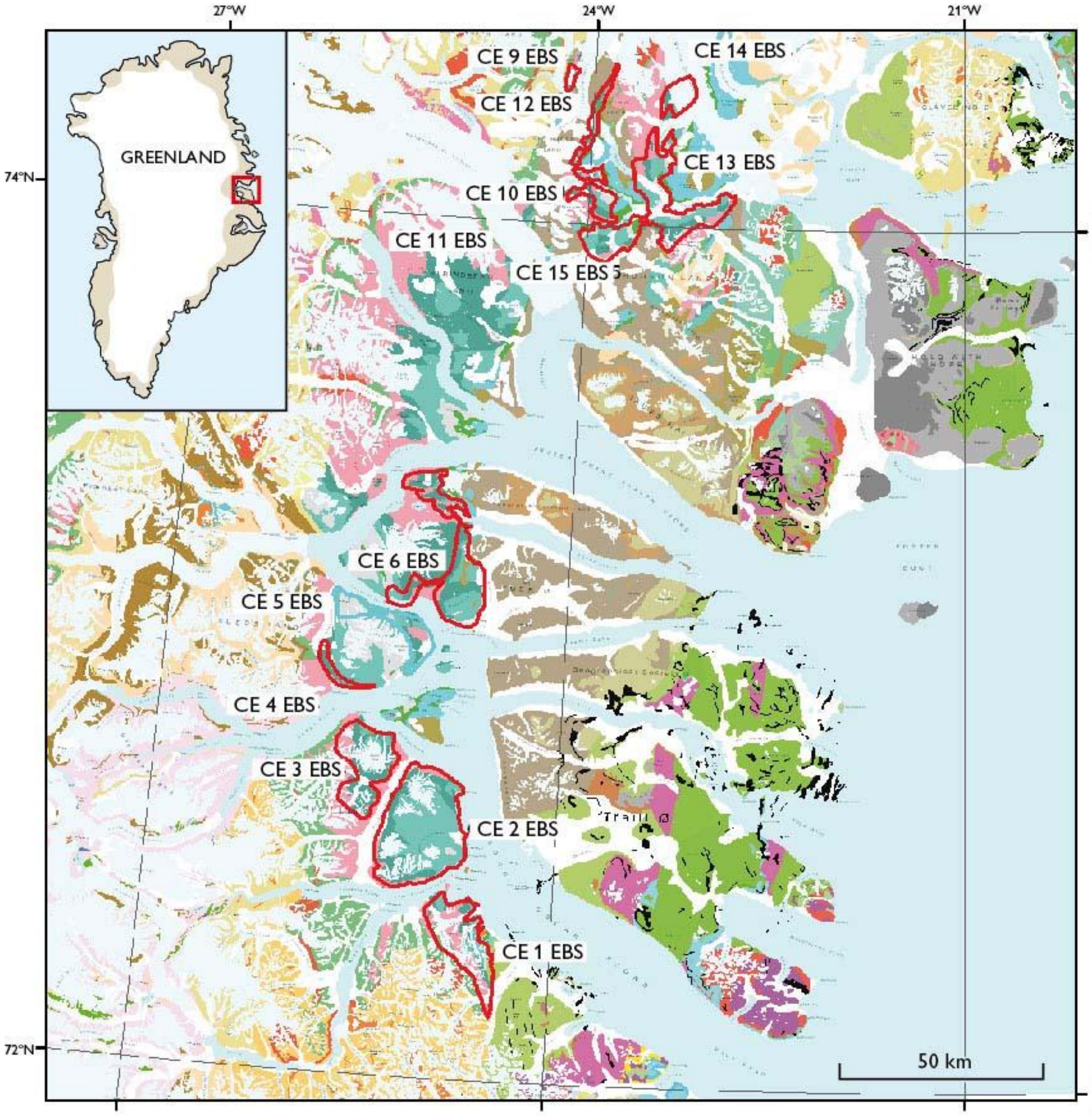

Figure 42A. *Distribution of the Neoproterozoic tracts CE 1-6 EBS and CE 9-15 EBS, The tracts contain the Neoproterozoic Elenore Bay Supergroup (EBS) assessed for undiscovered Reduced Facies Copper type deposits at the boundary zone between the Lyell Land Group and Ymer Ø Group.*

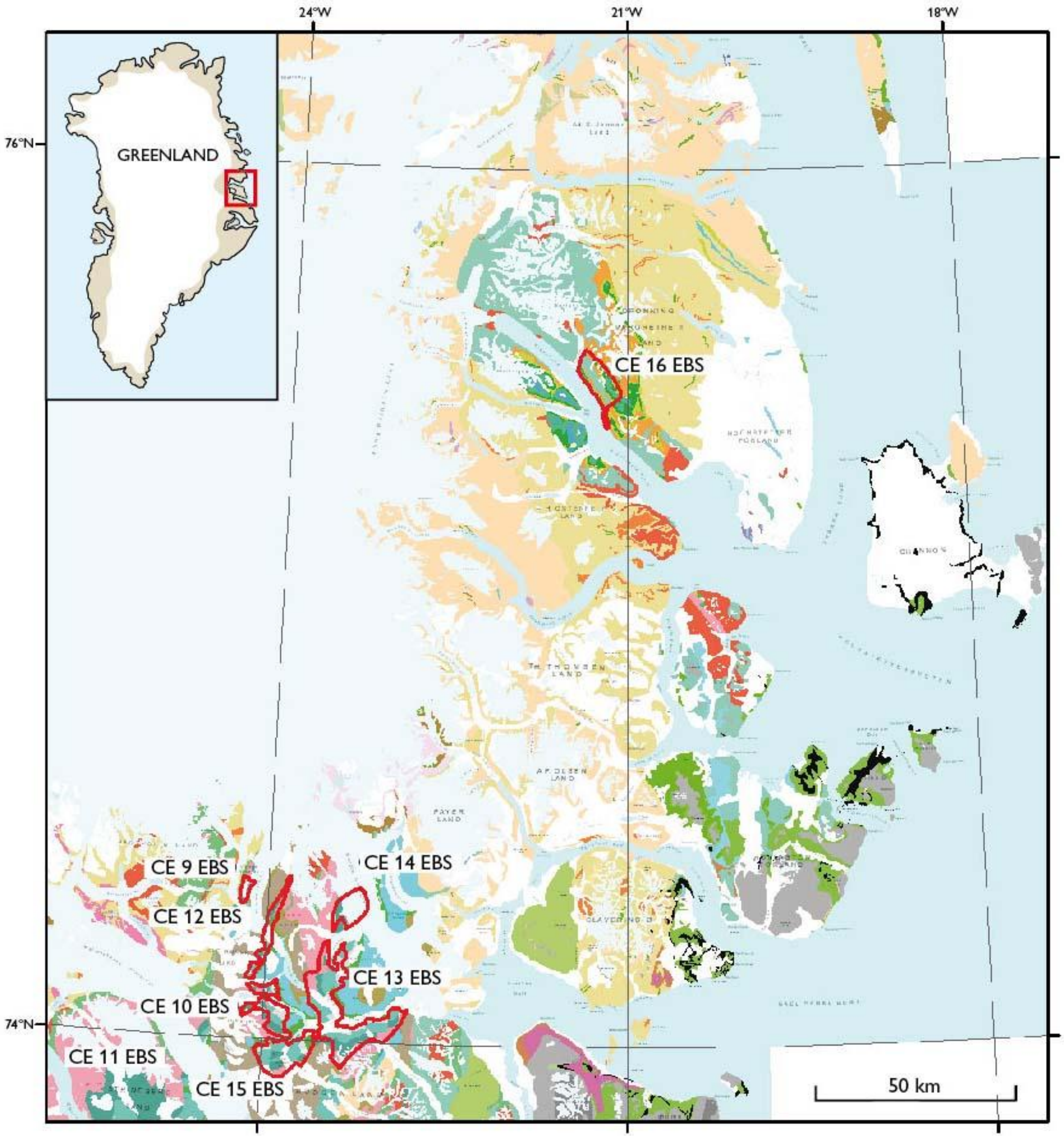

Figure 42B. *Distribution of the Neoproterozoic tract CE 9-15 EBS and Tract CE 16 EBS. The tracts contain the Neoproterozoic Elenore Bay Supergroup (EBS) assessed for undiscovered Reduced Facies Copper type deposits at the boundary zone between the Lyell Land Group and Ymer Ø Group.*

Table 37. *Summary of selected resource assessment results for the Neoproterozoic tracts CE 1-6 EBS and CE 9-16 EBS of the Eleonore Bay Supergroup assessed for Reduced Facies Copper type deposits*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	2111	0	730,000

Geological feature assessed

Tract CE 1-6 EBS, CE 7-15 EBS and CE 16 EBS contains the allochtonous sedimentary sequence of the Neoproterozoic Eleonore Bay Supergroup (EBS) (~663 Ma to 920 Ma) which has a total thickness of approximately 14 km, of which the Lyell Land Group and Ymer Ø Group, hosting known copper mineralizations, constitute the uppermost ~3 km of the EBS. The sediments were deposited in a Neoproterozoic basin along the Laurentian margin in response to early rifting of the Iapetus ocean. The basin is exposed north-south along 450 km and east-west for 200 km. Four stages of basin evolution are recorded. Stage 1 involves formation of a rapidly subsiding siliciclastic shelf followed by a stage 2 that involves a more stable siliciclastic shelf. This was followed by stage 3 in which a carbonate platform developed, which was followed by Stage 4, a glaciogenic deposition of the Tillite Group (not part of the EBS). The unconformity of the base of the Tillite Groups is estimated to 610–570 Ma. The basin has uniform depositional conditions parallel to the strike of the basin for at least the dominant siliciclastic part of the succession. The EBS succession is characterised by large-scale cyclic sedimentary patterns. The early part of the EBS succession (at ~920 Ma) was probably at a palaeolatitude around 30°S. The late part of the succession is estimated to have ended at a palaeolatitude of ~40°S.

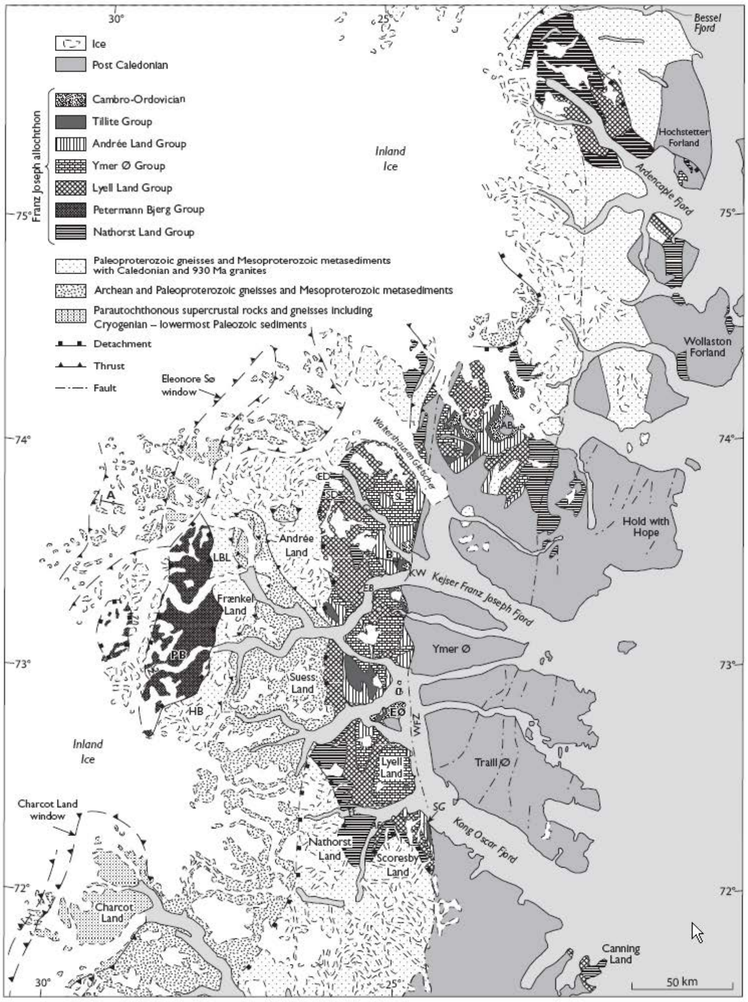

Figure 43. *Simplified geological map showing the distribution of the sediments of the Neoproterozoic Eleonore Bay Basin. From Sønderholm et al. 2008.*

The EBS is subdivided into four stratigraphic groups; the lowermost Nathorst Land Group, the Lyell Land Group, the Ymer Ø Group, and the Andrée Land Group (Figs 43, 44, 45, 46 and 49). The lower 12 km thick Nathorst Land and Lyell Land groups are made up mainly of shallow-marine siliciclastic sandstones and mudstones, related to stage 1 and 2 of the basin evolution. The upper ~2 km Lyell Land Group, the Ymer Ø Group (~1.2 km), and the Andrée Land Group (~1.2 km) are dominated by carbonate-platform deposits with both shallow marine carbonates and deep marine carbonate mud.

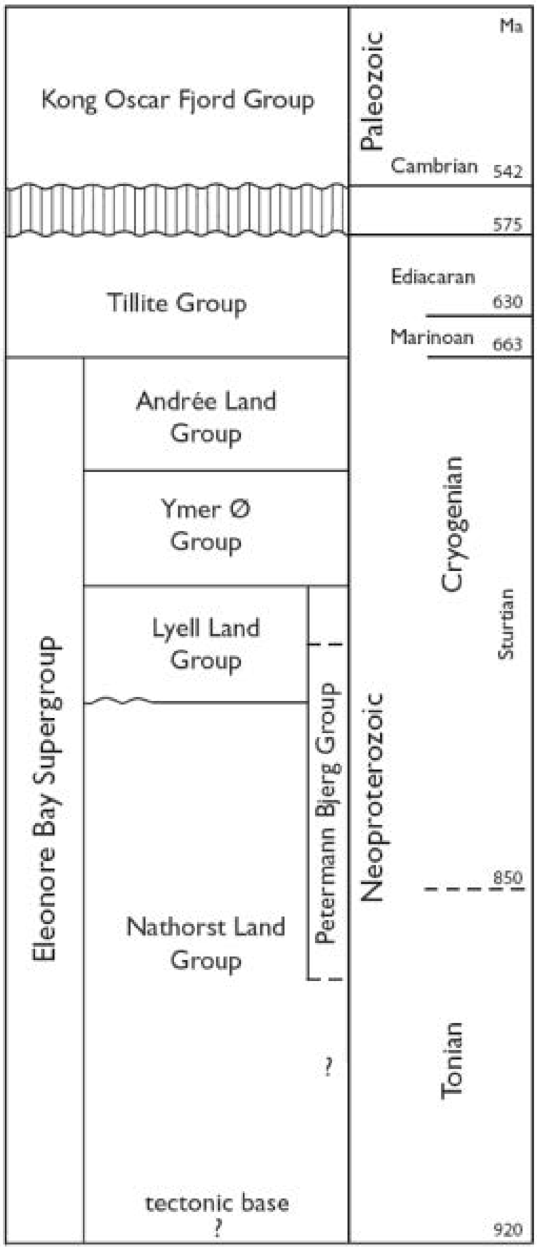

Figure 44. *Lithostratigraphic subdivision of the Neoproterozoic Eleonore Bay Basin. From Sønderholm et al. 2008.*

Delineation of the permissive tract

The boundaries of the individual tracts are defined from the mapped extent of the boundary zone between the Lyell Land Group and the Ymer Ø Group of the EBS, hosting the most persistently mineralised horizon and therefore chosen by the assessment team to be the focus for the assessment; the team decided to treat 14 tracts (CE 1-6 EBS and CE 9-16 EBS) together, due to the same level of information available for them.

Geological criteria

Eight levels of stratiform and stratabound copper mineralization have been observed within a 3 km (Fig. 48). thick stratigraphic section comprising the uppermost part of the Narhorst Land Group, Lyell Land Group and lower part of Ymer Ø Group of the EBS. The characteristics, thickness, grades and consistency of the eight Cu mineralised horizons are summarised in (Table 38). This summary is largely adopted from Harpøth *et al.* (1986). Pb isotopic ratios of strata-bound copper sulphides (chalcocites) yields radiogenic values, and $^{206}Pb/^{204}Pb$ ranges from 18.5 to 26.4 (Jensen 1994), and Pb-Pb isochron of 680 ± 65 Ma have been defined (Jensen 1993). This age is in agreement with the depositional age of the upper part of the EBS. Genetically, the mineralised horizons in the EBS are interpreted as being of syn-sedimentary to early diagenetic in origin. This interpretation is supported by the cementing nature of the copper sulphides, by the selective precipitation in the coarser grained lamina, and by the occurrence of copper mineralised boulders of identical types in the overlying tillites of the Tillite Group. Organic matter is believed to have acted as the reducing agent for sulfide precipitation.

Based on the review and discussions on the copper mineralised horizons and their individual potential for hosting copper deposits of sufficient size the assessment team decided to focus on the copper mineralised horizon number 7‘ (Table 38). This horizon is the most consistent and most mineralised horizon within the EBS.

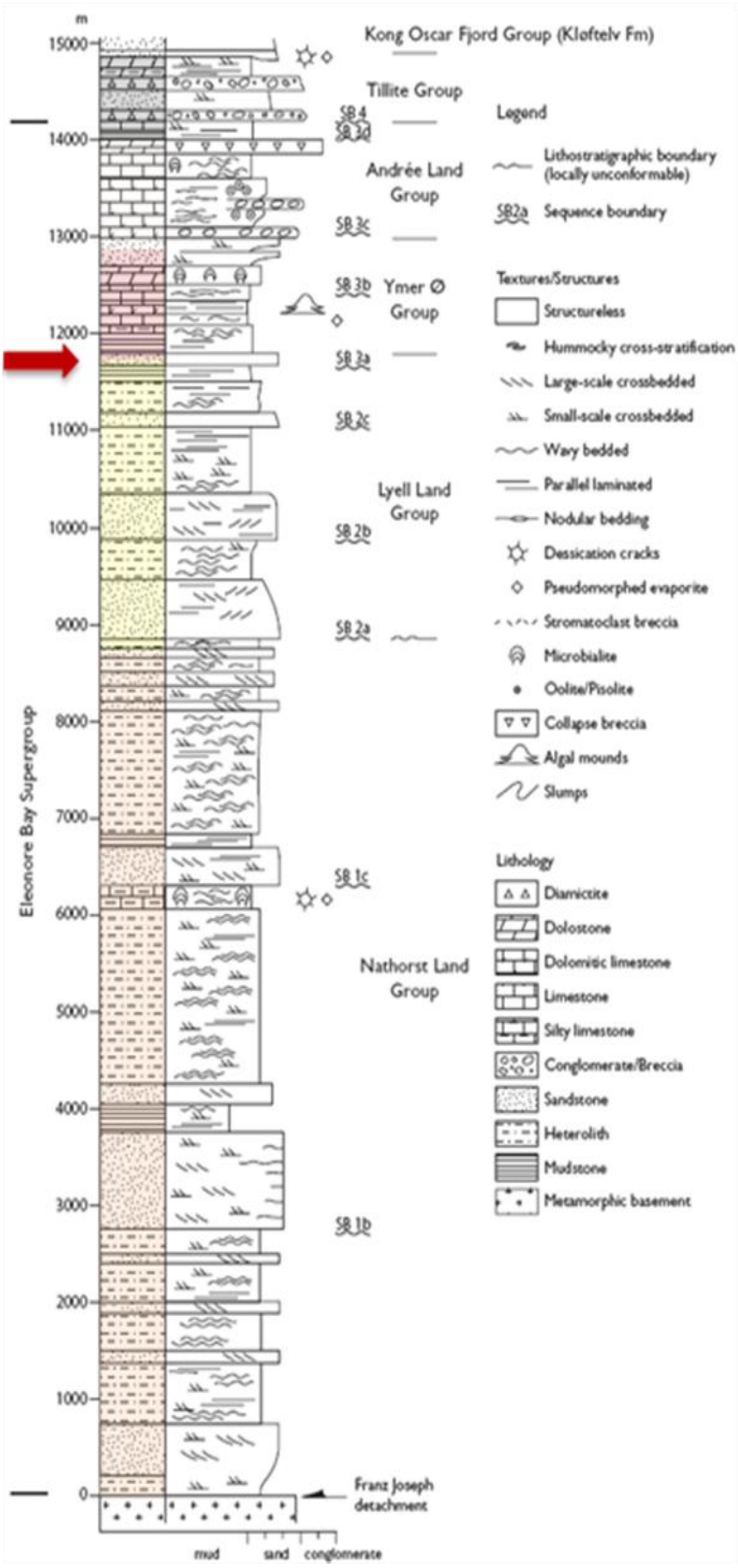

Figure 45. *Generalized section of the Eleonore Bay Supergroup. The red arrow indicates the most widespread and persistent copper mineralization - the „mineralised horizon number 7"* (**Table 38**) *included in the assessment. From Sønderholm et al. (2008).*

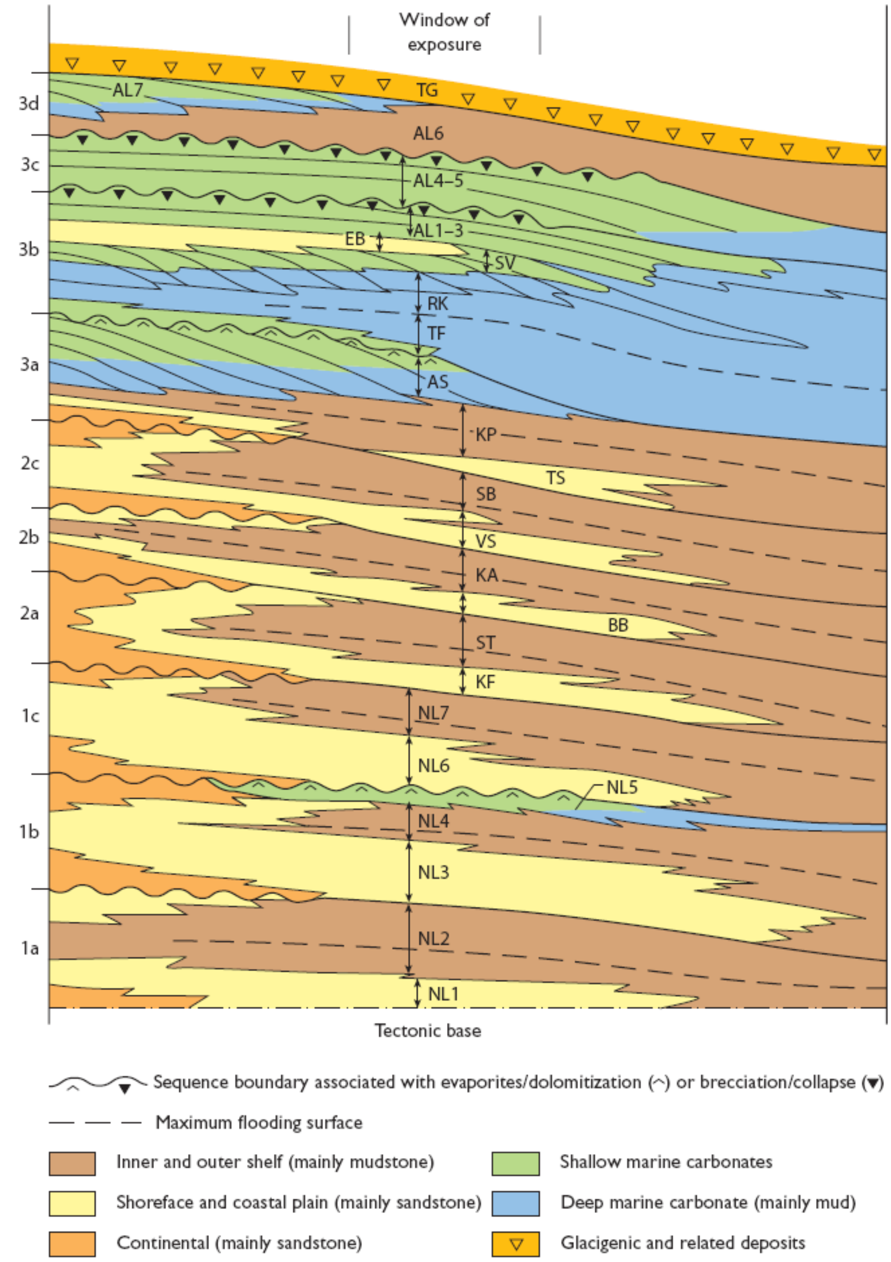

Figure 46. *Tentative sequence stratigraphic cross section for the four stage basin evolution of the Eleonore Bay Basin. From Sønderholm et al. (2008).*

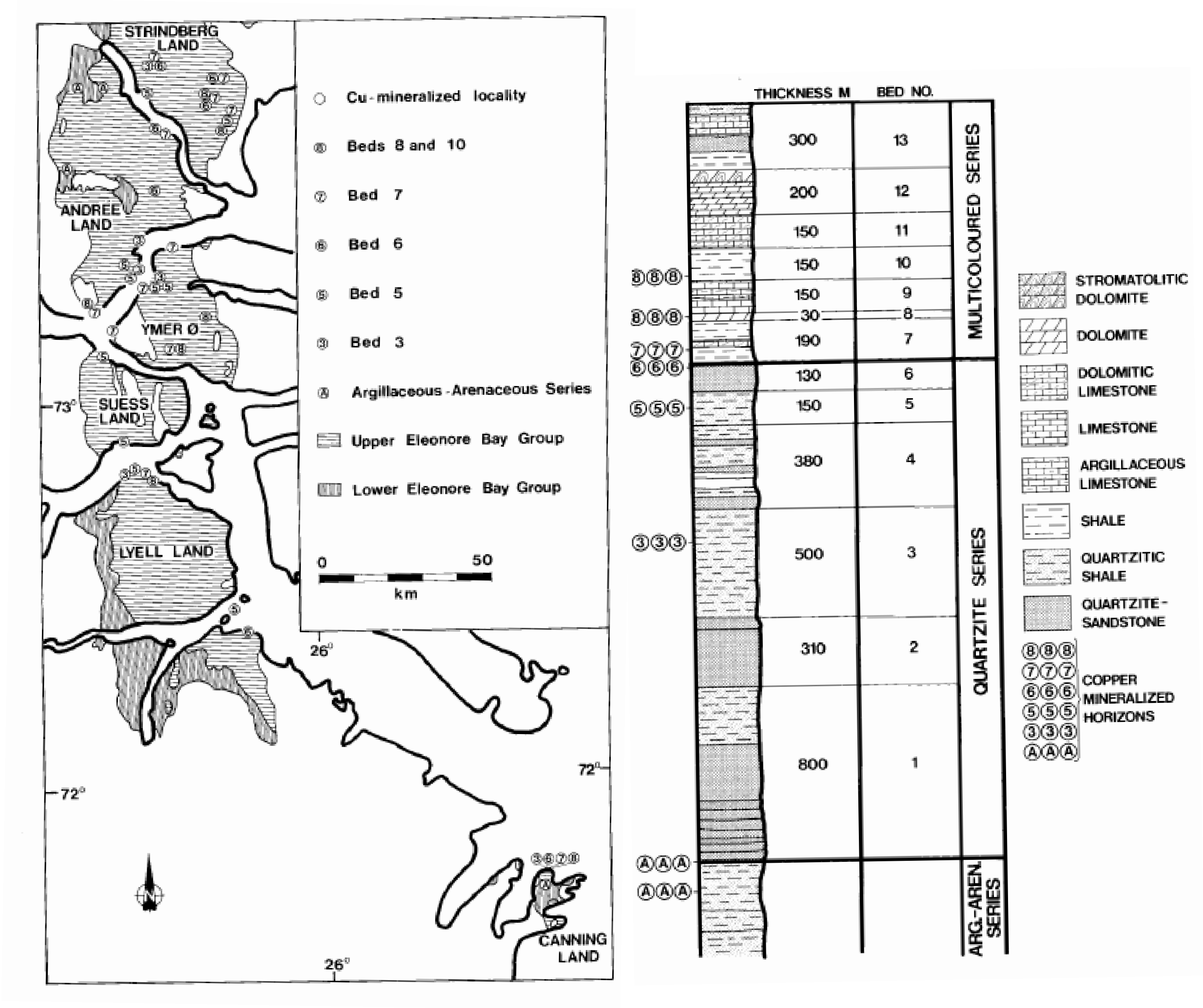

Figure 47. ***A:*** *Distribution of the major copper occurrences outcropping in the EGS south of 74°N.* ***B:*** *Stratigraphic column of the uppermost Nathorst Land Group, the Lyell Land Group, and the lower part of the Ymer Ø Group. Both figures from Harpøth et al. (1986).*

Table 38. *Overview of Cu mineralizations in the EBS based on Harpøth et al. (1986)*

Stratigraphy	Riphean			
Litho-stratigraphy	Lyell Land Group	Ymer Ø Group		
Age		663 Ma		
Lithology (total thickness)	sandstones and mudstones; 2.8 km	sandstones, mudstone and carbonates; 1.3 km		
Cu mineralised horizon number	**6**	**7**	**8a**	**8b**
Thickness of mineralization (m)	0.2 – 1.0	1.0 – 2.0	0.1 – 0.25	0.1 – 0.15
Description of Cu mineralization	Widespread but non-persistent mineralization within pinkish and white quartzite beds. Disseminated sulphides interstitially to coarse-grained quartz.	Most widespread and persistent Cu mineralization in the EBS. Observed distribution of 275 km from south (Canning Land) to north (Strindberg Land). Host rock is monotonous red shale. Shale is calcareous and dolomitic. Mineralization in green intercalations of carbonaceous shale ranging in thickness from a few cm to a few m. Two distinct mineralised horizons occur 10–15 m and 60–70 m above the top of a white quartzite bed that marks the top of the Lyell Land Group. Cu-sulphides occur as disseminated fine grains, locally discrete blebs (up to 5 cm). Where chalcopyrite is absent, the mineralization is difficult to recognise in the field as chalcocite line up parallel to bedding planes that rarely exceed a few mm.	Scattered but widespread stratiform copper-mineralised beds in dolomite or dolomitic shale.	Scattered but widespread stratiform copper-mineralised beds in dolomite or dolomitic shale.
Mineralization (in brackets reported Cu grades in percent)	Tetrahedrite-chalcopyrite-pyrite (Cu values from 0.4 – 3.1% in hand-specimens; 35 kg bulk sample from 100 kg of blasted rock from a 1–2 m thick zone mineralised mainly along joints yields 1.35% Cu, 1.07% Sb, 0.14% Zn and 24 g/t Ag.	Chalcocite-chalcopyrite (average content of mineralised green shales is from 0.25% to 1.5 % with an average of 0.7 %; selected samples yield up to 6 % Cu; average Ag content is low with a Cu/Ag ratio of 1000–1500).	Chalcocite (Cu content low).	Chalcocite-(bornite-chalcopyrite-pyrite) (grade estimated to be 0.1 % Cu over a thickness of 10–25 cm).

			Stratigraphy
Nathorst Land Group	Lyell Land Group		**Litho-stratigraphy**
920 Ma			**Age**
sandstones, mudstones and carbonates; 9 km	sandstones and mudstones; 2.8 km		**Lithology** (total thickness)
A (two horizons; the label of the horizons is adopted from Harpøth et al. 1986)	(the label of the horizons is adopted from Harpøth et al. 1986)	**5**	**Cu mineralised horizon number**
0.2 – 5.0	0.5 – 2.0	0.2 – 2.0	**Thickness of mineralization (m)**
Two stratabound Cu-mineralised levels within quartzite; one 150 m below the top of the Nathorst poor lateral persistency, graphite always associated with the sulphides, traceable for more than 10 km.	Widespread Cu mineralization in dark green quartzitic shale interbedded with quartzites. Three types of mineralization: I) stratiform Cu in the more coarse grained units within finely laminated shales siltstone, II) disseminated framboids of sulphides associated with organic matter in shale and III) coarse-grained quartzites cemented by quarts and minor chalcopyrite and pyrite.	Widespread mineralization within intercalations of white quartzites and green quartzitic shale in a sequence dominated by dark red quartzitic shale. Sulphides partly in detrital quartz grains, partly as cementing phases.	**Description of Cu mineralization**
Pyrrhotite- pyrite-chalcopyrite (0.25 – 2.5 %, average grade estimated to be < 0.1 %).	Pyrite-chalcopyrite-(galena-sphalerite) (Cu values between 0.05 – 0.5 %; average copper grade is estimated to be < 0.1 %).	Chalcopyrite-(bornite-chalcocite-pyrite) (from 0.1 – 1.25 %, average grade is estimated to be < 0.1 %).	**Mineralization** (in brackets reported Cu grades in percent)

Known deposits

There are no known deposits within the tracts.

Prospects, mineral occurrences, and related deposit types

The description of the various copper occurrences within the EBS is given in Table 38. The highest grades and most promising copper prospects related to ‗mineralised horizon number 7‘ (Figs 47A and 50). The location of known copper occurrences related to this horizon can be seen in Fig. 47B. The known highest grades occurrences related to ‗mineralised horizon number 7‘ are located outside tracts CE–1-6 EBS and CE 9–16 EBS at Strindberg Land at Andrée Land (tracts CE 7–8 EBS). Stratabound scheelite- and arsenopyrite mineralization is known from Alpefjord (East of tract CE 1 EBS) within quartzites and sandstones of the Lyell Land and Nathorst groups (Ghisler 1981).

Exploration history

The description of the exploration history for copper in the EBS below is given by Ghisler *et al.* (1980), and summarized by Harpøth *et al.* (1986). Copper mineralization in the Lower and Upper EBS were found by the Geological Survey of Greenland (GGU) in Canning Land in 1971. These discoveries were followed up by several other investigations through the mid-seventies by various research groups and the exploration company Nordic Mining Company A/S, who later carried out investigations on Ymer Ø and Canning Land.

Grade and tonnage model selection

The model for the copper mineralization in the ‗mineralised horizon number 7‘ (Table 38) was discussed at the workshop. The Reduced-facies Copper Model was found to be appropriate, but the mineralization as an exact analogy to the Kupferschiefer in Poland was found to be somewhat problematic. Stendal & Ghisler (1984) suggest that the stratabound mineralization in the EBS displays similarities with part of the Zambian copper belt and the Precambrian Belt Supergroups in Idaho and Montana with respect to geological setting, regional extent, and types of host rock as well as sulfide paragenesis. Also it was pointed out by members of the assessment team that the stratabound mineralization in the EBS may have similarities with Cu deposits in the Neoproterozoic Adelaidean Sequence of the Stuart Shelf, South Australia.

It was also pointed out that algal mounds and pseudomorphed evaporate were present immediately above the ‗mineralised horizon 7‘. These could act as sources for brines in the copper mineralising process, which is of importance in the Reduced Facies Copper model. Also, Stendal & Ghisler (1984) reports framboidal pyrite with $\delta^{34}S$ = 5.5‰ associated with organic matter in some stratigraphic levels suggest influence of biochemical activity; another important ore control in Reduced Facies Copper type mineralization. Dr. Sønderholm, who presented the stratigraphic details of the EBS, agreed that it could be possible that evaporates may have been present in the vicinity of the shale units. It was also noted, that the lowermost part of the Ymer Ø Group was induced by a major transgressive event, possibly accompanied by a shift to more arid climate. Most Reduced-facies Copper deposits are formed during transgression of reduced marine sediments over redbed deposits (Cox et al. 2003).

Based on the discussion and the reviews of previous work by various researchers on the mineralization, the assessment team found it justified to use the Sediment-hosted Copper, Reduced Facies Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

The assessment team found that the setting of the Eleonore Bay basin and the observed persistent nature of the mineralization make Reduced-facies Copper mineralization an interesting target within the EBS. Furthermore, only limited investigation has been carried out for this model within the tracts CE1–6 EBS and CE 9–16 EBS. This, together with the consistent lateral extent of the mineralization, the vast area that the tracts occupies, and the very uniform depositional conditions that characterised the EBS, makes the tracts interesting targets for undiscovered Reduced Facies Copper type mineralization. It should also be kept in mind, that most of the ‗mineralised horizon number 7‘ is un-exposed and has been investigated only were it outcrops in cliffs. No geophysical surveys focused on Cu-sulphides or drilling have been carried out. However, the assessment team raised questions about the grades of the known mineralizations within these tracts (which is lower than those found in tracts CE 7 and 8 EBS). Also, questions were raised about the lack of evidence for an efficient long-lived fluid system.

Table 39. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for the tracts CE 1-6 EBS CE 9-16 EBS Eleonore Bay Supergroup, Reduced Facies Copper type deposits*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	0	1	4	0.17	0.69	420	0	0.17	2,111	0.000078

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	1	3
Individual 2	0	0	0	2	4
Individual 3	0	0	0	2	2
Individual 4	0	0	0	1	3
Individual 5	0	0	0	2	4
Individual 6	0	0	0	1	2
Individual 7	0	0	0	1	2
Individual 8	0	0	0	1	5
Individual 9	0	0	0	2	7
Individual 10	0	0	0	1	1
Consensus	0	0	0	1	4

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 39), Reduced Facies Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Reduced Facies Copper, model 30b.2' using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 40, and the results of the Monte Carlo simulation are presented as cumulative frequency plots in Fig. 48. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 40. *Results of Monte Carlo simulations of undiscovered resources in the tracts CE1-6 EBS and CE 9-16 EBS Eleonore Bay Supergroup, Reduced Facies Copper type deposits [t=metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	1,300,000	780,000	0.06	0.92
Ag (t)	0	0	0	0	0	260	0.02	0.97
Co (t)	0	0	0	0	0	25,000	0.03	0.97
Rock (mt)	0	0	0	0	51	33	0.06	0.92

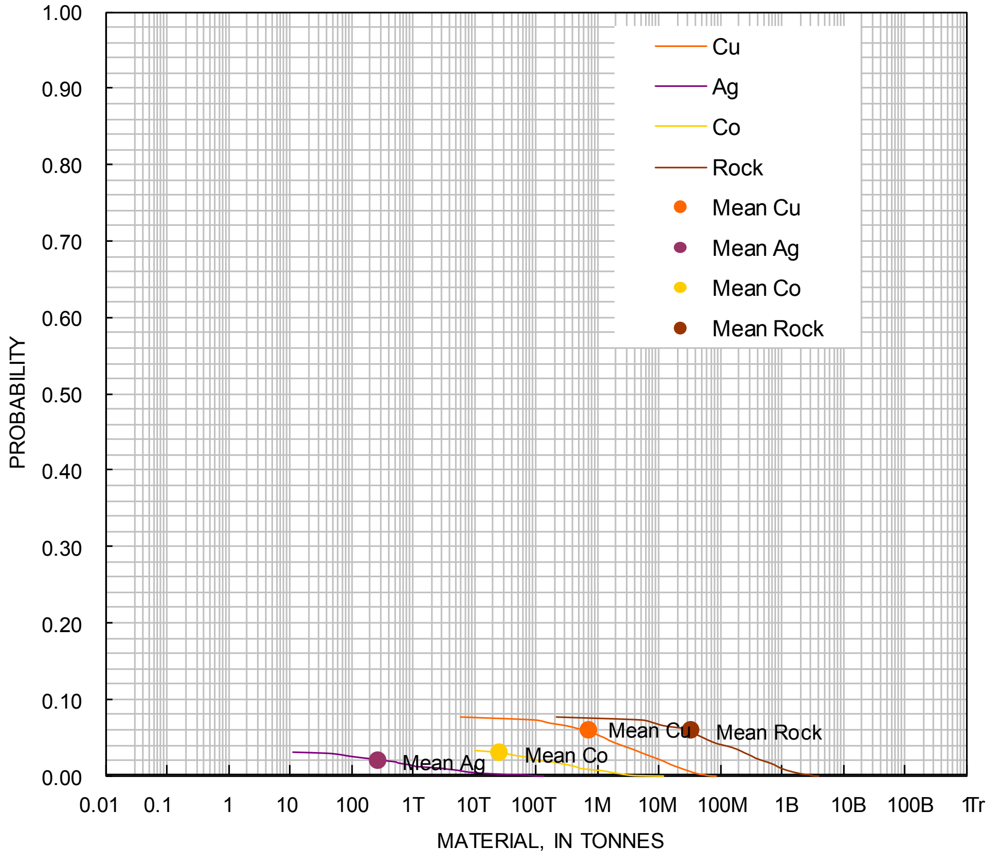

Figure 48. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the tracts CE 1-6 EBS and CE 9-16 EBS Eleonore Bay Super-group, Reduced Facies Copper type deposits, Greenland. T=thousands, M=millions, B=billions, Tr=trillions.*

Figure 49. *Panorama the Eleonore Bay Supergroup along coastal cliffs of Geologfjord. From Sønderholm et al. 2008 (for abbreviations see this publication).*

Figure 50. *The „mineralised horizon number 7", Kap Tyrrell, Canning Land, tract CE EBS 1 - 6 and CE EBS 9-16: Chalcocite-bearing green shale-siltstone interbedded with red siltstone of the lowermost part of Ymer Ø Group. From Harpøth, (1982).*

The Neoproterozoic tracts CE 7–8 EBS, of the Eleonore Bay Supergroup – Reduced Facies Copper type

Location

The Neoproterozoic tracts CE 7-8 EBS of the Eleonore Bay Supergroup encompasses areas in central East to Northeast Greenland at Strindberg Land and Andrée Land between 73°N and 74°N (Fig. 51).

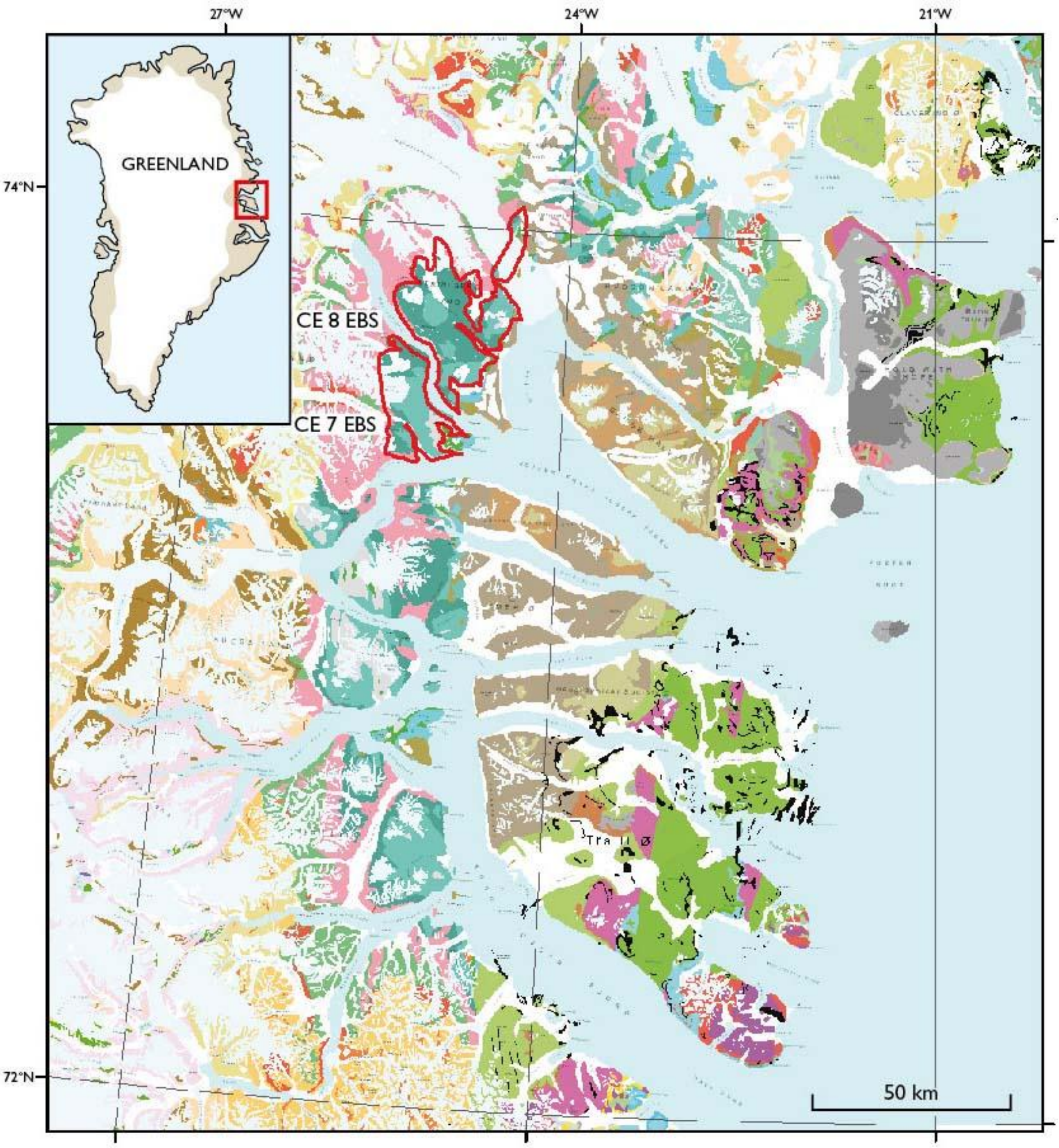

Figure 51. *The tracts Neoproterozoic CE 7-8 EBS of the Elenore Bay Supergroup (EBS) assesses for undiscovered Reduced Facies Copper type deposits at the boundary zone between the Lyell Land Group and Ymer Ø Group.*

Table 41. *Summary of selected resource assessment results for the Neoproterozoic tracts CE 7-8 EBS of the Eleonore Bay Supergroup assessed for Reduced Facies Copper type deposits*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	1000	0	810,000

Geological feature assessed

See description under the assessment of the Neoproterozoic tracts CE 1-6 EBS and CE 9-16 EBS, Eleonore Bay Supergroup.

Delineation of the permissive tract

The boundaries of the individual tracts are defined from the mapped extent of the boundary zone between Lyell Land Group and Ymer Ø Group of the EBS. This zone hosts the most consistently mineralised horizon and was chosen by the assessment team to be the focus for the assessment.

Geological criteria

See description under the assessment of the Neoproterozoic tracts CE 1-6 EBS and CE 9-16 EBS, Eleonore Bay Supergroup.

Known deposits

There are no known deposits within the tracts.

Prospects, mineral occurrences, and related deposit types

Eight levels of stratiform and stratabound copper mineralizations have been observed within a 3 km thick stratigraphic pile comprising the uppermost part of the Narhorst Land Group, Lyell Land Group and lower part of Ymer Ø Group of the EBS. The characteristics, thickness, grades and persistency of the eight copper mineralised horizons are summaries in Table 38, and the known copper mineralizations are shown in Fig. 47 (Harpøth *et al.* 1986).

The highest grades and most promising copper prospects related to ‗mineralised horizon number 7' are located inside the tracts CE EBS 7 and 8. It is observed over a length of 275 km from Canning Land in the south to Strindberg Land in the north, and it is hosted in monotonous, calcareous and dolomitic red shale. Mineralization occurs in green intercalations of carbonaceous shale ranging in thickness from a few centimetres to a few metres. Two distinct mineralised horizons occur 10–15 m and 60–70 m, respectively, above the top of a white quartzite bed that marks the top of the Lyell Land Group. Cu-sulphides occur as disseminated fine grains, locally as discrete blebs (up to 5 cm). Where chalcopyrite is absent, the mineralization is difficult to recognise in the field as chalcocite occurs parallel to bedding planes and rarely exceeds a few millimetres in size. The ore minerals are chalcocite and chalcopyrite, and the copper content of mineralised green shale varies from 0.25 % to 1.5 % with an average grade of 0.7 %. Selected samples yield up to 6 % Cu; average Ag content is low with a Cu/Ag ratio of 1,000–1,500.

Exploration history

See description under the assessment of the Neoproterozoic tracts CE1-6 EBS and CE 9-16 EBS Eleonore Bay Supergroup.

Grade and tonnage model selection

See description under the assessment of the Neoproterozoic tracts CE 1-6 EBS and CE 9-16 EBS Eleonore Bay Supergroup.

Estimate of the number of undiscovered deposits

Rationale for the estimate

See description under the assessment of the Neoproterozoic tracts CE 1–6 EBS and CE 9-16 EBS Eleonore Bay Supergroup.

The tracts CE 7-8 EBS were treated separately from tract CE 1-6 EBS and CE 9-16 EBS because more investigations have been undertaken in the tracts CE 7-8 EBS, and because they host most of the known mineralizations and the highest copper grades.

Table 42. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for the tracts CE 7-8 Eleonore Bay Supergroup, Reduced Facies Copper type deposits*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	0	2	4	0.21	0.76	360	0	0.21	1,000	0.00021

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	1	2	4
Individual 2	0	0	1	2	3
Individual 3	0	0	0	3	4
Individual 4	0	0	0	2	3
Individual 5	0	0	0	1	3
Individual 6	0	0	0	1	2
Individual 7	0	0	0	2	4
Individual 8	0	0	0	3	5
Individual 9	0	0	0	1	2
Consensus	0	0	0	2	4

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 42), Reduced Facies Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Reduced Facies Copper, model 30b.2‘ using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in the Table 43, and the results of the Monte Carlo simulation are presented as cumulative frequency plots in Fig. 52. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 43. *Results of Monte Carlo simulations of undiscovered resources in the tracts CE 7-8 EBS Eleonore Bay Supergroup, Reduced Facies Copper type deposits [t=metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	1,900,000	810,000	0.07	0.91
Ag (t)	0	0	0	0	0	370	0.02	0.96
Co (t)	0	0	0	0	0	33,000	0.03	0.96
Rock (mt)	0	0	0	0	80	40	0.06	0.91

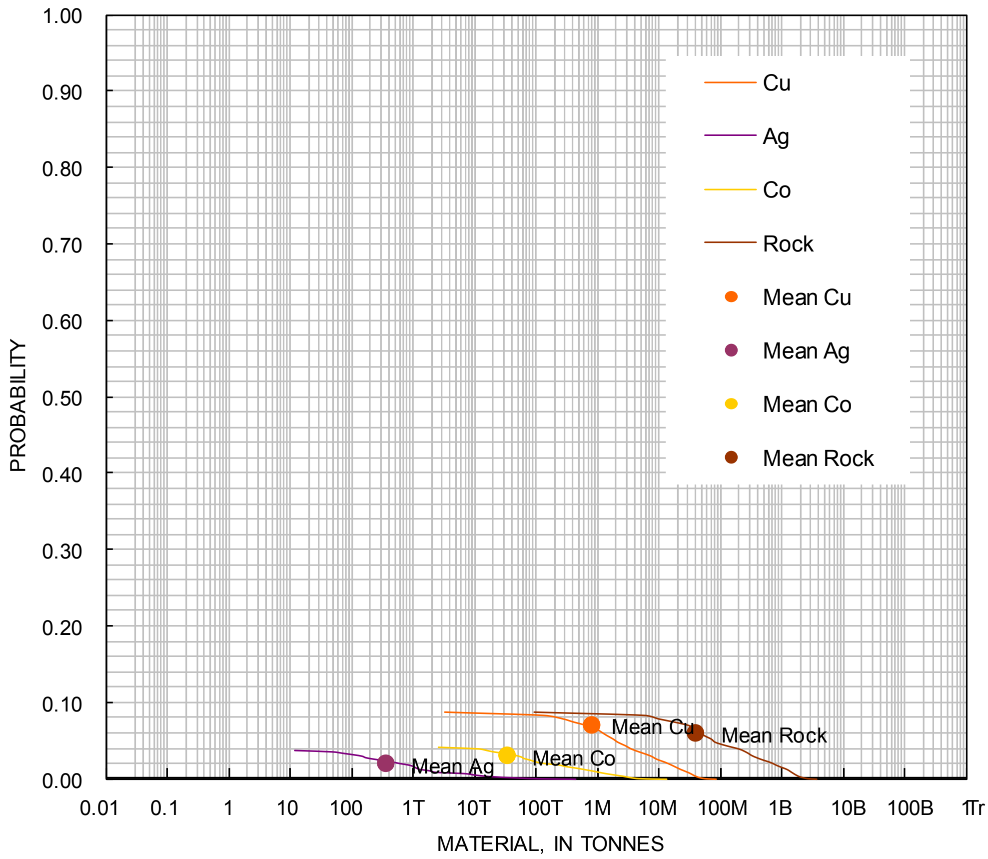

Figure 52. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the tracts CE 7-8 EBS, Reduced Facies Copper type deposits. T=thousands, M=millions, B=billions, Tr=trillions.*

Assessment of Sediment-hosted Copper deposit for Meso- to Neoproterozoic Thule Basin North West Greenland – Redbed Copper type

The Proterozoic intracratonic sedimentary-volcanic Thule Basin (Fig. 53), with total area of approximately 6,000 km^2 and an exposed area of ca. 2,000 km^2 comprises the Thule Supergroup, and is continuous from Greenland to Canada. The six kilometre thick Supergroup contains 5 lithostratigraphic groups, Smith Sound Group; Nares Strait Group; Baffin Bay Group; Dundas Group; and Narssarssuk Group (Fig. 54). Redbed Copper mineralizations are known within (i) the Northumberland Formation of the Nares Strait Group; (ii) Cape Camperdown Formation of the Smith Sound Group and (iii) the Qaanaaq Formation of the Baffin Bay Group. The amount of continental to lacustrine and shallow marine red bed siliciclastics sandstone and shales within the formations is large.

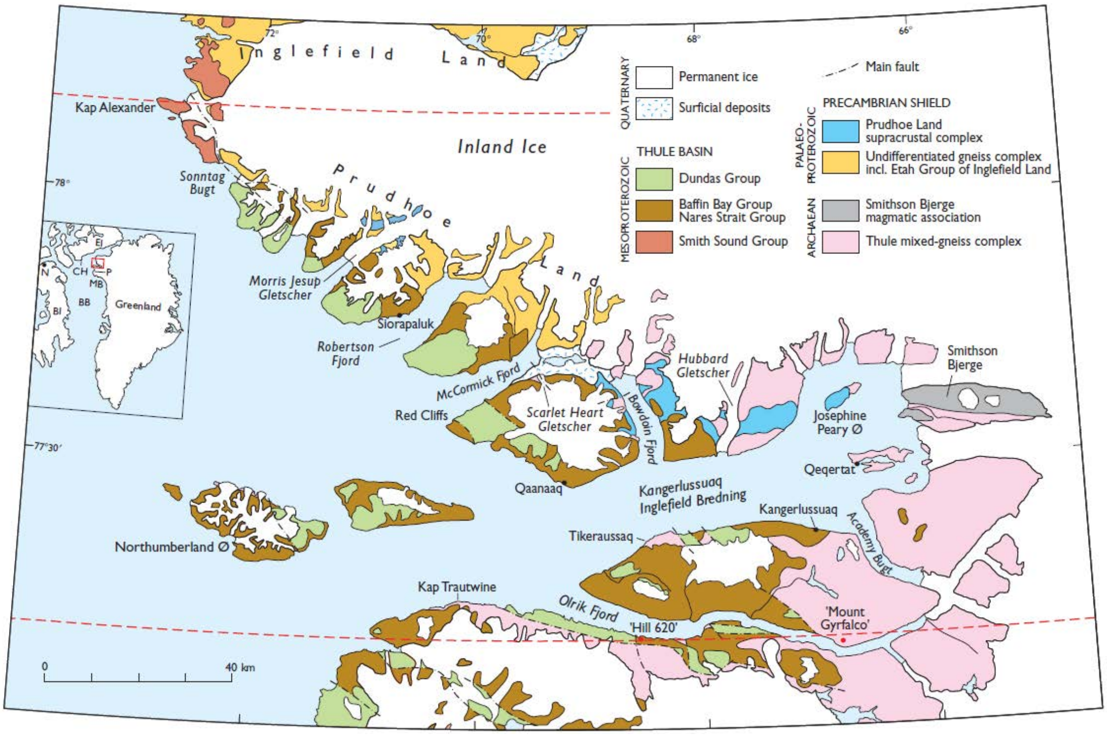

Figure 53. *Geological map of the Qaanaaq (Thule) region. From Thomassen et al. (2002).*

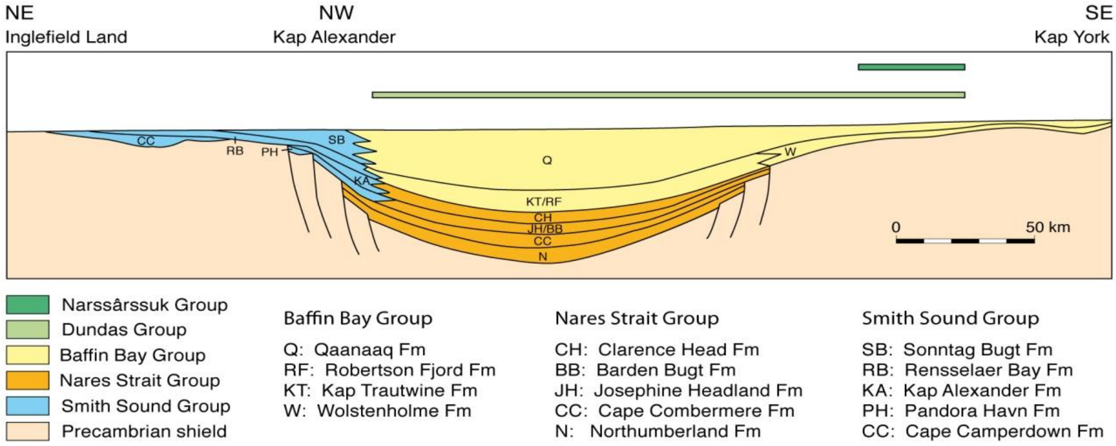

Figure 54. *Cross-section of the lower Thule Supergroup. Figure from the workshop presentation by Peter Dawes.*

Deposit type assessed

Deposit type: Sediment-hosted Copper.

Descriptive model: Sediment-hosted Copper, Redbed Copper type (Cox et al. 2003).

Grade and tonnage model: Sediment-hosted Copper, Redbed Copper type (Cox et al. 2003).

Sources of information

The principal sources of information used for the assessment of the tracts in the Meso- to Neoproterozoic Thule Basin for the Redbed Copper type are given in Appendix A.

Tracts NW 1–2 Baffin Bay Group and NW 5–10 Baffin Bay Group – Redbed Copper type

Location

The tracts NW 1–2 Baffin Bay Group and NW 5–10 Baffin Bay Group are located in the Thule Basin in North West Greenland (Fig. 55). The southernmost tract is NW 1, located at De Dødes Fjord (76°N) and the northernmost is NW 10 north of Murchison Sund (from 77°30‘N to 78°N).

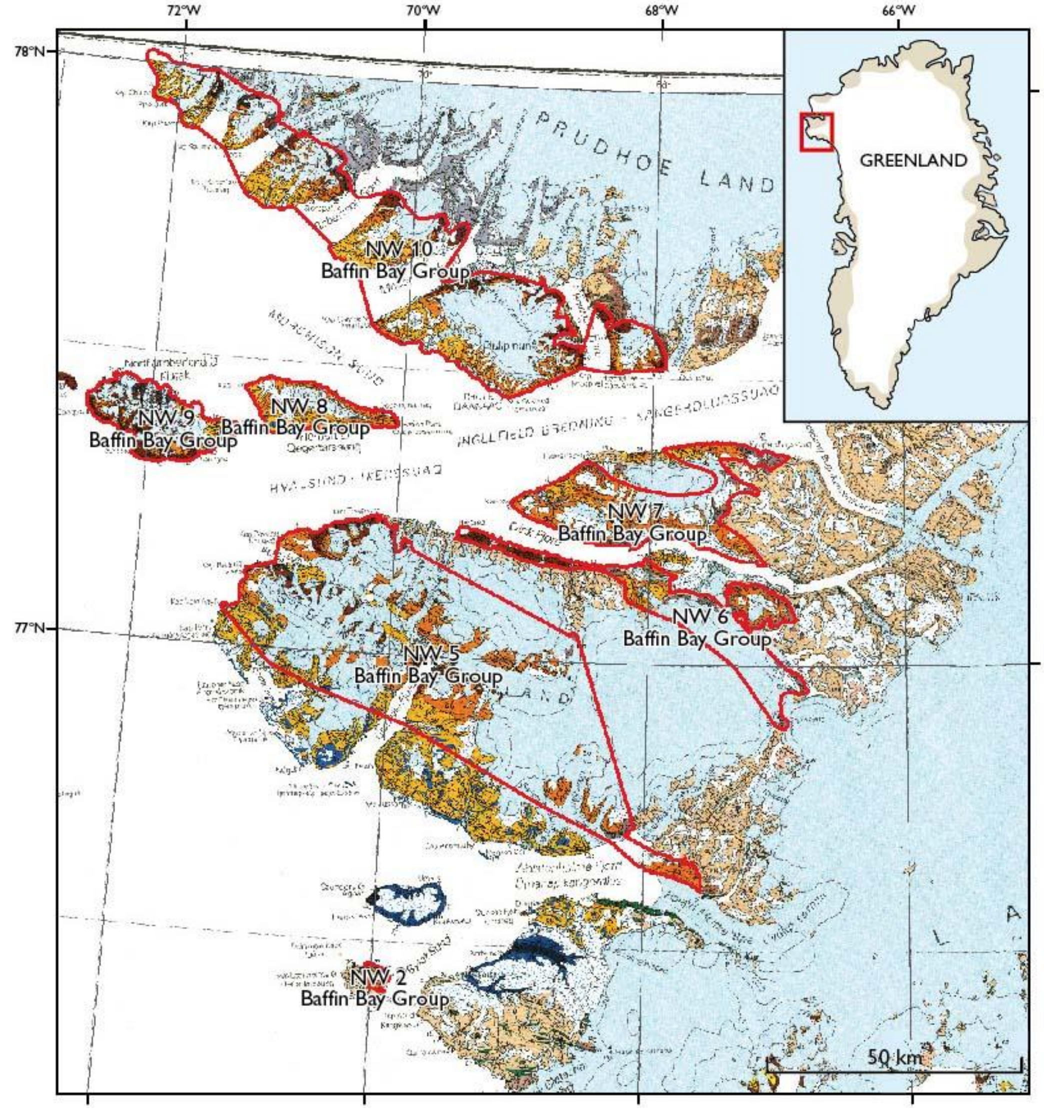

Figure 55. *Tracts NW 1–2 and NW 5–10 Baffin Bay Group, assessed for undiscovered Redbed Copper type deposit.*

Table 44. *Summary of resource assessment results for the tracts NW 1–2 and NW 5–10 Baffin Bay Group assess for Redbed Copper type deposits*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	5,740	0	41,000

Geological feature assessed

The assessment of the tracts NW 1–2 and NW 5–10 Baffin Bay Group for undiscovered Redbed Copper deposits included only the Baffin Bay Group of the Thule Supergroup of the Mesoproterozoic to Neoproterozoic Thule Basin.

Delineation of the permissive tract

The NW 1–2 and NW 5–10 Baffin Bay Group tract boundaries are defined by the area extent of the Baffin Bay Group to an estimated depth of 1 km below surface. It should be noted, that a large part of the tracts are covered by ice.

Geological criteria

The following is from Dawes (2006). 'The Thule Basin is an intracratonic fracture basin with block faulting and basin sagging formed in a divergent plate region. The base of the basin is defined by an unconformity with underlying peneplained shield rocks. The basin is defined by an unmetamorphosed sedimentary-volcanic succession - The Thule Supergroup, comprising five lithostratigraphic groups; the Smith Sound Group, the Nares Strait Group, the Baffin Bay Group, the Dundas Group and the Narssârssuk Group.'

The Baffin Bay Group (BBG) has a thickness ranging from 300 m at the margin of the basin to 1,300 m in the central part of the basin, and consists of multicoloured siliciclastics with units of shallow-water to terrestrial siltstone and shale. The sediments were deposited in a mixed continental to marine shoreline environment with intervals of prodelta or offshore. The Group comprises five formations of which four are present in Greenland: The Trautwine Formation, Robertson Fjord Formation, Wolstenholme Formation, and Qaanaaq Formation. Redbed successions (siliciclastics) are present in two of the four formations, equivalent to about 35% of the Group exposed in Greenland. The redbed succession of the Wolstenholme Formation, which varies in thickness from 100 to 250 m, is composed of highly ferruginous sandstone and conglomerate and represents a strongly oxidizing mixed continental to marine shoreline environment. Redbed successions are also present in the Qaanaaq Formation, which is the thickest formation within the BBG with thickness from 200 m to 1,000 m. The formation consists of a monotonous succession of pale sandstones with conglomerate beds and minor shale and siltstone; redbed units are present in the upper strata.

Known deposits

There are no known deposits within the tracts.

Prospects, mineral occurrences, and related deposit types

The Olrik Fjord copper occurrence (also denoted ‗Hill 620 showing') outcrops as an isolated 100 m^2, bright green showing; the mineralization is seen as malachite-staining in a pale sandstone of the Qaanaaq Formation, but chalcopyrite, pyrite, bornite, digenite and covellite have been identified as well (Dawes 2006), and grab samples have yield up to 0.4% Cu. Several other localities with this type of mineralization occur within the Qaanaaq Formation, e.g., at ‗Red Cliffs', McCormick Fjord, near the Kap Cleveland Fault, similar Cu mineralization have yielded values up to 1.5% Cu. It is suggested that the mineralization is fault-controlled (Dawes 2006) (Figs 57–59).

Exploration history

Limited exploration has been carried out in the Thule region, North West Greenland. The exploration company Greenarctic Consortium discovered the malachite-stained sandstone Olrik Fjord Copper occurrence in 1969 (the ‗Hill 620 showing; Greenarctic 1971). During regional mapping, the Geological Survey of Greenland (GGU) investigated selected mineral occurrences in the region. This also led to the discovery of banded iron formation at Smithson Bjerge (Dawes 2006). In 1994 and1995, the Greenarctic Consortium exploration company explored in the Qaanaaq region and reported scattered malachite staining in the Thule Supergroup. In 2001 field work by the Geological Survey of Denmark and Greenland (GEUS) was directed towards visual inspections of signs of mineral occurrences, and regional sediment sampling was undertaken (Fig. 56; Thomassen *et al.* 2002). Furthermore, the publically financed ‗hunt for minerals' program (Ujarsassiorit), has returned Cu values >10% on samples from Robertson Fjord and Northumberland Ø (the tracts NW9 and NW10).

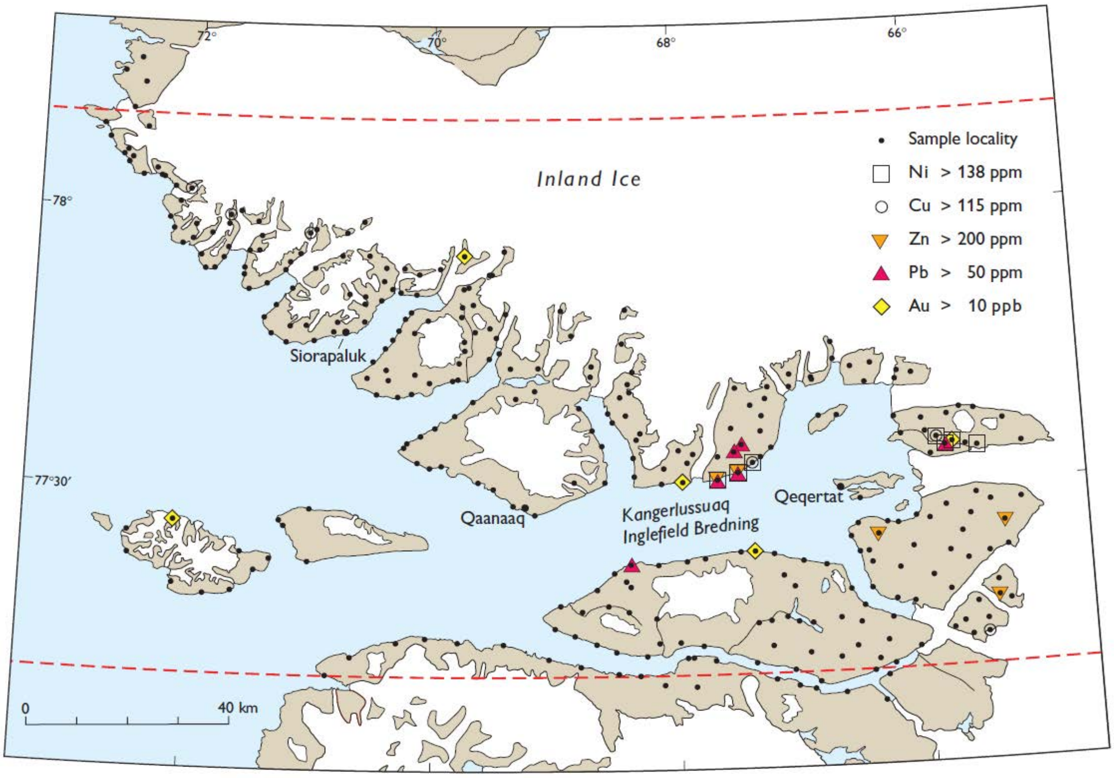

Figure 56. *Map of the Qaanaaq region showing anomalous concentrations of copper and other selected elements based on stream sediment samples. From Thomassen et al. 2002.*

Grade and tonnage model selection

Based on the characteristics of the mineralization in the Baffin Bay Group and the geological setting of the host rock and established dispositional palaeoenvironment the assessment team found it justified to use the Sediment-hosted Copper, Redbed Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

Redbed successions constitute a major part of the Baffin Bay Group sediments, and several Redbed Copper type mineralizations are known from these sediments. Additionally, Dawes (2006) describes bleaching and reduction effects as common in the redbed successions, which indicate, that extensive fluid/brine activity has taken place in the Thule Basin (Fig. 57). This is observed at all scales from effects within bedding planes, joints and fissures, to bed scale with development of fish-eye spots and irregular bleach patterns. At a larger scale, purple sandstones tens of meters thick is observed to change into an interfingering network of dark and pale bed, which finally turns into pale, sandstones in which purple colour has been eliminated. Strong reduction patterns have been recorded particularly in the basal strata, both in the marginal and central part of the basin. The unconformity may have acted as an important pathway for the reducing fluids causing the bleaching and reduction.

The defined tracts also outline a large area with only limited previous exploration activity, so a potential for undiscovered mineralizations is present.

Figure 57. *Extensive bleaching of ferruginous redbed succession within the Northumberland Formation of the Baffin Bay Group c. 10 m above the basal unconformity of the Thule Basin and the underlying crystalline shield. Arrows indicates late generation of reduction spot. From Dawes (2006).*

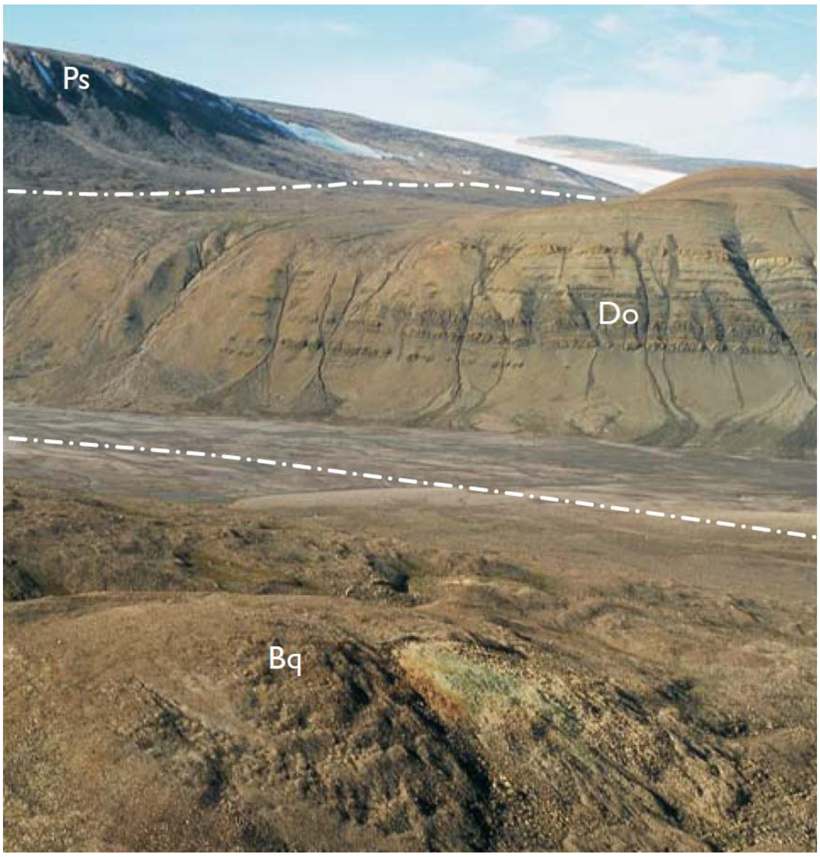

Figure 58. *The green patch, in the foreground, outlines the Olrik Fjord Copper occurrence („Hill 620 showing") within the Qaanaaq Formation. The juxtaposing Dundas Group (Do) against the shield (Ps) is seen in the background; dotted lines indicate the faults in the Olrik halfgraben. From Dawes (2006).*

Figure 59. *The Red Cliffs Copper occurrence within the Qaanaaq Formation. The occurrence has yielded up to 1.5% Cu. Photo from the work-shop presentation by B. Thomassen.*

Table 45. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tracts NW 1–2 and NW 5–10 Baffin Bay Group, Redbed Copper type*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	**N50**	**N10**	**N05**	**N01**	**N_{und}**	**s**	**Cv%**	**N_{known}**	**N_{total}**		
0	0	0	2	5	0.24	0.88	370	0	0.24	5,740	0.000042

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	1	2	3
Individual 2	0	0	0	2	4
Individual 3	0	0	0	1	3
Individual 4	0	0	0	2	3
Individual 5	0	0	0	2	5
Individual 6	0	0	0	1	4
Individual 7	0	0	0	3	7
Individual 8	0	0	1	3	7
Individual 9	0	0	1	2	3
Individual 10	0	0	0	2	4
Individual 11	0	0	0	2	5
Consensus	0	0	0	2	5

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 45), Redbed Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Reduced Facies Copper, model 30b.3' using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 46 and the results of the Monte Carlo simulation are presented as cumulative frequency plots in Fig. 56. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 46. *Results of Monte Carlo simulations of undiscovered resources in the tracts NW 1–2 and NW 5–10 Baffin Bay Group Redbed Copper type [t=metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	180,000	41,000	0.07	0.91
Ag (t)	0	0	0	0	0	28	0.03	0.95
Co (t)	0	0	0	0	0	460	0.01	0.99
Rock (mt)	0	0	0	0	9	3	0.07	0.91

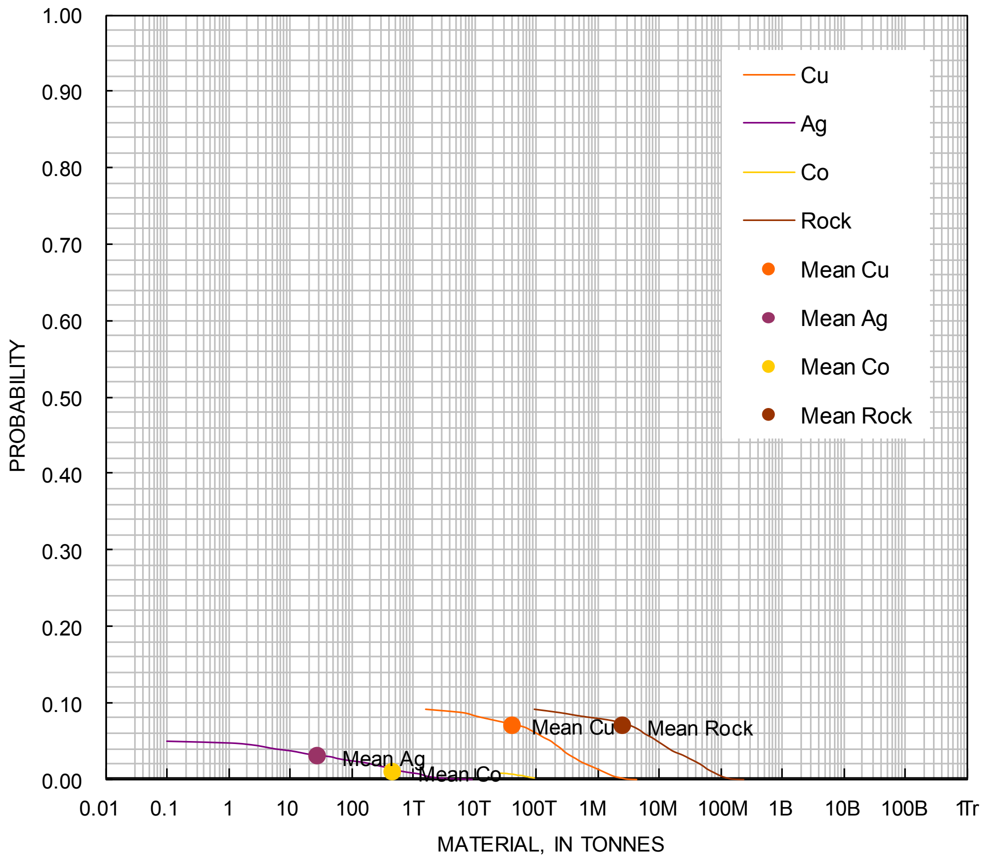

Figure 60. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the tracts NW 1–2 and NW 5–10 Baffin Bay Group Redbed type. T=thousands, M=millions, B=Billions, Tr=Trillions.*

Tracts NW 5–10 Nares Strait Group – Redbed Copper type

Location

The tracts NW 5–10 (Fig. 61) are located within the sediments of the Thule Basin at Saunders Ø and east of Bylot Sund, North West Greenland.

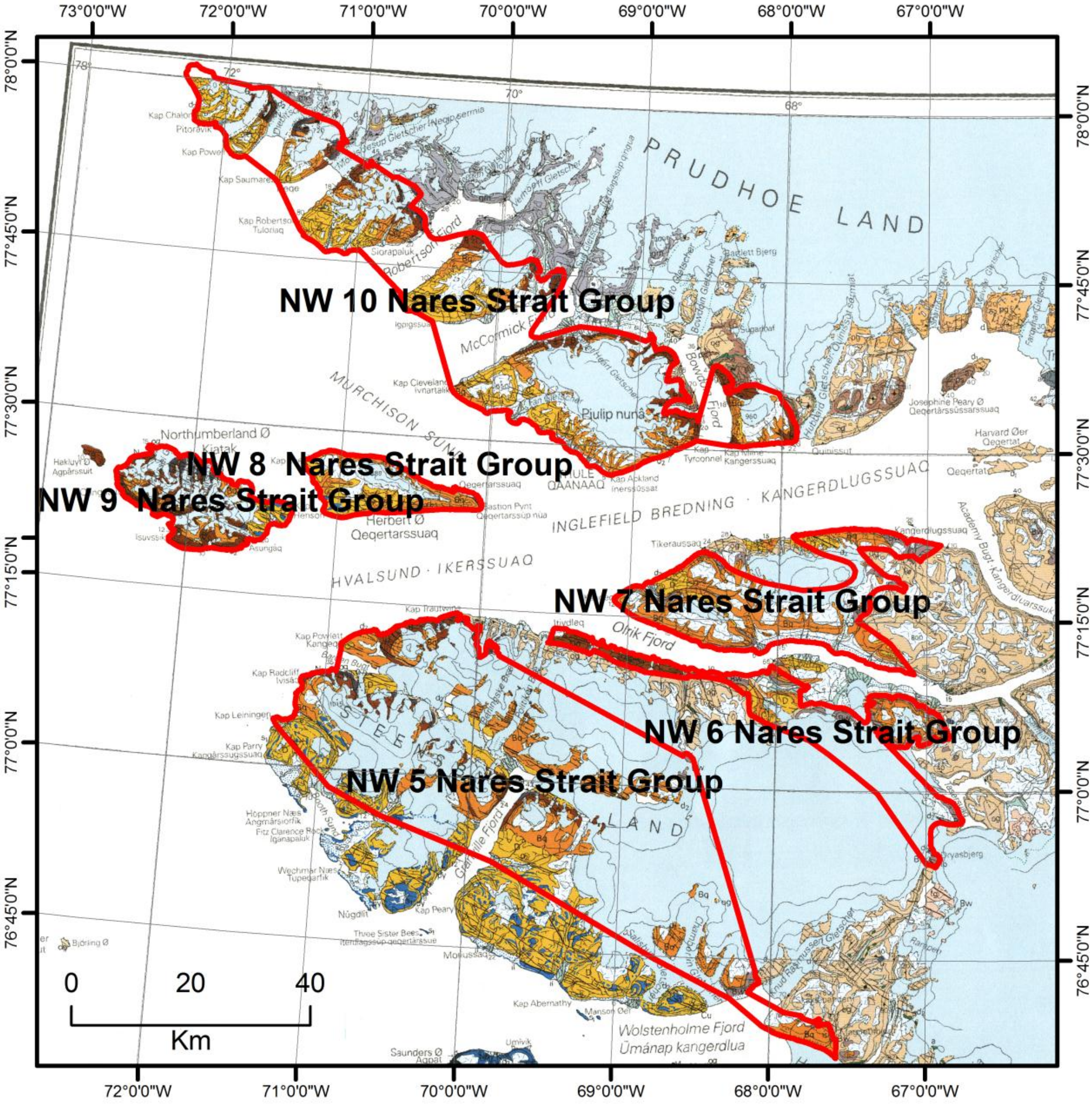

Figure 61. *Tracts NW 5–10 Nares Strait Group in North West Greenland, assessed for undiscovered Redbed Copper type deposit plotted on top of the 1:500 000 geological map for the area (Dawes 1991).In dark grey (N) the Nares Strait Group. Refer to this map for a full legend.*

Table 47. *Summary of resource assessment results for the tracts NW 5–10 Nares Strait Group assess for Redbed Copper type deposits*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	5,680	0	79,000

Geological feature assessed

The tracts NW 3–4 Nares Strait Group were assessed with regard to undiscovered Redbed Copper deposits within the Nares Strait Group of the Thule Supergroup of the Mesoproterozoic to Neoproterozoic Thule Basin.

Delineation of the permissive tract

The NW 5–10 tract Nares Strait Group boundaries are defined by the extent of the Nares Strait Group to an estimated depth of 1 km below surface. It should be noted, that a large part of the tract is covered by ice.

Geological criteria

The Thule Basin is an intracratonic fracture basin with block faulting and basin sagging formed in a divergent plate region. The base of the basin is defined by an unconformity with underlying peneplained shield rocks. The basin is defined by an unmetamorphosed sedimentary-volcanic succession; the Thule Supergroup. The Supergroup comprises five lithostratigraphic groups; the Smith Sound Group, the Nares Strait Group, the Baffin Bay Group, the Dundas Group and the Narssârssuk Group (Dawes 2006). The tracts NW 5–10 have been assessed with regard to undiscovered Redbed Copper deposits within the Nares Strait Group.

The thickest section of Nares Strait Group, at Northumgerland Ø, is ca 700 m with thinning towards the mainland where it is pinching out. The thickness it estimated to be between 200 m to 1200 m and redbed units constitute 2 out of 4 formations amounting 45% of the entire stratigraphical column of the Nares Strait Group (see workshop presentation by P. Dawes). In ascending stratigraphic order the Group comprises multi-coloured sandstone with subordinate siltstone and shale, with occasional sills (Northumberland Formation, Fig. 63), a volcanic/redbed sequence of tholeiitic lavas with coeval sills, agglomerates, tuffaceous strat (lithic tuffs, tuff breccias and ash flows) and interflow clastic sandstone-siltstone-shale packages (Cape Combermere Formation, Fig. 63) and stromatolitic carbonates, sandstone and shale with tuffaceous elements (Josephine Headland and Barden Bugt Formations, Fig. 63). The deposits represent shallow-water deposition in mainly alluvial plain and littoral environments, with one main interval terrestrial volcanishm including plateay basalts (Dawes 2006).

Known deposits

There are no known deposits within the tracts.

Prospects, mineral occurrences, and related deposit types

Grab samples from the Nares Strait Group (Northumerland Formation; Figs 64 and 65) have yield up to 0.85 % Cu.

Exploration history

The limited exploration in the Thule region, North West Greenland is summarized above. (See also Fig. 57; and Thomassen *et al.* 2002).

Grade and tonnage model selection

Based on the characteristics of the settings of the mineralization in the Nares Strait Group and the geological setting of the host rock and established dispositional palaeoenvironment the assessment team found it justified to use the Sediment-hosted Copper, Redbed Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate
Redbed successions constitute a major part of the sediments of the Nares Strait Group.

The defined tracts also outline a very large area were very limited exploration activity have been carried out, so a potential for undiscovered mineralizations is present.

Table 48. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tracts NW 5–10* Nares Strait *Group, Redbed Copper type*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	1	2	5	0.47	1.1	230	0	0.47	5,680	0.000082

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	1	3	4
Individual 2	0	0	1	2	5
Individual 3	0	0	0	1	3
Individual 4	0	0	0	2	4
Individual 5	0	0	1	2	3
Individual 6	0	0	0	1	4
Individual 7	0	0	1	4	7
Individual 8	0	0	0	4	7
Individual 9	0	0	1	3	6
Individual 10	0	0	0	2	4
Consensus	0	0	1	2	5

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper, Redbed Copper type (Cox et al. 2007) deposits with the Grade and Tonnage model of the Reduced Facies Copper, model 30b. using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 49 and the results of the Monte Carlo simulation are presented as cumulative frequency plots in Fig. 62. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 49. *Results of Monte Carlo simulations of undiscovered resources in the tracts NW 5–10 Nares Strait Group Redbed Copper type [t – metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	160,000	460,000	79,000	0.14	0.70
Ag (t)	0	0	0	3	110	57	0.06	0.88
Co (t)	0	0	0	0	0	1,100	0.02	0.98
Rock (mt)	0	0	0	9	36	5	0.14	0.70

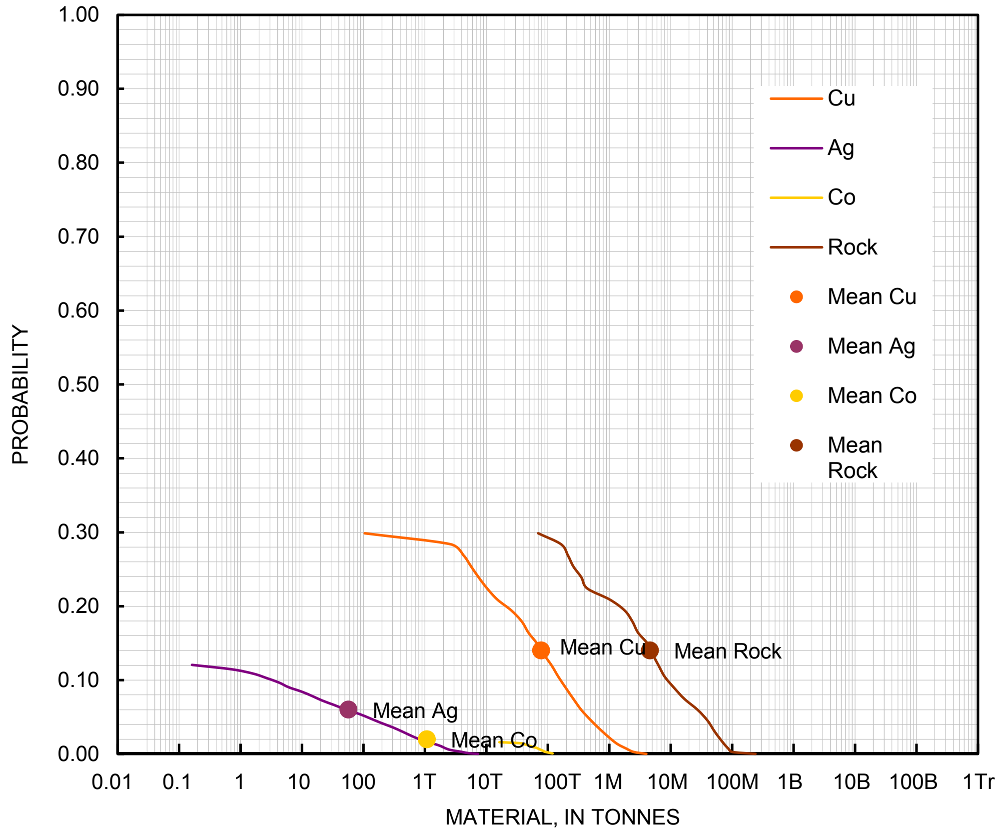

Figure 62. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the tracts NW 5–10 Nares Strait Group Redbed type. T=thousands, M=millions, B=Billions, Tr=Trillions.*

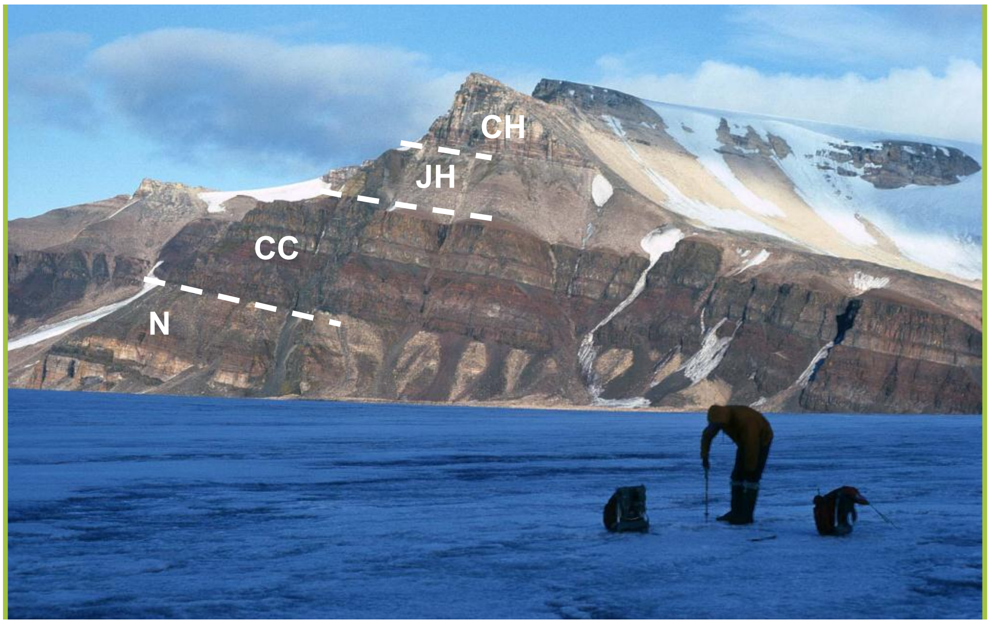

Figure 63. *Section through the Nares Strait Group (**N**orthumgerland, **C**ape **C**ombermere, **Jo**sephine **H**eadland and **C**learence **H**ead Formations). Photo from workshop presentation by P. Dawes.*

Figure 64. *Section through the multicoloured sandstone and siltstone of the Northumberland Formation of the Nares Strait Group. Grab samples from this section have yielded 0.85% Cu. Photo from Northumberland Ø. Rucksacks in front for scale. Photo from workshop presentation by B. Thomassen.*

Figure 65. *Multicoloured sandstone and siltstone of the Northumberland Formation of the Nares Strait Group. Photo from workshop presentation by P. Dawes.*

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Tracts NW 3–4 Narssârssuk Group – Redbed Copper type

Location

The tracts NW 3–4 (Fig. 66) are located within the sediments of the Thule Basin at Saunders Ø and east of Bylot Sund, North West Greenland.

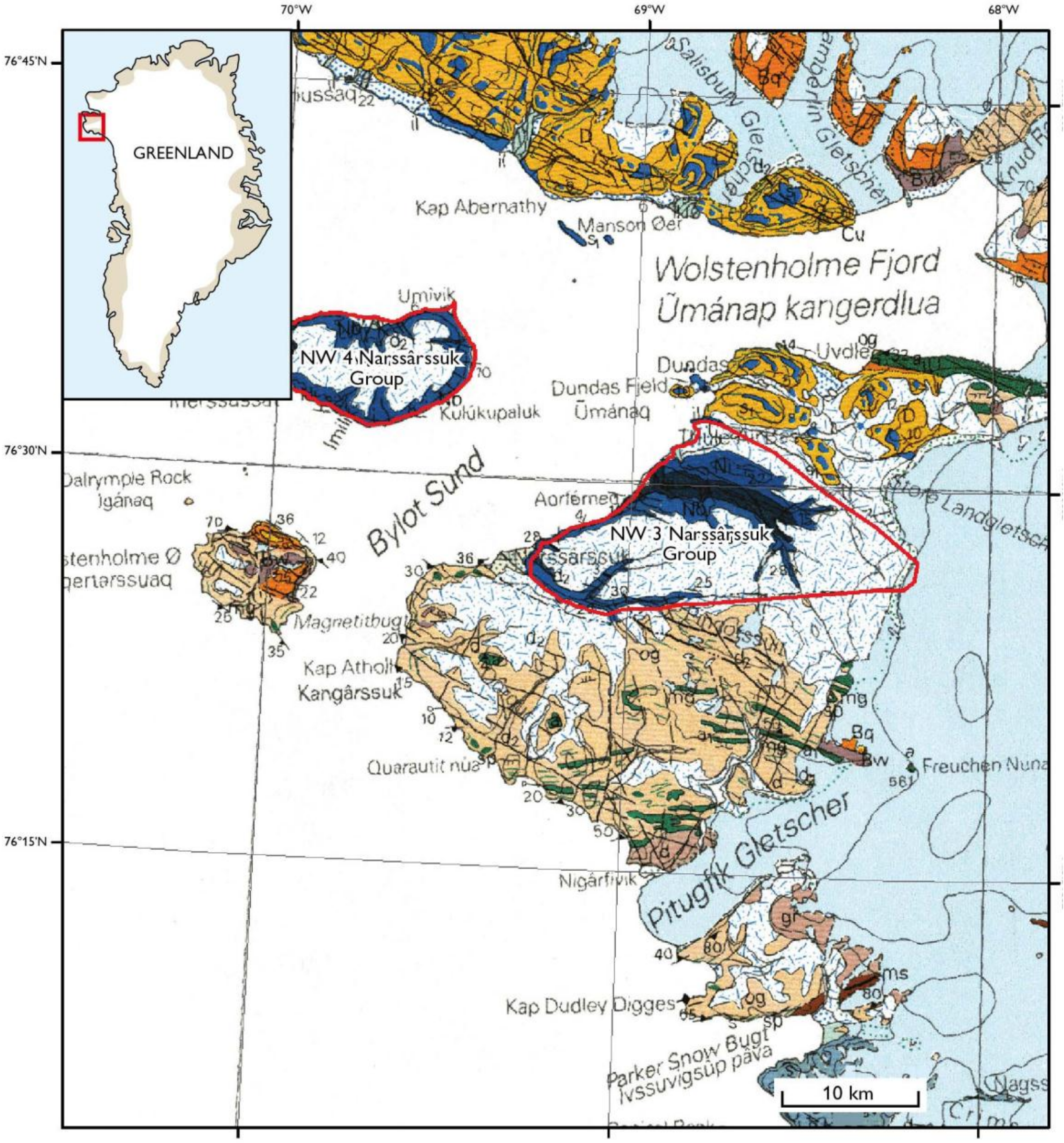

Figure 66. *Tracts NW 3–4 Narssârssuk Group in North West Greenland, assessed for undiscovered Redbed Copper type deposit plotted on top of the 1:500 000 geological map for the area (Dawes 1991).In dark blue (Ni and Nb) the Narssârssuk Group. Refer to this map for a full legend.*

Table 50. *Summary of resource assessment results for the tracts NW 3–4 Narssârssuk Group assess for Redbed Copper type deposits*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
25/03/2009	1 km	5,740	0	41,000

Geological feature assessed

The tracts NW 3–4 Narssârssuk Group were assessed with regard to undiscovered Redbed Copper deposits within the Narssârssuk Group of the Thule Supergroup of the Mesoproterozoic to Neoproterozoic Thule Basin.

Delineation of the permissive tract

The NW 3–4 tract Narssârssuk Group boundaries are defined by the extent of the Narssârssuk Group to an estimated depth of 1 km below surface. It should be noted, that a large part of the tract is covered by ice.

Geological criteria

The Thule Basin is an intracratonic fracture basin with block faulting and basin sagging formed in a divergent plate region. The base of the basin is defined by an unconformity with underlying peneplained shield rocks. The basin is defined by an unmetamorphosed sedimentary-volcanic succession; the Thule Supergroup. The Supergroup comprises five lithostratigraphic groups; the Smith Sound Group, the Nares Strait Group, the Baffin Bay Group, the Dundas Group and the Narssârssuk Group (Dawes 2006). The tracts NW 3–4 have been assessed with regard to undiscovered Redbed Copper deposits within the Baffin Bay Group.

The Narssârssuk Group has an unknown thickness but is estimated to 1.5 to 2.5 kilometres thick. It consists of well-layered, fine-grained, cyclic multicoloured carbonate-siliciclastic sequence (Fig. 68) with evaporates, carbonate shelf subtidal to supratidal environment under arid to semi-arid climate (coastal sabkda). The Group comprises three formations; the Imilik, the Aorfêrneq and the Bylot Sund Formations. Redbed sandstone and siltstone units occur in both the Imilik and the Airfêrneq formations and are estimated to constitute 20% of the strata in these formations (Figs 68–70).

Known deposits

There are no known deposits within the tracts.

Prospects, mineral occurrences, and related deposit types

There are no known prospects or mineral occurrences within the Narssârssuk Group.

Exploration history

The limited exploration in the Thule region, North West Greenland is summarized above. (See also Fig. 57; and Thomassen *et al.* 2002).

Grade and tonnage model selection

Based on the characteristics of the settings of the mineralization in the Narssârssuk Group and the geological setting of the host rock and established dispositional palaeoenvironment the assessment team found it justified to use the Sediment-hosted Copper, Redbed Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate
Redbed successions constitute a major part of the sediments of the Narssârssuk Group.

The defined tracts also outline a very large area were very limited exploration activity have been carried out, so a potential for undiscovered mineralizations is present.

Table 51. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tracts NW 3–4 Narssârssuk Group, Redbed Copper type*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	0	0	2	0.06	0.37	610	0	0.06	320	0.0019

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	0	1
Individual 2	0	0	0	0	1
Individual 3	0	0	0	1	2
Individual 4	0	0	0	0	1
Individual 5	0	0	0	0	1
Individual 6	0	0	0	1	3
Individual 7	0	0	0	0	2
Individual 8	0	0	1	1	2
Individual 9	0	0	1	0	2
Individual 10	0	0	0	0	2
Individual 11	0	0	0	0	1
Consensus	0	0	0	0	2

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper, Redbed Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Reduced Facies Copper, model 30b. using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 52 and the results of the Monte Carlo simulation are presented as cumulative frequency plots in Fig. 67. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 52. *Results of Monte Carlo simulations of undiscovered resources in the tracts NW 3–4 Narssârssuk Group Redbed Copper type [t – metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	0	9,300	0.03	0.96
Ag (t)	0	0	0	0	0	8	0.01	0.98
Co (t)	0	0	0	0	0	81	0.00	1.00
Rock (mt)	0	0	0	0	0	1	0.03	0.96

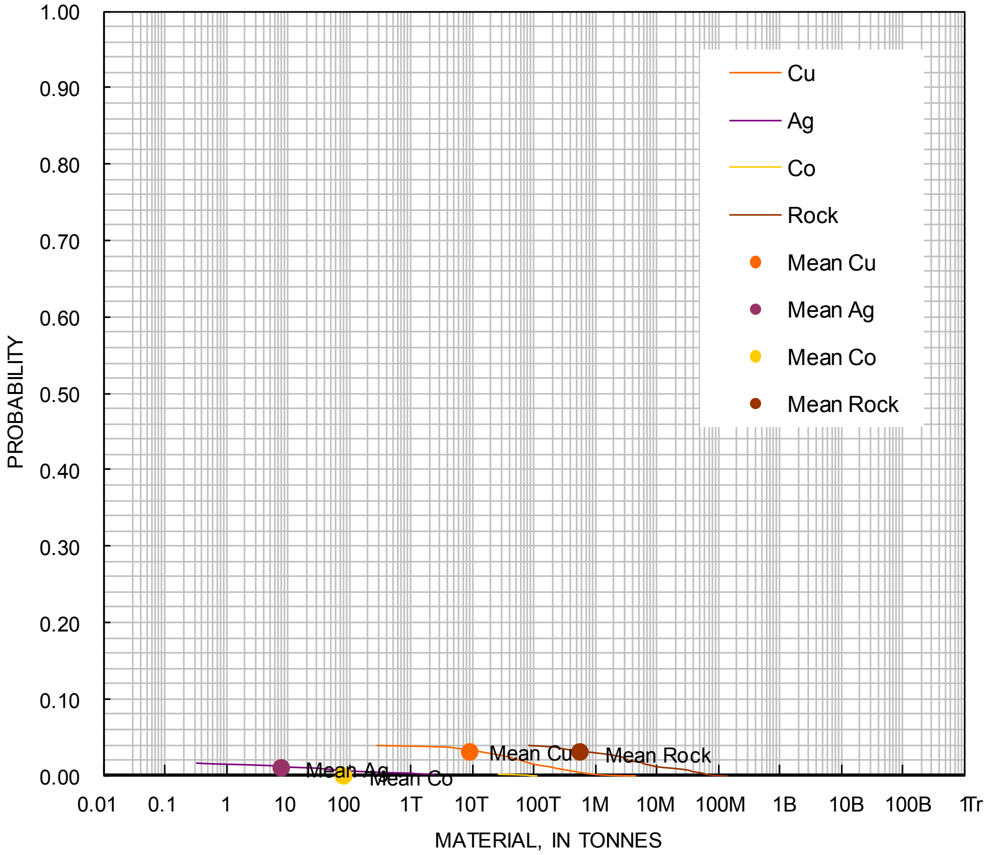

Figure 67. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the tracts NW 3–4 Narssârssuk Group Redbed type. T=thousands, M=millions, B=Billions, Tr=Trillions.*

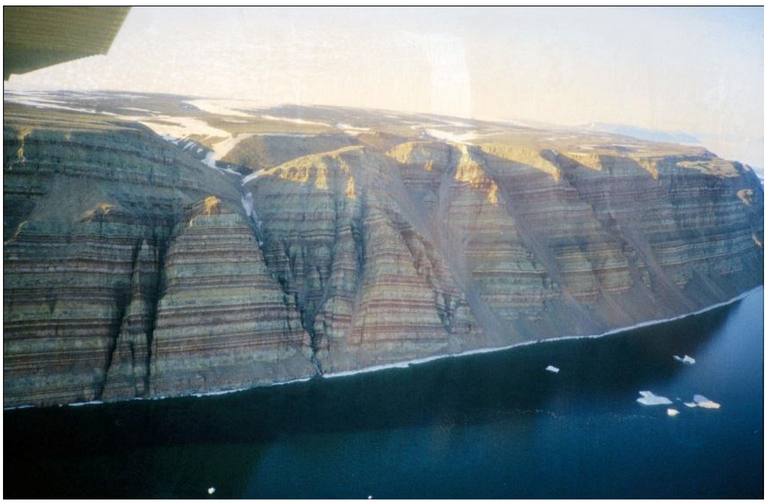

Figure 68. *Cyclic carbonate-siliciclastic sequence of the Narssârssuk Group. Figure from workshop presentation by P. Dawes.*

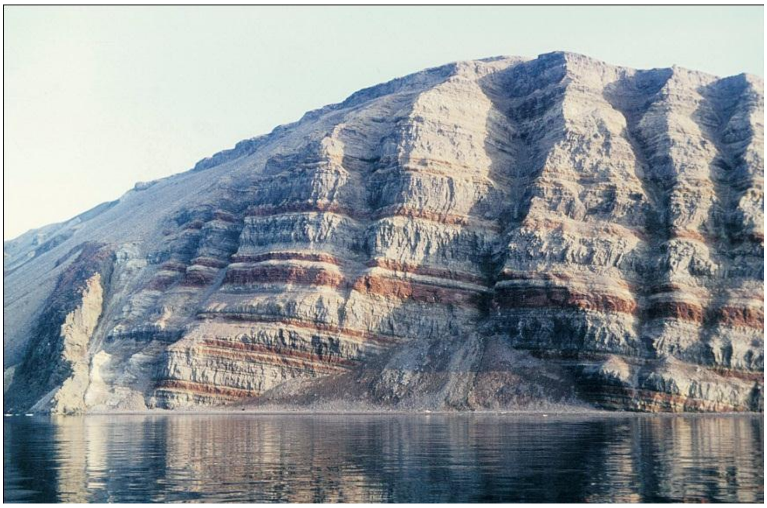

Figure 69. *Imilik Formation (cyclic carbonates and red siltstone) and Aoerfêrneq Formation (carbonate dominated) of the Narssârssuk Group. To the left the succession is intruded by a basic dyke of the Thule dyke swarm; cliff height approximately 150 m. From Dawes (2006).*

Figure 70. *Redbed (siliciclastics) silt- and sandstone of the Narssârssuk Group. From the work-shop presentation by P. Dawes.*

Tracts NW 11–13 Smith Sound Group – Redbed Copper type

Location

The tracts NW 11–13 Smith Sound Group are located within the sediments of Smith Sound Group of the Thule Basin at Kap Alexander and Rensselaer Bay north of Qaanaaq (Fig. 66).

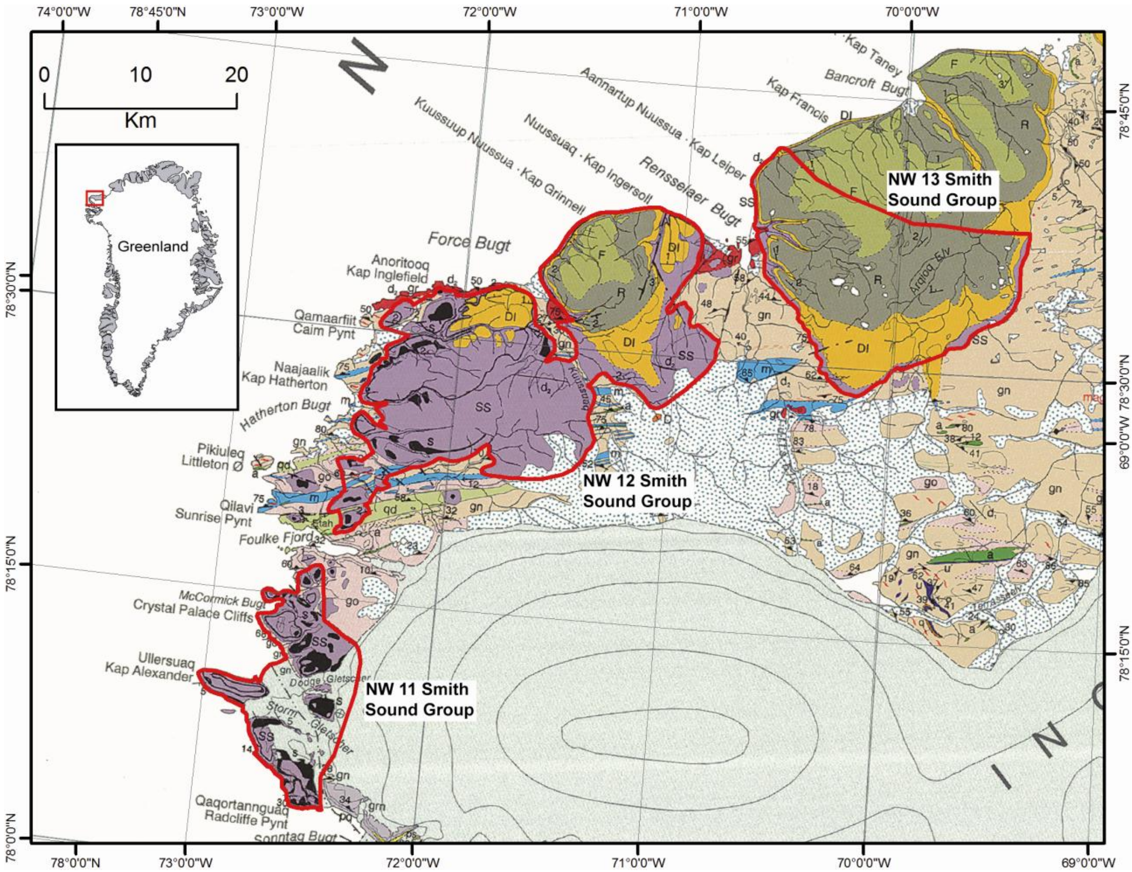

Figure 71. *Tracts NW 11–13 Smith Sound Group, assessed for undiscovered Redbed Copper type deposits. SS refers to Smith Sound Group and DI, R and F to the overlying Cambrian Dallas Bugt, Cape Leiper and Cape Ingersoll Formations (DI) Wulff River, Cape Kent and Cape Wood Formations (R) and Cass Fjord Formation (F). S refers to Mesoproterozpic dolerite sills intruded into the Smith Sound Group. Map plotted on top of the 1:500 000 geological map for the area (Dawes & Garde 2004).Refer to this map for a full legend.*

Table 53. *Summary of resource assessment results for the tracts NW 11–13 Smith Sound Group assessed for Redbed Copper type deposits*

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (metric tons)	Mean estimate of undiscovered copper resources (metric tons)
27/03/2009	1 km	1,230	0	31,000

Geological feature assessed

The tracts NW 11–13 Smith Sound Group have been assessed with regard to undiscovered Redbed Copper deposits within the Smith Sound Group of the Thule Supergroup of the Mesoproterozoic to Neoproterozoic Thule Basin.

Delineation of the permissive tract

The boundaries of the NW 11–13 Smith Sound Group tracts are defined by the extent of the Smith Sound Group to an estimated depth of 1 km below surface (Fig. 71).

Geological criteria

The Thule Basin is an intracratonic fracture basin with block faulting and basin sagging formed in a divergent plate region. The base of the basin is defined by an unconformity with underlying peneplained shield rocks. The basin is defined by an unmetamorphosed sedimentary-volcanic succession; The Thule Supergroup. The Supergroup comprises five lithostratigraphic groups; the Smith Sound Group, the Nares Strait Group, the Baffin Bay Group, the Dundas Group and the Narssârssuk Group (Dawes 2006). In the assessment of the tracts NW 11–13 Smith Sound Group undiscovered Redbed Copper deposits within the Smith Sound Group were assessed.

The Smith Sound Group represents the northern Thule basin margin and platform succession and the thickness varies from a feather edge at the very northern exposures in central Inglefield Land to a composite thickness of 700 m. The lithologies are characterised by a varicoloured sequence of sandstones and shales, including red beds, with subordinate carbonates cut by basic sills. Redbed sequences are found within two of the five formations constitution the Smith Sound Group and are estimated to constitute 55% of the strata in these formations. Quartz arenites dominate with, in places, interbedded shales with distinct intervals of algal and stromatolitic dolomites that are variously arenaceous. Thick units of clean quartz arenites with pebbly sandstone and quartz-pebble conglomerate characterise the lower and upper parts of the group in southern exposures. The depositional environment is interpreted to be a stable shelf, shallow water (marginally marine to supratidal/lacustrine) to subaerial.

Known deposits

There are no known deposits within the tracts.

Prospects, mineral occurrences, and related deposit types

There are no known prospects or mineral occurrences within the Smith Sound Group.

Exploration history

The limited exploration in the Thule region, North West Greenland is summarized above. (See also Fig. 57; and Thomassen *et al.* 2002).

Grade and tonnage model selection

Based on the characteristics of the high amount of redbed sequences, the settings and characteristics of the Smith Sound Group, the assessment team found it justified to use the Sediment-hosted Copper, Redbed Copper type (Cox et al. 2003) as the appropriated grade and tonnage model in the estimation of undiscovered deposits.

Estimate of the number of undiscovered deposits

Rationale for the estimate

Redbed successions constitute a major part of the sediments of the Smith Sound Group. The presence of evaporititic deposits and the basin margin settings was found to be of importance. The defined tracts outline a very large area where only limited exploration activities have been carried out, so a potential for undiscovered mineralizations is present.

Table 54. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tracts NW 11–13 Smith Sound Group, Redbed Copper type*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	0	2	4	0.21	0.76	360	0	0.21	1,230	0.00017

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	1	2
Individual 2	0	0	1	2	4
Individual 3	0	0	0	1	2
Individual 4	0	0	0	1	1
Individual 5	0	0	1	2	4
Individual 6	0	0	0	1	2
Individual 7	0	0	1	3	5
Individual 8	0	0	0	1	5
Individual 9	0	0	0	0	2
Individual 10	0	0	0	1	2
Consensus	0	0	0	2	4

Quantitative assessment simulation results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered Sediment-hosted Copper (Table 54), Redbed Copper type (Cox et al. 2007) deposits with the ‗Grade and Tonnage model of the Redbed Copper, model 30b.3' using the EMINERS program (Root et al. 1991; Duval 2004).

Selected simulation results are reported in Table 55 and the results of the Monte Carlo simulation are presented as cumulative frequency plots are shown in Fig. 72. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 55. *Results of Monte Carlo simulations of undiscovered resources in the tracts NW 3–4 Narssârssuk Group Redbed Copper type [t=metric tons; Mt; megatonne or million tons]*

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	0	0	140,000	31,000	0.07	0.91
Ag (t)	0	0	0	0	0	20	0.03	0.95
Co (t)	0	0	0	0	0	410	0.01	0.99
Rock (mt)	0	0	0	0	8	2	0.08	0.91

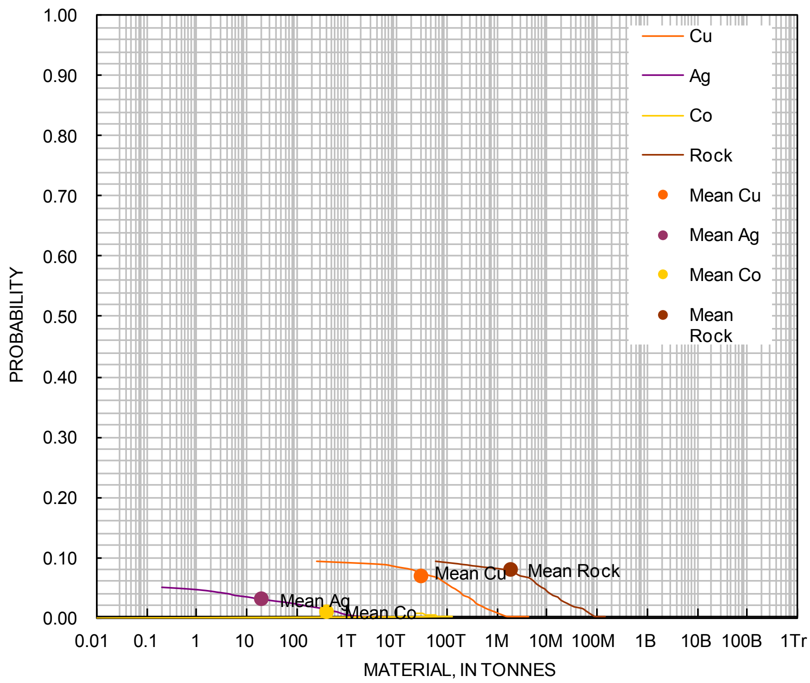

Figure 72. *Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in the tracts NW 11–13 Smith Sound Group Redbed type. T=thousands, M=millions, B=Billions, Tr=Trillions.*

Figure 73. *Radcliffe Pynt with sandstones of the Sonntag Bugt Formation (quartz arenites) overlying Rensselaer Bay Formation (reddish sandstones and siltstones and red and green shales and pale dolomitic rocks); a 50 m thick sill is intruded in the contact of the two formations. From workshop presentation by P. Dawes.*

Figure 74. *The Hatherton Bugt Member of the Rensselaer Bay Formation, dominated by purple shales with thin arenaceous stromatolitic dolomite and breccia beds. From workshop presentation by P. Dawes.*

Assessment of Basaltic Copper type within the Meso- to Neoproterozoic Thule basin in North-West Greenland

Based on the presented information for the Thule basin, the tracts NW 5 and NW 8–10 Nares Strait Group (Fig 75), all within the Nares Strait Group, the assessment team decided to assess for undiscovered deposit of the ‗Basaltic Copper deposit model‘ type instead of the ‗normal‘ sedimentary ‗Redbed Copper deposit model‘. Basaltic Copper type has been described by Cox and Singer (1986) and Kirkham (1984).

Even though no grade and tonnage model have been compiled and published for this type of mineralization, the assessment team found that it would be appropriate to assess the tract with an estimation of the number of believed undiscovered Basaltic Copper deposits within the tract but leaving out the resulting estimation of tonnage ore and copper.

Sources of information

The principal sources of information used for the assessment of the tracts in the Thule Supergroup for Basaltic Copper type mineralizations are given in Appendix A.

Tracts NW 5, 8 and 10 Nares Strait Group and tract NW 9 – Basaltic Copper type

Location

The tracts NW 5, 8, 9 and 10 Nares Strait Group are located within the Thule basin of North-West Greenland (Fig. 75).

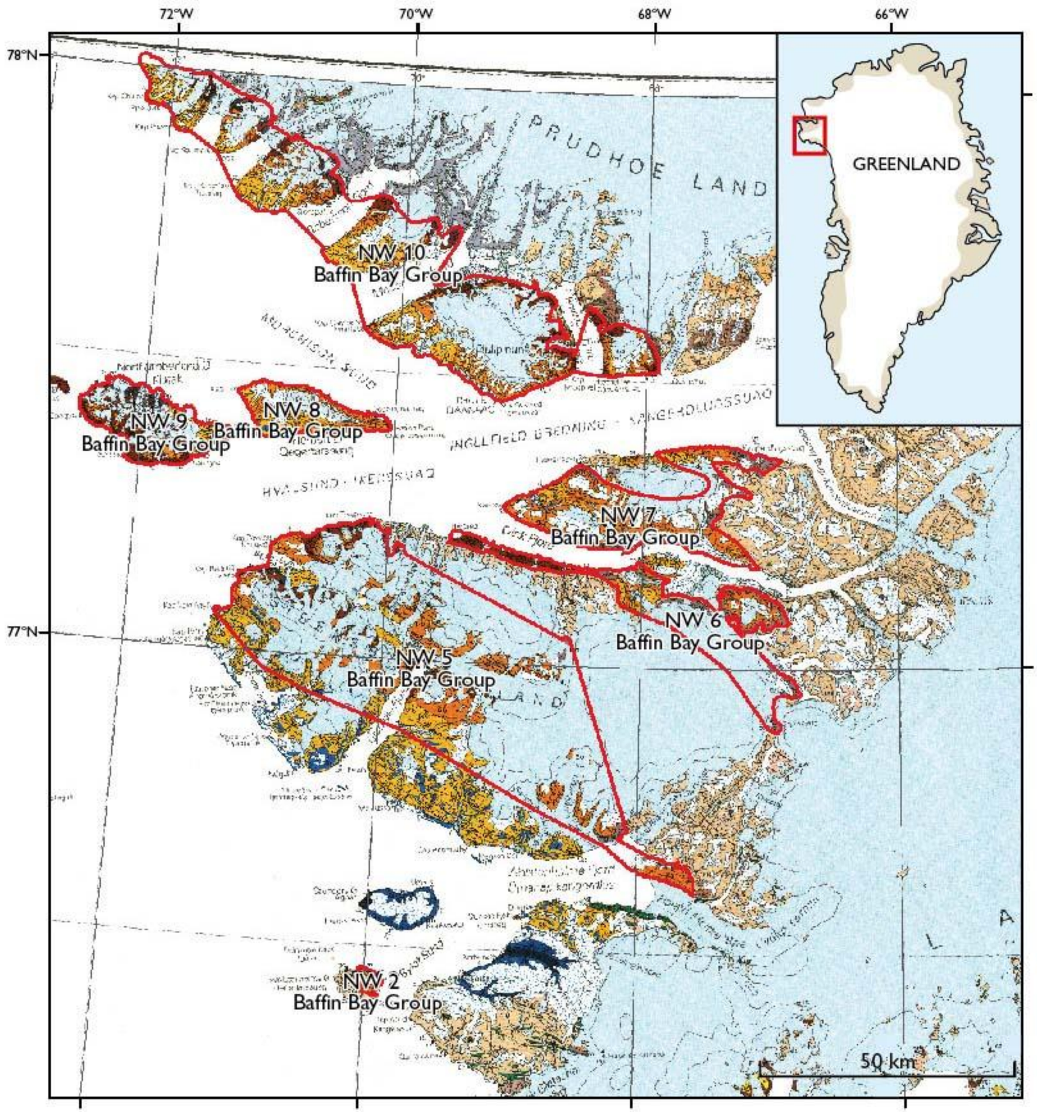

Figure 75. *Distribution of tracts NW 5 and NW 8–10 Nares Strait Group plotted on top of the 1:500 000 geological map for the area (Dawes 1991). Refer to this map for a full legend.*

Geological feature assessed

The Nares Strait Group, which constitutes the oldest Thule basin strata and overlies the basement shield rocks in the central part of the basin, was assessed for undiscovered Basaltic Copper.

Delineation of the permissive tract

The extent of the Nares Strait Group was used to delineate the permissive tract for Basaltic Copper type deposits.

Geological criteria

The Thule Basin is an intracratonic fracture basin with block faulting and basin sagging formed in a divergent plate region. The base of the basin is defined by an unconformity with underlying peneplained shield rocks. The basin is defined by an unmetamorphosed sedimentary-volcanic succession; the Thule Supergroup. The Supergroup comprises five lithostratigraphic groups; the Smith Sound Group, the Nares Strait Group, the Baffin Bay Group, the Dundas Group and the Narssârssuk Group (Dawes 2006). The tracts NW 5–10 have been assessed with regard to undiscovered Redbed Copper deposits within the Nares Strait Group.

The thickest section of Nares Strait Group, at Northumgerland Ø, is ca 700 m with thinning towards the mainland where it is pinching out. The thickness it estimated to be between 200 m to 1200 m and redbed units constitute 2 out of 4 formations amounting 45% of the entire stratigraphical column of the Nares Strait Group (see workshop presentation by P. Dawes). In ascending stratigraphic order the Group comprises multi-coloured sandstone with subordinate siltstone and shale, with occasional sills (Northumberland Formation, Fig. 63), a volcanic/redbed sequence of tholeiitic lavas with coeval sills, agglomerates, tuffaceous strat (lithic tuffs, tuff breccias and ash flows) and interflow clastic sandstone-siltstone-shale packages (Cape Combermere Formation, Fig. 63) and stromatolitic carbonates, sandstone and shale with tuffaceous elements (Josephine Headland and Barden Bugt Formations, Fig. 63). The deposits represent shallow-water deposition in mainly alluvial plain and littoral environments, with one main interval terrestrial volcanishm including plateay basalts (Dawes 2006). Especially the Cape Combermere Formation (Fig. 76) is found to be permissive for Basaltic Copper mineralisation.

Known deposits

There are no known deposits within the tracts.

Prospects, mineral occurrences, and related deposit types

There are no known prospects or mineral occurrences of the Basaltic Copper type, however, Redbed Copper type occurrences within the Thule basins are known. Hematite-chalcocite-mineralised lose blocks of vesicular volcanic rock have been collected in scree/moraine beneath exposed Cape Combermere Formation of the Nares Strait Group next to Parish Gletscher on Northumberland Ø (Figs 76–79). These samples have yield 1.7% Cu and 1.3% Cu.

Exploration history

The limited exploration in the Thule region, North West Greenland is summarized above. (See also Fig. 57; and Thomassen *et al.* 2002).

Grade and tonnage model selection

Based on the geological setting and characteristics of the known copper occurrences within the tract, the assessment team found, that the tracts did not show the normal characteristic of Sedimentary-hosted Redbed, Reduced Facies or Revett Copper type mineralization, but to a larger degree resembled those related to Basaltic Copper type which has been described by Cox and Singer (1986) and Kirkham (1984); no grade and tonnage models have been compiled and published for this type. The lack of this model in principle prevents a estimation of undiscovered deposits size (grade and tonnage) to be made.

However, the assessment team still found that it would be appropriate to assess the tract and make an estimate of the believed number of undiscovered Basaltic Copper type deposits although an estimation of the contained tonnage ore and Cu-grade could not be made. The assessment team agreed to consider an undiscovered Basaltic Copper type as being the size (grade and tonnage) similar to those of the Redbed Copper type which constitute the smallest mean grade and tonnage of the three Sedimentary-hosted Copper types described by Cox et al. 2003. One individual amongst the assessment team found that the lacking grade and tonnage model for the Basaltic Copper type made it impossible to evaluate the number of undiscovered deposits and declined to estimate the numbers of deposits, but agreed that a potential for undiscovered Basaltic Copper type mineralization is present.

Estimate of the number of undiscovered deposits

Rationale for the estimate

The sedimentary successions, especially the volcanic/redbed sequence of tholeiitic lavas and sills, encountered in the Nares Strait Group are found to be permissive for Sedimentary-hosted Basaltic Copper type mineralization. Also, samples from the public financed „hunt for minerals‘ program (Ujarsassiorit) have returned Cu values >10% on samples from Robertson Fjord and Northumberland Ø (the tracts NW9). Consequently, separate estimates have been made tract NW 5, 8 and 10 together, and tract NW9 (Tables 56 and 57).

The tracts have seen very little exploration and no campaigns have been directed towards the potential for Basaltic Copper type mineralization.

Table 56. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tracts NW 5b, 8 and 10 Nares Strait Group, Basaltic Copper type*

Consensus undiscovered deposit estimates					Summary statistics					Tract Area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	0	1	2	0.11	0.44	420	0	0.11	3,000	0.000035

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	1	2
Individual 2	0	0	0	0	1
Individual 3	0	0	0	1	2
Individual 4	0	0	0	1	4
Individual 5	0	0	0	1	2
Individual 6	-	-	-	-	-
Individual 7	0	0	0	1	2
Individual 8	0	0	0	1	2
Individual 9	0	0	0	1	2
Individual 10	0	0	0	0	1
Consensus	0	0	0	1	2

Table 57. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract NW 9 Nares Strait Group, Basaltic Copper type*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv %	N_{known}	N_{total}		
0	0	0	1	2	0.11	0.44	420	0	0.11	290	0.00037

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	1	1
Individual 2	0	0	0	1	2
Individual 3	0	0	0	0	1
Individual 4	0	0	0	0	2
Individual 5	0	0	0	2	4
Individual 6	-	-	-	-	-
Individual 7	0	0	0	1	4
Individual 8	0	0	0	1	2
Individual 9	0	0	0	1	2
Individual 10	0	0	0	0	1
Consensus	0	0	0	1	2

Figure 76. *Volcanics of the Cape Combermere Formation of the Nares Strait Group at eastern side of Kissel Gletscher, height of cliff is ca. 500 m. Photo from workshop presentation by B. Thomassen.*

Figure 77. *Exposed Cape Combermere Formation east of Parish Gletscher. Hematite-chalcocite-mineralised scree blocks have been found in the scree-fan. Photo from workshop presentation by B. Thomassen.*

Figure 78. *Moraine block from Parish Gletscher beneath exposed Cape Combermere Formation of vesicular lava with hematite-chalcocite blebs and 1.3% Cu, 5.3% Fe. Match is 5 cm. Photos from workshop presentation by B. Thomassen.*

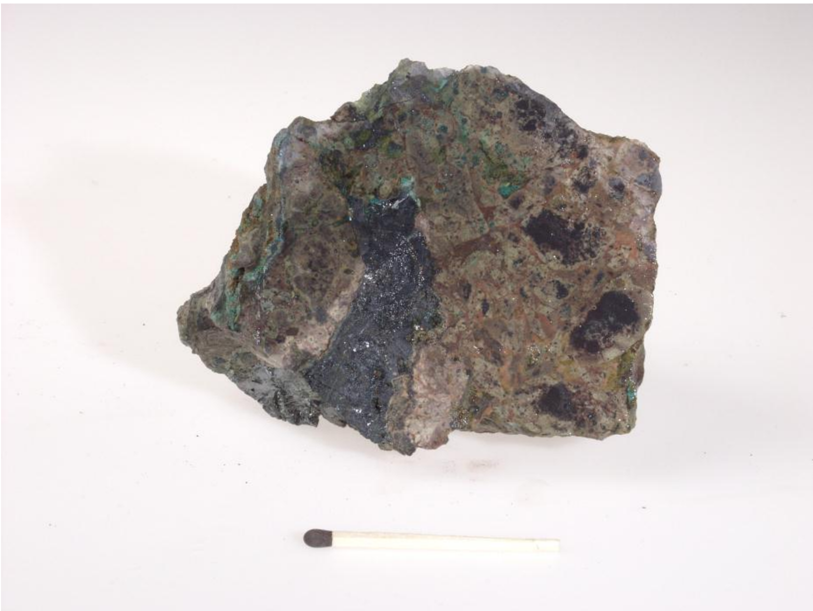

Figure 79. *Hematite-chalcocite-bearing volcanic float with 1.7% Cu, 21.9% Fe. Lose scree-block from Parish Gletscher beneath exposed Cape Combermere Formation. Match is 5 cm. Photos from workshop presentation by B. Thomassen.*

Assessment of Basaltic Copper type within Meso- to Neoproterozoic basin in North-East Greenland

Deposit type assessed

The assessment team found that the settings and known copper mineralization within the Meso- to Neoproterozoic basin in North-East Greenland resembled those of the related Basaltic Copper type, which have been described by Cox and Singer (1986) and Kirkham (1984); this type of mineralization is sometimes referred to as Basaltic Copper type.

Even though no grade and tonnage model have been compiled and published for this type of mineralization, the assessment team found that it would be appropriate to assess the tract with an estimation of the number of believed undiscovered Basaltic Copper deposits within the tract but leaving out the resulting estimation of tonnage ore and copper.

Sources of information

The principal sources of information used for the assessment of the tracts in the Meso- to Neoproterozoic Hekla Basin for the Basaltic Copper type are given in Appendix A.

Tract NE 1–9 Hagen Fjord Group and NE 10–11 Independence Fjord Group – Basaltic Copper type

The tracts NE 1–9 Hagen Fjord Group and NE 10–11 Independence Fjord Group are located in the North-East Greenland sedimentary basin between Independence Fjord and Hekla Sund (Fig. 80).

Location

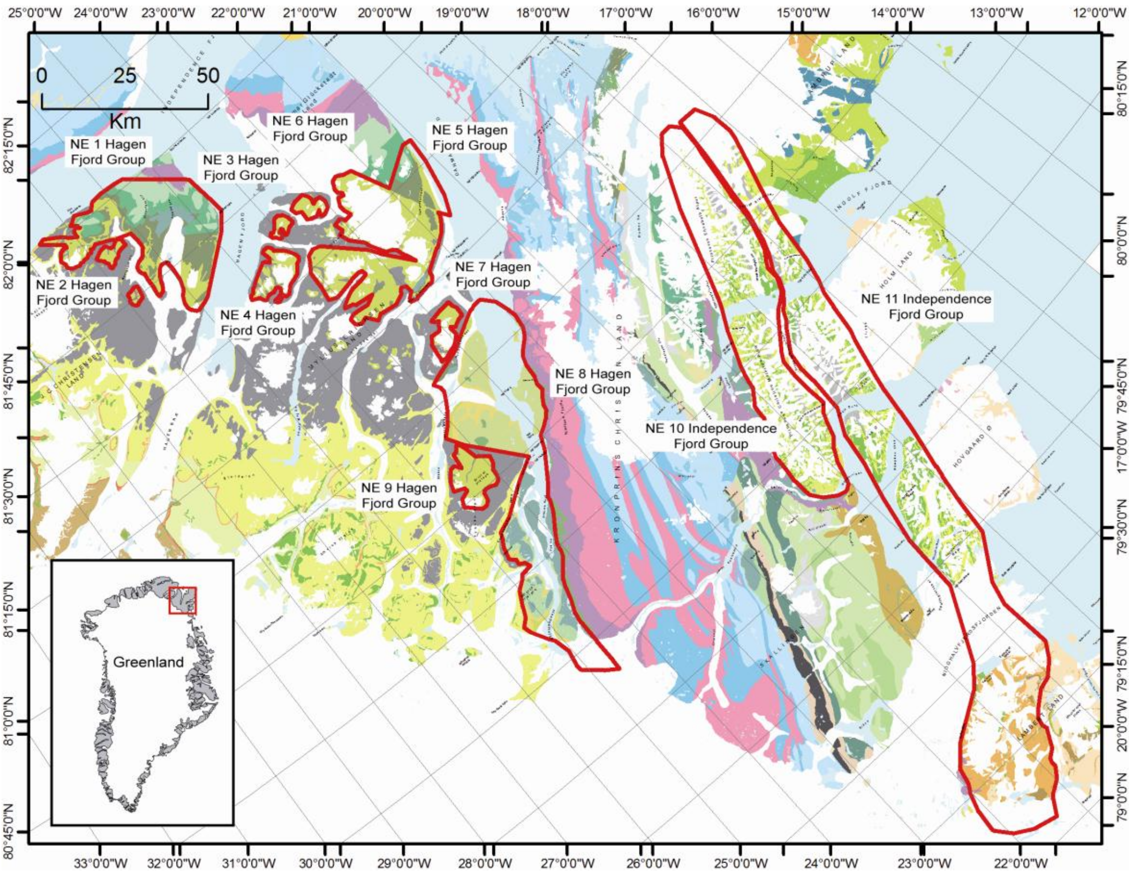

Figure 80. *Distribution of tracts NE 2–9 Hagen Fjord Group and NE 10–11 Independence Fjord Group 5 plotted on top of the 1:250 000 geological map for the area (Christoffersen & Jepsen 2007). Refer to this map for a full legend.*

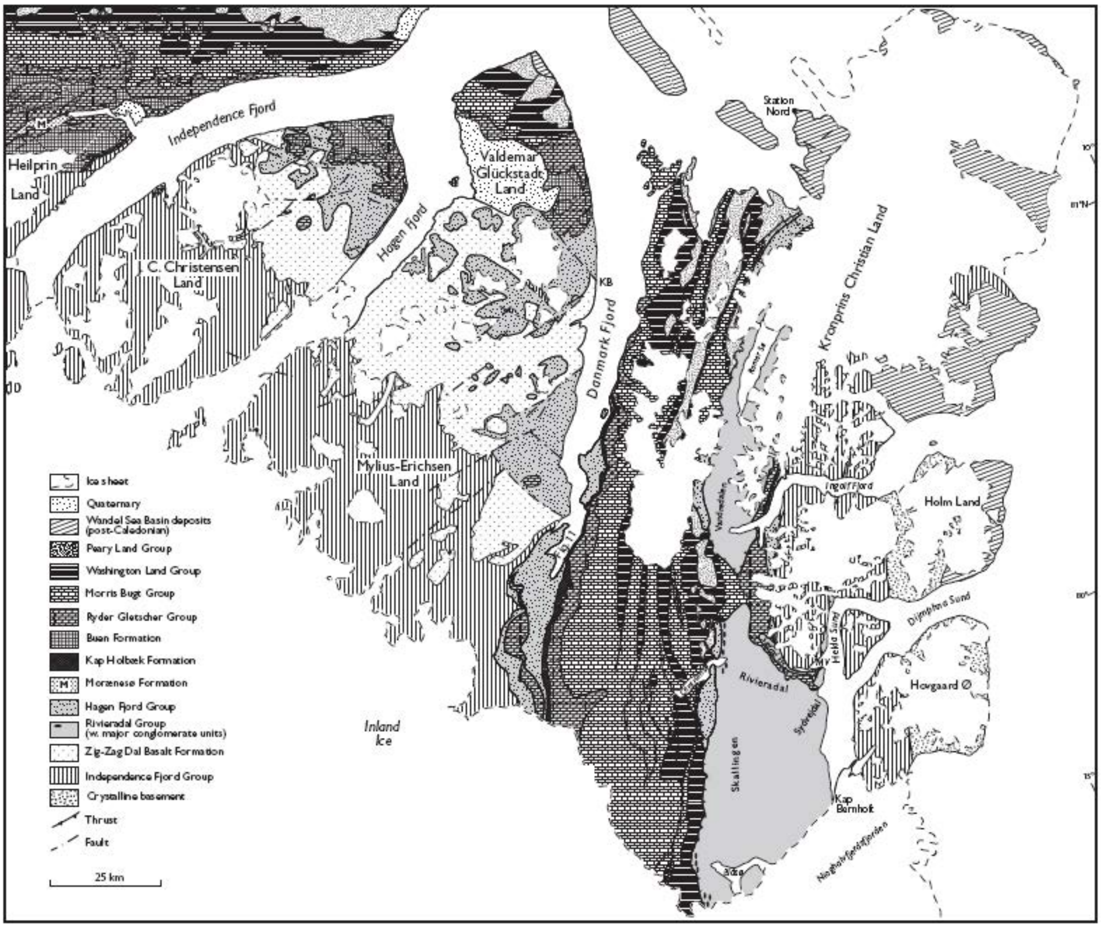

Figure 81. *Simplified map showing the distribution of Hagen Fjord Group, the underlying Zig-Zag Dal Basalt Formation and the Independence Fjord Group. From workshop presentation given at the workshop by M. Sønderholm.*

Geological feature assessed

In the assessment of the tracts NE 1–9 Hagen Fjord Group and NE 10–11 Independence Fjord Group undiscovered Basaltic Copper deposits within the Hagen Fjord Group of the Meso- to Neoproterozoic Hekla Sund Basin and within sediments of the Palaeoproterozoic Independence Fjord Group were assessed respectively.

Delineation of the permissive tract

The extent of the Hagen Fjord Group and the Independence Fjord Group was used to delineated the permissive tract for Basaltic Copper type deposits (Figs 80 and 81).

Geological criteria

The Neoproterozoic sedimentary basins in North-East Greenland were treated by the assessment team. Initial tracts were defined within the post-rift thermal subsidence depositional environment sediments of the Hagen Fjord Group (tract NE1–9 Hagen Fjord Group) of the Meso- to Neoproterozoic Hekla Sund Basin and within sediments of the Palaeoproterozoic Independence Fjord Group (tract NE 10–11 Independence Fjord Group) that were deposited in a intracratonic extensional basin during a period of slow subsidence.

The Hagen Fjord Group reaches a maximum thickness of approximately 1,100 m and consists of a succession of sandstones overlain by sandstone-siltstone association and an upper part that is characterised by limestone and dolomites with abundant stromatolites. The sediments of the Hagen Fjord Group is deposited on top of an up to 1,350 m thick succession of well-preserved tholeiitic flood basalts of the Mesoproterozoic Proterozoic Zig-Zag Dal Basalt Formation which in turn overlies the more than 2 km thick Independence Fjord Group sandstones that are intruded by numerous mafic sheets and sills of the Midsommersø Dolerite Formation (Fig. 82). The sheets and sills have been dated to be 1382 ± 2 Ma (Henriksen et al. 2009).

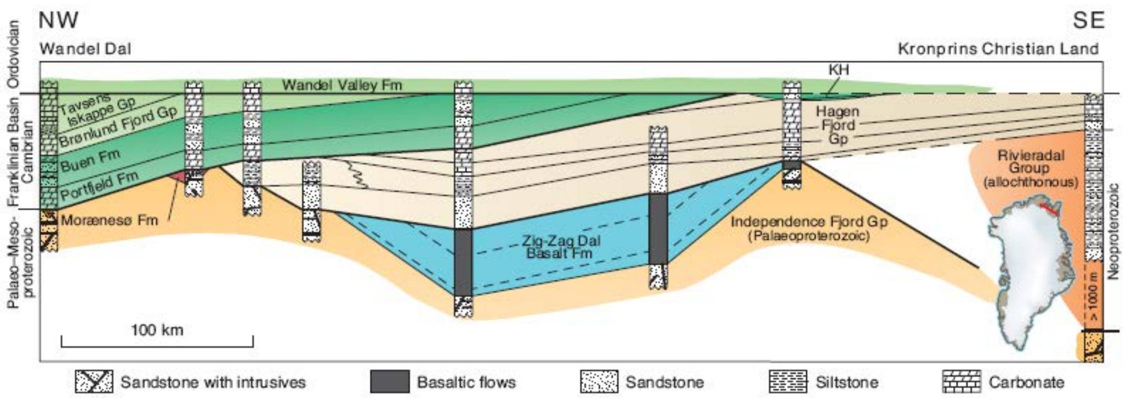

Figure 82. *Schematic cross-section of the Proterozoic–Ordovician succession in eastern North Greenland between 82°N and Kronprins Christian Land ~ 80°N. From Henriksen et al. 2009.*

Known deposits

There are no known deposits within the tracts.

Prospects, mineral occurrences, and related deposit types

Chalcopyrite and native copper in stream sediment samples have been picked from numerous locations in the J.C. Christensen Land area between Danmark Fjord and Independence Fjord (Figs 83 and 84). Also, several copper occurrences in outcrop have been found in this area. The copper occurrences are hosted within fluviatile whitish sandstone of the Jyske Ås Formation of the lowermost part of Hagen Fjord Group. The occurrence seems to be aligned with E–W-oriented regional scale graben fault patterns and there might be a relationship between these and the copper mineralizations (Figs 85–87). Bornite and chalcosite are found interstitial between sand grains in mineralised samples and as veinlets crosscutting the sandstone. Composite grab samples of this mineralization returns up to 3% Cu and 100 ppm Ag. Large native copper cobbles (up to 5–10 cm long) have also been found. Cobber mineralization as stratabound disseminated chalcopyrite, pyrite and galena have been found within the Campanuladal Formation (Fig. 87) that conformably overlies the Jyske Ås Formation of the lowermost Hagen Fjord Group. The 110–175 m thick Campanuladal Formation is dominated by green and red fine-grained sandstones, siltstones and mudstones. The disseminated sulphides are found within pale sandstone and siltstone.

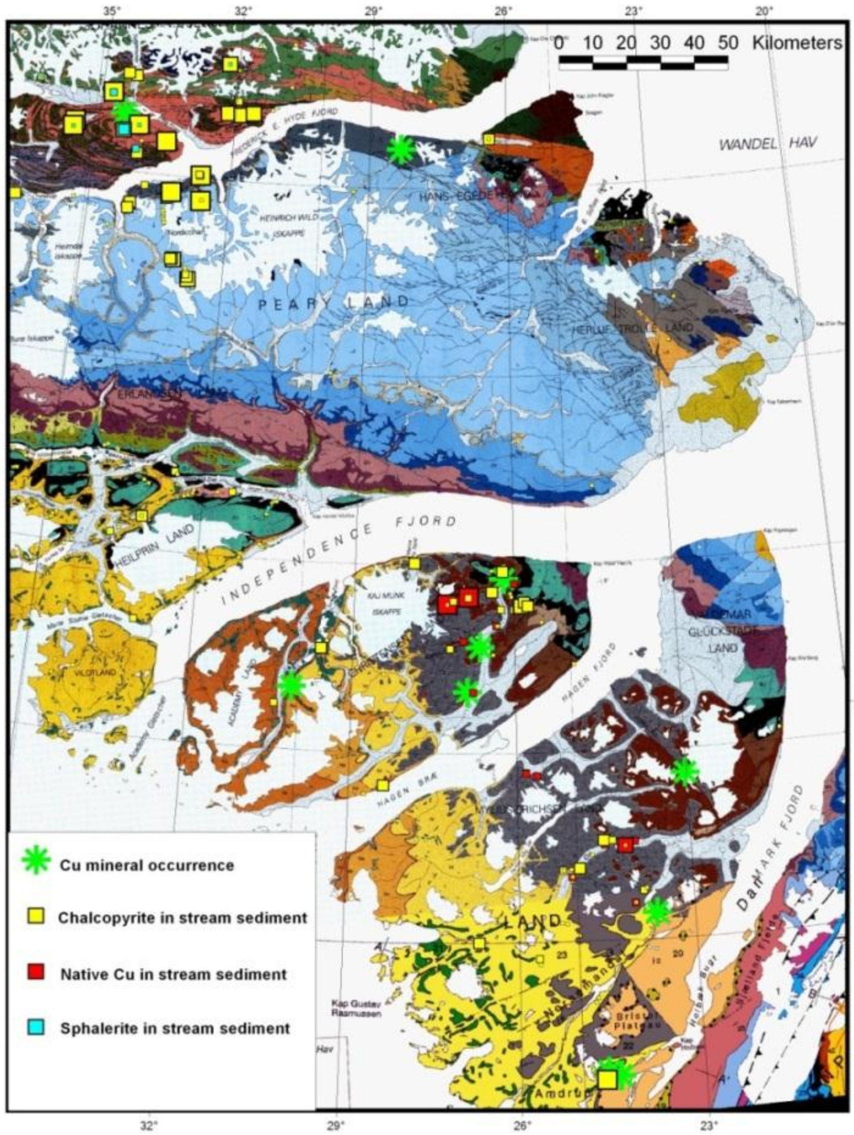

Figure 83. *Distribution of known copper occurrences and chalcopyrite, native Cu, and sphalerite from stream sediment samples in the region between Danmark Fjord and Frederik E. Hyde Fjord. Hagen Fjord Group is shown in brown and beige, while the underlying Zig-Zag Dal Basalt Formation in grey. For full legend refer to Bengaard and Henriksen (1986). From presentation given at the workshop by Tukiainen & Lind.*

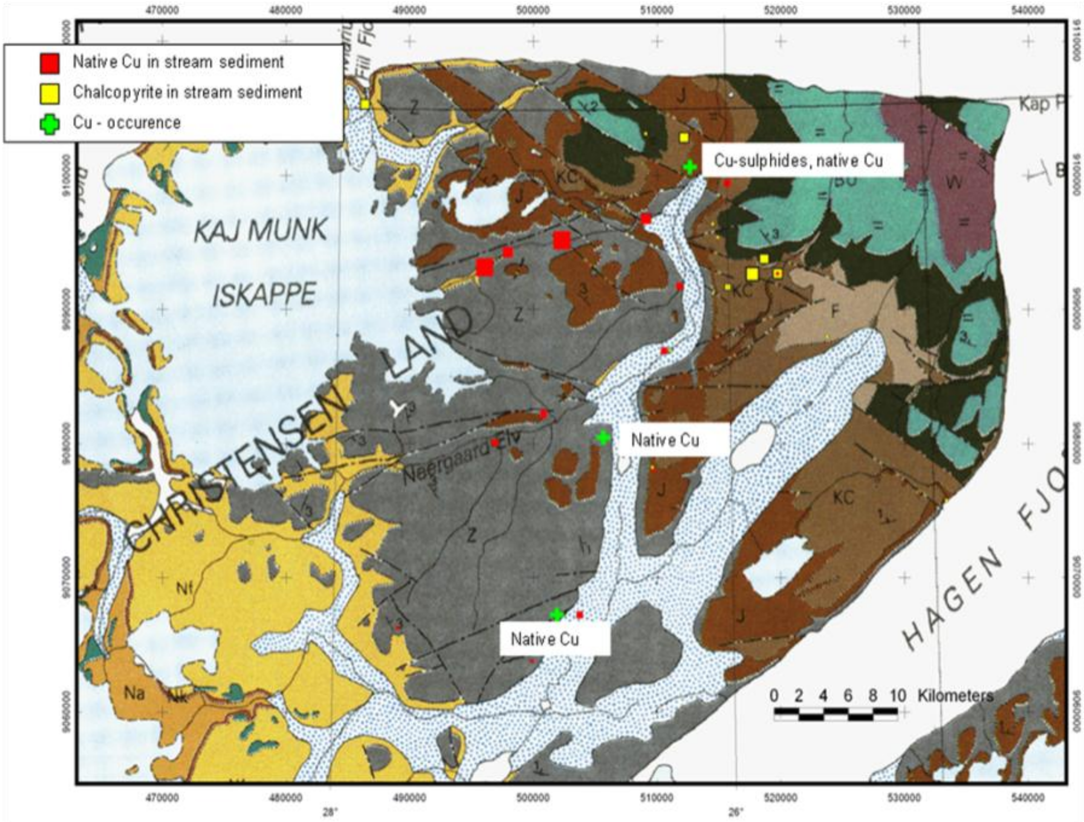

Figure 84. *Copper mineralizations in the Hagen Fjord Group For full legend, see Bengaard & Henriksen (1986). From workshop presentation by Tukiainen & Lind.*

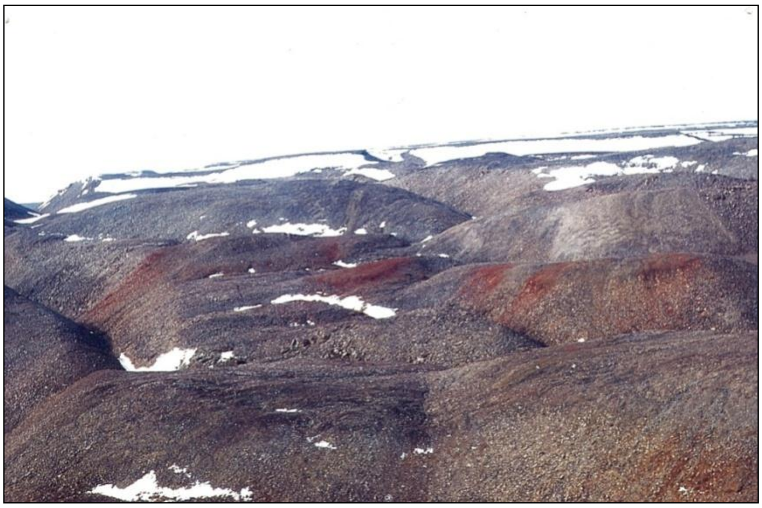

Figure 85. *Jyske Ås Formation sandstones with rusty alteration along lineaments extending westwards from one of the copper occurrences at J.C. Christensen Land. From workshop presentation by Tukiainen & Lind.*

Figure 86. *Malachite stained pale whitish sandstone of the Jyske Ås Formation. Figure from workshop presentation by Tukiainen & Lind.*

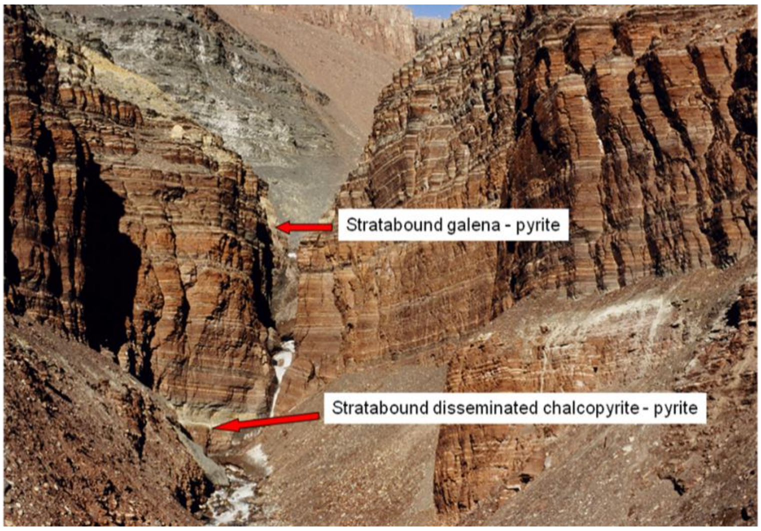

Figure 87. *Stratabound disseminated copper mineralised horizons within pale sandstone and siltstone of the Campanuladal Formation. From workshop presentation by Tukiainen & Lind.*

Exploration history

The private group Greenarctic Consortium conducted a regional aeromagnetic survey and regional gossan follow-up in the years 1969–1973.

The Geological Survey of Greenland (GGU) and later the Geological Survey of Denmark and Greenland (GEUS), have carried out regional geological mapping campaigns in 1978-1980 and 1993-1995. As part of these campaigns regional sampling of drainage sediments (Fig. 84) and limited economic geological reconnaissance was carried out.

Copper mineralization was first discovered in the Neoproterozoic sandstones by GEUS in 1995 (Fig. 84). In 1998, an airborne electromagnetic (GEOTEM method) and magnetic survey was carried by GEUS and the Greenlandic Home rule Government out over the north-eastern J.C. Christensen Land, eastern North Greenland, with additional reconnaissance lines in eastern Peary Land, North Greenland. The survey was flown with lines directed along NE45.8^{o} and line spacing of 400 metres. Orthogonal tie-lines were flown with a line separation of 4,000 metres. A total of 4,492 line-kilometres were collected, and a total of 485 line-kilometres were flown in eastern Peary Land as reconnaissance lines. Nominal flight altitude is 120 metres over terrain with the total field magnetic sensor and electromagnetic sensor 75 metres and 70 metres above ground, respectively.

North of Independence Fjord, at Citronen Fjord, Platinova Ltd 1992–2000, located the Citronen Fjord Zinc-Lead deposit (SEDEX type), on which extensive drilling- and detailed geophysical surveys have subsequently been undertaken. Ironbark Gold Ltd licensed the Citronen Fjord –Zinc-Lead deposit in 2007 and has continued with extensive drilling and exploration campaigns. However, very little work has been carried out within the tracts NE 1–9 and NE 10–11.

Following the assessment workshop documented in this report, the company Avannaa Resources Ltd. has taken up exploration rights to more than 4,500 km^2 licenses in North-East Greenland covering the Hagen Fjord Group. The company interprets the geological settings and mineralizations to be similar to the copper mineralizing systems, known from the Kantangan Supergroup on the Zambian Copper Belt. In particular the company considers the green, reduced siltstones of the Campanuladal Formation above the copper mineralised breccia zones to make ideal trap-sites for copper. The Campanuladal Formation is virtually unexplored and is, by the company, considered to having the potential to host large tonnage copper deposits. Avannaa Resources conducted a preliminary field campaign in 2010 over the area and reports chip samples though mineralised breccias with 0.8-3.4 wt% copper together with 33-79 g/t silver, across 4.5 m width and grab samples returning up to 12.5 wt% Cu and 385 g/t Ag; extensive field work will be undertaken in 2011 including remote sensing, acquisition of airborne hyperspectral data and ground testing of existing and new mineralization targets.

Grade and tonnage model selection

Based on the geological setting and characteristics of the known copper occurrences within the tract, the assessment team found, that the tracts did not show the normal characteristic of Sedimentary-hosted Redbed, Reduced Facies or Revett Copper type mineralization, but to a larger degree resembled those related to Basaltic Copper type which has been described by Cox and Singer (1986) and Kirkham (1984); no grade and tonnage models have been compiled and published for this type. The lack of this model in principle prevents a estimation of undiscovered deposits size (grade and tonnage) to be made.

However, the assessment team still found that it would be appropriate to assess the tract and make an estimate of the believed number of undiscovered Basaltic Copper type deposits although an estimation of the contained tonnage ore and Cu-grade could not be made. The assessment team agreed to consider an undiscovered Basaltic Copper type as being the size (grade and tonnage) similar to those of the Redbed Copper type which constitute the smallest mean grade and tonnage of the three Sedimentary-hosted Copper types described by Cox et al. 2003. One individual amongst the assessment team found that the lacking grade and tonnage model for the Basaltic Copper type made it impossible to evaluate the number of undiscovered deposits and declined to estimate the numbers of deposits, but agreed that a potential for undiscovered Basaltic Copper type mineralization is present.

Estimate of the number of undiscovered deposits

Rationale for the estimate

The sedimentary successions, encountered in the Hagen Fjord Group and the Independence Fjord Group, are found to be permissive for Sedimentary-hosted Basaltic Copper type mineralization given the large underlying reservoir for copper (the underlying thick sequence of the tholeiitic Zig-Zag Dal Basalt Formation. Also the team pointed to well-developed half-graben system and its distinct fault patterns. The tracts cover a very large area within which only limited exploration activity has been undertaken. However, the limited data all show positive indications for larger mineralizations systems, and thus a potential for undiscovered deposits were believed to be present.

The assessment team found, that the settings, discovered occurrences and indications of additional mineralization were more favourable within the tracts NE 1–9 Hagen Fjord Group than within the NE 10–11 Independence Fjord Group tracts. Therefore, the assessment team found it appropriated to make two separate estimations (Tables 58 and 59).

Table 58. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tracts NE 1–9 Hagen Fjord Group, Basaltic Copper type*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	**N50**	**N10**	**N05**	**N01**	**N_{und}**	**s**	**Cv %**	**N_{known}**	**N_{total}**		
0	0	2	3	6	0.77	1.4	190	0	0.77	~15,000	0.000051

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	3	5	7
Individual 2	0	1	2	3	6
Individual 3	0	0	1	2	4
Individual 4	0	0	1	3	7
Individual 5	0	0	2	3	4
Individual 6	-	-	-	-	-
Individual 7	0	0	0	0	5
Individual 8	0	1	2	4	8
Individual 9	0	0	1	3	6
Consensus	0	0	2	3	6

Table 59. *Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tracts NE 10–11 Independence Fjord Group, Basaltic Copper type*

Consensus undiscovered deposit estimate					Summary statistics					Area (km^2)	Deposit density (N/km^2)
N90	**N50**	**N10**	**N05**	**N01**	**N_{und}**	**s**	**Cv %**	**N_{known}**	**N_{total}**		
0	0	0	1	3	0.14	0.56	420	0	0.14	~15,000	0.000023

	Estimated number of undiscovered deposits				
Estimator	**N90**	**N50**	**N10**	**N05**	**N01**
Individual 1	0	0	0	1	2
Individual 2	0	0	0	0	1
Individual 3	0	0	0	1	2
Individual 4	0	0	0	3	5
Individual 5	0	0	0	0	1
Individual 6	-	-	-	-	-
Individual 7	0	0	0	0	3
Individual 8	0	0	0	1	3
Individual 9	0	0	0	1	3
Consensus	0	0	0	1	3

Conclusion

Sedimentary basin environments younger than 1,600 million years (Ma) constitute approximately 40% of Greenland's 410 000 km^2 ice-free land. Of this, the Phanerozoic basins account for around 20%, the Lower Palaeozoic and the Neoproterozoic basins for around 50%, and the Mesoproterozoic basins for 30%. These basins are well-known for several sediment-hosted copper mineralizations. This assessment study evaluates three sub-types of sedimentary copper mineralizations: (i) Revett Copper type, (ii) Reduced Facies Copper type, and (iii) Redbed Copper type, for which statistical models exists and can be used in a quantitative resource assessments. Additionally, the Basaltic Copper type was used for North-East Greenland, though excluding the quantitative assessment, because of the absence of a statistical model for this type.

The assessment was undertaken in a three-day workshop in Copenhagen, and a team of thirteen geologists made up the assessment team. Team members were selected to include specific knowledge about sedimentary-hosted copper deposit models, the geology of the assessment areas, and exploration for sedimentary-hosted copper deposits.

A total of fifty-two tracts were found permissive for sedimentary-hosted copper in Greenland. For each of these areas available data on the geology, settings, rock units, exploration history and known mineralizations (showings, occurrences, prospects, deposits) were assessed. The assessments were undertaken in strict accordance with the guidelines provided by USGS, and the outcome is summarized in Tables 60–62.

It should be emphasized, that the assessments are made under the presumption of *"the best circumstances",* and that the confidence level reflects the overall level of knowledge about individual areas. Commonly, some of the key questions are related to lack of descriptions on already discovered copper occurrences, which in turn reflects that high exploration costs and inaccessibility hampers follow-up work on discovered copper occurrences. Key missing data and information could be identified in some cases, and may be used to direct future work in the tracts.

The total mean of undiscovered copper resources, for Reduced-facies, Revett and Redbed Copper types, was estimated to 3,676,300 tons Cu (Table 62). An estimate of undiscovered copper resources for Basaltic Copper was not possible because no tonnage-grade curve have been established for this type of mineral deposit model.

The Reduced-facies and Basaltic Copper types appear to have the highest potential for hosting undiscovered sedimentary copper deposits. However, it should be noted, that though rarer, large tonnage and high grade deposit are also found of both Revett and Redbed Copper types, and thus the potential for mineable deposits of these types is present.

The greatest potential for large-grade tonnage deposits of the Reduced-facies Copper type is within the Neoproterozoic Eleonore Bay Supergroup in North-East Greenland and the Upper Triassic Pingel Dal Bed of the Fleming Fjord Formation in central East Greenland. Though Reduced-facies Copper type mineralization are known, the tracts that were assessed for these settings have seen very limited exploration campaigns for larger mineralised systems and only surface-work have been conducted. Both settings constitute large sedimentary packages that have the right ingredients for the formation of Reduced-facies Copper type mineralization. Better understanding of possible fluid flow (including understanding local and regional fault systems, and variation in permeability) and redox potential, might be important in targeting exploration for large copper mineralised systems in these settings.

The Hagen Fjord Group in Northeastern Greenland is regarded as having a large potential for deposits of the Basaltic Copper type. An understanding of the redox potential of the different lithologies, with an assessment of both reducing siltstone and carbonate lithologies is of importance. Also investigation of the larger fault systems might lead to mineralizing systems. Later remobilization and up-concentrations of copper in later fault systems should also be investigated.

Revett Copper type mineralization is only recognised within the Upper Permian Huledal Formation. Two copper deposits, the Rubjerg Knude and the Ladderbjerg, are known from this setting with chip sample based resource estimates yielding 5 Mt @ 0.3% Cu and 2.5 Mt @ 0.15% Cu. A potential for undiscovered deposits within the settings exists and a large part of the tracts have not been investigated in details.

Redbed Copper type mineralizations are known from several different sedimentary basins in Greenland. They form mostly restricted ore bodies though they in some cases are found laterally distributed continuous in large areas.

Table 57. *Most important presently known sediment-hosted copper occurrences in Greenland*

Mineral deposit model / type	Name of deposit/ occurrence	Region	Host rock	Grades and size
Reduced-facies Copper	Vimmelskaftet Cu occurrence	Central East Greenland, Jameson Land Basin	Black shales of the Upper Permian Ravnefjeld Formation.	Widespread mineralization. Chip samples (n=39) over 20 m run 200–850 ppm Cu, 1300–7000 ppm Pb and 350–1260 ppm Zn. Thin, 1-3 cm thick mineralised beds are known from several localities and contain 10% combined zinc and lead.
	Devondal Cu occurrence			Widespread mineralization. A chip sample over 2.5 m averages 200 ppm Cu, 200 ppm Pb and <500 ppm Zn.
	Pingel Dal Beds Cu occurrence		Silty mudstone of the Upper Triassic Pingel Dal Beds of the Edderfugledal Member, Fleming Fjord Formation.	Widespread and laterally persistent mineralization known over 1000 km^2. Thickness of mineralised horizons between 0.2–2 m. Chip samples (n=29) yield averages of 0.2% Cu over 1.1 m with a range of 0.02–0.50% Cu over 0.3–1.9 m.
	Ymer Ø Group Cu occurrence	North-East Greenland, Eleonore Bay Supergroup	Calcareous and dolomitic shales of the uppermost part of the Neoproterozoic Ymer Ø Group.	Widespread and persistent mineralization. Observed over 275 km from north to south. Thickness of mineralised horizons is from a few cm to a few metres. Cu content of mineralised green shales is from 0.25% to 1.5% Cu with an average of 0.7%; selected samples yield up to 6% Cu; average Ag content is low with a Cu/Ag ratio of 1000–1500.
Redbed Copper	Nordenskiøld Cu occurrences Fleming Fjord Formation Cu occurrences	Central East Greenland, Jameson Land Basin	Grey and red intercalated mudstones of playa flat origin of the Upper Triassic Fleming Fjord Formation.	Mineralization has been recorded continuous in two or more 0.1–1 m thick sandstone beds over ca. 1000 km^2. Chip samples from 21 sections collected for 650 m laterally show an average content of 500 ppm Cu (range 27–3500 ppm) and 1.3 ppm Ag (range 0.8–4.8 ppm) over a thickness of 0.38 m (range 0.25–0.6 m) Maximum values stem from a selected grab sample with 27.5% Cu, 787 ppm Ag.
	Olrik Fjord Cu occurrences	North-West Greenland, Thule Basin	Pale sandstones of the Meso- to Neoproterozoic Qaanaaq Formation of the Baffin Bay Group.	Mineralization restricted to a 100 m^2 area. A composite grab sample has 0.4% Cu.
	‗Red Cliffs‘ Cu occurrence			Isolated outcrops of copper mineralised sandstone. Grab samples yield up to 1.5% Cu.
Revett Copper	Rubjerg Knude Cu deposit	Central East Greenland, Jameson Land Basin	Braided alluvial plain conglomerate consisting of well-rounded quartzite, carbonate, granite pebbles/cobbles with a sand matrix and carbonate matrix of Upper Permian Huledal Formation.	In places, Cu mineralization extends over 20 m but on average the outcropping thickness is between 5 m and 10 m. Continuous mineralization is observed for 200–300 m. In an area of 1.3×2.5 km a tonnage-grade of 5 Mt with 0.3% Cu has been estimated (based on 13 chip samples).
	Ladderbjerg Cu deposit			Thickness of Cu mineralization ~10 m in an area of 1×4 km with estimated tonnage-grade of 2.5 Mt with 0.15% Cu. Associated lead mineralization extends over an average thickness of 8 m and is estimated to contain 1.5 Mt with an estimated grade of 1% Pb (based on eight chip samples from the area).
Basaltic Copper	Jyske Ås Formation / Hagen Fjord Group Cu occurrences	North-East Greenland, Hekla Sund Basin	Shallow shelf sediments of Jyske Ås Formation of the Neoproterozoic Hagen Fjord Group.	Composite grab samples from Jyske Ås Formation run up to 3% Cu and 100 ppm Ag.

Table 58. *Consensus bids on the number of undiscovered copper deposits per area (tract)*

Mineral deposit model / type	Region	Geological period	Area (tract name)	Areal extent (km^2)	Number of undiscovered Cu deposits at different confidence levels*				
					N90	N50	N10	N05	N01
Reduced-facies Copper	Central East Greenland	Permian	CE 2 and CE4–15 Ravnefjeld Fm	2,250	0	0	0	0	2
		Triassic	CE 1A Pingel Dal Bed	2,000	0	0	0	2	4
			CE 1B Pingel Dal Bed	1,000	0	0	0	0	2
	North-East Greenland	Neoproterozoic	CE 1–6 EBS and CE 9–16 EBS	2,111	0	0	0	1	4
			CE 7–8 EBS	1,000	0	0	0	2	4
Revett Copper	Central East Greenland	Permian	CE 2 Huledal Fm	436	0	0	0	1	2
			CE 4–7 Huledal Fm	882	0	0	0	1	3
			CE 8–12 Huledal Fm	449	0	0	0	2	4
			CE 13–14 Huledal Fm	361	0	0	0	1	3
			C15 Huledal Fm	165	0	0	0	0	1
Redbed Copper	Central East Greenland	Triassic	CE 1A Malmros Klint /Ørsted Dal Mb	2,310	0	0	0	2	4
			CE 1B Malmros Klint/ Ørsted Dal Mb.	1,150	0	0	0	0	2
	North-West Greenland	Meso- to Neoproterozoic	NW 1–2 and NW 5–10 Baffin Bay Group	5,740	0	0	0	2	5
			NW 5–10 Nares Strait Group	5,680	0	0	1	2	5
			NW 3–4 Nars-sarssuk Group	320	0	0	0	0	2
			NW 11–13 Smith Sound Group	1,230	0	0	0	2	4
Basaltic Copper	North-West Greenland	Meso- to Neoproterozoic	NW 5b 8, 10 Nares Strait Group	3,000	0	0	0	1	2
			NW 9 Nares Strait Group	290	0	0	0	1	2
	North-East Greenland	Neoproterozoic	NE-1–9 Hagen Fjord Group	15,000	0	0	2	3	6
			NE-10–11 Independence Fjord group	5,810	0	0	0	1	3

***** N90, N50, N10, N05, N01 = Confidence levels; a measure of how reliable a statistical result is, expressed as a percentage that indicates the probability of the result being correct. A confidence level of 10% means that there is a probability of at 10% that the result is reliable.

Table 59. *Summary of assessment results including undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tracts – Reduced-facies, Redbed and Revett Copper deposit models. Abbreviations: EBS = Eleonore Bay Supergroup*

Tract name	Copper deposit model/ type	Tract area	Number of known deposits	Total number of deposits (including estimate of undiscovered deposits)	Deposit density	Known copper resource	Mean estimate of undiscovered copper re sources	Ranking within specific type
		km^2	N_{Known}	$N_{Total} = N_{known}$ + statistical estimated undiscovered deposits)	N_{Total} / tract area in km^2	Metric tons	Metric tons	According to deposit density only!
CE 2 and CE4–15 Ravnefjeld Fm	Reduced- facies Copper	208	0	0.06	0.000027	0	240,000	5
CE 1A Pingel Dal Bed		2,000	0	0.21	0.000110	0	830,000	2
CE 1B Pingel Dal Bed		1000	0	0.06	0.000060	0	300,000	4
CE 1–6 EBS and CE 9–16 EBS		2,111	0	0.17	0.000078	0	730,000	3
CE 7–8 EBS		1,000	0	0.21	0.000210	0	810,000	**1**
CE 2 Huledal Fm	Revett Copper	436	0	0.11	0.000252		95,000	3
CE 4–7 Huledal Fm		827	0	0.14	0.000017	0	130,000	4
CE 8–12 Huledal Fm		452	1	1.21	0.002650	15,000	190,000	**1**
CE 13–14 Huledal Fm		345	1	1.14	0.002520	37,500	130,000	2
C15–16 Huledal Fm		208	0	0.03	0.000140	0	23,000	5

(Table 59 continued)

Tract name	**Copper deposit model/ type**	**Tract area**	**Number of known deposits**	**Total number of deposits (including estimate of undis-covered deposits)**	**Deposit density**	**Known copper re-source**	**Mean esti-mate of undiscov-ered copper re sources**	**Ranking within specific type**
		km^2	N_{Known}	N_{Total} = N_{known} + **statistical estimated undiscov-ered de-posits**	N_{Total} / tract area in km^2	Metric tons	Metric tons	According to deposit density only!
CE 1A Malm-ros Klint/ Ørsted Dal Mb.		1,000	0	0.06	0.000006	0	10,000	5
CE 1B Malm-ros Klint/ Ørsted Dal Mb.	Redbed Copper	2,000	0	0.21	0.000110	0	28,000	4
NW 1–2 and NW 5–10 Baffin Bay Group		5,740	0	0.24	0.000042	0	41,000	2
NW 5–10 Nares Strait Group		5,680	0	0.47	0.000082	0	79,000	1
NW 3–4 Narssarssuk Group		5,740	0	0.06	0.000190	0	9,300	6
NW 11–13 Smith Sound Group		1,230	0	0.21	0.000170	0	31,000	3
Reduced-facies, Revett and Redbed mineral deposit mode								
Total tons of undiscovered copper resource:							**3,738,000 tons Cu**	

(Table 59 continued)

Sedimentary-hosted copper mineral deposit model with no established grade-tonnage curves; no quantitative undiscovered resource estimation (na = not applicable) being made:

Basaltic copper deposit model

NW 5b 8, 10 Nares Strait Group	**Basaltic Copper**	3,000	0	0.11	0.000035	na	na	3
NW 9 Nares Strait Group		290	0	0.11	0.000370	na	na	**1**
NE 1–9 Hagen Fjord Group		~15,000	0	0.77	0.000051	na	na	2
NE 10–11 Independence Fjord Group		~15,000	0	0.14	0.000023	na	na	4

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Appendix A: Bibliography on Sedimentary-hosted copper in Greenland

The bibliography covers the most important references on sedimentary-hosted copper mineralization in Greenland and some of the most important references on regional geology for areas. The bibliography was compiled by Bo Møller Stensgaard and Bjørn Thomassen. References marked with * are considered key papers.

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North-West Greenland

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Appendix B: CD-ROM

Presentation number (on accompanying CD-ROM)	**Presenter**	**Title**
1	Cliff Taylor	Overview of Threee-Part quantitative Mineral Resource Assessment Method
2	Cliff Taylor	Progress towards a global estimate of undiscov-ered sediment-hosted copper resources: Porgress in Europe and elsewhere as of March 2009
3	Cliff Taylor	A review of the USGS sediment-hosted copper deposit model
4	Henrik Stendal	Sedimentary copper models – prospective regions in Greenland
5	Bjørn Thomas-sen	Upper Permian–Triassic sediments, central East Greenland: Overview of copper localities and exploration history.
6	Jesper K. Niel-sen & Mikael Pedersen	Permian and Triassic sedimentary environments of the East Greenland Basin.
7	Bjørn Thomas-sen	Overview of Cu localities and exploration history in the Thule Supergroup, North-West Greenland.
8	Peter Dawes	The Proterozoic thule basin: an intracratonic sed-imentary-volcanic depocentre across Baffin Bay.
9	Tapani Tukiainen & Mogens Lind	North-East Greenland: Overview of copper locali-ties and exploration history.
10	Henrik Stendal	Elenore Bay Supergroup and sedimentary copper.
12	Martin Sønder-holm	Neoproterozoic sedimentary basins fof eastern Greenland.