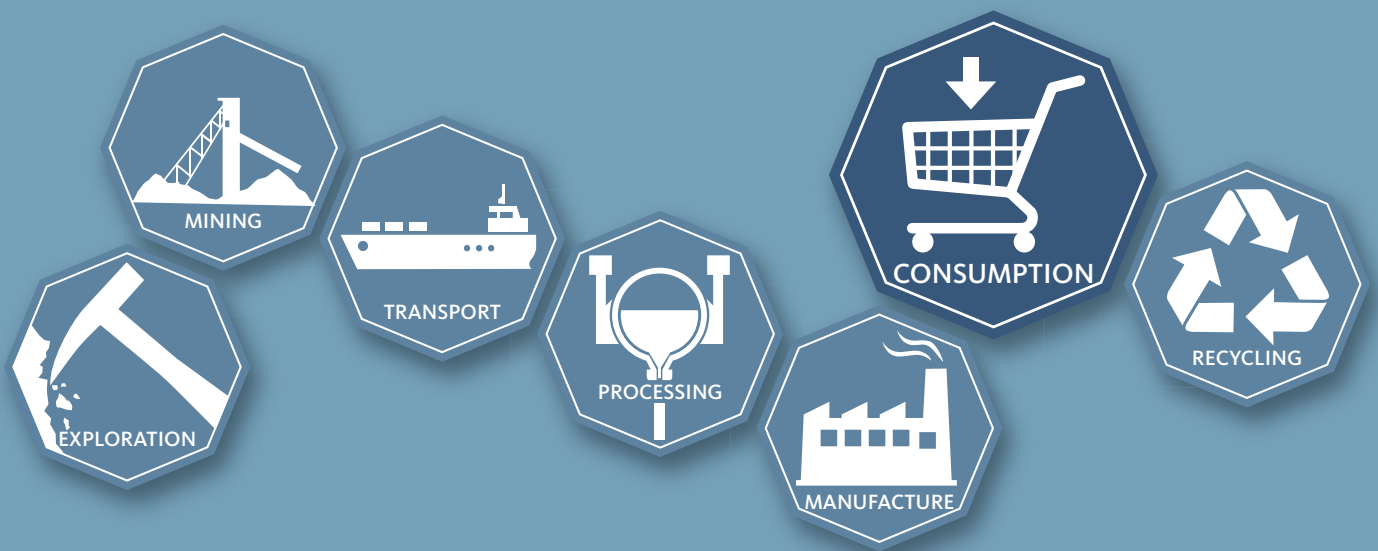


Rare Earth Element (REE) exploration potential and projects in Greenland

Authors: Paulick, H., Rosa, D. and Kalvig, P.

MiMa report 2015/2



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**Rare Earth Element projects and exploration potential in Greenland – MiMa Rapport
2015/2**

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Summary

This report aims to provide a comprehensive overview for the exploration industry, investors and others in need of knowledge about geology, Rare Earth Element (REE) deposits, ongoing activities, and a possible scenario for the production of REE from Greenland. In conjunction with the increased awareness regarding the potential of raw material supply criticality there has been a significant increase in global REE exploration. Consequently, the REE potential of Greenland has attracted significant attention in recent years and, overall, the known Greenlandic Total Rare Earth Oxide (TREO) resources have increased from 10.4 Mt TREO in 2011 to 38.5 Mt TREO in 2015.

Today, most of the existing global production of REE is based on exploitation of the REE ore minerals bastnäsite, monazite, xenotime, and loparite. However, REE exploration has recently also focused on new geological REE occurrence types containing previously unconsidered REE silicate ore minerals such as allanite, eudialyte, fergusonite, and steenstrupine. This is because of their elevated heavy REE/light REE ratios making them a potentially highly valuable resource. In Greenland, two of the largest REE resources are associated with REE silicates.

The current understanding of Greenland's REE potential is based on more than 50 years of research activities and exploration by private companies. This knowledge base was synthesised during an assessment workshop in 2010 organized by the Geological Survey of Denmark and Greenland (GEUS) and the Greenlandic Bureau of Minerals and Petroleum (BMP, now Ministry of Mineral Resources [MMR]), following the guidelines developed by the United States Geological Survey for assessing undiscovered global resource endowments. The aim of the workshop was to evaluate the potential for undiscovered REE resources in Greenland. The workshop assessed 35 tracts, defined by geological features, encompassing alkaline intrusives, carbonatites, pegmatites, palaeo-placers and areas with potential for Iron-Oxide Copper Gold mineralisation that may carry REE resources as a by-product.

Greenland's most promising REE deposits and occurrences are linked to alkaline intrusions in the Gardar Province (South Greenland) and the Gardiner Intrusive Complex (East Greenland) as well as carbonatite intrusions in West Greenland (e.g. Sarfartoq, Qaqarssuk, Qassiarsuk, and Tikiusaaq). Importantly, there is also one occurrence of a REE palaeo-placer deposit in East Greenland (Milne Land) and one REE mineralisation in West Greenland that is strongly linked to hydrothermal processes (Niaqornakavsak, Karrat area). Currently, eight companies hold licences dedicated to REE exploration (19 licences with a total of approximately 3,200 km²).

In this report, geological descriptions of the known Greenlandic REE deposits are presented following deposit type categories. The most important known REE deposits are the world-class Kvanefjeld and Kringlerne deposits both part of the Ilímaussaq Complex of the Gardar Province (South Greenland). Current resource estimates are 673 Mt of ore for the Kvanefjeld deposit (average grade 1.10% TREO) and 4,300 Mt of ore for Kringlerne (average grade: 0.65% TREO). Furthermore, the Motzfeldt Alkaline Centre in the Igaliko Nephe-

line Syenite Complex (eastern Gardar Province) contains several REE mineralisations with one resource defined at 340 Mt of ore yielding 0.26% TREO. Carbonatite intrusions have also been a focus of recent exploration and a resource has been defined at the Sarfartoq deposit (West Greenland, 8 Mt grading 1.72% TREO).

Furthermore, the principles of the Greenlandic exploration and mining licence permitting system are described, which includes regulated steps such as submission of a Social Impact Assessment (SIA) and Environmental Impact Assessment (EIA) and public hearings. An application for a mining licence has been submitted for the Kringlerne deposit by the private company Tanbreez Mining Greenland A/S in 2013. The mining licence application for the Kvanefjeld deposit is anticipated in 2015 according to announcements by the project owner Greenland Minerals and Energy Ltd. If both projects initiate mining according to current plans, it is possible that an annual Greenlandic REE production of 26,000 tonnes TREO could be realised from around 2018.

1 Introduction

The increasing demand for various Rare Earth Oxide (REO) commodities appeared during the early 2000's and generated interest in exploration for new resources on a global scale. This also resulted in investigations of raw material supply security issues and the current awareness of political and public stakeholders regarding critical raw materials, in particular for the high-tech and green-tech industries. The price peak in 2011 generated even more exploration activities and the efforts are reflected in the amount of new REE resources defined by exploration companies during the last few years. Also, the amount of geoscientific studies on REE deposits and economic investigations in the REE value chain has increased substantially (e.g. Castor 2008; Castor & Hedrick 2006; Chakhmouradian & Wall 2012; European Commission 2010; Goonan 2011; Hong 2006; Öko-Institut 2011; Campbell 2014).

Currently, REE mining is strongly concentrated in China contributing 100,000 tonnes TREO of a global total production of 111,800 tonnes in 2013 (USGS 2014). Approximately 10,000 tonnes are produced in the USA, Australia, India, and Russia. Small operations (100 to 200 tonnes range) are present in Brazil, Malaysia, and Vietnam. The biggest producing mine is Bayan Obo, Inner Mongolia, China, accounting for nearly 50% of the global TREO supply. Here, REO are a by-product of an iron-ore operation exploiting a relatively low-grade iron resource (37% Fe₂O₃).

In general, REE are fairly abundant in the Earth's crust, but known mineable concentrations are less common than for most other metals. Also, the distributions of REE reserves and resources show that potentially mineable REE deposits are not exclusive to China. The total REE reserves for ROW (Rest Of the World outside China) are currently in the order of 85 Mt (compared to 55 Mt in China, source: USGS 2014). Furthermore, new REE resources have been defined during the recent phase of exploration. Advanced exploration projects in ROW countries account for 98 Mt of TREO resources (reported according to NI43-101, JORC or equivalent, TMR 2015).

In line with these global exploration efforts, there has been a substantial amount of exploration activity in Greenland leading to a more than three-fold increase in reported REE mineral resources from 10.4 Mt TREO in 2011 (Polinares 2012) to 38.5 Mt TREO in 2015 (TMR 2015). Hence, the aim of this report is to summarize the geological information on the known REE deposits and to highlight the REE exploration potential of Greenland. For this purpose, the deposits are presented in a geological context within the framework of REE deposit models. Also, the results of a resource assessment workshop will be summarized in order to highlight the additional discovery potential (Sørensen *et al.* 2011). Advanced REE projects are discussed in more detail focusing on recent advances of their development towards eventual mine production.

2 REE ore minerals

The REE are incorporated into different mineral types (carbonates, oxides, silicates, phosphates), typically by replacing other, more common, chemical elements of similar size in the crystal lattice. However, historic and current mining operations have been restricted to a small number of REE ore minerals, namely bastnäsite (fluorocarbonate), monazite (phosphate), xenotime (phosphate), and loparite (oxide). As can be seen on Figure 1 bastnäsite is dominated by Light Rare Earth Elements (LREE) whereas xenotime and monazite are relatively enriched in Heavy Rare Earth Elements (HREE). Industrial-scale processing technologies for these REE ore minerals are well established (Jordens *et al.* 2013) and, currently, facilities for separation of individual REO and production of high purity REO-commodities are strongly concentrated in China. With regard to mine production volumes, bastnäsite is the most important REE ore mineral and is extracted at the Chinese mining operations in Bayan Obo, Weishan and Maoniuoing as well as at Mountain Pass (USA).

In addition, there are abundant small scale operations active in southern China exploiting ion-adsorption clay REE deposits which are HREE enriched (see Figure 1). These provide a substantial part of the low volume/high value supply of HREE that are of particular economic importance. However, since the REE are often extracted applying in-situ leaching methods, there are considerable environmental hazards associated with this mining practice. Consequently, more stringent regulatory measures in China may reduce the overall output from these types of operations.

The recent exploration phase resulted in the definition of REE resources outside of China which consist of a variety of REE-bearing minerals including (fluoro)carbonates (e.g. ancylite, parisite, bastnäsite), phosphates (e.g. apatite, monazite, xenotime), oxides (e.g. pyrochlore, loparite), and silicates (e.g. allanite, eudialyte, fergusonite, steenstrupine). A compilation of compositional data for these minerals, including the sometimes elevated contents of Th and U, is presented in Wall (2014) and their association with particular REE deposit types is examined in Linnen *et al.* (2014).

In comparison to bastnäsite and other REE-bearing (fluoro)carbonates, the silicates are often relatively enriched in HREE (see Figure 1). This implies that such resources could be more valuable due to the higher HREE/LREE ratio of the ore. Also, the REE percentage varies between the REE minerals, which are of importance for the overall grade of an REE occurrence and potential beneficiation processes. Currently, a great number of separation and beneficiation research studies are ongoing for “non-traditional” REE ore minerals.

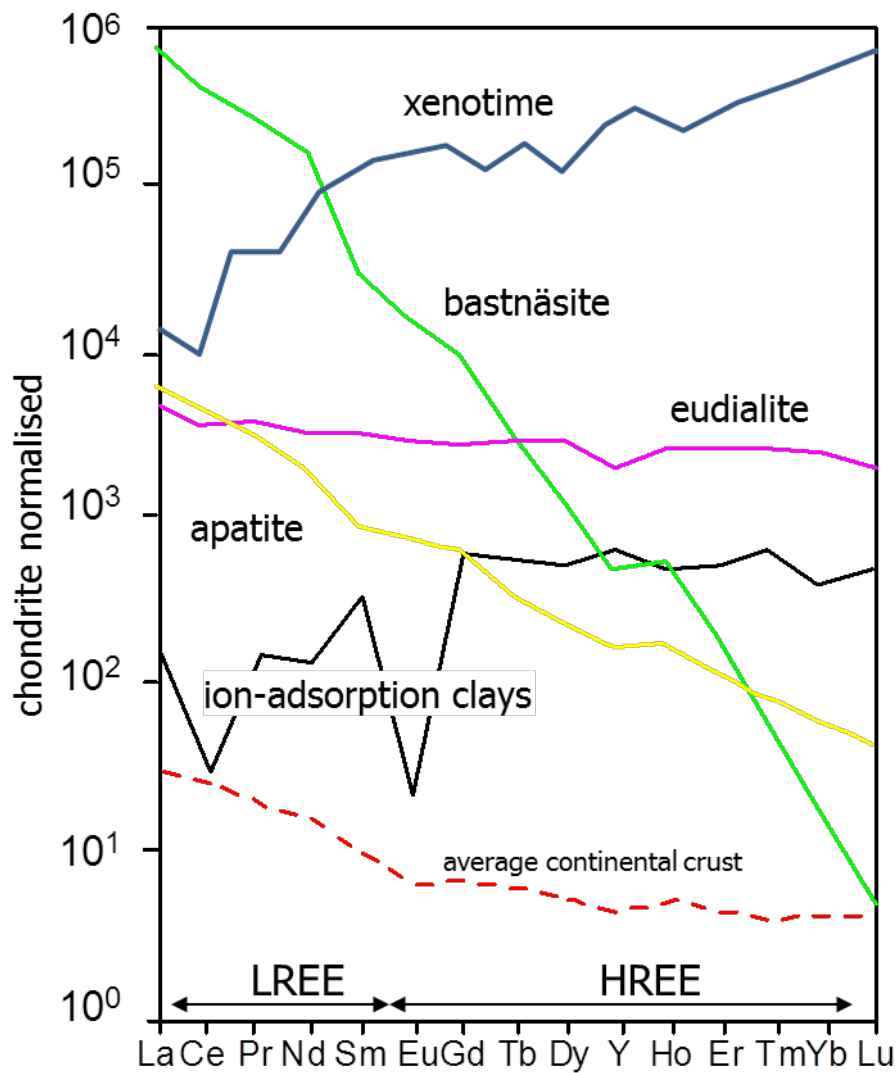


Figure 1. Comparison of REE concentrations in a variety of REE ore minerals. Data: Chakhmouradian & Wall (2012) and Linnen et al. (2014). Note that the data are normalised to the composition of chondrite meteorite (i.e. bulk Earth chemical composition). The assignment of La, Ce, Pr, Nd, and Sm to the Light REE (LREE) and Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu to the Heavy REE (HREE) follows the definition of the International Union of Pure and Applied Chemistry (IUPAC). Following convention, Y is included in the HREE and placed between Dy and Ho according to its ionic radius.

3 Geological setting of REE deposits

Rare Earth Elements can become locally concentrated as a result of a diverse range of geological processes. These include magmatism and hydrothermal fluid-rock interaction (forming “endogenous deposits”) as well as weathering and sedimentary transport (forming “exogenous deposits”). The global distribution of REE deposit types is summarized in Figure 2 which also provides an overview of REE production sites, advanced REE projects and important REE occurrences.

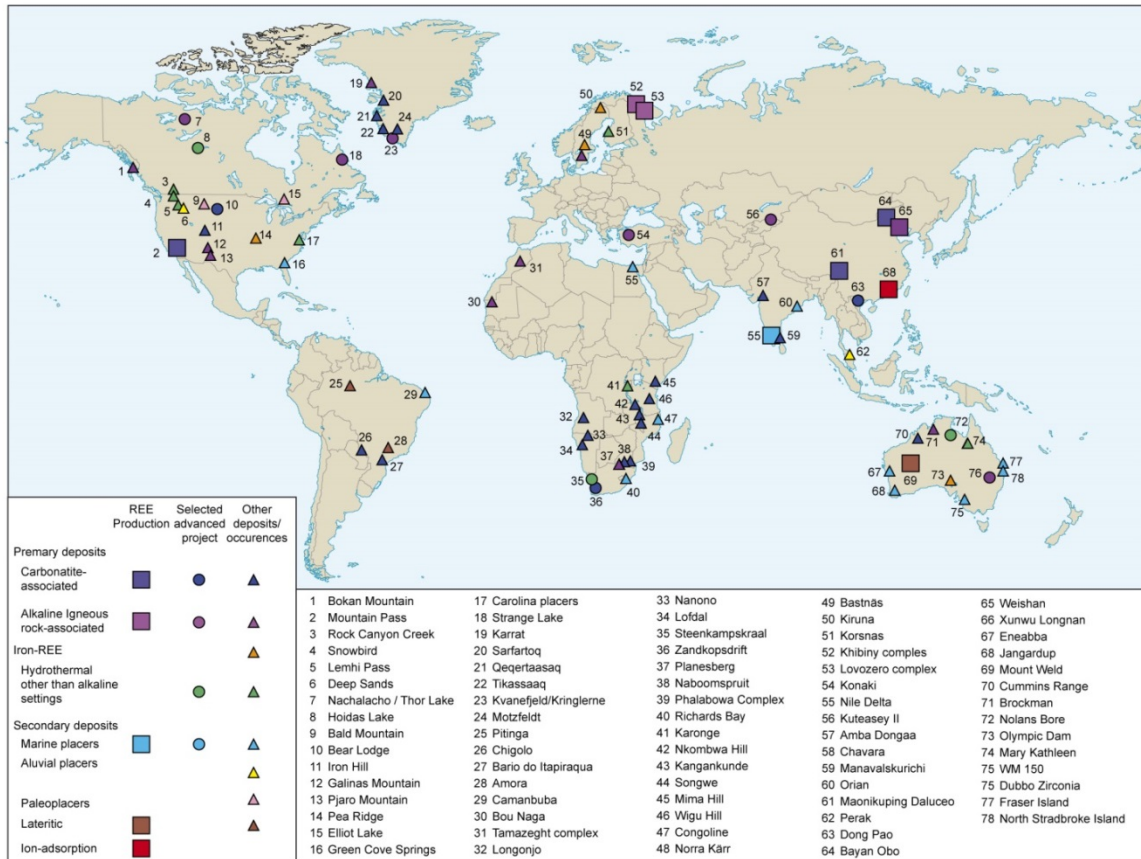


Figure 2. Overview of REE mining operations, advanced projects and known deposits and occurrences according to deposit type (British Geological Survey 2011).

3.1 Endogenous deposits

In the magmatic environment, REE deposits are typically associated with alkaline suites. In these magmas, REE-rich oxides, phosphates and/or silicates may crystallise during the late stages of the fractionation process as a consequence of the incompatible behaviour of REE. Significant deposits hosted by alkaline, potassium and sodium-rich intrusions include Lovozero (Russia), Kvanefjeld and Kringlerne (Greenland), Strange Lake and Nechalacho/Thor Lake (Canada), and Norra Kärr (Sweden). Similar magmatic processes are responsible for the formation of pegmatitic REE deposits, which were the first source of REE

to be exploited in the early twentieth century. While historically important, they are rarely promising exploration targets due to their small tonnage and diverse mineralogy. However, they often carry the potential for by-products such as Be, F and/or Li.

A particular type of magmatism, restricted to continental-rift tectonic environments, is represented by carbonatites. These low-degree mantle melts may contain high concentrations of REE and crystallise REE carbonates and REE fluorocarbonates (e.g. bastnäsite) as well as REE phosphates (monazite and xenotime). Mountain Pass (USA), Mt Weld (Australia), and Bayan Obo (China) constitute examples of carbonatites that are presently being mined for REE.

Hydrothermal REE deposits are characterised by mineralisation processes involving hot, aqueous solutions forming vein-style and replacement ore bodies. Carbonatite and/or alkaline magmatic bodies may be spatially associated and act as a metal and/or energy source. As a result, the distinction between magmatic and hydrothermal mineralisation processes often remains a matter of scientific debate. Examples of REE deposits where hydrothermal processes are recognized to have been important include Bayan Obo (China), Nolans Bore (Australia), and Steenkampskraal (South Africa).

Finally, it has been realised that some Iron-Oxide Copper Gold (IOCG) deposits such as Olympic Dam (Australia) have the potential to produce REE as a by-product. This is also the case for Iron Oxide-Apatite (IOA) deposits such as Kiruna (Sweden), where REE-bearing apatite is currently treated as waste during iron ore processing.

Greenland has large REE resources that are associated with alkaline magmatism (e.g. Gardar Province, South Greenland) and the potential of several carbonatite-hosted REE deposits has been explored. These potentials are outlined in Section 5.

3.2 Exogenous deposits

Some of the REE-bearing minerals, such as monazite and xenotime, are relatively resistant to weathering and sedimentary transportation. As a result, and together with other so-called heavy minerals, they can become concentrated in mineral sand deposits, referred to as placers. Such placer deposits can form in arid environments (dunes) or in beach to shallow marine environments. Currently, mineral sand mining operations in India, Malaysia and Australia, that are targeted at Sn (cassiterite), Ti (rutile), and/or Zr (zircon) resources, stockpile monazite and/or xenotime as by-products. This deposit type is also known from the geological record (palaeo-placer) where metamorphic processes may have upgraded the REE resource (e.g. Olserum, Sweden). From Greenland, the Milne Land deposit represents an example of a palaeo-placer REE deposit.

Chemical weathering under tropical conditions can lead to the formation of laterite. This process has the potential to generate surface-near zones with upgraded REE contents in carbonatites, through REE mobilization and recrystallisation (e.g. Mt Weld, Australia). In detail, for the formation of REE laterites, a redox front progresses downwards through the weathering profile, leaving secondary phosphates and aluminophosphates with high REE

contents. Laterites typically accumulate goethite, hematite, aluminium hydroxides, clay minerals and quartz and, therefore, P and Al can be important by- or co-products.

A quite particular type of REE deposit is represented by ionic clays formed by in-situ chemical weathering of alkaline granites or rhyolites resulting in adsorption of REE to clay mineral surfaces. Such ion-adsorption clay deposits are typified by the occurrences in the Jiangxi, Guangdong, Hunan, and Fujian provinces of southern China and, despite being of low-grade, constitute sources for the more valuable HREE. These clay deposits are easily mined because the adsorbed REE can be released from the clays using various types of acids. Due to climatic conditions, laterite and ion-adsorption REE deposits are not known in Greenland.

4 Outline of the geology of Greenland

A brief outline of Greenland's geology is given below (based on www.geus.dk/program-areas/raw-materials-greenl-map/greenland/gr-map/anhstart-dk.htm). For further details on the geology of Greenland please see Escher & Watt (1976) and Henriksen (2005).

The geological development of Greenland spans a period of 4 Ga, from the earliest Achaean to the Quaternary; see Figure 3. Greenland is dominated by crystalline rocks of the Precambrian shield formed during a succession of Achaean and Palaeoproterozoic orogenic events which consolidated 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 Achaean rocks (3.1–2.6 Ga old, with locally older units), almost entirely unaffected by later activity; (2) the Achaean 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 reaching 10–15 km in accumulated thickness. Palaeozoic orogenic belts, the Ellesmerian fold belt of North Greenland and the East Greenland Caledonides, affected parts of these successions; the latter also includes 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 on-shore and offshore. Their development was closely related to continental break-up and the formation of rift basins. Rifting in East Greenland already occurred in late Devonian to early Carboniferous time and succeeding phases with the latest expression represented by 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, 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.

The mining history of Greenland includes the exploitation of one cryolite mine, two lead-zinc mines, one gold mine, and one open pit olivine mine. In addition, some minor coal and graphite mines and aggregate quarries for domestic use have been in operation. Current prospecting activities in Greenland are concentrated on gold, base metals, iron, diamonds, as well as REE and other critical minerals. In terms of REE exploration, there are currently eight companies holding 19 licences (total of 3,186 km²) on prospects in different stages of exploration and development.

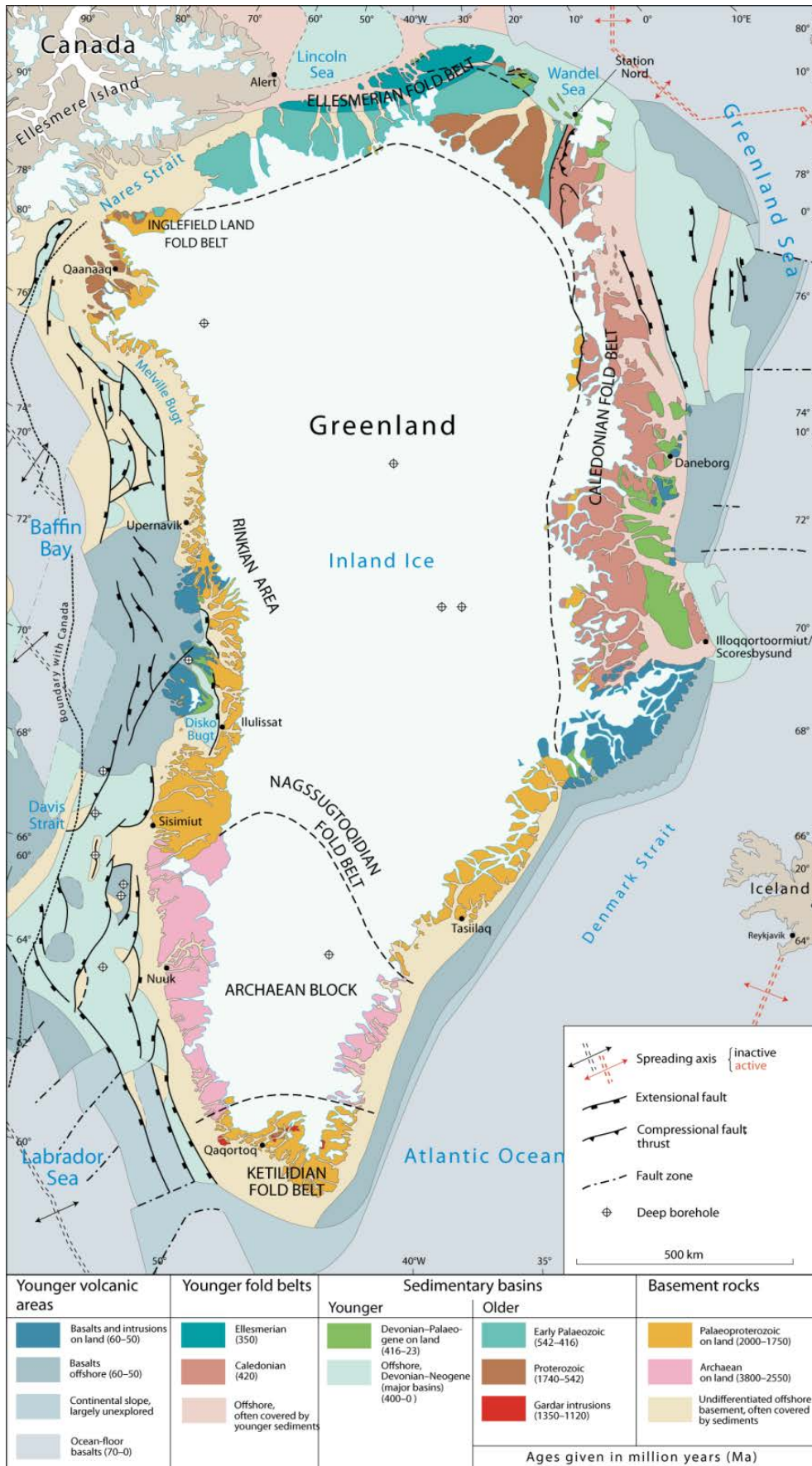


Figure 3. Simplified geological map of Greenland. From Henriksen (2005).

5 REE deposits and exploration potential of Greenland

In this chapter, the geological features of REE deposits in Greenland are presented following the ore deposit models outlined above (section 3: Geological setting of REE deposits). Where appropriate, the description of currently active exploration projects is highlighted. Furthermore, the potential for undiscovered REE deposits is described.

5.1 Assessment of undiscovered REE resource potential

The undiscovered REE endowment of Greenland was examined by a resource assessment workshop hosted by GEUS and the Greenlandic Bureau of Minerals and Petroleum (BMP, now Ministry of Mineral Resources [MMR]) in 2010. The assessment and ranking methods of the individual REE tracts were designed to comply, as much as possible, with the procedures of the Global Mineral Resource Assessment Program (GMRAP). Hence, a compilation of information on known REE deposits and geological provinces in Greenland was used in conjunction with REE deposit models. The aim was to assess the potential for REE deposits in Greenland in the uppermost kilometre of the crust. The workshop panel included two internationally recognized experts, in addition to geologists from six exploration companies and researchers from GEUS and BMP. The workshop findings are presented in Sørensen *et al.* (2011).

The REE workshop discussed and assessed 35 tracts with a potential for undiscovered REE deposits. The location of the tracts can be seen in Figure 4. The detailed results for each tract from the workshop assessment are given in Appendix A. The scores range from 0 to 50 points where 50 points represent tracts with the highest undiscovered REE potential and 0 points represent tracts with no potential.

In summary, the assessment workshop concluded that the following tracts have particularly good potential for hosting undiscovered REE deposits:

- Central East Greenland: Kap Simpson Alkaline Intrusion (tract A11.1)
- South-East Greenland: Skjoldungen Alkaline Province (tract A5)
- South Greenland (aside from of 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 Ivittuut Alkaline Intrusion (tract A17).

5.2 REE deposits related to alkaline intrusions

5.2.1 General geological setting

Alkaline magmatism is characterised by potassium and/or sodium -rich compositions that are deficient in quartz, and are formed in anorogenic settings. While many alkaline intru-

sions are barren, others have significant quantities of exotic REE mineral phases, resulting from the incompatible behaviour of REE, and ensuing concentration in residual melt as fractionation proceeds. In some cases, the magmatic mineralisation processes can be followed by further concentration by hydrothermal processes. Therefore, the distinction of this deposit type from the hydrothermal type is not always straightforward.

In the alkaline intrusion deposit type, the REE minerals are apatite group phosphates, complex zircono- and titanosilicates, and oxides, such as eudialyte, vlasovite, gittinsite, gadolinite, and loparite. As a result, while evolved alkaline intrusions constitute attractive exploration targets, the complex mineralogy often creates processing challenges.

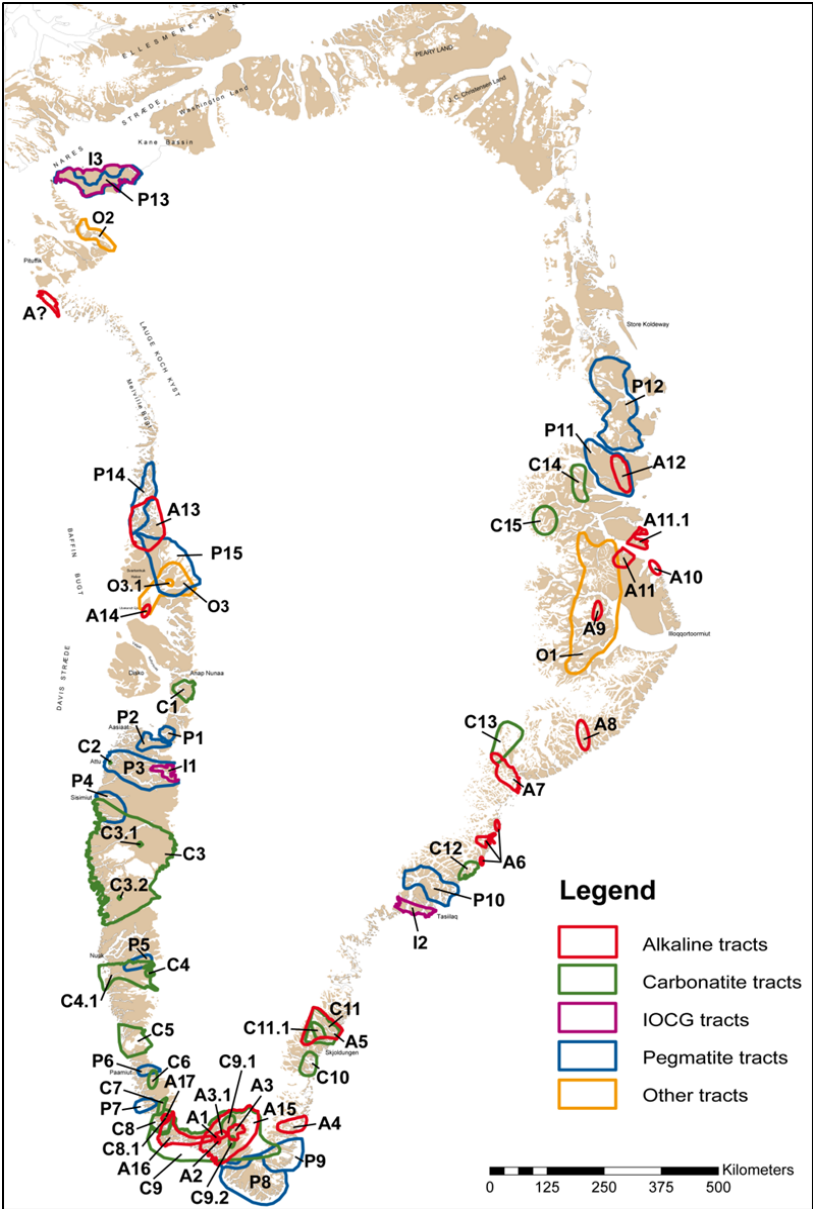


Figure 4. Outlines of the tracts used for the REE potential assessment (Sørensen et al. 2011). The tracts are grouped according to deposit type model applicable. "Other tracts" include areas with the potential for REE placer and palaeo-placer deposits. IOCG: Iron–Oxide Copper Gold.

5.2.2 Relevant deposits outside of Greenland

Current production is limited to the Lovozero deposit in the Kola Peninsula, Russia. This deposit is situated in a layered intrusion composed of rhythmic nepheline sequences, which have been mined for more than 50 years. Current annual production is approximately 2,400 tonnes of REO, extracted from loparite concentrates together with Nb and Ta (USGS 2014; Zaitsev & Kogarkov 2012).

Norra Kärr (Sweden), Strange Lake, Kipawa, and Nechalacho/Thor Lake (Canada) are other alkaline deposits which have been the focus of exploration and development efforts. Several of these have U, Zr, Hf, Nb, Zn, and/or F as by-products. The Dubbo deposit in Australia has been of special geological interest, as it has been interpreted to be related to a lava flow rather than an intrusion.

5.2.3 Known deposits/occurrences in Greenland

Greenlandic alkaline REE deposits include the important deposits related to the Gardar Igneous Province in South Greenland and the Gardiner Complex in East Greenland.

The Gardar Province is situated in an east-west trending Mesoproterozoic failed rift system within a granite-gneiss basement (Julianehåb Batholith, *c.* 1.8 Ga, Garde *et al.* 2002). Two separate periods of magmatism can be distinguished (*c.* 1,280–1,250 Ma and 1,180–1,140 Ma; Upton *et al.* 2003, Upton 2013) emplacing a suite of dykes and central intrusive complexes of highly variable, mostly alkaline compositions (see Figure 5). The overlying Eriksfjord Formation sequence consists of Gardar sandstone and basalt. Several intrusive bodies are known to host significant REE mineralisation, in particular in the Ílímaussaq (i.e. Kvanefjeld and Kringlerne deposits) and the Igaliko Igneous Complexes (Motzfeldt Centre).

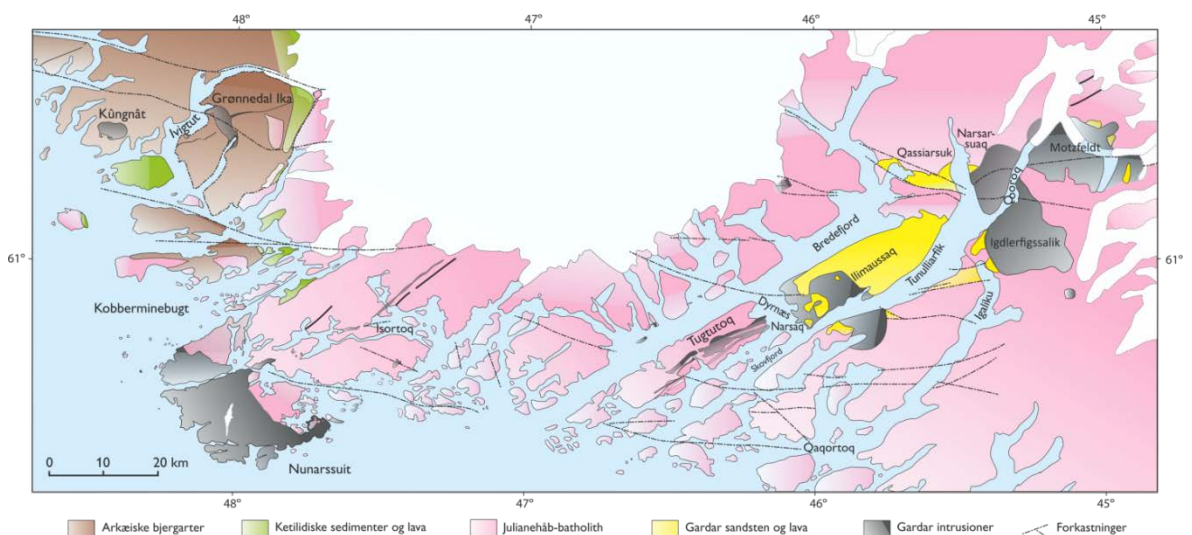


Figure 5. Geological map of the Gardar Province in South Greenland with associated intrusive complexes and dyke systems.

The Ilímaussaq Complex was emplaced at 1,160–1,130 Ma (Krumrei *et al.* 2006) and hosts some of the chemically most evolved magmatic rocks of the Gardar Province. It is the type locality for agpaitic nepheline syenites. These are highly peralkaline rocks with molar $(\text{Na}+\text{K})/\text{Al} > 1.2$ and typically characterised by the presence of complex Na-Ti-Zr silicates, such as eudialyte and rinkite. Agpaitic nepheline syenites are highly enriched in incompatible elements (Zr, Nb, Ta, Be, REE, U, Th etc.). The extreme enrichment is thought to have occurred by extensive fractional crystallisation of alkali basaltic and nephelinitic magmas during magma ascent through the lithosphere (Larsen & Sørensen 1987; Marks *et al.* 2011). The complex mineralogy of Ilímaussaq is reflected by the presence of more than 225 different minerals, of which 34 were discovered at this location and 12 remain unique to it (Sørensen 2001; Sørensen 2006a). Within the complex two deposits are present: (1) the Kringlerne deposit, hosted in the cyclically layered floor cumulates (kakortokite), and (2) the Kvanefjeld deposit representing the most evolved melt fractions (lujavrites) of the complex. The location of the two deposits within the complex can be seen in Figure 6.

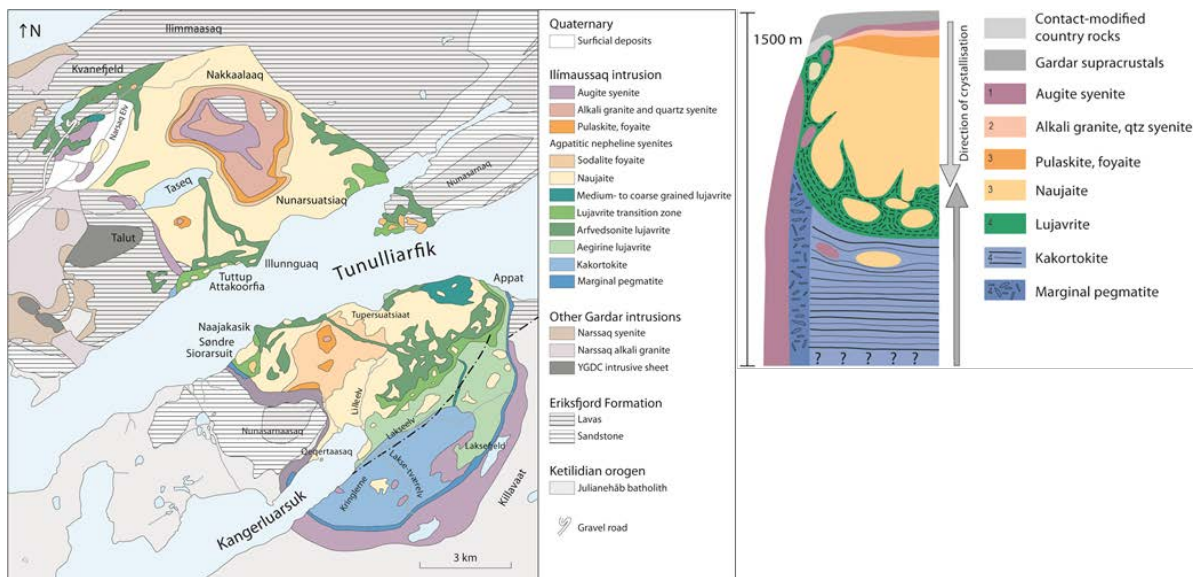


Figure 6. Geological map of the Ilímaussaq Complex and surroundings (modified after Ferguson 1964; Upton 2013) and a schematic cross-section. The Kringlerne REE deposit is hosted in the rhythmically layered basal kakortokite series whereas the Kvanefjeld REE deposit is associated with the highly fractionated arfvedsonite-lujavrite.

The Kringlerne deposit (exploration licences 2006/04 and 2007/45 held by Tanbreez Mining Greenland A/S and Rimbal Pty. Ltd.) covers the lowermost exposed part of the complex consisting of a series of rhythmically layered nepheline syenites (kakortokites) in the southernmost portion of the Ilímaussaq Complex. A total of 29 recurring units, each approximately 8 m thick, have been mapped and numbered from -11 to +17 (Bohse *et al.* 1971); see Figure 7. Individual units consist of three density-stratified layers: a basal arfvedsonite-dominated kakortokite layer, a red layer of eudialyte-dominated kakortokite and a whitish kakortokite layer dominated by alkali feldspar and nepheline (see Figure 8). The red layer is of variable thickness and absent in some units. The units dip gently towards the centre of the intrusion and steepen towards the margin of the complex (changing from ~10° to ~50° bedding angle). The exposed thickness of the deposit is about 500 m with an aerial expo-

sure of roughly 3 by 6 km. The REE, Zr, and Nb mineralisation is largely hosted in cumulus eudialyte, its subsolidus alteration products, and accessory late-magmatic rinkite.



Figure 7. Layered kakortokite sequence exposed in the southern part of the Ilímaussaq Complex, as seen from the Kangerluarsuk Fjord, in westerly direction. The high ranges in the background are the Killavaat (Redekammen) consisting of Julianehåb granite (photo K. Secher).

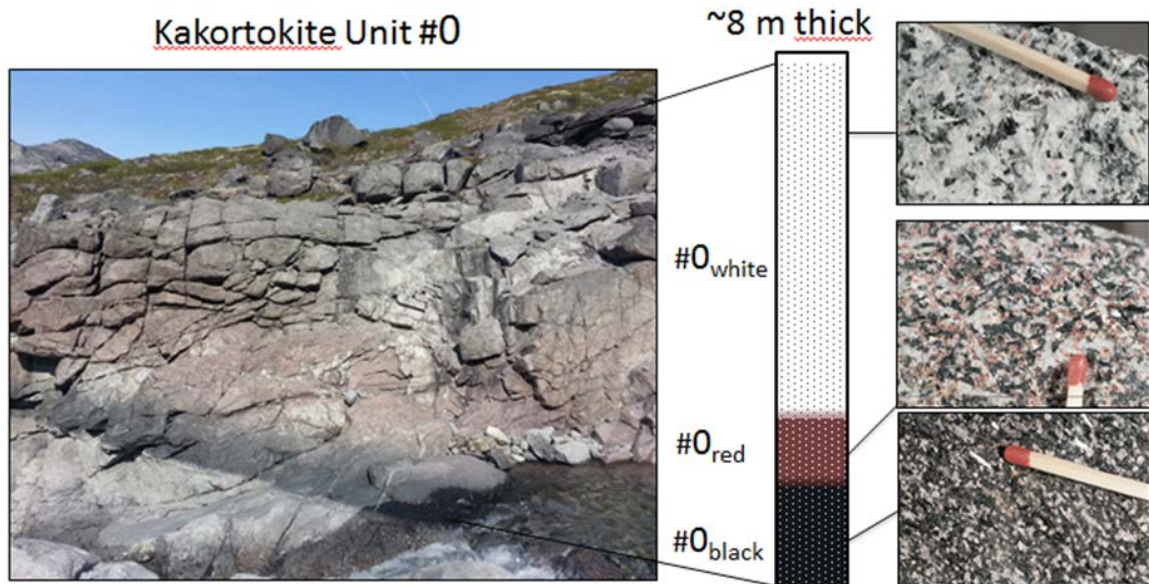


Figure 8. Characteristic layering in the kakortokites and images of black, red, and white kakortokite in hand specimen. Major minerals are: arfvedsonite (black), alkali feldspar (white), nepheline (grey), eudialyte (red) and aegirine (green) (from Sørensen 2006b).

The Kvanefjeld deposit (exploration licences 2011/26, 2010/02, and 2011/27 held by Greenland Minerals and Energy Ltd.) in the north-westernmost part of the Ilímaussaq Complex (Figure 6) crystallised during the final and most evolved stages of magmatism. The ore body mostly comprises hyperagpaitic lujavrites and fenitised country rocks. The agpaitic magmas experienced strong fractionation of incompatible elements and volatiles, which generated a reactive, low viscous melts at the final stage of differentiation. This melt intruded, brecciated, and fenitised the country rocks in the roof of the Ilímaussaq Intrusion, as well as earlier units of the complex itself. Hence, a mega-breccia formed, which consists of various igneous rocks including supracrustal blocks as well as rocks from the early phases of the alkaline intrusion hosted within the later agpaitic magma.

Lujavrites are mineralogically similar to kakortokites, but they have a different texture and a higher modal abundance of aegirine and arfvedsonite. Lujavrites are meso- to melanocratic, fine-grained and laminated, with a strong horizontal alignment of the prismatic minerals. At Kvanefjeld, they can be subdivided into a series of aegirine-rich lujavrites and arfvedsonite-rich lujavrites, respectively coloured dark green and black. The main exposures of lujavrite are at the eastern contact of the complex (northern coast of the Tunulliarfik Fjord), and northeast of the Elv Valley in the southern part of the complex (see Figure 9). Steenstrupine is the major REE-bearing mineral and formed during the advanced stages of crystallisation marking the transition from the agpaitic to the hyper-agpaitic stage (Sørensen *et al.* 2006). In addition to strong enrichments in U, Th, REE, Nb, and Ta the lujavrites also contain considerable concentrations of Li, Be, and F, largely contained in sørensenite, tugtupite, chkalovite, and polyolithionite in hydrothermal veins and pegmatites with F mainly hosted in villiaumite.



Figure 9. Kvanefjeld lujavrites seen from Elv valley. The road leads up to the entrance of the mine adit used for uranium exploration in the 1980's (photo H. Friis).

The Kvanefjeld deposit and associated ore bodies are classified as one of the world's largest resources of REE and the twelfth largest proven uranium resource (Kalvig *et al.* 2014). In fact, early exploration in the area was initially targeted on the U potential and included the construction of an exploration adit (Kalvig 1983); see Figure 9.

The Motzfeldt Alkaline Centre (exploration license 2014/01 held by Regency Mines Plc.) covers an area of c. 300 km² in the Igaliko Nepheline Syenite Complex, which intruded the Julianehåb batholith at 1,280 Ma (Bradshaw 1988; Upton *et al.* 2003). A geological map of the Motzfeldt Alkaline Centre can be seen in Figure 10. This intrusion attracted economic interest during the Syduran campaign when the Nb anomaly in the northeastern portion was discovered (Tukiainen *et al.* 1984). The Motzfeldt Sø Formation can be divided into three genetically related facies of syenite: (1) the marginal arfvedsonite syenite, (2) the altered syenite, and (3) the nepheline syenite, which are hosting a large number of late microsyenite sheets.

A drilling campaign was undertaken in 2001 revealing a preliminary resource potential of 15 Mt grading 500 ppm Ta₂O₅ and 6,000 ppm Nb₂O₅ (Armour-Brown 2001) mainly concentrated in pyrochlore within the hydrothermally altered syenite. Subsequent exploration also revealed REE-anomalies in the Drysdale, Voskop, and Aries prospect areas, where the REE are mainly concentrated in bastnäsite and monazite, as well as in unidentified REE, Zr, Nb-Ta, U-Th phases. For the Aries prospect, a total inferred maiden mineral resource has been presented with 340 Mt grading 0.26% TREO, 0.46% ZrO₂, 1,850 ppm Nb₂O₅, and 340 ppm Ta₂O₅ (RAM Resources 2012).

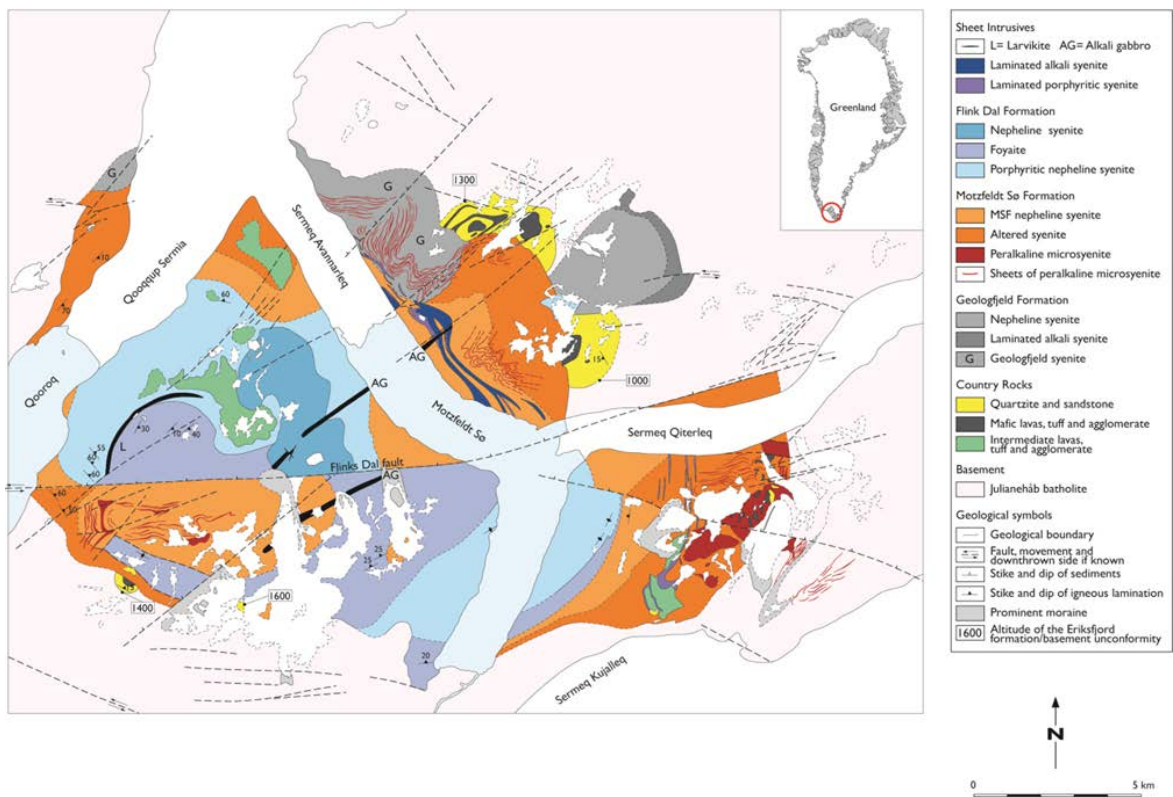


Figure 10. Geological map of Motzfeldt Alkaline Centre (after Bradshaw 1988; Tukiainen *et al.* 1984). For clarity, the late-Gardar dyke swarm dominated by alkali trachytes has been omitted.

The Gardiner Complex in East Greenland corresponds to a circular alkaline intrusion emplaced 50 Ma ago in relation to the opening of the North Atlantic. The intrusion has a diameter of approximately 6 km and is associated with NNW-trending alkaline dyke swarm. It consists predominantly of alkaline mafic rock types, e.g. melilitites and nephelinites with some carbonatites. The REE occur in perovskite, titanite, and apatite.

5.2.4 Potential for undiscovered REE resources in Greenland

In addition to the known deposits listed above, several tracts were considered in the evaluation of potential for undiscovered REE resources related to alkaline igneous rocks (Sørensen *et al.* 2011). These tracts were assessed by the described expert panel and ranked according to prospectivity. The locations of the tracts can be seen in Figure 11 and descriptions are available in Appendix A. Among the assessed tracts, the Kvanefjeld (A1), Kringlerne (A2), Motzfeldt (A3), Qassiarsuk (A3.1), Ivigtût (A17), and wider Gardar (A15) tracts were considered to have good to excellent potential to host a undiscovered REE deposit. The Werner Bjerger and Kap Simpson tracts (A10 and A11) were considered to have moderate to good potential. Remaining tracts were considered to have less than moderate potential for undiscovered alkaline REE deposits.

5.3 REE deposits in carbonatites

5.3.1 General geological setting

Carbonatites are derived from alkali-rich carbonate-silicate parental magmas that are primarily sourced from the subcontinental lithospheric mantle. Carbonatite melts may evolve by either liquid immiscibility or fractional crystallisation. Due to their incompatible behaviour, the REE become concentrated in the magma and can be incorporated in bastnäsite, allanite, apatite, or monazite at a late stage of magmatic differentiation. In some cases, REE concentrations may be further enriched by subsequent hydrothermal processes. Therefore, the division of this deposit type from hydrothermal type is not always straightforward. In other instances, and since carbonates are relatively soluble in tropical climates, carbonatite deposits can be transitional to the lateritic deposit type. In general, the carbonatite deposits are dominated by LREE since bastnäsite is commonly the main REE ore mineral. The beneficiation and processing technology for bastnäsite is well-established on industrial-scale and facilities are concentrated in China.

5.3.2 Relevant deposits outside of Greenland

Two of the main REE deposits being mined outside of China, Mountain Pass (USA) and Mt Weld (Australia), are carbonatite deposits. These are presently producing approximately 4,000 and 2,000 tonnes of TREO per year, respectively (USGS 2014). Interestingly, the principal REE ore mineral at the Mt Weld deposit is monazite which is a consequence of lateritisation processes that also caused significant upgrading of the resource. Other significant carbonatite REE deposits include Bayan Obo (China), Araxá (Brazil), Tomtor (Rus-

sia), Bear Lodge (USA), Lofdal (Namibia), Zandskopdrift (South Africa), and the deposits along the East African rift, such as Xiluvo (Mozambique), Ngualla (Tanzania), and Kangakunde (Malawi).

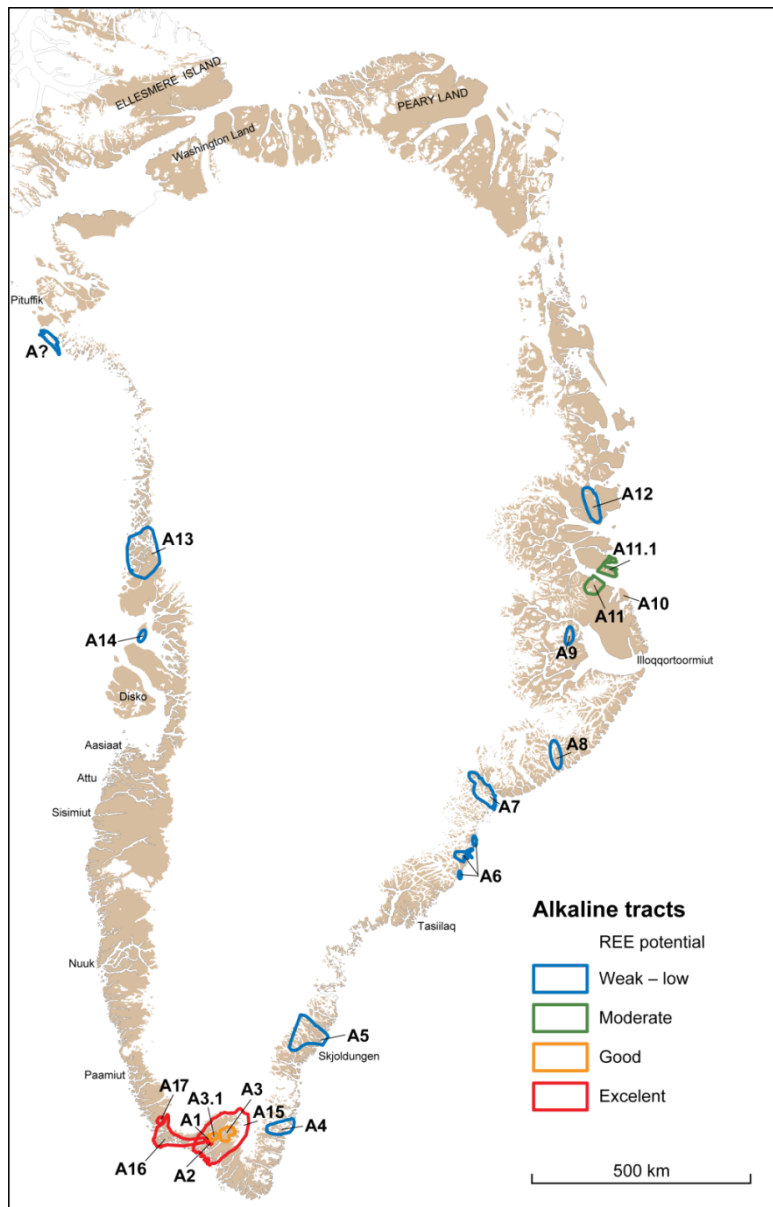


Figure 11. Tracts characterised by alkaline intrusions. The colour coding reflects the potential for undiscovered REE deposits (after Sørensen et al. 2011).

5.3.3 Known deposits/occurrences in Greenland

Several REE carbonatite deposits are known in West Greenland and principal features and exploration results have recently been summarized by Thrane *et al.* (2014). Below the occurrences are described from south to north; the locations can be seen in Figure 12.

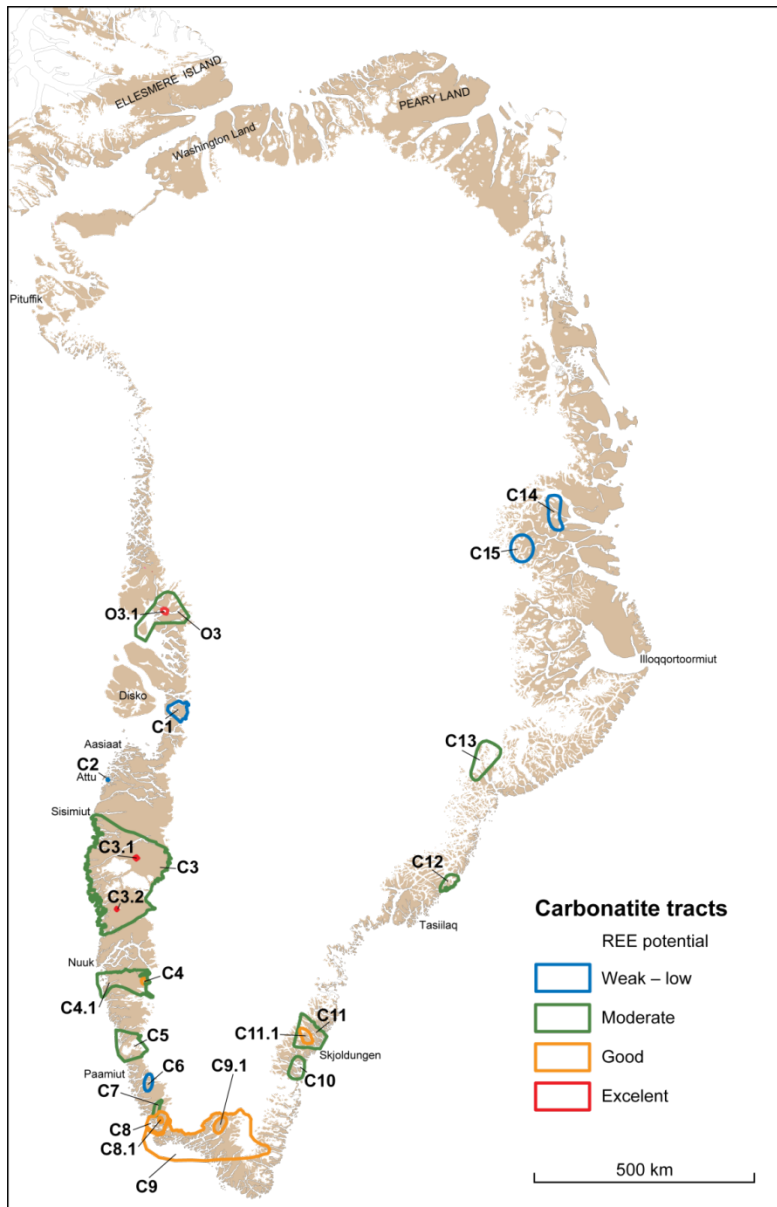


Figure 12. Carbonatite intrusion tracts in Greenland. The colour coding reflects the potential for undiscovered REE deposits (after Sørensen *et al.* 2011). Note that tracts C9, C9.1 and C11.1, which were classified as “moderate to good”, are included in the “good” category here.

The southernmost REE carbonatite deposit is Grønnedal-Ika, tract C8 (exploration licence 2007/45 held by Rimbald Pty. Ltd.). It is part of the Gardar Province, and hosted in a nepheline syenite with a central carbonatite plug emplaced at $1,299 \pm 1.7$ Ma (Larsen *et al.* 1983). The carbonatite plug is enriched in REE due to the presence of significant quantities of bastnäsite. The tract was evaluated for undiscovered REE carbonatite deposits, and was classified to have good potential.

The Tikusaaq carbonatite, tract C4 (exploration licence 2010/27 held by NunaMinerals A/S), was intruded into Archaean basement around 158–155 Ma (Steenfelt *et al.* 2006), and as such represents the earliest manifestation of rifting processes related to the opening of the Labrador Sea Basin. The complex consists of a central intrusive carbonatite sur-

rounded by a fenite zone with carbonatite and aillikite dykes. The exposed carbonatite sheets cover 2 km x 3 km, and the alteration zone extends up to 14 km in diameter. Remote sensing data suggest that a massive carbonatite is hidden below the glacial terraces. The main REE mineral is bastnäsite; however, ancylite and monazite are also present. Low TREO grades have been identified in carbonatite sheets exposed in gullies, but high TREO grades of up to 9.6% have been reported in carbonatite floats. The tract was evaluated for undiscovered REE carbonatite deposits, and was classified to have good potential.

The Qeqertaasaq Complex, tract C3.2 (also known as Qaqarssuk; exploration licence 2007/51 held by NunaMinerals A/S), intruded into Archaean basement at 165.7 ± 1.9 Ma (Secher *et al.* 2009), and is also associated to the opening of the Labrador Sea Basin. It is dominated by carbonatite but contains kimberlite and alkaline intrusions. The complex consists of an outer suite of steeply outward dipping concentric sheets, and an inner suite of less steeply dipping circular sheets with sövitic to rauhaugitic compositions. REE occur mostly in dykes in the core of the complex with mineral assemblages including ancylite, burbankite, huanghoite, and qaqarssukite. A maximum grade of 13.2% REO was identified in one of the dykes, and 25% of the samples from a surface sampling program have been reported to contain more than 3.3% REO. The tract was evaluated for undiscovered REE carbonatite deposits, and was classified to have excellent potential.

The Sarfartoq carbonatite, tract C3.1, (exploration licence 2010/40 held by Hudson Resources Inc.) was intruded at 560 ± 13 Ma along the transition zone between the Archaean craton to the south and the Palaeoproterozoic Nagssugtoqidian mobile belt to the north (Garde *et al.* 2000; Secher *et al.* 2006; Willigers *et al.* 2002). The intrusion has a conical structure with a magnetic core surrounded by narrow, closely spaced, carbonatite sheets with interleaved fenitised and altered country rock, and with an outer rim of aegirine-bearing fenite. The dominant carbonatite type is ferrocarbonatite with rauhaugite in the core, and beforosite in the marginal dykes. Sövitite only occurs as subordinate units in the core. The main REE minerals are bastnäsite, synchysite, zhonghuacerite, and monazite. The tract was evaluated for undiscovered REE carbonatite deposits, and was classified to have excellent potential.

The Niaqornakavsak deposit in the Karrat area, tract O3.1 (exploration licence 2010/05 held by Avannaq Resources Ltd.), is of unclear typology, but could possibly be a deformed and metamorphosed carbonatite. The host rocks are Palaeoproterozoic metasedimentary and metavolcanic rocks of the Karrat Group. REE mineralisation occurs within a lithologically distinct horizon of banded carbonates, striking along 1.5 km and with a thickness between 10 and 33 m. REE are mainly hosted by bastnäsite, monazite, allanite, and other REE silicates. An average grade of 1.4 wt% TREO, of which 13% are HREO, has been reported. The tract was evaluated for undiscovered REE carbonatite deposits, and was classified to have good to excellent potential.

5.3.4 Potential for undiscovered REE resources in Greenland

In addition to the known deposits listed above, several tracts were evaluated for the potential of undiscovered REE resources related to carbonatites (Sørensen *et al.* 2011). All the

evaluated tracts can be seen in Figure 12 and further information are available in Appendix A). As described above the Sarfartoq, Qeqertaasaq (Qaqarssuk) and Niaqornakavsak (despite its poorly understood setting) tracts were considered to have good to excellent potentials, while the Tikiusaaq and Grønnedal-Ika were assessed to have good potential. Wider Grønnedal-Ika, wider Gardar, Qassiarsuk, and Singertât tracts were assessed as having moderate to good potential for undiscovered carbonatite-hosted REE deposits.

5.4 Hydrothermal REE deposits

5.4.1 General geological setting

This deposit type results from REE transportation in hot fluids that are precipitated in veins or during reaction with host rock units. These fluids may originally have been derived from magmas, where REE behaved incompatibly and ultimately accumulate in late stage hydrothermal fluids. As such, this deposit type can be transitional to alkaline, carbonatite or pegmatite deposit types. Their mineralogy is often complex with bastnäsite, allanite, monazite, gadolinite, and parasite as common minerals. Uranium, Th, Cu, and Au can constitute potential by-products. However, as this deposit type tends to be mainly LREE-enriched and the veins are generally rather thin, their production potential is limited.

5.4.2 Relevant deposits outside of Greenland

As this deposit type often is transitional to magmatic deposit types (alkaline, carbonatite or pegmatite deposit types) definitive examples are hard to establish. Lehmi Pass (USA), Holdans Lake (Canada), Nolans Bore (Australia), Steenkampskraal (South Africa), and Bayan Obo (China), constitute examples where hydrothermal processes have been confirmed to have played an important role.

5.4.3 Known deposits/occurrences in Greenland

The Greenlandic REE deposits of magmatic type (alkaline, carbonatite, pegmatite types) can also have undergone hydrothermal REE enrichment processes to different degrees. However, the only Greenlandic deposit which has been proposed to have had a significant contribution of hydrothermal processes is Bjørnedal, tract A11.1 (Kap Simpson, East Greenland; exploration licence 2014/18 held by Czech Geological Research Group Ltd.). At this deposit, the mineralisation occurs in felsic dykes and veins, intruding a Palaeogene caldera succession. The REE minerals include euxenite, samarskite, fergusonite, monazite, and bastnäsite. Grab samples have yielded up to 3% REE (along with Zr, Nb, and Ta).

5.4.4 Potential for undiscovered REE resources in Greenland

Due to the transitional character between this deposit type and magmatic deposit types, resources related to hydrothermal processes are likely included in the estimates for alkaline and carbonatite-hosted REE deposits. Due to this transitional character the wider area sur-

rounding the Bjørnedal deposit (Kap Simpson tract A11.1 in Appendix A) was actually assessed under the alkaline deposit model (Sørensen *et al.* 2011) despite the importance of hydrothermal processes. As such, while no tracts were assessed specifically for undiscovered hydrothermal deposits, the potential for undiscovered deposits of this type can certainly be present within tracts assessed for magmatic deposit types.

5.5 REE potential of Iron-Oxide Apatite and Iron-Oxide Copper Gold deposits

5.5.1 General geological setting

This deposit type includes Iron-Oxide Apatite (IOA) and Iron-Oxide Copper Gold (IOCG) deposits. These are very complex deposits with diverse hosts, including felsic to intermediate plutonic or volcanoclastic rocks, or clastic and carbonate metasedimentary rocks. This deposit type is believed to have formed in intracratonic, extensional settings, and is associated with anorogenic, A-type, silicic magmatism. These deposits can be enriched in LREE with apatite, bastnäsite, monazite, xenotime, and allanite as the main REE minerals.

5.5.2 Relevant deposits outside of Greenland

Examples of IOA and IOCG REE deposits include the giant Olympic Dam deposit (Australia), but also Ernest Henry (Australia), Kiruna (Sweden), Sossego (Brazil), Candelaria (Chile), and Marcona (Peru).

5.5.3 Known deposits/occurrences in Greenland

No Greenlandic deposits have been assigned to this deposit type.

5.5.4 Potential for undiscovered REE resources in Greenland

Even though no Greenlandic IOCG deposits have been discovered so far, the potential for undiscovered REE deposits of this type has been mentioned for three tracts by Sørensen *et al.* (2011). The three tracts are located in Inglefield Land (North Greenland), tract I3; Arfersirofik (West Greenland), tract I1; and Ammassalik (Southeast Greenland), tract I2, and can be seen on Figure 13.

5.6 REE placer deposits

5.6.1 General geological setting

Placer deposits are formed through the action of water concentrating heavy and weathering resistant minerals. This can result in REE enriched deposits with monazite, xenotime, and/or allanite as common minerals. This deposit type is amenable to low cost surface min-

ing, commonly with Sn, Ti, Zr as main products. However, the common association with Th and U as by-products requires particular precautions during processing and must be taken into account when this deposit type is targeted.

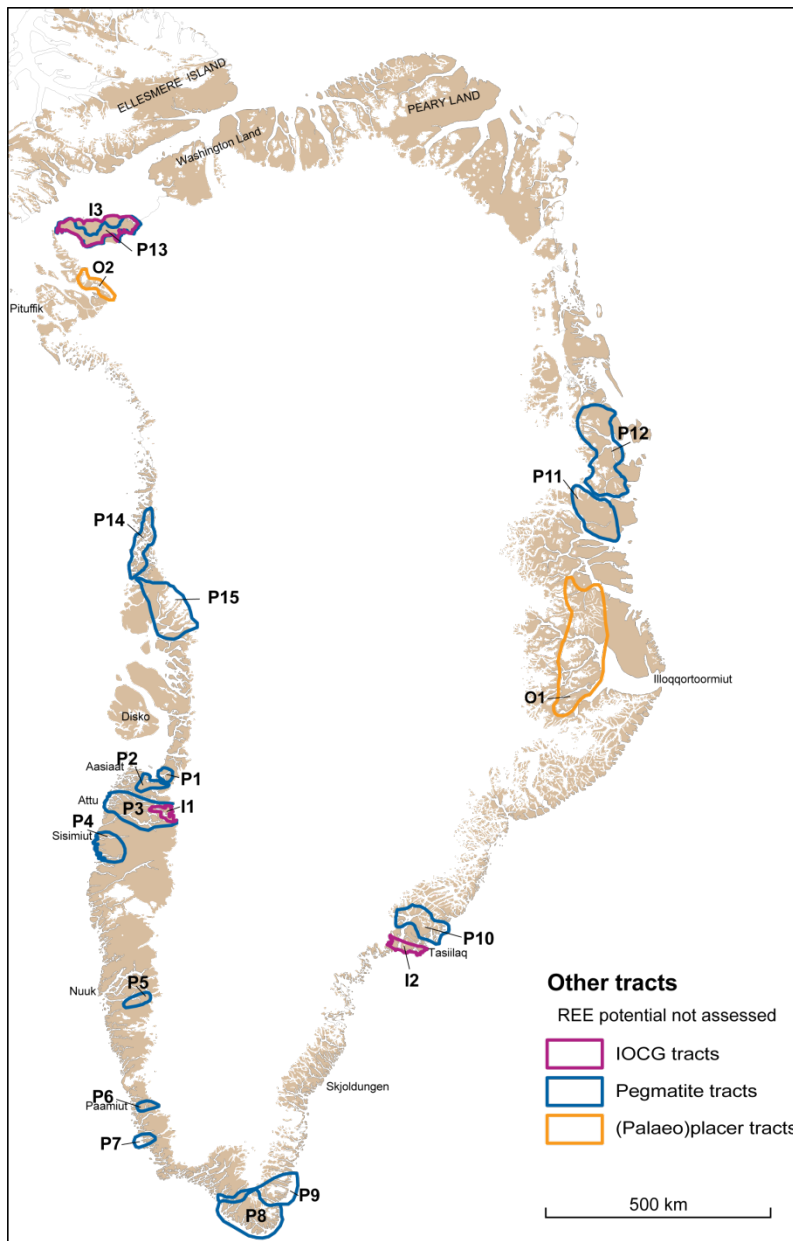


Figure 13. Possible undiscovered REE deposits associated with tracts representing Iron-Oxide Copper Gold environments or areas with prominent pegmatite occurrences. Furthermore, there is local potential for REE placer and palaeo-placer deposits (after Sørensen et al. 2011).

5.6.2 Relevant deposits outside of Greenland

The vast Indian, Brazilian, Malaysian, and Australian mineral sand deposits are examples of REE-enriched placers. Ancient placers such as Olserum (Sweden) in the rock record constitute palaeo-placers.

5.6.3 Known deposits/occurrences in Greenland

The Mesozoic Milne Land palaeo-placer is in the basal part of the Charcot Bugt Formation, and the most anomalous locality, “Hill 800” in Bays Fjelde, is approximately 500 m in diameter and 40–50 m thick. It consists of three units of arkosic sandstones and breccias. The heavy minerals are hosted by the basal unit which is approximately 20 m thick. REE, U, and Th are mainly hosted in monazite. The area is currently claimed by Czech Geological Research Group Ltd. (exploration licence 2011/53).

5.6.4 Potential for undiscovered REE resources in Greenland

The potential for undiscovered (palaeo)placer REE deposits has been highlighted in two tracts located in the Thule region (North Greenland), tract O2, and Milne Land–Lyell Land (East Greenland; Sørensen *et al.* 2011), tract O1, see Figure 13. While the former was considered to only hold a weak potential, the latter was considered to hold a moderate-good potential for undiscovered deposits; see Appendix A.

6 Status of the REE exploration in Greenland

Several junior exploration companies have invested in REE projects in Greenland and the knowledge of REE resources in Greenland has taken a large leap forward in recent years. This includes advances in the development of two world-class REE deposits (Kvanefjeld and Kringlerne). Overall exploration expenditure for projects mainly focused on REE was approximately 10.7 million € in 2013 (MMR, personal communication). Currently, there appears to be a shift from a focus on field exploration and drilling to more project development activities including technical, environmental, and social aspects.

The moratorium on uranium exploration in Greenland was lifted by the Government of Greenland in October 2013. This was important, given that several REE projects are enriched in U and the new legislation has allowed these projects to move ahead with ore-beneficiation studies. However, there is still no official decision whether it will be possible to exploit U during mining operations. Official policies on this are anticipated to be published in 2015.

Currently, a total area of 3,186 km² is claimed for REE exploration in Greenland (www.govmin.gl/index.php/minerals/geology-of-greenland/greenland-portal, as per March 1, 2015 and public company information). Exploration licences targeted at REE deposits and licence holders can be seen in Figure 14. Licence holders include publicly listed companies such as Greenland Minerals and Energy Ltd. (ASX, Australia), Regency Mines Plc. (LSE, London), Hudson Resources Inc. (TSX, Toronto), and NunaMinerals A/S (OMX, Copenhagen). Furthermore, there are also unlisted entities active in this space: Tanbreez Mining Greenland A/S with subsidiary Rimbald Pty. Ltd., Avannaa Resources Ltd., and Czech Geological Research Group Ltd. The information regarding licence holdings, deposit types, and project status is summarized in Table 1.

Overall, claims are concentrated within and adjacent to the Gardar Province due to the known REE prospectivity of the alkaline intrusions in this area, see Figure 14. Furthermore, there are REE targets covered by licences along the western and eastern coasts of Greenland. Most of these targets are in carbonatites, however, some more unusual settings (palaeo-placer, possible hydrothermal deposits) are also explored.

Currently, there are four advanced REE projects in Greenland with defined mineral resources. These are: the Kvanefjeld (Greenland Minerals and Energy Ltd.), Kringlerne (Tanbreez Mining Greenland A/S), and Motzfeldt (Regency Mines Plc.) projects in the alkaline Gardar Province and the carbonatite-hosted Sarfartoq mineralisation (Hudson Resources Inc., West Greenland); the locations can be seen on Figure 15. The projects are in different stages of development and their status is discussed in more detail in the following section. The published information regarding deposit size and grade distribution is summarized in Table 2.

Furthermore, drilling campaigns have been carried out at the Qeqertaasaq (NunaMinerals A/S) and Niaqornakavsak project (Karrat, Avannaa Resources Ltd.) in West Greenland proving the potential for further exploration in these areas. Other targets are still in the

greenfield stage of exploration with field work, surface geochemistry and geophysical data as the main sources of information.

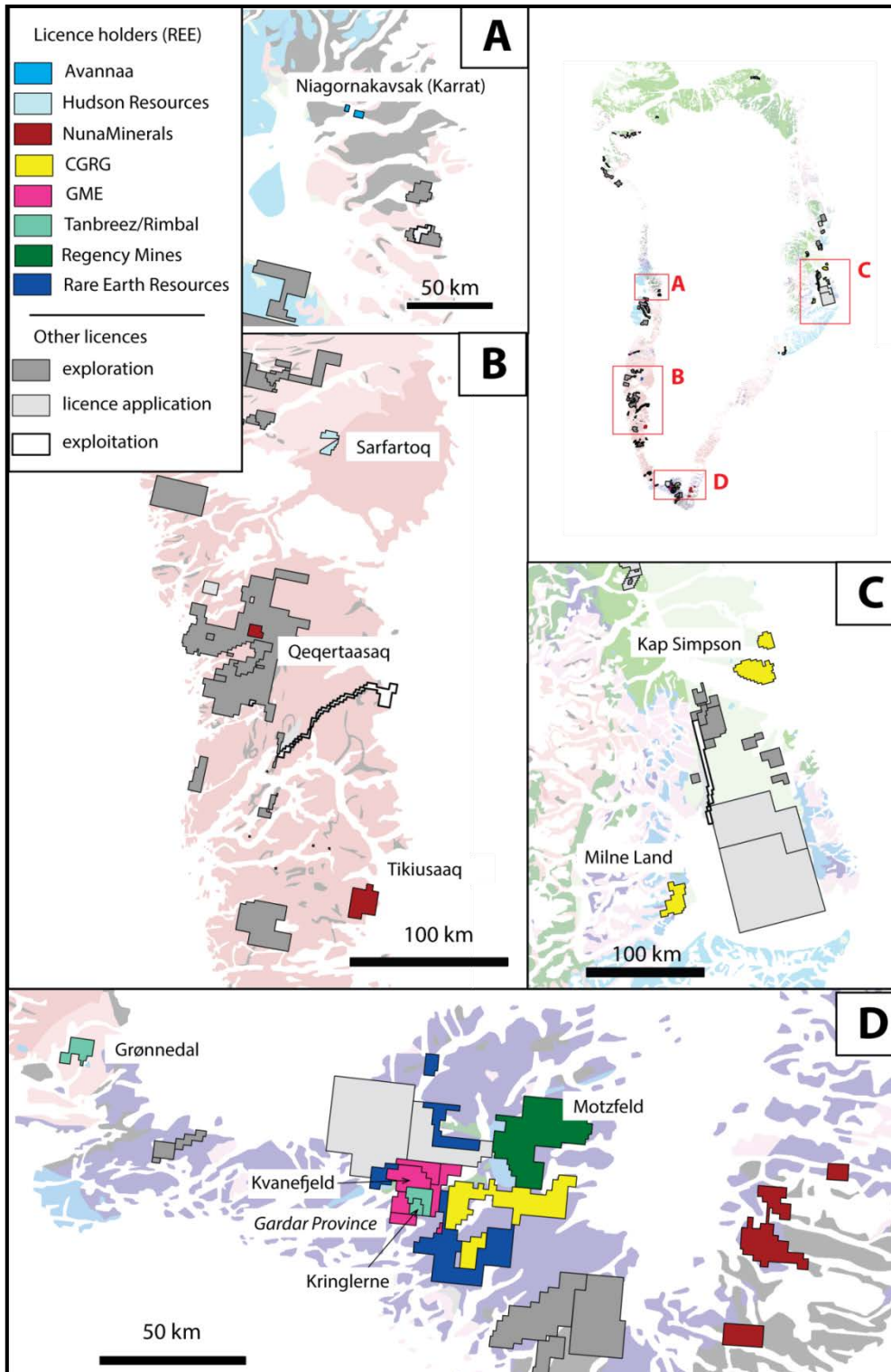


Figure 14. Exploration licences in Greenland targeted at REE deposits and licence holders (GME=Greenland Minerals and Energy Ltd.; CGRG=Czech Geological Research Group Ltd.). Data compiled from www.licence-map.bmp.gl and company information. Background: Geological map of Greenland. More detailed information presented in Table 1.

Table 1. Exploration licences for REE targets in Greenland.

Company	Area (km ²)	Licence	Prospect name	Deposit type	Status
Avannaa Resources Ltd.	12	2010/05	Niaqornakavsak, Karrat (West Greenland)	Carb/HT	EP, d
Czech Geological Research Group Ltd.	370	2011/53	Milne Land (East Greenland)	Ppl	EP, fw
	101	2013/12	Kap Parry (East Greenland)	Alk, PC	EP, fw
	432	2013/15	Igaliku, Gardar Province (South Greenland)	Alk	EP, fw
	487	2014/18	Kap Simpson (East Greenland)	Alk, PC	EP, fw
Greenland Minerals and Energy Ltd.	68	2011/26	Kvanefjeld (South Greenland)	Alk	AP
	80	2010/02	Kvanefjeld (South Greenland)	Alk	AP
	67	2011/27	Kvanefjeld (South Greenland)	Alk	AP
Hudson Resources Inc.	92	2010/40	Sarfartoq (West Greenland)	Carb	AP
Nuna Minerals A/S	64	2007/51	Qeqertaasaq (West Greenland)	Carb/HT	EP, d
	288	2010/27	Tikiusaaq (West Greenland)	Carb	EP, fw
Rare Earth Resources Ltd.	25	2012/13	Gardar Province (South Greenland)	Alk	EP, fw
	78	2012/14	Gardar Province (South Greenland)	Alk	EP, fw
	334	2012/15	Gardar Province (South Greenland)	Alk	EP, fw
	21	2013/20	Gardar Province (South Greenland)	Alk	EP, fw
Regency Mines Plc.	555	2014/01	Motzfeldt (South Greenland)	Alk	AP
Tanbreez Mining Greenland A/S / Rimbald Pty. Ltd.	18	2006/04	Kringlerne (South Greenland)	Alk	AP
	50	2007/45	Grønnedal (South Greenland)	Carb	EP, fw
	44	2010/24	Kringlerne (South Greenland)	Alk	AP

Company websites: Avannaa Resources Ltd.: www.avannaa.com; Greenland Minerals and Energy Ltd.: www.ggg.gl and www.gme.gl; Tanbreez Mining Greenland A/S; www.tanbreez.com; Regency Mines Plc.: www.regency-mines.com; Hudson Resources Inc.: www.hudsonresources.ca; NunaMinerals A/S: www.nunaminerals.com; Czech Geological Research Group Ltd.: www.cgrg.cz. Rare Earth Resources Ltd.: www.rareearthmineralsplc.com.

Deposit type: Alk: alkaline intrusion; Carb: carbonatite; carb/HT: carbonatite and hydrothermal veining; Ppl: palaeo-placer; Alk, PC: Alkaline intrusions in Palaeogene caldera settings.

Status: AP: Advanced project, EP, d: Exploration project with drilling results; EP, fw: Exploration project with mainly field work.

Table 2. Summary of REE resource estimates for Greenlandic projects.

Project	Resource (Mt)	TREO (%)	LREO (%)	HREO (%)
Kringlerne	4300	0.65	0.50	0.15
Kvanefjeld	673	1.10	0.96	0.13
Motzfeldt	340	0.26	NR	NR
Karrat*	20	1.02	0.89	0.13
Sarfartoq	8	1.72	1.68	0.04

Data sources: Kringlerne – Data for the resource are company estimates from the company's homepage www.tanbreez.com. Kvanefjeld – Measured, indicated and inferred resources of Kvanefjeld (note that there are additional inferred resources in the adjacent Sørensen Zone and Zone 3; see Table 3), JORC code. By-products: U, Zn, and F (estimates based on a cut-off grade of 150 ppm U₃O₈; Greenland Minerals and Energy Ltd. 2015); Motzfeldt – Data from RAM Resources press release (RAM Resources 2012). By and co-products: Zr, Nb, Ta. JORC compliant maiden resource. Sarfartoq – Combined inferred and indicated resource, cut-off: 1% TREO; NI 101-43 code (Hudson Resources Inc. 2013).

*: Based on drilling results and bulk sample analyses Avannaa Resources Ltd. presented estimates for "potential resources" (Avannaa Resources 2011): optimistic estimate: 26.3 Mt @ 0.996% TREO (0.13% HREO) and conservative estimate: 19.5 Mt @ 1.02% TREO (0.13% HREO). Avannaa states: "estimates of tonnage and grade are still conceptual in nature and do not constitute compliant resource estimates". An investment volume of \$4.5 million is estimate for additional work required to produce an inferred resource estimate.

NR: Not reported. LREO: sum of La₂O₃, CeO₂, Pr₆O₁₁, Nd₂O₃, Sm₂O₃; HREO: sum of Eu₂O₃, Gd₂O₃, Tb₄O₇, Dy₂O₃, Ho₂O₃, Er₂O₃, Tm₂O₃, Yb₂O₃, Lu₂O₃, Y₂O₃.

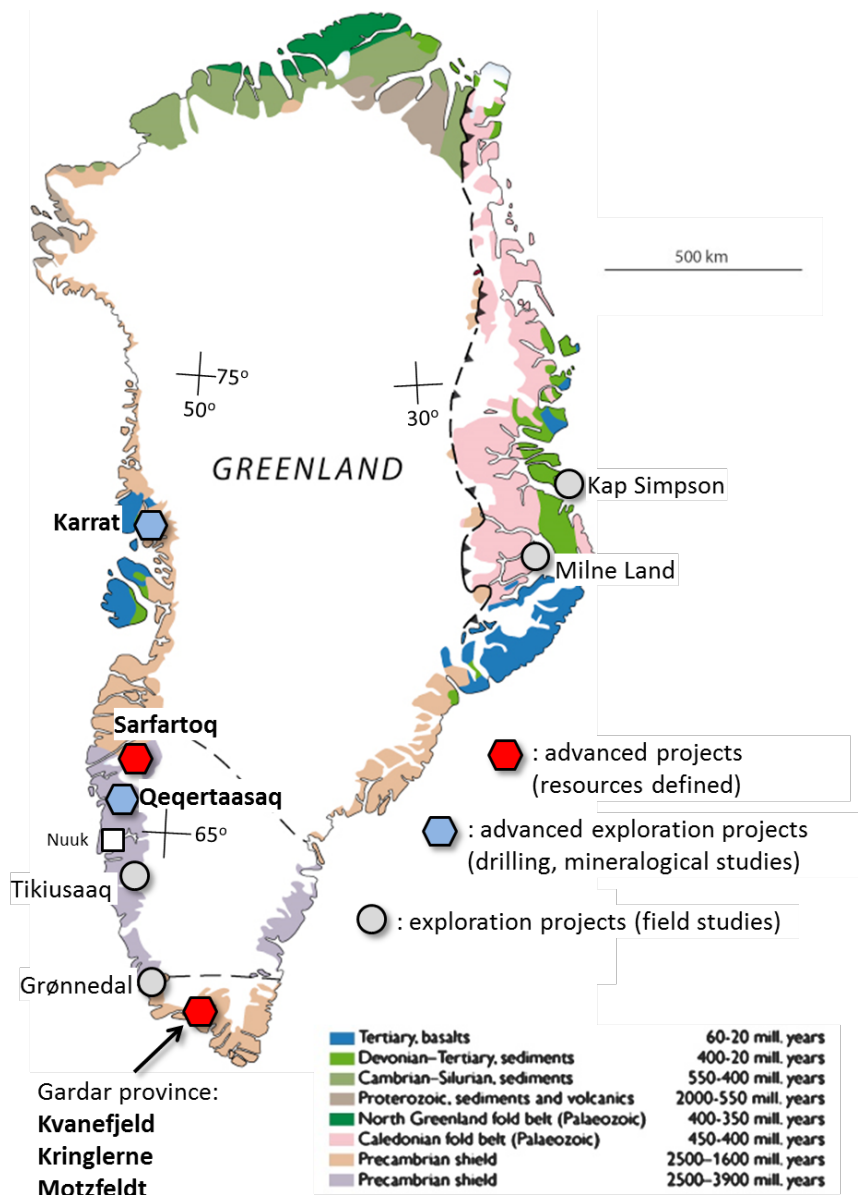


Figure 15. Location of current REE exploration projects. Most of the advanced projects are located in the alkaline Gardar Province of South Greenland. Note that Avannaar Resources presented estimates for “potential resources” based on drilling results and bulk sample analyses (Avannaar Resources 2011); see Table 2.

6.1 Advanced REE projects: Gardar Province (South Greenland) and Sarfartoq (West Greenland)

Three advanced REE projects with defined resources are present in the Gardar province, South Greenland, where the Ilímaussaq Alkaline Intrusive Complex (hosting the Kvanefjeld and Kringlerne deposits) and the Motzfeldt Alkaline Centre of the Igaliko Complex have attracted most interest. In addition to the exploration licences containing the actual identified REE resources there are claimed areas surrounding these licences (held by Czech Geological Research Group Ltd. and Rare Earth Resources Ltd.); see Figure 14.

6.1.1 The Kvanefjeld REE-U-Zn-F Project

The Kvanefjeld multi-element project, situated 8 km northeast of Narsaq, has been subject to U exploration since the 1950's undertaken by the Greenland Geological Survey and National Laboratory Risø (Sørensen *et al.* 1974). Currently, the Kvanefjeld area is being explored by Greenland Minerals and Energy Ltd. (GME) focusing on REE. GME holds three exploration licences (2010/02, 2011/26, and 2011/27), encompassing three exploration targets, namely Kvanefjeld Zone, Zone 3, and Sørensen Zone. The Kvanefjeld Zone is the main target, and is being advanced through the preparation phase for the submission of an application for an exploitation licence including the preparation of a Social Impact Assessment (SIA) and an Environmental Impact Assessment (EIA). To date, PEA (Preliminary Economic Assessment) and PFS (Pre-Feasibility Study) have been completed and the FS (Feasibility Study) is scheduled to be completed in the third quarter of 2015.

The bulk of the REE mineralisation in the three exploration areas of Kvanefjeld is hosted in the phosphor-silicate steenstrupine¹, which also hosts the U. Additional potential by-products are zinc hosted by sphalerite and fluorine hosted mainly by villiaumite. Physical mineral beneficiation studies on the complex ore mineral assemblage have been accomplished and chemical beneficiation studies have reached advanced stages.

For the Kvanefjeld Zone, the JORC compliant measured, indicated and inferred resources are 673 Mt (based on a 150 ppm U₃O₈ cut-off) with a TREO average grade of 1.10% (Greenland Minerals and Energy Ltd. 2015). In addition, inferred resources have been identified for the Sørensen Zone and Zone 3; see Table 3. The relative distribution of HREOs in the mineral resource of the Kvanefjeld Zone is 11.7%, the relative distribution of CREOs (Critical Rare Earth Oxides: Nd, Pr, Dy, Tb, Eu) is 18.4%, and the notable relative distributions of Dy and Y are 1.1% and 7.7%, respectively (data from TMR 2015).

The Kvanefjeld project concept involves an open pit mine working 360 days annually and a mineral beneficiation plant. The concept also encompasses tailings facilities, roads, and port facilities for ships delivering supplies to the mine and transporting products from Greenland to the clients abroad. The estimation for the required capital expenditure (CAPEX) is 1,450 million US\$.

The mineral beneficiation involves a flotation circuit for the separation of sphalerite and steenstrupine from gangue minerals, and a subsequent sulphuric acid leach circuit under atmospheric conditions, and solvent extraction and separation of U and REE concentrates.

Planned annual mine throughput is 7.2 Mt, of which 4.2 Mt is waste rock and 3 Mt is planned to be processed. According to the PFS the project aims to produce approximately 23,000 tpa TREO, along with 500 tpa U₃O₈, 6,000 tpa Zn, and 9,000 tpa fluorspar. Production costs (OPEX) are estimated to be US\$ 3.07/kg TREO with U credits at US\$ 70/lb. Commercial products of lanthanum and cerium will be produced aiming at the European market (6,000 tpa La₂O₃ and 10,000 tpa CeO₂). The remaining REO concentrate (c. 6,400 tpa) will be shipped for separation into commercial products in China. GME has estimated

¹ Na₁₄Ce₆Mn²⁺Mn³⁺Fe²⁺2Zr_{0.75}Th_{0.25}(Si₆O₁₈)₂(PO₄)₇·3(H₂O)

the revenue proportions of the products as follows: Nd: 33%; Pr: 18%; Dy: 13%; Ce: 8%, U 7%; La: 5%; Y, Tb and Eu 4% each; Zn, Gd, Er, and Lu 1% each.

Table 3. Resource figures for the Kvanefjeld Zone, Sørensen Zone and Zone 3.

		Tonnage	Grade	Contained metal
Kvanefjeld Zone	Measured	143 Mt	TREO: 1.21% U ₃ O ₈ : 303 ppm Zn: 2,370 ppm	TREO: 1.72 Mt U ₃ O ₈ : 95.21 M lbs Zn: 0.34 Mt
	Indicated	308 Mt	TREO: 1.11% U ₃ O ₈ : 253 ppm Zn: 2,290 ppm	TREO: 3.42 Mt U ₃ O ₈ : 171.98 M lbs Zn: 0.71 Mt
	Inferred	222 Mt	TREO: 1.00% U ₃ O ₈ : 205 ppm Zn: 2180 ppm	TREO: 2.22 U ₃ O ₈ : 100.45 M lbs Zn: 0.48
Sørensen Zone	Inferred	242 Mt	TREO: 1.10% U ₃ O ₈ : 304 ppm Zn: 2,602 ppm	TREO: 2.67 Mt U ₃ O ₈ : 162.18 M lbs Zn: 0.63 Mt
Zone 3	Inferred	95 Mt	TREO: 1.16% U ₃ O ₈ : 300 ppm Zn: 2,768 ppm	TREO: 1.11 Mt U ₃ O ₈ : 63.00 M lbs Zn: 0.26 Mt

From Greenland Minerals and Energy (February 2015) – based on cut-off value of 150 ppm U₃O₈. The total for Kvanefjeld is 673 Mt; the grand total for the entire project is 1010 Mt. The grade distribution for the Kvanefjeld resource (673 Mt) is La₂O₃: 0.301%; CeO₂: 0.460%; Pr₆O₁₁: 0.046%; Nd₂O₃: 0.141%; Sm₂O₃: 0.018%; Eu₂O₃: 0.001%; Gd₂O₃: 0.012%; Tb₄O₇: 0.002%; Dy₂O₃: 0.012%; Ho₂O₃: 0.002%; Er₂O₃: 0.007%; Tm₂O₃: 0.001%; Yb₂O₃: 0.005%; Lu₂O₃: 0.002%; Y₂O₃: 0.084% (TREO: 1.10%, TMR 2015).

6.1.2 The Kringlerne Zr-REE-Nb-Ta project

The Kringlerne deposit, forming the lower part of the Ilímaussaq intrusion and situated 15 km south of Narsaq, has been investigated since the 1970's for Zr, Ce-Y, and sodalite by Kryolitselskabet Øresund, Superfos A/S, A/S Carl Nielsen, MDI A/S, Highwood Resources, and Platinova Resources. In 2001, Tanbreez Mining Greenland A/S acquired the licence 2006/04 and Rimbald Pty. Ltd. acquired the licence 2010/24, both entities belong to one privately owned group. Licence 2006/04 encompasses the enormous sequence of layered kakortokites, comprising about 300 m of cyclic eudialyte-rich layers, which are the main REE target.

Regarding the grade and tonnage of the deposit, Tanbreez reports that the “current inferred resource is more than 4,300 Mt of eudialyte bearing ore, which contains 1.8% ZrO₂, 0.2% Nb₂O₅, 0.5% LREO, 0.15% HREO” (www.tanbreez.com/en/project-overview/resource-calculation; accessed 2015-01-11). Values for the grade distribution are La₂O₃: 0.116%; CeO₂: 0.217%; Pr₆O₁₁: 0.021%; Nd₂O₃: 0.08%; Sm₂O₃: 0.015%; Eu₂O₃: 0.002%; Gd₂O₃: 0.017%; Tb₄O₇: 0.003%; Dy₂O₃: 0.019%; Ho₂O₃: 0.004%; Er₂O₃: 0.016%; Tm₂O₃: 0.002%; Yb₂O₃: 0.013%; Lu₂O₃: 0.002%; Y₂O₃: 0.127% (TMR 2015).

A portion of the total resource in the lower part of the sequence is considered as a measured reserve sufficient for a 10 year mining operation (personal communication from Greg Barnes, Sept. 2014). In addition to the kakortokite target, Tanbreez Mining Greenland A/S is working on several other potential REE-targets within the two licences.

Tanbreez Mining Greenland A/S has submitted the application for an exploitation licence in March 2012, including EIA, SIA, and FS. A revised version of the Social Impact Assessment report was submitted in 2013. Currently, the application is being processed by the Greenlandic authorities. The proposed mining project involves an open pit mine near the fjord, and an adjacent mineral separation plant, mainly based on magnetic separation circuits. The project also involves port facilities, storage facilities, tailings deposit, and mine camp.

For the processing, three types of products are considered: (1) eudialyte concentrate (REE, Nb, Zr) (100,000 tpa); (2) feldspar concentrate (200,000 tpa), and (3) arfvedsonite concentrate, all to be shipped for further processing outside of Greenland. The planned mill throughput is 500,000 tpa equal to about 3,250 tonnes TREO (including 400 tpa Nd_2O_3 and c. 90 tpa Dy_2O_3) and 9,000 tpa Zr_2O_5 (company presentation at European Rare Earth Resources Conference, Milos, 2014).

6.1.3 Motzfeldt Nb-Ta-REE project

The Motzfeldt Sø REE deposit, located c. 25 km east of the international airport Narsarsuaq, is part of the Motzfeldt Alkaline Centre. This is one of the intrusions of the Igaliko Nepheline Syenite Complex in the eastern part of the Gardar Province. The Motzfeldt mineralisation was discovered in the early 1980's by the Syduran project and at that time was mainly considered for its potential as a Nb-Ta resource. The main ore mineral is pyrochlore which is associated with syenite and minor pegmatite and diorite dykes (Tukiainen *et al.* 1984). Various exploration groups have been active in the area, including Angus & Ross Plc., RAM Resources, and recently Regency Mines Plc.

The exploration target has been extended to include the REE, in addition to Nb and Ta and, since 2010, a number of prospects have been investigated (e.g. Aries, Voskop, Drysdale, Merino, Romney, Rams Head, Swaldale, Black Ram, and Dorpe) and can be seen in Figure 16. The ore minerals include pyrochlore, columbite, bastnäsite, monazite, zircon, thorite as well as unidentified REE, Zr, Nb-Ta, U-Th minerals. Since only a portion of the known mineralised system has been tested by drilling it is likely that there is significant exploration potential.

At the Aries prospect, an exploration potential of 200–500 Mt grading 1,800–2,200 ppm Nb_2O_5 , 130–160 ppm Ta_2O_5 , and TREO grading 3,000–5,000 ppm was identified by RAM resources (RAM 2010). Subsequently, the prospect was drilled and two mineralised zones have been defined: (1) altered syenite enriched in Ta-Nb and some REE; and (2) pegmatites enriched in REE with lower Ta-Nb contents. As a result of a drilling program, an inferred maiden mineral resource has been subsequently presented with 340 Mt grading 0.26% TREO, 0.46% ZrO_2 , 1,850 ppm Nb_2O_5 , and 340 ppm Ta_2O_5 (RAM Resources 2012). Furthermore, typical assay results from the Aries prospect are reported to contain the following relative proportions of REE: Ce: 41%; La: 22%; Nd: 14%; Pr: 4%; Other LREO: 3%; Gd: 2%; Dy: 2%; Y: 10% and other HREO 2% (RAM Resources 2010).

Exploration results from other prospects within the Motzfeldt Alkaline Centre can be summarized as follows. The Voskop prospect is underlain by altered syenite and peralkaline microsyenite intruded into the Geologfjeld Formation and best results reported are 8,550 ppm TREO, 3,288 ppm Nb₂O₅, 182 ppm Ta₂O₅, and c. 4% ZrO₂. At Drysdale, the heavily altered and mineralised microsyenite is radiometrically anomalous and shows elevated concentrations of Nb, Ta, Zr, and REE (1.42% Nb₂O₅; 210 ppm Ta₂O₅; 2% ZrO₂ and 1.08 % TREO). Swaldale is situated within the altered syenite of the Motzfeldt SØ Formation and high grades of Nb and Ta have been reported (Tukiainen *et al.* 1984). The Black Ram prospect is dominated by syenites and radiometric and geochemical anomalies were observed by GEUS.

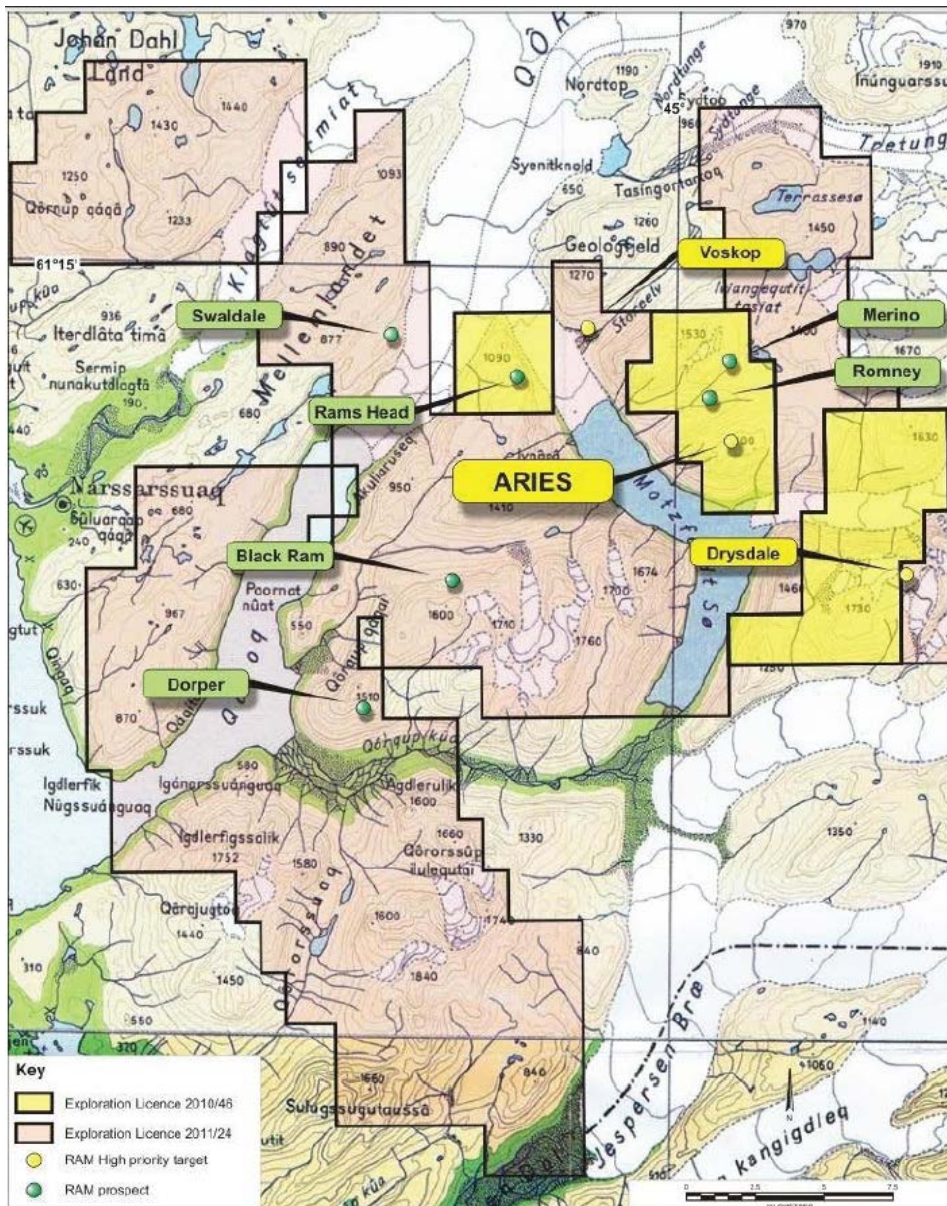


Figure 16. The Motzfeldt licence areas and main exploration targets. A statement for an inferred resource at the Aries prospect (near Motzfeldt SØ) was presented by RAM Resources in 2012. Figure from RAM Resources (2012).

6.1.4 The Sarfartoq LREE project

The Sarfartoq area (exploration licence 2010/40, Hudson Resources Inc.) is located c. 200 km north of Nuuk and 60 km from the international airport of Kangerlussuaq. Here, carbonatites (560 Ma) intruded into Archaean basement at the boundary between the approximately 3 Ga Meso-Archaean North Atlantic Craton (Garde *et al.* 2000) and Archaean rocks affected by the 1.9–1.8 Ga Palaeoproterozoic Nagssugtoqidian Orogen (Willigers *et al.* 2002).

Previous exploration efforts in the 1980's and 1990's by Hecla Mining and New Millennium Resources NL concentrated on a small but high grade Nb resource (hosted in pyrochlore), which is located near the core of the intrusion. Since Hudson Resources Inc. acquired the exploration licence in 2009 there has been an exploration focus on REE occurrences that are arranged along the outer rim of the carbonatite complex forming a circular array with c. 13 km diameter. Field work and drilling demonstrated the high potential for REE mineralisation in this setting.

For one of these prospects, ST1, a NI 43-101 resource estimate was presented by Hudson Resources Inc. which consists of 5.9 Mt indicated resource at 1.8% TREO and 2.5 M tonnes inferred resource at 1.6% TREO (1% cut-off, Hudson Resources 2013; Druecker & Simpson 2012). The resource is LREE dominated with high proportions of Nd and Pr (25% of TREO); see Table 2 and Table 4.

The PEA (Preliminary Economic Assessment) indicates capital costs (CAPEX) of 343 million US\$ for a 2,000 tonnes per day open pit operation and processing facilities (Hudson Resources 2011). An annual production of 6,500 tonnes rare earth carbonate concentrate is envisaged at an operation cost (OPEX) of 105 US\$ per tonne. The proposed metallurgical flow sheet includes bastnäsite and monazite flotation, leaching, acid bake solvent extraction, and precipitation to produce a 42–45% REO carbonate product. A metallurgical test program, including acid baking and leach tests, returned 94% recovery rates for the rare earths. An application for an exploitation licence has not been submitted yet.

Table 4. Resource estimate for ST1 prospect in the Sarfartoq carbonatite (Hudson Resources Inc. 2013).

Re-source	COG	Mt	TREO	La ₂ O ₃	Ce ₂ O ₃	Pr ₂ O ₃	Nd ₂ O ₃	Sm ₂ O ₃	Eu ₂ O ₃	Gd ₂ O ₃	Tb ₂ O ₃	Dy ₂ O ₃	Y ₂ O ₃
	TREO (%)		%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Indicated	1.00	5.88	1.77	3,855	8,844	1,012	3,296	321	71	181	14	34	68
Inferred	1.00	2.46	1.59	3,343	7,930	932	3,073	310	69	162	13	33	67

COG = cut-off grade.

6.2 Scenarios for the Greenlandic contribution to the REE market

The status of the advanced REE projects in Greenland is summarized in Table 5. Currently, there are two REE projects, namely Kvanefjeld and Kringlerne actively advancing in the permitting process towards an exploitation licence.

The timelines for the Kvanefjeld project involves application for an exploitation licence in the third quarter of 2015. Greenland Minerals and Energy Ltd. plans to commence construction at the end of 2016 and undertake the commissioning in 2018. Also, Tanbreez Mining Greenland A/S is in the process of negotiation with the authorities with regard to the exploitation licence for the Kringlerne project. This project might be able to initiate commissioning in 2017.

Table 5. Status overview for the advanced REE projects in Greenland.

Prospect name	Company	REE ore minerals	Resource estimate	PEA	PFS	BFS	Exploitation licence application	Capex MUS\$	OPEX US\$	TREO tpa	Start of opera.
Kvanefjeld	GME	steenstrupine lovozerite	JORC - indicated	Y	Y	N	expected for 2015	1,450	3.07	23,000	2018
Kringlerne	Tanbreez	eudialyte	"inferred"	Y	Y	?	submitted	?	?	3,250	2017
Sarfartoq	Hudson Resources Inc.	bastnäsité, monazite	NI 43-1010 indicated	Y	Y	N	no schedule	343	0.11*	6,500*	n.a.
Motzfeldt	Regency Mines Plc	pyrochlore, eudialyte and others	"maiden resource"	N	N	N	no schedule	n.a.	n.a.	n.a.	n.a.

CAPEX: base capital costs in million US\$; OPEX: US\$ per kilo TREO per year. PEA: Preliminary Economic Assessment; PFS: Preliminary Feasibility Study; BFS: Bankable Feasibility Study. *: OPEX for the production of 6,500 tpa carbonate concentrate. Tanbreez: Tanbreez Mining Greenland A/S; GME: Greenland Minerals and Energy Pty. Ltd.

Greenland Minerals and Energy Pty. Ltd. are planning an annual TREO production in the order of 23,000 tonnes of which 16,000 tonnes are La and Ce products. On the basis of the grade figures (Table 2), the ratio between the individual REO can be calculated, and hence the annual production for the remaining REO-products are estimated, these can be seen in Table 6.

Tanbreez Mining Greenland A/S has not published the timing for their operation at Kringlerne nor has it made public any estimated production figures. However, based on the announced annual mined ore tonnage, the yield of this ore is estimated (Table 6). However, considering that the recovery rate is not known, actual figures are expected to be lower.

Table 6. Estimates for projected REO production (tpa) 2018 from Kvanefjeld and Kringlerne; figures are indicative only.

Project	La ₂ O ₃	CeO ₂	Pr ₆ O ₁₁	Nd ₂ O ₃	Sm ₂ O ₃	Gd ₂ O ₃	Dy ₂ O ₃	Er ₂ O ₃	Yb ₂ O ₃	Y ₂ O ₃
	tpa	tpa	tpa	tpa	tpa	tpa	tpa	tpa	tpa	tpa
Kvanefjeld	6,000	10,000	800	2,800	400	190	190	190		1,590
Kringlerne	600	1,100	100	400	100	100	100	100	50	650
Total	6,600	11,100	900	3,200	500	290	290	290	50	2,240

7 The legislation for the mineral industry in Greenland

In the following some relevant information related to the licensing and permitting procedures for the mining industry in Greenland are summarized. It should be noted that more detailed information is published on the relevant internet portal of the Government of Greenland (www.govmin.gl) which is continuously up-dated.

The main principles for the administration of mineral resource activities are laid out in the Greenland Parliament Act no. 7 of December 7, 2009, on Mineral Resources and Mineral Resource Activities (the Mineral Resources Act). This was a result of the increased autonomy under the Act on Greenland Self-Government from June 21, 2009 when the Danish/Greenlandic relations regarding mineral resource activities in Greenland changed and the Government of Greenland took over the responsibility for the mineral resources. The latest changes to these rules and regulations have been enacted in 2014.

Following the recent amendment to the Mineral Resources Act there are now three main authorities involved with the legal foundation and regulations for minerals and hydrocarbons in Greenland. These are the Mineral Licence and Safety Authority (MLSA), the Ministry of Mineral Resources (MMR), and the Environment Agency for the Mineral Resources Activities (EAMRA).

The MLSA is the one-door authority. Licensees and other parties covered by the Mineral Resources Act communicate with the MLSA and receive all notifications, documents, and decisions from the MLSA. It is the overall administrative authority for licences and mineral resource activities, and is the authority for safety matters including supervision and inspections.

The MMR is responsible for the overall strategy concerning mineral and energy resources, policies on the same subjects, legal issues, marketing of mineral and energy resources in Greenland, and socio-economic issues related to mineral and energy resource activities, such as SIA, IBA, and royalty schemes.

The EAMRA is the administrative authority for environmental matters relating to mineral resources activities, including protecting the environment and nature, environmental liability and EIA. The EAMRA is an agency under the Ministry of Nature, Environment and Justice.

7.1 Licensing and permitting procedures

7.1.1 Mineral exploration licences

Applications for mineral exploration licenses are submitted to the MLSA and handled according to the procedures defined in the Mineral Resource Act. (www.govmin.gl/minerals/terms-rules-laws-guidelines). In general, one licence area may consist of up to 5 subareas, but the distance between any two subareas must not exceed

100 km. Licences are granted for a period of 5 years with the option for renewal. The licensee is obligated to commit yearly exploration expenses regarding the licence area. These minimum exploration expenses are calculated for each particular exploration licence as the sum of the following two components: a) An amount per licence per calendar year as follows: Years 1–2: 100,000 DKK, Years 3–5: 200,000 DKK, Years 6–10: 400,000 DKK, and b) An amount per km² per calendar year as follows: Years 1–2: 1,000 DKK per km², Years 3–5: 5,000 DKK per km², Years 6–10: 10,000 DKK per km².

In 2014, the Government of Greenland introduced a new “open door” licensing procedure for mineral exploration licences for the onshore areas north of 81°N. Predefined licence areas in the so-called “81° North Open Door Licence area” are offered on special terms and exploration licences can be valid for 13 years.

In addition to traditional licences a small-scale licence can be granted to citizens living in Greenland. Claims of up to 1 km² can be held by individuals and activities are subject to certain restrictions. This licence type is typically granted to private collectors of gemstones.

7.1.2 Mineral exploitation licences

The permitting process for an exploitation licence required for the initiation of mining activities, involves the submission of an EIA and a SIA. Both assessments require baseline studies, consultations with stakeholders with a strong emphasis on public hearings and reviews by the authorities. The final outcome of this multi-stage process is the Impact Benefit Agreement (IBA) which forms the basis of the mining permit. The relevant rules and regulations are outlined on: www.govmin.gl/minerals/terms-rules-laws-guidelines.

An EIA must be prepared when a company plans to exploit a mineral deposit following the routines described in the guidelines (Bureau of Minerals and Petroleum 2011). The EIA must cover the entire exploitation period from mine development prior to the mine start until closure of the mine including a subsequent monitoring period. A diagram showing this process can be seen in Figure 17. Environmental studies must be able to predict impacts from the specific mining project and describe baseline conditions before areas are affected by construction and operations. Studies must cover a period of some years before construction starts, so that the annual and seasonal variations of environmental parameters are taken into account in the baseline description. The number of years needed to conduct the environmental studies will depend on the project and the site. Often 2–3 years of studies are needed in advance of the EIA report preparation.

Recommendations for the SIA process have been prepared after completion of a public hearing process (Ministry of Industry, Labour and Trade 2014). The aim was to incorporate the relevant experiences from the approvals of several mining projects since the Government of Greenland assumed full control over mineral resources in 2009. One important change is that this new report attaches great emphasis on process and preconditions for a good SIA process, whereas the former SIA guidelines from 2009 had a strong focus on the content of the SIA report.

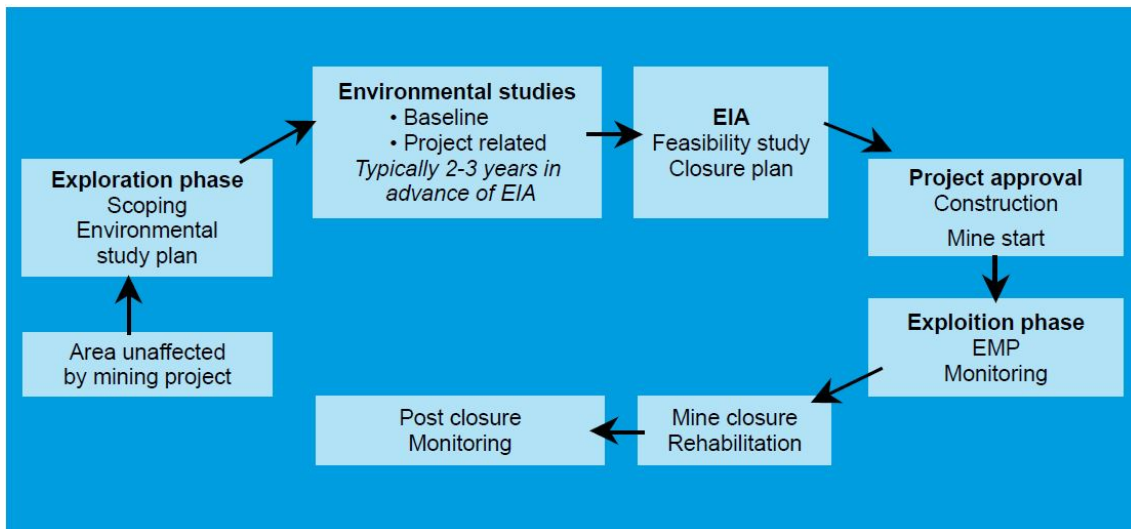


Figure 17. *The Environmental Impact Assessment (EIA) and its relationship to the planning and execution of a mining project. EMP: Environmental Management Plan (Bureau of Minerals and Petroleum 2011).*

The overall process that leads to the IBA is built around two stages of public consultation and hearing phases; see Figure 18. Based on a description of the project and the baseline data collected during the scoping study phase a period of public consultations and hearings is initiated. Based on these results a “Terms of Reference” document is prepared which represents the basis for the preparation of draft SIA and EIA reports. These are submitted together with the formal application for an exploitation licence. Following a second round of public consultations and hearings a “White Paper” is drafted which represents the basis for the negotiations of an IBA. When the SIA and the EIA are finalized and the IBA agreed upon, the project receives political approval and the exploitation license is issued.

In addition, the revised guidelines also take into account the “Large-Scale Projects Act”. The Large-Scale Projects Act relates only to the construction phase of mines, hydropower plants, infrastructure, etc., not the actual operations of such projects. The act is important legislation for supporting the construction of a large scale mining project and allows companies to use labour resources not subject to the collective agreements normally applicable in Greenland. However, wage and employment terms must be acceptable and objectively justifiable or subject to a foreign collective agreement. The hourly wage must as a minimum match the basic wage required under collective agreements in Greenland. This option is only open to so-called large-scale projects proposing to establish infrastructure costing a minimum of 5 billion DKK.

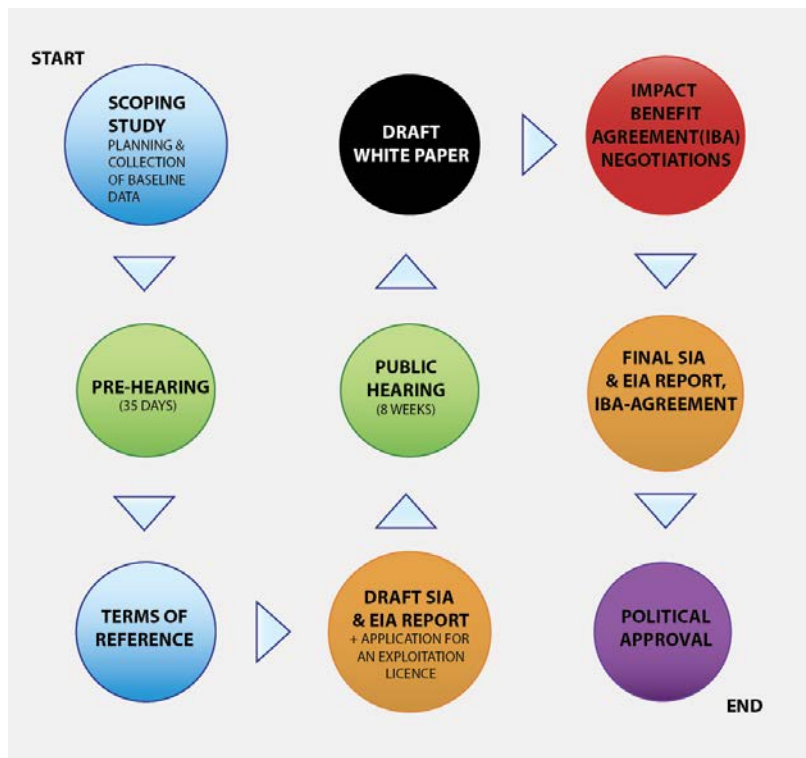


Figure 18. *The permitting process for a mining project in Greenland is based on SIA and EIA reports and two-stages of public hearing and consultation. Modified from Ministry of Industry, Labour and Trade (2014).*

7.2 Taxation model for mineral resources

The taxation model for mineral resources is published in Greenland's Oil and Mineral Strategy 2014-2018, February 2014. The taxation model for the mineral resources is based on the following principles:

- All metals and minerals except uranium, REE, and gemstones: Corporate or withholding tax at the applicable rate. In addition, a 2.5% royalty on turnover will be introduced and the corporate withholding tax will be deductible against the calculated royalty.
- Rare Earth Elements: Corporate or withholding tax at the applicable rate. In addition, a 5% royalty on turnover will be introduced and the corporate or withholding tax will be deductible against the calculated royalty.
- Uranium: Corporate or withholding tax at the applicable rate. In addition, a 5% royalty on turnover will be introduced.
- Gemstones: Corporate or withholding tax at the applicable rate. In addition, a 5.5% royalty on turnover will be introduced, as will a 15% surplus royalty based on gross profits in excess of 40%.

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Appendix A

Table A. List of the individual tracts that were evaluated during the REE resource potential assessment (Sørensen et al. 2011). Scores are from 50 (excellent) to 0 (poor).

Tract name	Location	Deposit model	Known deposits and settings	REE potential	Score
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 have 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 investigated much. Not much drilling – only Ta, Nb and U targets have been drilled. More work is needed to evaluate the REE potential.	Good - Excellent potential 1 prospect = 9 + 9 Element setting = 6 District setting = 7	31
A3.1	Qassiarssuk (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 is in question.	Weak - Moderate potential Element setting = 3 District setting = 5	8
A6	Kap Gustav Holm	Alkaline	Nephilinitic Syenite type intrusion. Lack of information from the area.	Weak potential Element setting = 1 District setting = 3	4
A7	Kangerlussuaq	Alkaline	Largest syenite intrusion in Greenland. Outer shell with quartz-syenite, Inner shell with Syenite, core with nephelinitic syenite. Veins with REE's. Extensive hydrothermal alteration (includes Flammefjeld). Several satellite intrusions. In general, syenitic intrusions in Greenland needs more weathering to further concentrate the REE's	Weak - Moderate potential Element setting = 2 District setting = 4	6
A8	Borgtinderne	Alkaline	Syenite intrusion intruded into basalts. 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 (are grouped with A12)	Kap Wardlaw	Not alkaline (were assessed as "other" category)	Roof zone of a granite intrusion. A-type? Slightly enriched in U & Th. Extensive fluorite enrichment. No showings. Similar settings as A12.	Weak potential Element setting = 2 District setting = 1	3
A11	Werner Bjerger	Alkaline	No showings. Two deep seated faults = active pathways. Th mineralisations in veins. Nb & REE mineralised rocks. Werner Bjerger 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	Moderate - Good potential	19

Tract name	Location	Deposit model	Known deposits and settings	REE potential	Score
			samples enriched in REE's (3%) & Nb (3.2%). Malmberg type alteration (high temp alt) seen via hyperspectral mapping. Several sources of mineralised rocks seen from glaciers.	1 showing = 9 Element setting = 5 District setting = 5	
A12 (are grouped with A10)	Kap Franklin (Hudson Land)	Not alkaline (were assessed as "other" category)	Devon 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 located in the border zone.	Low potential	Not assessed
A14	Ubekendt Island	Alkaline	Micro Syenite (Paleogene) Hydrothermal alteration, REE anomalies. The island is very inaccessible. 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 have been conducted in the area.	Weak - Moderate potential Element setting = 2 District setting = 5	7
A17	Ivittuut 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
C1	Ataa Sund	Carbonatite	Ultramafic lamprophyric 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 has been intruded in the region = highly 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. Terrain boundary in the area. Active pathways.	Excellent potential 1 undiscovered deposit = 9 + 9 + 9 Element setting = 7 District setting = 7	41
C3.2	Qaqarssuk (Qeqertaasaq)	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	Tikiussaqa	Carbonatite	1 known carbonatite showing. Lamprophyres are found in the area. Possible terrain 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 Tikiussaqa 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 lamprophyric 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	Carbonatite	No known carbonatite	Weak potential	3

Tract name	Location	Deposit model	Known deposits and settings	REE potential	Score
	(Kvanefjord), SW Greenland		deposits. Lamprophyres/ Kimberlites (Ailikites) are found in the area. Major structures running through the area associated with dolerite dykes of Paleoproterozoic age.	Element setting = 1 District setting = 2	
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
C8	Grønnedal-Ika, South Greenland	Carbonatite	1 known carbonatite showing (The Ika carbonatite). Elevated REE stream sediments. The carbonate is elevated in Ce. No evidence of 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. Radiactive dykes (Ce enriched) are present in the area – radiates from the 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 possibility for undiscovered showing	Moderate – Good potential Element setting = 5 District setting = 7	12
C9.1	Qassiarssuk	Carbonatite	There is som uncertainty whether if 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 are found just west of the area. Rift Environment = active pathways. No showings.	Moderate – Good potential Element setting = 5 District setting = 7	12
C9.2	Igdlerfigsalik 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	Timiarmit	Carbonatite	Carbonate bearing dykes are found in the area. Elevated REE in stream sediments. Are located on the boundary to the Ketilidian. Limited amount of work have been conducted in the area.	Moderate potential Element setting = 4 District setting = 5	9
C11.1	Singertat	Carbonatite	Carbonatite rocks are found in the area. Elevated REE in stream sediments and grab samples. Fenitisation are seen. Major structures. Limited amount of work have been conducted in the area.	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 have been conducted in the area.	Moderate potential Element setting = 3 District setting = 5	8
C12	Kap Gustav Holm	Carbonatite	Carbonate bearing dykes are	Moderate potential	4

Tract name	Location	Deposit model	Known deposits and settings	REE potential	Score
			known. The Kap Gustav Holm nefellinitic complex are located within the tract. Coast parallel structures = Possible pathways.	Element setting = 1 District setting = 3	
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



MiMa Report 2015/2

Rare Earth Element (REE) exploration potential and projects in Greenland

A substantial increase in global exploration for Rare Earth Element (REE) deposits has taken place in recent years and resulted in considerable advances in defining new resources globally. A large portion of these are located in Greenland, where reported total rare earth oxides resources hosted by advanced projects reached 38.5 Mt in 2015. This is due to substantial exploration efforts that build on geological knowledge accumulated over decades of investigations by research organisations and private exploration groups.

This report aims to provide an overview of the exploration potential in Greenland using ore deposit models to structure the description of the currently known REE districts. The potential for future discoveries is highlighted based on the results of an assessment workshop that focused on the characterization of the Greenlandic REE endowment. There is particularly good potential for future discoveries of alkaline intrusion-hosted and carbonatite-hosted REE deposits in Central East Greenland, South-East Greenland and in South Greenland.

The report also provides an overview of the ongoing REE projects. The status of the REE exploration in Greenland is presented in some detail, and describes the activities and licence claims of exploration companies at the time of writing (spring 2015). At this point, there are eight companies holding a total of 3,186 km² of licence areas for REE exploration. Four projects have published a resource statement. For the two major REE projects (Kvanefjeld and Kringlerne, Gardar Province, South Greenland) an annual Greenlandic REE production of 26,000 tonnes TREO from around 2018 is tentatively forecasted by the exploration groups. Currently, both projects are in the permitting process towards an exploitation licence.

Center for Minerals and Materials (MiMa) is an advisory center under The Geological Survey of Denmark and Greenland (GEUS).

MiMa imparts knowledge on mineral resources, mineral occurrences, their circuit and influence on society.