DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/80

Rare Earth Element potential in Greenland

Reporting the BMP/GEUS mineral resource assessment workshop 29 November – 1 December

Lars Lund Sørensen, Per Kalvig & Karen Hanghøj

2. revised version

(1 CD-Rom included)

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Executive summary

The fast growing global demand for rare earth elements (REE) has over the past few years, reached a level where REE supply cannot match the demand. It is expected to grow worse in the coming years. In response to this increased demand, the REE mineral exploration industry is searching for new high potential REE prospects.

REE resources are unevenly distributed across the globe, and production is concentrated to a few countries. Greenland is endowed with several REE deposits, related to a wide range of geological settings. Some of these are licensed and have reached advanced stages of exploration. However, in addition to these localities, Greenland also holds geological terrains favourable for hosting undiscovered REE deposits.

In order to provide geological information on the REE potential in Greenland to the exploration industry, the Geological Survey of Denmark and Greenland (GEUS) and the Bureau of Minerals and Petroleum in Greenland (BMP) organised a REE mineral assessment workshop in November-December 2010. A group of 22 geologists with special knowledge on REE and the geology of Greenland assessed about 35 tracts carrying the potential of hosting undiscovered REE deposits.

This report provides a brief introduction to the eight known REE deposits, as well as the REE potential assessments made by the workshop expert panel on all the prospective tracts. The assessment is based on the mineralogy or elements, the source, the pathways, the trap potential, and finally, other relevant information, like the regional geological setting. In addition to the eight known REE deposits, the panel found that the following tracts carried a strong or medium potential for undiscovered REE deposits: (1) the Grønnedal-Ika carbonatite; (2) the Qassiarsuk/Green Dyke; (3) the Kap Simpson alkaline intrusion; (4) the Ivigtut alkaline intrusion and (5) the Skjoldungen alkaline province.

The expert panel recommends that future exploration activities among others focuses on: (i) the REE potential associated with trachytic lavas, as has been successfully done in Norway; (ii) analyses of the stream and heavy mineral concentration samples available from the most prospective tracts; and (iii) interpretation of magnetic anomalies where available from the tracts, to better assess the 3D and depths to a potential body.

Introduction

The demand for rare earth elements (REE) is growing fast due to innovation in so-called ‘green technologies’, electronic devices, defence systems and petroleum refining catalysts. The global demand in 2010 is estimated at 134,000 tonnes, and the global production was around 124,000 tonnes. The global demand is projected to continue to grow rapidly.

In response to this rising global demand, Greenland has experienced a strong international interest, over the past decade, in exploration for new REE deposits. Greenland is endowed with geological terrains favourable to REE mineralisation processes, as well as a simple mineral resource administration system, making it attractive to the mining industry.

It is with this background that the Geological Survey of Denmark and Greenland (GEUS) and the Greenland Bureau of Minerals and Petroleum (BMP), organised and sponsored a three-day workshop (30 November – 2 December 2010) with the purpose of assessing the potential for undiscovered REE deposits in Greenland, and to provide geological information to facilitate the REE exploration in Greenland.

During the workshop approximately 35 potential tracts were included in the assessment and ranked individually, based on thorough discussions amongst the workshop expert panel members. The panel consisted of a team of researchers and exploration and mining geologists with experience with REE deposits and Greenland geology and its mineralising systems. Two REE experts (Dr. Jock Harmer of *Jock Harmer Consulting* and Pete Siegfried of *GeoAfrica Prospecting Services*) participated in the workshop to give an overview on deposit models for REE mineralisation processes, and shared their expertise in keynote lectures. In addition to the staff geologists from GEUS and BMP, six exploration companies interested in REE exploration in Greenland participated in the workshop, and presented news and results from their current work in Greenland.

The REE workshop is not part of the ongoing Global Mineral Resource Assessment Program (GMRAP) lead by the US Geological Survey (USGS). However, the procedures for the assessment and ranking of the individual REE tracts applied, is designed to comply, as much as possible, with the GMRAP procedures. Compiled information on known REE deposits and geological provinces in Greenland were used in conjunction with models for REE deposits with the purpose of assessing the potential for REE deposits in Greenland in the uppermost kilometre of the crust.

This report provides the basic assessment together with the overall conclusions. In addition the report includes a list of approximately 15 tracts related to pegmatite REE deposits, which were defined by an internal GEUS assessment team prior to the workshop. However, the pegmatite tracts were considered low priority and were not assessed at the workshop due to time constraints.

The usage of the term rare earth element in this report is restricted to 16 elements including Y, La and the lanthanides.

Given the fact, that many REE deposits also contain various amounts of U and Th, it should be stressed, that the Greenland Government has introduced a zero-tolerance policy with regard to exploitation of radioactive minerals. This issue is not dealt with in this report.

Greenland geology

A brief outline of the Greenland geology is given below (based on http://www.geus.dk/program-areas/raw-materials-greenl-map/greenland/gr-map/anhstart-dk.htm); for further details on the geology of Greenland the reader is referred to Escher & Watt 1976; Henriksen 2008; and Henriksen et al. 2009.

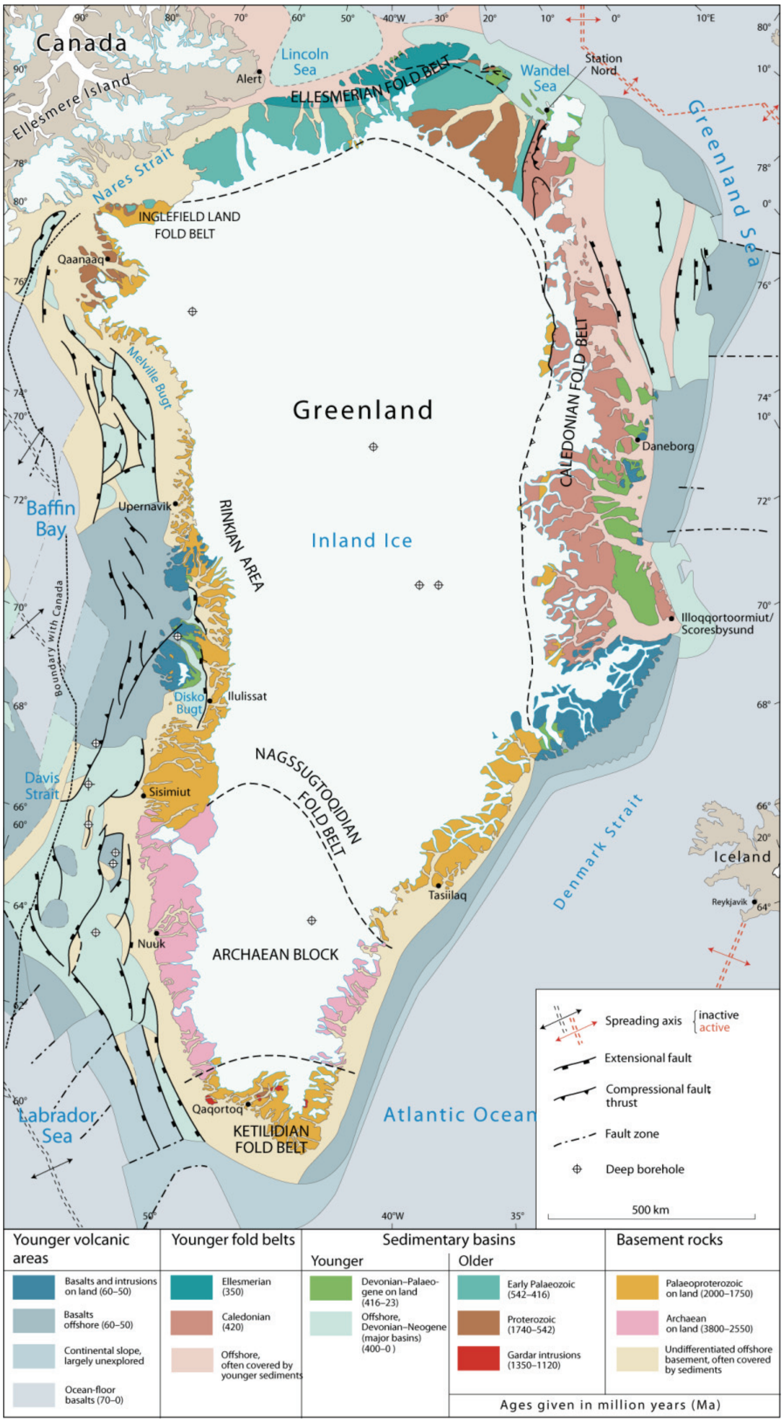

Figure 1. *Simplified geological map of Greenland. From Henriksen 2008.*

The geological development of Greenland spans a period of 4 Ga, from the earliest Archaean to the Quaternary. Greenland is dominated by crystalline rocks of the Precambrian shield, formed during a succession of Archaean and early Proterozoic orogenic events which were stabilised as a part of the Laurentian shield about 1.6 Ga ago.

The shield area can be divided into three distinct basement provinces: (1) the Archaean rocks (3.1 - 2.6 Ga old, with locally older units), almost entirely unaffected by later activity; (2) The Archaean terrains reworked during the early Proterozoic around 1.85 Ga ago; and (3) terrains mainly composed of juvenile early Proterozoic rock (2 - 1.75 Ga old).

Subsequent geological developments mainly took place along the margins of the shield. During the late Proterozoic and throughout the Phanerozoic, major sedimentary basins formed, notably in North and North-East Greenland, and in some places sedimentary successions accumulated reaching 10 - 15 km in thickness. Palaeozoic orogenic belts, the Ellesmerian fold belt of North Greenland, and the East Greenland Caledonides, affected parts of these successions; the latter also incorporates reworked Precambrian crystalline basement complexes.

Upper Palaeozoic and Mesozoic sedimentary basins developed along the continent ocean margins in North, East and West Greenland and are now preserved both onshore and offshore. Their development was closely related to continental break-up with formation of rift basins. Initial rifting in East Greenland in latest Devovian to earliest Carboniferous time and succeeding phases culminated with the opening of the North Atlantic in the late Paleocene. Sea-floor spreading was accompanied by extrusion of Tertiary plateau basalts in both central West and central East Greenland.

During the Quaternary, Greenland was almost completely covered by ice sheets, and the present Inland Ice is a relic of the Pleistocene ice ages. Vast amounts of glacially eroded material were deposited on the coastal shelves offshore Greenland.

Mineral exploitation in Greenland has included one cryolite mine, two lead-zinc deposits, one gold mine, and one open pit olivine mine, in addition to some minor coal mines and aggregate quarries for domestic use. Current prospecting activities in Greenland are concentrated on the gold, base metals, iron, diamonds, and REE and other critical minerals.

Introduction to the known REE occurrences in Greenland

Greenland is endowed with quite a few REE mineral deposits and occurrences, of which at least three may well be amongst the ten largest REE deposits in the world, and the favourable geology has attracted many international exploration companies. The geological settings for the various REE deposits and occurrences varies, as well as the ages cover a wide span. Below, a brief introduction to the known deposits and occurrences are given, starting in the south and then moving northwards on the west coast. The only known REE deposit from the east coast of Greenland is described last.

Ilímaussaq intrusion (hosts the Kvanefjeld and Kringlerne REE deposits)

The Ilímaussaq intrusion (17 x 8 km) in South Greenland belongs to the Meso-proterozoic Gardar province. The province is a cratonic rift province, consisting of sandstones, and a variety of volcanic and plutonic igneous rocks many of which are alkaline. The alkaline rocks evolved towards Si-rich melts such as comendites and alkali granites, and towards Si-poor melts such as phonolites and neheline syenites (Bailey et al. 1981). The alkaline Ilímaussaq intrusion is one of the later intrusions (1160 Ma), largely implaced by block subsidence, and formed by three pulses of which the third formed a layered series of nepheline syenites. The Ilímaussaq intrusion is unusual in terms of the enrichment of the elements U, Th, Nb, Be, Zr, Li, F and REE, which is reflected in the great number of minerals recorded. The Ilímaussaq intrusion hosts two different types of REE deposits e.g. Kvanefjeld (dominated by lujavrites) and Kringlerne (dominated by the kakortokite bottom cumulates).

Kringlerne (Ta-Nb-REE-Zr-Y)

The multi-element occurrence at Kringlerne is hosted in the lower cumulates of the layered agpaitic nephenline syenites, referred to as kakortokite (microcline, nepheline, arfvedsonite, aegirine, eudialyte) (fig. 2) and is situated near the townships of Narsaq and Qaqortoq in South Greenland,. The kakortokite cumulates form a total of 29 cyclic, and regular layers, with a total thicknes of about 200 m, made by units composed of black (arfvedsonite dominated), red (eudialyte dominated) and white (feldspar dominated). Individual layers are up to 20 m thick. The mineral eudialyte (Greek for ‘easily dissolved’) is enriched in Ta-Nb-REE-Zr-Y and thus is the main exploration target for REE by the licence holder Rimbal Pty Ltd. The kakortokites have been investigated for decades focusing in particular on Zr, Y, Nb and REE.

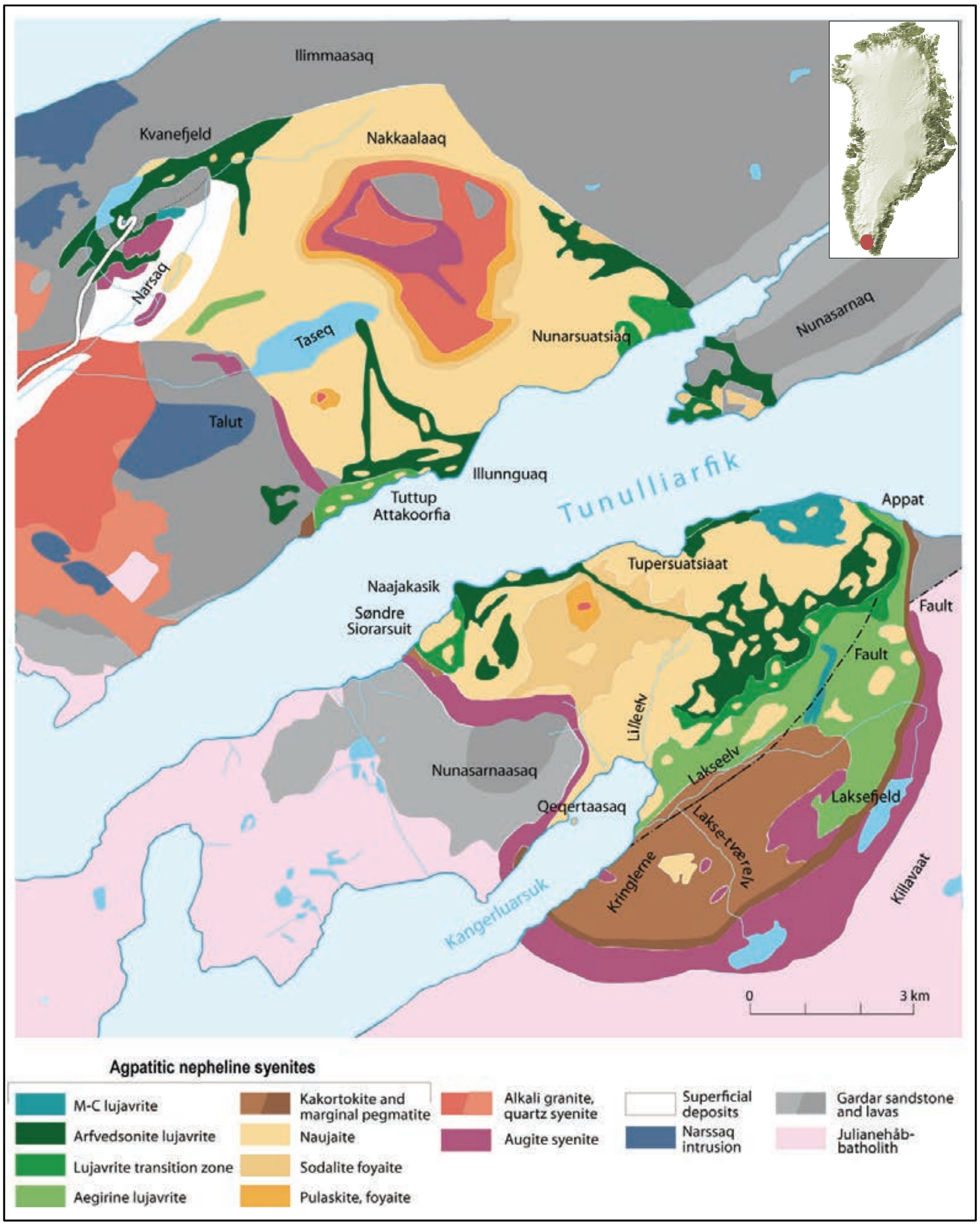

Figure 2. *Simplified geological map of the Ilímaussaq alkaline intrusion. From Sørensen et al. 2007.*

Recent estimates by the present licence holder[1] indicate the resource to be not less than 1,000 million tonnes grading 2% ZrO_2, 0.25% Nb_2O_5, 0.5% Re_2O_3, 0.1% Y_2O_3 and 0.025% Ta_2O_5. The distribution of light and heavy REEs in eudialyte is reported to be 88% and 12% respectively (fig.3).

Key papers on the Kringlerne deposit

- Bailey et al. 1981
- Cuttenberg & LeCouteur 1992
- Sørensen 1992
- Rimbal PTY LTD. 2002

[1] Based on information from TANBREEZ Mining Greenland A/S website – May 2011

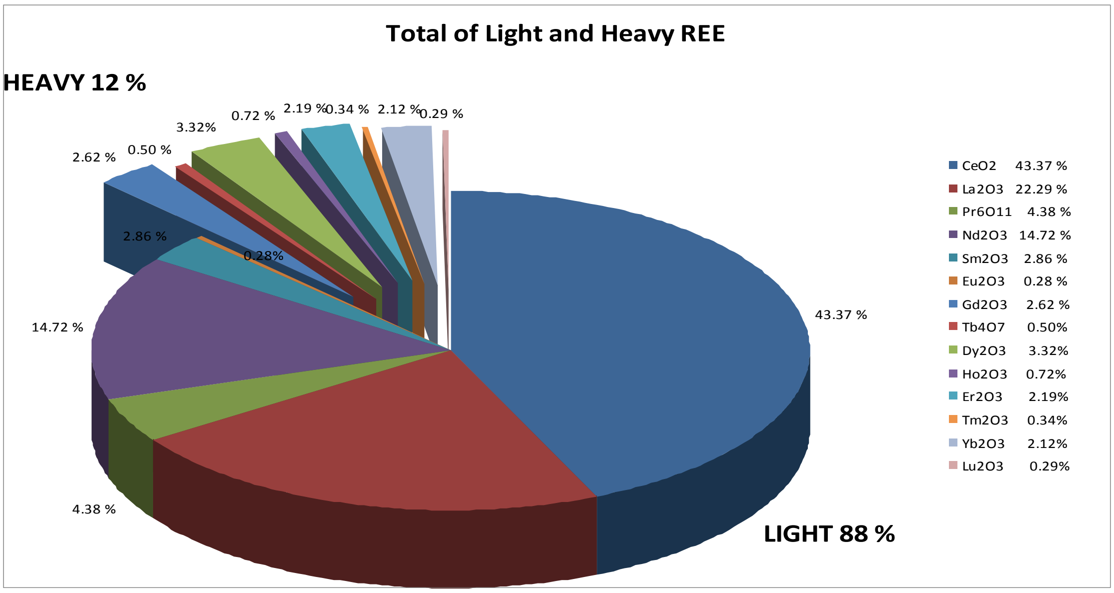

Figure 3. *The distribution of light and heavy REE constituents of eudialyte in the Kringlerne deposit. From TANBREEZ Mining Greenland A/S, May 2011.*

Kvanefjeld (REE-U-Th-Zn-F)

The Kvanefjeld REE deposit, is located north of Narsaq, South Greenland, and is a mega-breccia formed by various igneous rocks and supracrustals from the roof of the Ilímaussaq intrusion as well as rocks from the early phases of the alkaline intrusion, forming blocks and sheets within the later agpaitic magma (fig. 2). The bulk of the REE (as well as U and Th) is associated with the lujavrite rocks. This project is mainly targetting the lujavrites hosting disseminated steenstrupine -being the primary mineral of both REEs, U and Th, while vitusite, lovozerite and eudialyte also host REEs and U in parts of the deposit, but are minor components in this part of the intrusion. The deposit also contains zinc, occurring as disseminated sphalerite in the lujavrite, and fluorine hosted in the water soluable mineral villiaumite (NaF). The Kvanefjeld deposit has been explored for decades by various groups, but mainly focusing on the potential for U and Th.

The licence holder Greenland Minerals and Energy A/S published on the company web-site, May 2011, the following resource estimate figures, based on 150 ppm U_3O_8 cut-off:

- Total JORC resource of 619 Mt
- Indicated JORC resources of 437 Mt
- Inferred resources of 182 Mt
- Contained metal inventory of 6.6 Mt TREO including 0.24 Mt heavy REO and 0.53 Mt Y_2O_3 as well as 350 Mlbs U_3O_8 and 3 Blbs Zn
- Near surface, higher grade zones defined, including 122 Mt @ 1.4% TREO, 404 ppm U_3O_8 (0.05% heavy REO, 0.12% Y_2O_3)

Key papers on the Kvanefjeld deposit

- ❖ Bailey et al. 1981
- ❖ Kalvig 1983
- ❖ Sørensen 1992

Motzfeldt Sø (Ta-Nb-REE- Zr-U)

The Motzfeldt Sø REE deposit is part of the Motzfeldt Centre which in turn is part of the Igaliko Nepheline Syenite Complex.

Pyrochlore accumulations in the Motzfeldt Sø syenite show significant grades of Ta. The estimated resource is 600 Mt grading 120 ppm Ta, based on earlier investigations carried out by GEUS. High grade zones carry up to 426 ppm Ta. Additionally a Nb resource of at least 130 Mt grading 0.4 - 1.0% Nb_20_5 is known. The deposit is regarded as a ‘low grade - large tonnage’ type of resource.

Ram Resources Ltd. are currently investigating the intrusion for REEs. The 2010 work indicates that the known Ta-Nb mineralisation is only weakly correlated with REE mineralisation. In the central part of the intrusion, where the richest Ta-Nb mineralisation is found, the lithology is predominantly altered syenite, with minor pegmatite and diorite dykes. However, high grade REE intersections are concentrated in the pegmatite intrusives at depth, but are also found scattered throughout the drill holes, gradually decreasing in grade towards the east (fig. 4). Estimated Inferred Mineral Resource figures are anticipated at the beginning of 2012.

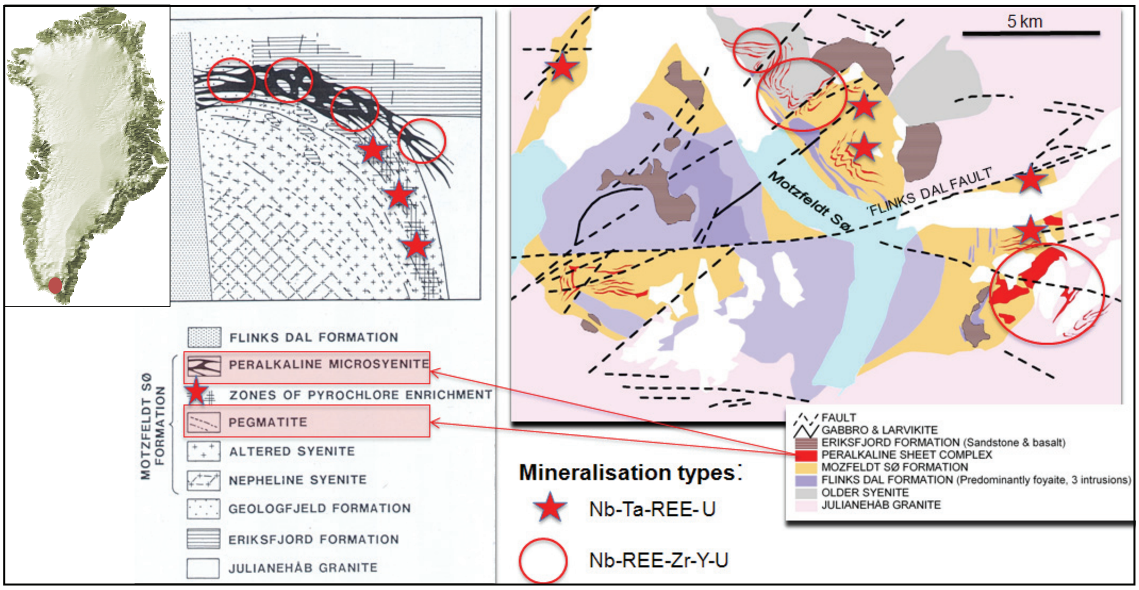

Figure 4. *Geology of the Motzfeldt Sø intrusion and associated mineralisation types. From Tukiainen REE workshop presentation on Motzfeldt Sø (2010).*

Key papers on the Motzfelt Sø deposit

- ❖ Armour-Brown & Parry 2001
- ❖ Thomassen 1988
- ❖ Tukiainen 1988

Tikiusaaq

The Tikiusaaq carbonatite, discovered by GEUS in 2005 by use of regional stream sediment data, regional airborne magnetic data and radiometric data (fig 5) consists of massive dolomite-calcite carbonatite sheets intruded along a ductile shear zone at approximately 158 - 155 Ma. The carbonatite is later intruded by carbonate-rich ultramafic silicate dykes (fig 5). The deep volatile rich magmatism at Tikiusaaq forms part of a larger Jurassic alkaline province in southern West Greenland and represents the earliest manifestation of rifting processes related to the opening of the Mesozoic–Cenozoic Labrador Sea Basin.

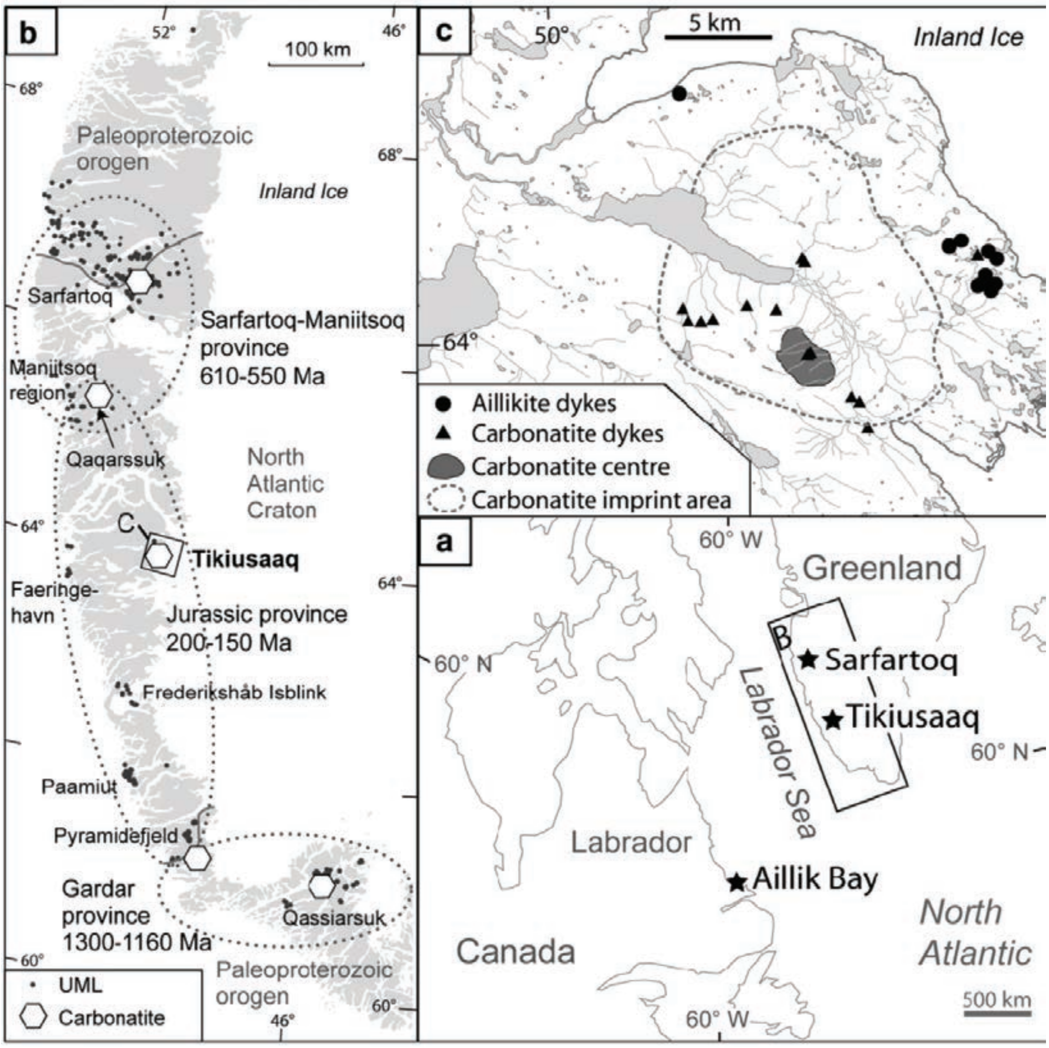

__Figure 5.__ Location of the newly discovered Tikiusaaq carbonatite-aillikite occurrence in southern West Greenland. (a) Tikiusaaq location in the greater North Atlantic cratonic region including the aillikite type locality at Aillik Bay in Labrador. (b) Distribution of carbonatite-aillikite occurrences across southern West Greenland. (c) Outline of the Jurassic Tikiusaaq carbonatite intrusion and associated aillikite dykes at 64°N close to the Inland Ice margin. From Tappe et al. 2009.

NunaMinerals A/S initiated exploration of the Tikiusaaq carbonatite in 2010, and focussed on the aeromagnetically defined ‘carbonatite core’ (fig 6a). Sampling was restricted to a series of widely spaced, sub-parallel gullies where 2 - 10 m thick, vertical carbonatite dykes and fenitised country rocks are well exposed. Most of the carbonatite sheets within the core represent early intrusive phases. REEs are typically enriched in the latest phases of carbonatite magmatism, and the rock is dominated by iron-rich dolomite and hematite. The main REE mineral is ancylite (Sr-REE carbonate). The REE composition of Tikiusaaq samples is 47% Ce, 33% La, 12% Nd, 4% Pr and 4% other REEs. REE enriched carbonatite float containing up to 9.6% TREO (predominantly LREE), have been found in an area of anomalous thorium counts. High phosphate grades (up to 8.5% P_2O_5) were returned from within the magnetic core of the carbonatite.

Interpretation of radiometric and magnetic data indicates a separate body about 750 m long and 100 m wide and that the carbonatite dykes continue to a depth of at least 500 m (fig 6b).

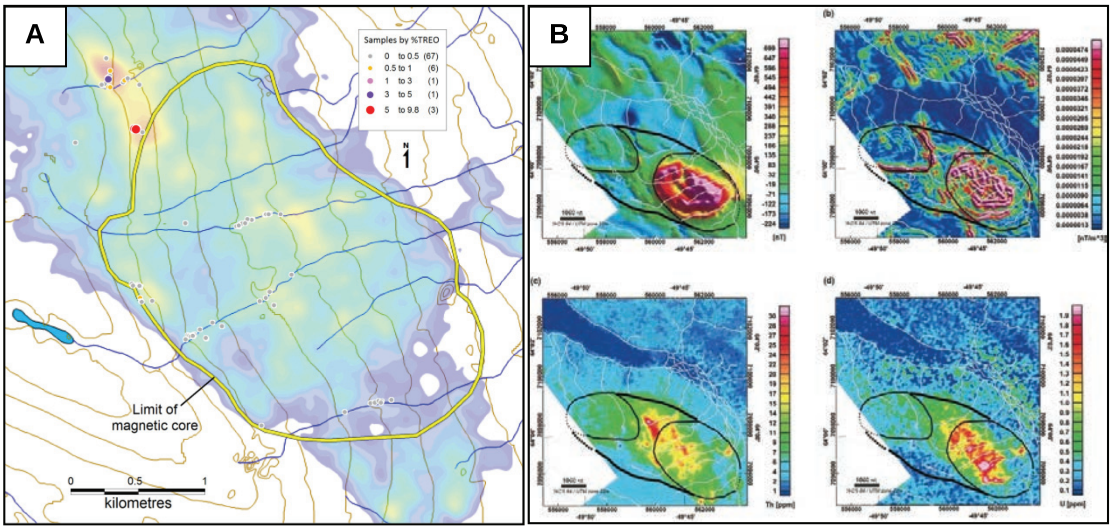

Figure 6. *The Tikiusaaq carbonatite (**A**) Yellow line bounds the magnetic carbonatite core. Positions and grades of surface samples superimposed on a topographic map. Coloured contours represent the airborne thorium radiometric survey flown in 2010: red = highest, blue = low values. (**B**) Different images of interpretated radiometric and magnetic data indicating a possible twin core structure. From www.nunaminerals.com.*

Key paper on the Tikiusaaq deposit

- Steenfelt et al. 2007

Qaqarssuk

The Qaqarssuk carbonatite complex, situated 60 km east of Maniitsoq, West Greenland, is intruded into the Archaean gneiss complex (fig 5b) about 170 Ma ago, along with kimberlite and alkaline intrusions; the intrusion of the carbonatite is accompanied by extensive fenitisation. The complex consists of an outer suite of steeply outward dipping concentric carbonatite sheets and an inner suite of less steeply dipping circular sheets (fig. 7). The composition of the carbonatite is sovite to rauhaugite -i.e., mainly calcite to dolomite dominated intrusive lithologies.

In 2010 NunaMinerals A/S explored the carbonatite with the focus on locating potentially REE enriched carbonatite dykes in the core of the carbonatite complex.

Concentric Th-anomalies just outside the complex boundary, identified from historic radiometric data, were also investigated, but little REE prospective carbonatite was discovered there. The main potential appears to lie in the core of the complex. NunaMinerals A/S reports the average grade for a 1.5 km^2 area to 2.4% TREO. The carbonatite is LREE dominated with 50% Ce, 27% La, 16% Nd, 5% Pr and 2% other REEs. The REE mineralised dykes are generally less than one metre thick, although thicker dykes (>3m) have been observed. Some of the thick dykes had promising grades up to 13.2% TREO. The main REE mineral at Qaqarssuk is coarse grained ancylite (Sr- REE carbonate).

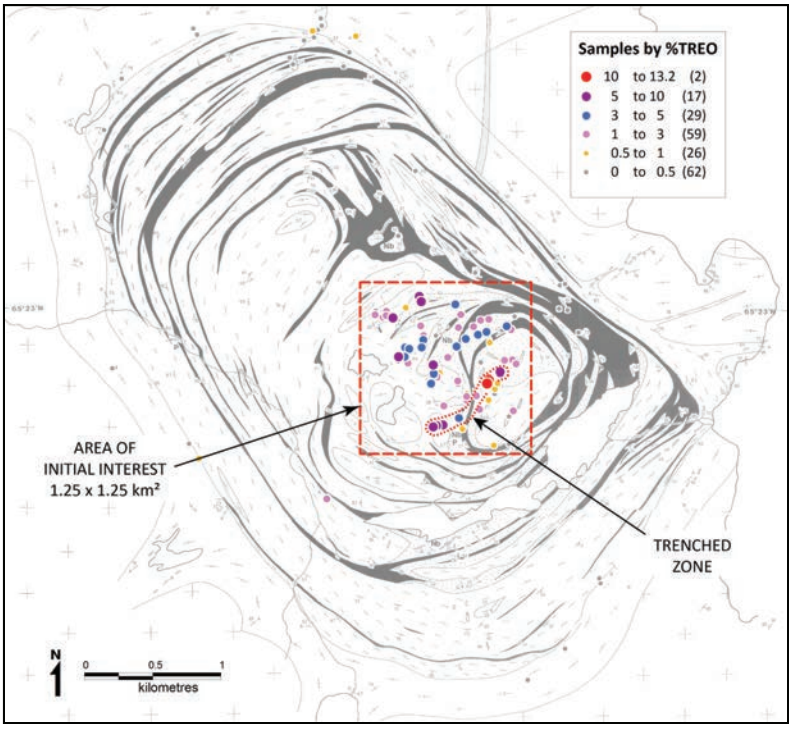

***Figure 7**. The Qaqarssuk carbonatite structure. Positions and grades of surface grab and surface trench samples super-imposed on a geological map. The sample and trench positions are shown on the figure. For location see fig. 5b. Figure from www.nunaminerals.com.*

Key paper on the Qaqarssuk deposit

- *Knudsen 1991*

Sarfartoq

The Sarfartoq carbonatite complex (565 Ma) is exposed in the Arnangarnup Qoorua valley (Paradise valley) located on the transition zone between the Archaean craton to the south and the Palaeoproterozoic Nagssugtoqidian mobile belt to the north (fig. 5b). The host rocks are granite and granodioritic gneisses cut by Palaeoproterozoic diabase dykes, the Kangâmiut dyke swarm. The complex was discovered by GGU in 1976 on the basis of a regional airborne radiometric survey and later fieldwork. Subsequently, the complex has been target by various exploration campaigns focusing on Nb and REE. Presently, Hudson Resources Inc. holds the licence over the complex.

The carbonatite has a conical structure with a magnetic core (fig. 8b) and consists of apatite and magnetite rich ferrocarbonatites. The core is surrounded by narrow closely spaced carbonatite sheets with interleaved fenitised and altered country rock, and with a partial rim of sodic fenite. The dominant carbonatite type is ferrocarbonatite with rauhaugite (ankerite dominant) in the core and beforsite (ferrodolomite dominant) in the marginal dykes. Calciocarbonatite (sovite, calcite rich) only occurs as subordinate units in the core. The most common alteration is light-grey, aegirine-bearing fenite.

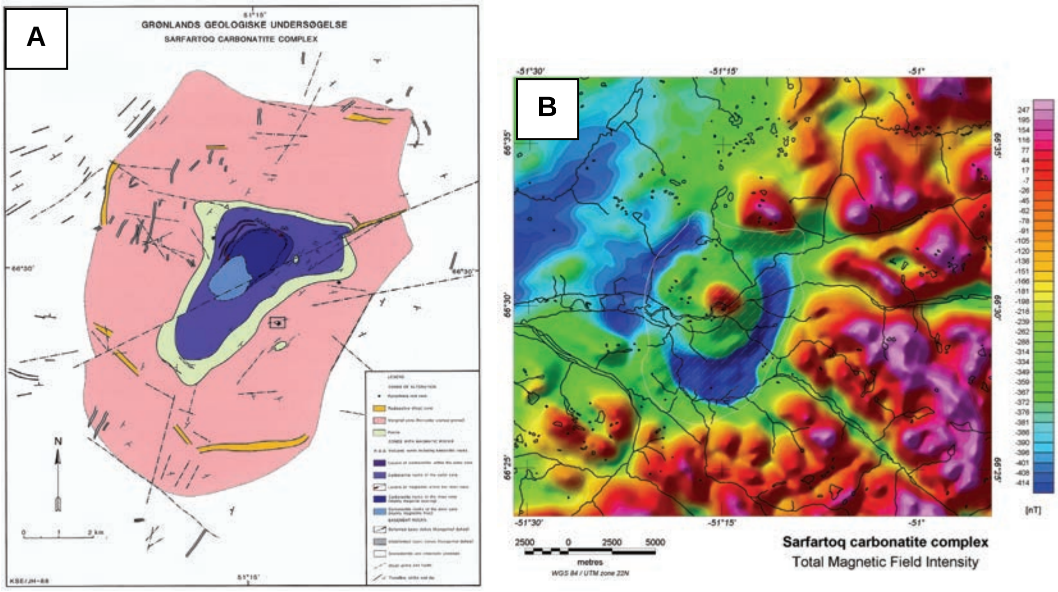

Figure 8. *The Sarfartoq carbonatite. (**A**) Geology of the Safartoq Carbonatite Complex (from Secher et al. 1986). (**B**) Regional magnetic map showing the carbonatite in the centre of the image. For location see fig. 5b. Figure from www.hudsonresources.ca*

The central core zone is surrounded by a series of ring-like zones or dykes, containing innumerable intrusive carbonate breccia veins. In addition, a number of radiating shears and dykes have been noted from the core; substantial fenitisation occurs around the core. Mineralisation of Nb and REE has been recorded in the outer fenitised zone. Mineralisation of the central core has not been examined in detail as it is covered with superficial deposits. The REE minerals identified by Hudson Resources included: bastnasite, synchysite, and monazite, and the LREO/HREO average ratios for the areas are reported as follows: 24 for ST40, 40 for ST1 and 52 for ST19.

Hudson Resources has focused their exploration campaigns on four main areas, which were chosen due to well-defined elevated Th-radiometric anomalies. In 2010 Hudson Resources published a NI43-101 compliant resources estimate result over the ST1 site: 14 Mt inferred resources avaraging 1.53% TREO at a cut-off grade of 0.8% TREO.

Key papers on the Sarfartoq deposit

- *New Millennium Resources 2003*
- *Secher & Larsen 1980*
- *Bedini 2009*

The Niaqornakassak and Umiammakku Nunaa REE deposits

The Niaqornakassak (NIAQ) REE mineralisation is located in central West Greenland on the island of Qeqertarsuaq (fig. 9), and was discovered in 2007 by Avannaa Resources Ltd. In 2009 an extension of the deposit was discovered on the Umiammakku Nunaa (UMIA) peninsula 7 km along strike from, the NIAQ site.

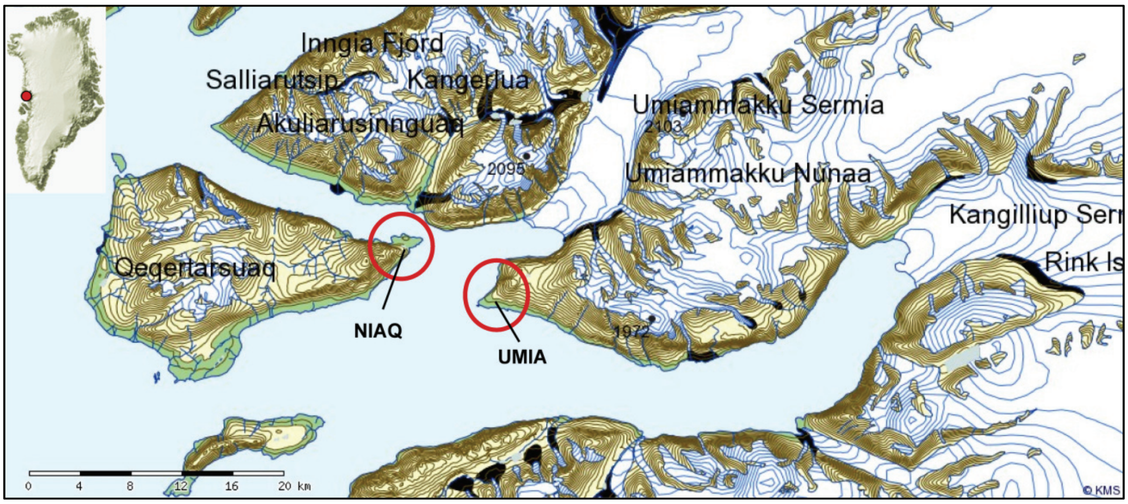

Figure 9. *Location of the NIAQ and UMIA REE mineralisation. From www.bmp.gl.*

Work conducted by Avannaa Resources Ltd. in 2010 on the NIAQ and UMIA deposit included diamond drilling and the collection of 13 mini-bulk samples. The REE mineralisation is a lithologically distinct horizon of banded carbonates hosted in an amphibolite unit of the Palaeoproterozoic Karrat Group. Strike length of NIAQ is 1.5 km but open at both ends where it is limited by the coastline. The tabular NIAQ ore body has been found to a maximum elevation of 56 m above sea level and down to 168 m below sea level; the thickness varies between c. 10 m and 33 m. The NIAQ bulk samples indicate an average of TREO + Y of 1.36%, of which the average HREO+Y content is c. 13%. Preliminary resource estimates of the NIAQ body are 26 Mt. The REE are mainly hosted by bastnaesite, monazite, allanite and other REE silicates. Very limited work has been undertaken on the UMIA body. Based on the three drill holes the TREO+Y of the UMIA deposit is in the range of 0.08 - 0.12%.

Milne Land REE deposit

The Mesozoic Milne Land palaeoplacer was discovered in 1968 by Nordisk Mineselskab A/S in connection with a heavy minerals concentrate sampling program, an airborne radiometric survey and ground follow-up in 1971 - 72. The placer is in the basal part of the Charcot Bugt Formation, and the most anomalous locality, “Hill 800” in Bays Fjelde, is c. 500 m in diameter (fig. 10) and 40 - 50 m thick. It consists of three units of arkosic sandstones and breccias. The heavy minerals are hosted by the basal c. 20 m thick unit. REE, U and Th are mainly hosted in monazite, and the Th/U ratio is around 10 and Ce is about 50% of the REE (Harpøth et al.1986). Schatzlmaier et al. 1973 estimated the 20 m thick basal unit to contain 5 Mt with 1.0 - 3.8% Zr and 0.5 - 1.9% REO.

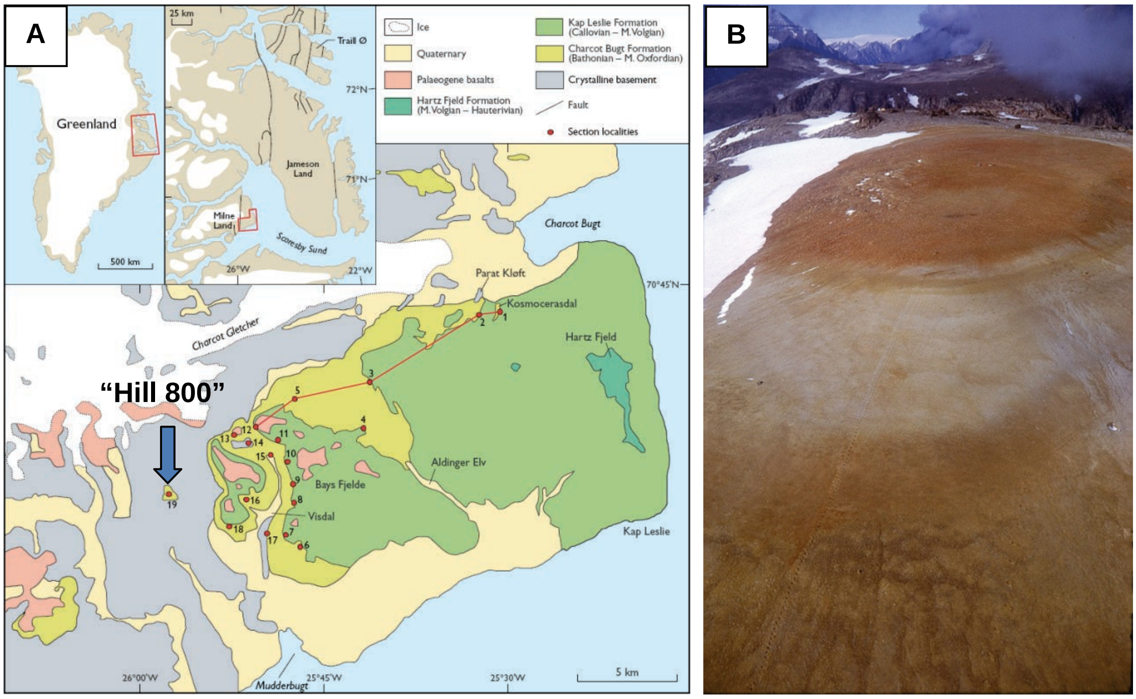

***Figure 10**. The Milne Land palaeoplacer. (A) Geological map of Milne Land and the "Hill 800" Palaeoplacer. From Larsen et al. 2003. (B) Aerial view of "Hill 800". The view is from the east. Copyright Bjørn Thomassen.*

In 1990, Coffs Harbour Rutile extracted a 15 tons selective bulk sample from 5 pits in the "Hill 800" area, and about 10 tons were investigated metallurgically. Recoveries from a pilot scale Kelsey Jig led to the conclusion that it is feasable to extract commercial products of monazite, zircon and garnet, but not of anatase due to its fine-grained and complex nature. Coff Harbour Rutile estimates the resource for "Hill 800" to 3.7 Mt with 1.1% zircon, 0.5% monazite, 2.6% anatase, 3.1% garnet and 0.03% xenotime. Sirius Minerals Ltd. are currently exploring the REE potential of the placer deposit.

Key papers on the Milne Land REE palaeoplacer

- *De Ross & Brown 1991*
- *De Ross 1992*
- *Schatzlmaier et al. 1973*

Results from the workshop – potential REE tracts in Greenland

The workshop discussed and assessed about 35 tracts with a potential for undiscovered REE deposits. The individual tracts are plotted on figure 11.

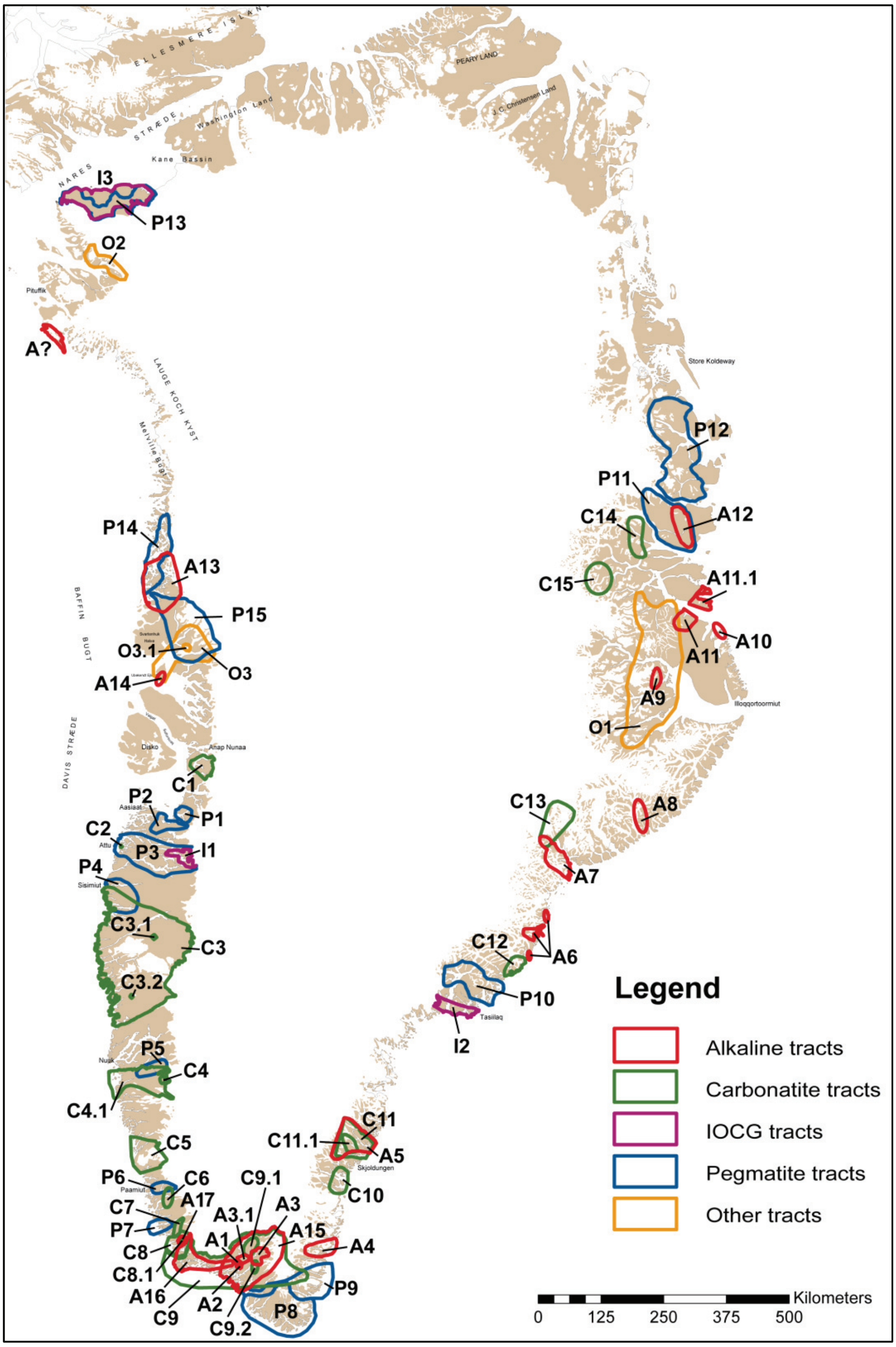

Figure 11. *Map showing the tracts used for the REE potential assessment. The tracts are grouped on the basis of the deposit type model e.g. A1, A2, A3 etc. represents tracts belonging to the alkaline deposit types. Pegmatite tracts and IOCGs were not assessed at the workshop.*

The number of tracts in the southern, eastern and southwestern part of Greenland is relatively high due to the Gardar intrusives, carbonatites and alkaline intrusions. In North Greenland only a few tracts were defined, a consequence of the extent of the carbonate platform and sedimentary basins (see fig. 11) hiding possible REE deposits connected to a lower crustal source.

A total of c. 50 tracts were identified prior to the workshop by the GEUS assessment team, and 35 of these were discussed, assessed and modified during the workshop. The remaining tracts related to pegmatites and IOCGs were not assessed at the workshop due to time constraints. However, the documentation for the tract definition and location of the pegmatite tracts are included in table 3 and fig. 11.

Compiled information on known REE deposits and geological provinces in Greenland were used by the assessment team in conjunction with models for REE deposits to rank and classify the individual tracts.

The REE mineral potential of each of the tracts were assessed and ranked based on the accumulated points from the 'Occurrence potential matrix' and the points from the 'Elements and settings potential matrix' (table 1), developed to comply – as much as possible - with the USGS procedures for their global mineral resource assessment.

Table 1. *The Occurrence potential matrix and Elements and settings potential matrix. Note; first row in the 'Occurrence potential matrix' yields 36 points, second 27 points, third 18 points, fourth 9 points and fifth 0 points. Maximum score from the Element and Settings Potential Matrix is 7 points for the elements of mineralisation and 7 points for the district settings – in total 14 points*

Occurrence potential matrix:	REE deposits/ mine known	REE deposits undiscovered	REE prospect	REE showings
Most potential	+ ≥1 deposits known 9	+ ≥1 undiscovered deposits 9	+ ≥1 prospects known 9	+ ≥1 showings known 9
	÷ No known deposit 0	+ ≥1 undiscovered deposits 9	+ ≥1 prospects known 9	+ ≥1 showings known 9
	÷	÷ No undiscovered deposits 0	+ ≥1 prospects known 9	+ ≥1 showings known 9
Less potential	÷	÷	÷ No prospects known 0	+ ≥1 showings known 9
No potential	÷	÷	÷	÷ No showings known) 0

Elements and settings potential matrix:	Points	Elements of mineralization (local scale)					District settings (regional scale)
		Source / fertility	Active Pathways	Trap	Deposition	Other	
Most potential	7	+ Excellent elements					+ Highly favourable settings
	6	+ Good to excellent elements					+ Good to very good settings
	5	+ Good elements					+ Good settings
	4	+ Moderate to good elements					+ Moderate to good settings
	3	+ Moderate elements					+ Moderate settings
	2	+ Weak to moderate elements					+ Weak to moderate settings
Less potential	1	+ Weak elements					+ Weak settings
No potential	0	÷ No-good elements					÷ No-good settings

Mineral deposit/mine - denotes an operating mine, abandoned mine, or a mineral occurrence that is believed to have a high potential for becoming economically feasible; it could be considered uneconomic because of lack of sufficient information.

Mineral prospect - denotes a mineral occurrence, which has been investigated or drilled in some detail and is believed to have a moderate or small potential for becoming economically feasible.

Mineral showing - denotes a mineral occurrence, which has a significant concentration of ore minerals, but is believed to have no economic feasibility on its own.

The specific ranking was based on open discussions between the expert team members facilitated by a workshop leader. For each tract the workshop leader would add up the arguments and rank the tract according to table 1. The scores range from 0 to 50 points with 50 points representing tracts with the highest REE potential and 0 points representing tracts with no or low potential. The results from the workshop assessment are given in table 2.

Table 2. *List of the individual tracts that were assessed during the workshop.*

Tract Name	Location	Deposit model	Known deposits and settings	REE potential	Score
C1	Ataa Sund	Carbonatite	Ultramafic lamprofyric dykes are known from the area.	Low potential	Not assessed
C2	Attu	Carbonatite	A carbonatitic dyke is known from the area	Low potential	Not assessed
C3	Overall tract covering the diamond province between Sisimiut and Fiskefjord (excluding C3.1 + C3.2).	Carbonatite	Two generations of carbonatite have been intruded in the region = higly prospective for more undiscovered carbonatites. Stream sediments are anomalous in Yb and P south of the Sukkertoppen Iskappe. No showings.	Moderate potential Element setting = 7 District setting = 3	10
C3.1	Sarfartoq	Carbonatite	1 known carbonatite showing. Kimberlites are found in the area. Terraine boundary in the area. Active pathways.	Excellent potential 1 undiscovered deposit = 9 + 9 + 9 Element setting = 7 District setting = 7	41
C3.2	Qaqarssuk	Carbonatite	1 known carbonatite showing. Lamprophyres are found in the area. Active pathways.	Excellent potential Prospect = 9 + 9 Element setting = 7 District setting = 7	32
C4	Tikiussaq	Carbonatite	1 known carbonatite showing. Lamprophyres are found in the area. Possible terraine boundary in the area. Active pathways.	Good potential 1 showing = 9 Element setting = 6 District setting = 6	21
C4.1	Overall tract west of the Tikiussaq carbonatite (excludes C4)	Carbonatite	Phosphorus anomaly located within the tract. Lamprophyres are found in the area = Active pathways.	Moderate potential Element setting = 3 District setting = 3	6
C5	Frederikshåb Isblink	Carbonatite	Geophysical anomaly beneath the glacier. Ultramafic and alkaline lamprofyric dykes (one is described as carbonatite type). Possible crustal block boundary. Stream sediments show no anomalies. No showings. Possible radioactive anomalies reported in the area.	Moderate potential Element setting = 3 District setting = 5	8
C6	Paamiut area (Kvanefjord), SW Greenland	Carbonatite	No known carbonatite deposits. Lamprophyres/ kimberlites (ailikites) are found in the area. Major structures running through the area associated with dolerite dykes of Palaeoproterozoic age.	Weak potential Element setting = 1 District setting = 2	3
C7	Pyramidefjeld, SW Greenland	Carbonatite	No known showings. Lamprophyres/ kimberlites (ailikites) are found in the area. Close to the Grønnedal-Ika carbonatite and the Gardar province. Stream sediment data show elevated REE and P. Clear radiometric signal from the Pyramidefjeld granite. Major structures running through the area = active pathways.	Moderate potential Element setting = 3 District setting = 3	6

Tract Name	Location	Deposit model	Known deposits and settings	REE potential	Score
C8	Grønnedal–Ika, South Greenland	Carbonatite	1 known carbonatite showing (The Grønnedal-Ika carbonatite). Elevated REE stream sediments. The carbonatite is elevated in Ce. No fenitisation. Magnetite is present.	Good potential 1 showing = 9 Element setting = 4 District setting = 5	18
C8.1	Overall tract (excluding C8)	Carbonatite	1 known showing. Lamprophyres/ kimberlites (ailikites) are found in the area. Greisen alteration at Ivittuut. Radioactive dykes (Ce enriched) radiates from the Grønnedal-Ika carbonatite.	Good potential 1 showing = 9 Element setting = 5 District setting = 5	19
C9	Overall tract covering the Gardar Igneous Province (excluding C9.1).	Carbonatite	Large region = increases prospectivity. High phosphorus in stream sediments. Ultramafic lamprophyres. Radioactive dykes. Difficult to collect stream sediments in parts of the area. Good possiblility for undiscovered showing.	Moderate – Good potential Element setting = 5 District setting = 7	12
C9.1	Qassiarsuk	Carbonatite	Uncertainty whether it is a carbonatite or a carbonate rich diatreme (the latter is not a good target for REE). No radiating dykes and no fenitisation are seen in the area. No radioactive dykes are observed. Ultramafic lamprophyres are observed . Phosphorus anomaly west of the area. Rift environment = active pathways. No showings.	Moderate – Good potential Element setting = 5 District setting = 7	12
C9.2	Igdlerfigssalik Centre	Carbonatite	Radioactive silicate dykes. No Lamprophyres. No carbonate related magmatic activity.	The tract was included in the overall C9 tract.	Assessed as part of C9.
C10	Timmiarmiut	Carbonatite	Carbonate-bearing dykes are found in the area. Elevated REE in stream sediments.Located on the boundary to the Ketilidian. Limited amount of work.	Moderate potential Element setting = 4 District setting = 5	9
C11.1	Singertât	Carbonatite	Carbonatite rocks are found in the area. Elevated REE in stream sediments and grab samples. Fenitisation seen. Major structures. Limited amount of work .	Moderate – Good potential Element setting = 5 District setting = 6	11
C11	Overall tract covering the Skjoldungen Alkaline Province (excluding C11.1).	Carbonatite	No known carbonatites. Large magnetic anomaly in southern side of Skjoldungen Sund. Limited amount of work.	Moderate potential Element setting = 3 District setting = 5	8
C12	Kap Gustav Holm	Carbonatite	Carbonate-bearing dykes are known. The Kap Gustav Holm nephelinitic complex is located within the tract. Coast parallel structures = Possible pathways.	Moderate potential Element setting = 1 District setting = 3	4
C13	The Gardiner Complex (includes Batbjerg)	Carbonatite	Carbonatite. Fenitisation. REE slightly elevated in stream sediments. Failed rift setting.	Moderate potential Element setting = 5 District setting = 4	9
C14+C15 (Were grouped + assessed together)	Central East Greenland	Carbonatite	U, La, Yb slightly elevated in stream sediments. Ultramafic lamprophyres. Regional lineament. Lack of information. C14 & C15 have similar settings.	Low potential Element setting = 1 District setting = 1	2

Tract Name	Location	Deposit model	Known deposits and settings	REE potential	Score
O1	Milne Land to Lyell Land	Other (Placer)	Known placer showing at "Hill 800" in Milne Land. REEs in monazite. High zircon content. Additional placer potential exists in the area. More sampling is needed to evaluate the REE potential.	Moderate - Good potential 1 showing = 9 Element setting = 2 District setting = 5	16
O2	Thule region	Other (Placer)	No showings. Stream sediments enriched in REE. Possible silicate source. Supracrustals in the area can be correlated with the Etah meta-igneous complex. Good environment for placer deposits.	Weak potential Element setting = 2 District setting = 4	6
O3	Karrat	Other	The REE prospect has been drilled which classifies it as an undiscovered deposit. Lamprophyric dykes are found in the area. The deposition model is not yet fully understood – more work required.	Good - excellent potential (setting not fully understood) 1 undiscovered deposit = 9 + 9 + 9 Element setting = 4 District setting = 4	35
O3.1	Overall tract covering the Karrat Group (excluding O3)	Other	Ultramafic lamprophyric dykes are found in the area. Major Dyke swarm (Age 1645 Ma)	Moderate potential Element setting = 4 District setting = 4	8
A?	Kap York (Thule)	Alkaline	Gabbro-Tonalitic-Granodiorite granite complex.	Low potential	Not assessed
A1	Kvanefjeld	Alkaline	Known deposit. High level of information. Extensive drilling has been conducted on the deposit. Contains uranium above background level.	Excellent potential 1 known deposit = 9 + 9 + 9 + 9 Element setting = 7 District setting = 7	50
A2	Kringlerne	Alkaline	Known deposit. High level of information. Extensive drilling has been conducted on the deposit. Low uranium content below or equal to background level.	Excellent potential 1 known deposit = 9 + 9 + 9 + 9 Element setting = 7 District setting = 7	50
A3	Motzfeldt Sø	Alkaline	Known REE prospect. Micro syenites (which host the REEs) not much investigated. Not much drilling – only Ta, Nb and U targets have been drilled. More work needed to evaluate the REE potential.	Good - Excellent potential 1 prospect = 9 + 9 Element setting = 6 District setting = 7	31
A3.1	Qassiarsuk (Green Dyke)	Alkaline	Dyke with aegirine as prime mineral. Showings of REE are known - up to 1 %. The dyke is up to 4 m thick and can be followed for several kilometres. High Th content.	Good potential 1 showing = 9 Element setting = 6 District setting = 7	22
A4	Kap Tordenskjold, SEG	Alkaline?	Large geophysical anomaly. No information from the area.	?	Not assessed
A5	Skjoldungen Alkaline Province	Alkaline	The region is elevated in REE. No showings. Large province. Many of the intrusions are aligned with structures = active pathways. Fertility in question.	Weak – Moderate potential Element setting = 3 District setting = 5	8
A6	Kap Gustav Holm	Alkaline	Nephelinitic Syenite type intrusion. Lack of information from the area.	Weak potential Element setting = 1 District setting = 3	4
A7	Kangerdlugssuaq	Alkaline	Largest syenite intrusion in Greenland. Outer shell with qz-syenite, Inner shell with Syenite, core with nephelinitic syenite.	Weak - moderate potential Element setting = 2 District setting = 4	6

Tract Name	Location	Deposit model	Known deposits and settings	REE potential	Score
			Veins with REEs. Extensive hydrothermal alteration (includes Flammefjeld). Several satellite intrusions. In general Syenitic intrusions in Greenland need more weathering to concentrate the REEs.		
A8	Borgtinderne	Alkaline	Syenite intrusion intruded into basalt. Not much information exists from the area.	Low potential Element setting = 0 District setting = 1	1
A9	Renland	Alkaline	Large Monzonite intrusion. Not much information exists from the area.	Low potential Element setting = 0 District setting = 0	0
A10 (Grouped with A12)	Kap Wardlaw	Not Alkaline. (Assessed as "other" category)	Roof zone of a granite intrusion. A-type? Slightly enriched in U & Th. Extensive flourite enrichment. No showings. Similar settings as A12.	Weak potential Element setting = 2 District setting = 1	3
A11	Werner Bjerge	Alkaline	No showings. Two deep seated faults = active pathways. Th mineralisation in veins. Nb & REE mineralised rocks. Werner Bjerge is a big multi intrusion complex. Extensive hydrothermal alteration.	Moderate potential Element setting = 3 District setting = 4	7
A11.1	Kap Simpson	Alkaline	Alkali Syenite Complex. Rock samples enriched in REEs (3%) & Nb (3.2%). Malmbjerg type alteration (high temp) seen via hyperspectral mapping. Several sources of mineralised rocks seen from glaciers.	Moderate - Good potential 1 showing = 9 Element setting = 5 District setting = 5	19
A12 (Grouped with A10)	Kap Franklin (Hudson Land)	Not Alkaline. (Assessed as "other" category)	Devonian magmatic activity (Myggbukta) + subalkaline and alkaline basaltic sills are found in the area.	Weak potential Element setting = 2 District setting = 1	3 (Assessed as part of A10)
A13	Prøven Granite	Alkaline	I-type granite (Not alkaline = Low potential). Fluids in the system . Possible anomalies should be locaed in the border zone.	Low potential	Not assessed
A14	Ubekendt Ejland	Alkaline	Microsyenite (Palaeogene) Hydrothermal alteration, REE anomalies. The island is very unacessable. More information is needed.	Low potential	Not assessed
A15	Overall tract covering the Garder province (excluding A1, A2, A3 & A3.1)	Alkaline	No known REE showings. Large region. Several deep seated structures in the region.	Good potential Element setting = 3 District setting = 5	8
A16	Nunarssuit	Alkaline	No showings. Stream sediments enriched in La & Yb. Limited amount of work hase been conducted in the area.	Weak – Moderate potential Element setting = 2 District setting = 5	7
A17	Ivigtut Cryolite deposit	Alkaline	Cryolite deposit. REE showings in the old pit. Stream sediments enriched in REE.	Good potential 1 showing = 9 Element setting = 5 District setting = 5	19

Table 3. *List of the individual pegmatite tracts that were identified by the internal GEUS assesment team before the workshop. The tracts were not assessed at the workshop.*

Tract Name	Location	Deposit model	Known deposits and settings
P1-P4	Between Ilulissat and Sisimiut	Pegmatite	Stream sediments enriched in Yb & La. High degree of melting of meta-sediments seen in this region, which is favourable for the formation of complex pegmatites. Large areas with pegmatites associated with the metasediments are observed in tract P1 & P2. Limited amount of work has been conducted in the area and most knowledge is from the outer coastal areas.
P5	East of Nuuk	Pegmatite	Tract defined on the basis of geological and geochemical data. It is noted that some of the YB/La anomalies may be influenced by the Tikiussaq carbonatite.
P6-P7	Paamiut to Taartoq	Pegmatite	Pegmatites are observed adjacent to the meta-pelites, considered to be formed by melting of the metapelites.
P8	South Greenland	Pegmatite	Pegmatites in the Pelite-zone, due to metasomatic processes. Geochemical anomalies are not distinct -except for uranium.
P9	South Greenland	Pegmatite	Pegmatites in the Pelite-zone, due to metasomatic processes. Geochemical anomalies are not distinct.
P10	Tasiilaq	Pegmatite	Very few indicators point to a tract in this area – except for large tourmaline crystals.
P11	Hudson Land	Pegmatite	Tract identified on the basis of geochemical Yb anomaly and the presence of a large amount of pegmatites.
P12	Wollaston Foreland	Pegmatite	Tract identified on the basis of high geochemical Yb/La anomalies and the presence of pegmatites.
P13	Inglefield Land	Pegmatite	Tract defined due to geochemical anomalies associated with to the Etah meta-igneous complex?
P14-P15	Upernavik to Ubekendt Ejland	Pegmatite	Pegmatites observed in relation to the migmatised metasediments. High geochemical Yb/La anomalies.

Conclusions and recommendations

Not surprisingly, the assessment panel found that the known REE deposits, described at the beginning of this report, have the highest assessment scores (Table 2).

However, South Greenland is believed to have a large potential for hosting undiscovered REE deposits in addition to the known deposits at Kvanefjeld (tract A1) and Kringlerne (tract A2). Among the more interesting tracts are; the Grønnedal-Ika carbonatite (tract C8); the Qassiarsuk/Green Dyke (tract A3.1) and the Ivigtut alkaline intrusion (tract A17).

In the more remote and less investigated areas of Greenland, e.g. the Kap Simpson alkaline intrusion in central East Greenland (tract A11.1) and the Skjoldungen Alkaline Province (tract A5) in South East Greenland are believed to have a good potential for hosting undiscovered REE deposits.

Many of the assessed tracts are already covered by exploration licences and extensive exploration and drilling is currently being carried out on several licence areas at various stages towards feasibility studies. Greenland has thus responded to the increased global demand and has a possibility to become an exporter of rare earth elements.

In order to provide more evidence for the existence of undiscovered REE deposits with economic potential in Greenland the following recommendations were made at the workshop:

1. It is recommended to look for REE deposits associated with trachytic lavas. At Sæteråsen[2] in the Oslo Graben area in Norway, a similar deposit of two lens-shaped bodies of aphyric trachytic lava host a REE deposit of more than 8 million tons of ore with reported grades of 0.245% Nb, 0.18% Ce, 0.11% La, 0.075% Y, 0.069% Nd and 0.049% Th. Trachytic lavas are known from the Garder area in South Greenland.

2. It is recommended to investigate the stream sediment and heavy mineral samples from the most prospective areas in Greenland, e.g. to identify the mineralogy of the different REE-bearing samples. Scanning electron microscopy (SEM) will be useful for such an investigation.

3. It is recommended to further study and interpret magnetic anomalies on some targets to better estimate extent and depth to the mineralisation.

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[2] http://www.ree-mining.com/html/ree.html

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Appendix A - The participants in the workshop (the assessment team)

- Jock Harmer (Jock Harmer Consulting)
- Peter Siegfried (GeoAfrica Prospecting Services cc)
- Henrik Stendal (BMP)
- Anette Clausen (BMP)
- Lars Lund Sørensen (Workshop organiser, GEUS)
- Bo Møller Stensgaard (Workshop leader, GEUS)
- Thomas Kokfelt (GEUS)
- Kristine Thrane (GEUS)
- Tapani Tukiainen (GEUS)
- Agnete Steenfelt (GEUS)
- Karsten Secher (GEUS)
- Emma Renström (Former GEUS employee now Avannaa Resources Ltd)
- Bjørn Thomassen (Avannaa Resources Ltd.)
- Hugh Mackay (Avannaa Resources Ltd.)
- James Tuer (Hudson Resources Inc.)
- Jim Cambon (Hudson Resources Inc.)
- Peter Brown (NunaMinerals A/S)
- Paul Armitage (NunaMinerals A/S)
- Jesper Koefod (QuadraFNX Mining Ltd.)
- Claus Østergaard (21st North)
- Michal Nekl (GET Ltd.)
- Lucie Sanza (GET Ltd)

Appendix B - Presentations at the workshop

The presentations that were given at the workshop are given below. All presentations, as PDF files, can be found in the CD-ROM accompanying this report.

Presenter	Title	Number on CD-ROM
Bo Møller Stens-gaard	Outline of the objectives of the workshop and the procedure for the assessment.	1
Keynote talk by REE specialists Jock Harmer & Peter Siegfried	An overview of the Rare Earth Minerals, mineralisa-tion models and systems including “pathfinders” – part 1.	2
Keynote talk by REE specialists Jock Harmer & Peter Siegfried	An overview of the Rare Earth Minerals, mineralisa-tion models and systems including “pathfinders” – part 2.	3
Keynote talk by REE specialists Jock Harmer & Peter Siegfried	An overview of the Rare Earth Minerals, mineralisa-tion models and systems including “pathfinders” – part 3.	4
Agnete Steenfelt	Overview of Greenland geochemical stream sedi-ment data with focus on geochemistry related to REE deposits.	5
Henrik Stendal	Geological settings of South Greenland (south of 62°N)	6
Tapani Tukiainen	Known REE deposits in South Greenland i. Kvanefjeld ii. Kringlerne iii. Narsaarsuk iv. Nunarsuit v. Motzfeldt Sø vi. Qassiarsuk	7
Tapani Tukiainen	Motzfeldt Sø Nb,Ta–deposit in details	8
Karsten Secher	Kringlerne REE deposit in details	9

Thomas Kokfelt and Bo Møller Stensgaard	Geological settings of southern West and southern East Greenland (62°N to 67°N)	10
Karsten Secher and Bo Møller Stensgaard	Known REE deposits in southern West and southern East Greenland (62°N to 67°N) i. Sarfartoq ii. Tikiusaaq iii. Qaqarssuk carbonatite complex iv. Skjoldungen V. Timmiarmiut	11
Christian Knud-sen	The Attu carbonatitic dyke (~68°N) and Qaqarssuk carbonatite complex in detail	12
James Tuer	Sarfartoq carbonatite complex in detail	13
Paul Armitage	Recent exploration at the Tikiusaaq and Qaqarssuk carbonatite complexes	14
Kristine Thrane, Agnete Steenfelt & Niels Henrik-sen	Geological settings of northern West, central West and North and North-East Greenland	15
Hugh Mackay	The REE mineralised horizon on the Niaqornakas-saq peninsula in detail	16
Emma Rehn-ström	Geological settings of Central East to North-East Greenland (north of 67°N)	17
Bjørn Thomas-sen & Thomas Kokfelt	Known REE deposits in central East to North-East Greenland (north of 67°N) i. Milne Land ii. Gardiner Complex	18