

The rare earth element potential in Greenland

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Supply of rare earth elements (REE) is complex. REE deposits are geographically unevenly distributed and the content of individual REEs varies from deposit to deposit; some deposits only containing a few of the REEs in demand. Greenland is endowed with several large REE deposits, related to various geological settings. Several projects have reached advanced stages of exploration. Additionally, Greenland also holds geological terrains favourable for hosting undiscovered REE deposits, as concluded in a recent REE workshop.

Introduction

Demand for REE is growing rapidly due to innovation in the so-called 'green technologies', electronic devices, defence systems and petroleum refining catalysts. The global requirement for REEs in 2010 was 134,000 t, with global production around 124,000 t. The difference was covered by utilising previously mined reserves. Global

demand is projected to rise to 180,000 t annually by 2012, and for neodymium, dysprosium, europium, terbium and yttrium in particular, forecasts show that supplies will become critical. In response to this rising global demand, Greenland has experienced a strong international interest over the past decade in search of new REE deposits. The fact that Greenland is endowed with geological environments favourable to hosting REE accumulation makes Greenland attractive to the REE exploration industry.

On this background the Geological Survey of Denmark and Greenland (GEUS) and the Greenland Bureau of Minerals and Petroleum (BMP), conducted a REE potential workshop in 2010 to provide the REE mineral exploration sector with the scientific background and necessary data to make qualified decisions. This magazine highlights some of the results from this workshop.

Highlights from the REE potential assessment workshop

A total of thirty-five areas were assessed by an expert panel during the REE workshop.

Information compiled on known REE deposits and geological provinces in Greenland, as well as compilations of geochemical stream sediment data were treated in conjunction with models for REE deposits in order to assess the potential for REE deposits in Greenland.

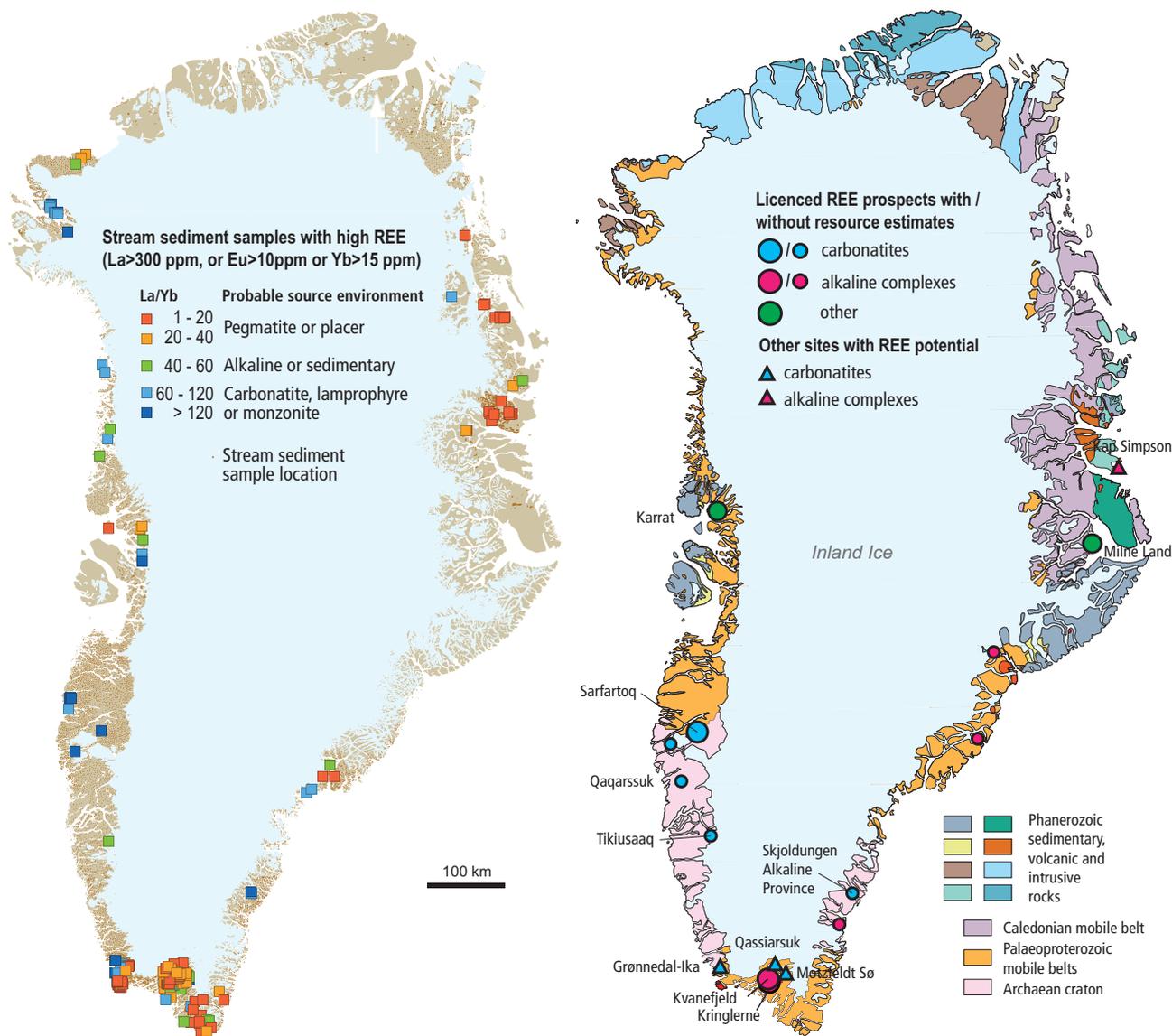
An overview of the REE distribution based on geochemical information from available stream sediment data is demonstrated by the compilation map of stream sediments.

The REE workshop assessed the following REE-prone geological environments:

- **Carbonatite magmatism**
REE accumulations are observed associated with carbonatite complexes. In Greenland the accumulation is often related to late hydrothermal activity,



View of the Kringlerne multi-element deposit with the characteristic mountain Redekammen in the background. Photo: Bureau of Minerals and Petroleum.



Left figure: Plot of REE-anomalous stream sediment samples in Greenland reflecting the presence of known and unknown REE mineralisation or very REE-enriched rocks. Symbol colour scale illustrates the variation in La/Yb ratio of the anomalies. Since fractionation among light and heavy REE shows considerable and characteristic variation among diverse REE-rich lithologies, and since these characteristics are reflected in the stream sediments, the La/Yb ratio can be used to indicate the probable source lithology of a stream sediment anomaly. Right figure: Simplified geological map with selected known REE prospects and other sites with REE potential.

where pathways in shear zones and joints play an important role.

• **Alkaline intrusions**

REE accumulations are typical during igneous processes in layered intrusions of strongly differentiated magmas with or without hydrothermal overprints.

• **Pegmatite settings**

In simple pegmatites related to granites, the minerals allanite and monazite are commonly enriched in light REEs, whereas a whole range of rare REE minerals occurs in alkaline pegmatites.

• **IOCG mineralising systems**

REE accumulations are typical in mineralising systems with low Ti - contents and where there are extensive Na and K - alterations, combined with increased contents of Co, Ag, U, Cu and P in coeval magmatism.

• **Paleoplacer environments**

Placer deposits are a result of secondary accumulation of heavy minerals, often REE bearing minerals like monazite and xenotime.

The individual tracts assessed during the workshop are shown on page 7.

The potential areas outlined in the southern, eastern and southwestern part of Greenland are due to the presence of the Gardar intrusives, carbonatites and alkaline intrusions. In North Greenland, however, only a few areas were defined, due to the extensive carbonate platform and sedimentary basins hiding possible REE deposits.

A list of the 10 REE occurrences with the highest assessment score from the workshop assessment is given in table 1.

Tract name	Location	Deposit model	Geological settings	Deposit size & grade*	Score
A1	Kvanefjeld	Alkaline	Known deposit. High level of information. Extensive drilling has been conducted on the deposit. Contains uranium above background level.	619 Mt (6.6 Mt TREO including 0.24 Mt heavy REO, 0.53 Mt Y ₂ O ₃ + 350 Mlbs U ₃ O ₈ and 1.4 Mt Zn).	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.	1,000 Mt @ 2% ZrO ₂ , 0.25% Nb ₂ O ₅ , 0.5% REO, 0.1% Y ₂ O ₃ and 0.025% Ta ₂ O ₅ .	50
C3.1	Sarfartoq	Carbonatite	Known carbonatite showing. Kimberlites & terraine boundary in the area = active pathways.	14 Mt @ 1.53% TREO.	41
O3	Karrat	Other	The REE prospect have been drilled which classifies it as an undiscovered deposit. Lamprophyric dykes are found in the area = active pathways. The deposition model is not yet fully understood – more work required.	26 Mt @ 1.36% TREO + Y.	35
C3.2	Qaqarsuk	Carbonatite	Known carbonatite showing. Lamprophyres are found in the area = active pathways.	REE resource is currently beeing investigated.	32
A3	Motzfeldt Sø	Alkaline	Known REE prospect. Micro syenites (which host the REEs) not much investigated. Limited drilling – only Ta, Nb and U targets drilled. More work is needed to evaluate the REE potential.	REE resource is currently beeing investigated. Historical data: 600 Mt @120 ppm Ta + 130 Mt grading 0.4 - 1.0% Nb ₂ O ₅ .	31
A3.1	Qassarsuk	Alkaline	Dyke with aegirine as prime mineral. The dyke is up to 4 m thick and can be followed for several kilometres. High Th content.	Unknown. Showings of REE known - up to 1%.	22
C4	Tikusaaq	Carbonatite	Known carbonatite showing. Lamprophyres and possible terraine boundary in the area = active pathways.	REE resource is currently beeing investigated.	21
A11.1	Kap Simpson	Alkaline	Alkali syenite complex. Malmbjerg type alteration (high temp) seen via hyperspectral mapping. Several sources of mineralised rocks sampled from glaciers.	Unknown. Rock samples enriched in REEs (3%) & Nb (3.2%).	19
C8.1	Overall tract around the Grønnedal-Ika carbonatite.	Carbonatite	Known showing. Lamprophyres and ailikites are found in the area. Greisen alteration at Ivittuut. Radioactive dykes (Ce enriched) are present in the area – radiates from the Grønnedal-Ika carbonatite.	Unknown.	19

Table 1. List of the 10 REE occurrences with the highest scores from the workshop assessment. Maximum score is 50. Tract name refers to the areas shown on map on page 7.

* Deposit size and grade numbers are based on company announcements and available online data as of September 2011. For specific and updated information please refer to the company websites of the individual deposits.

Known REE deposits

Eight REE deposits have been discovered up to now in Greenland, of which two may well be amongst the 10 largest REE deposits in the world. The geological settings for these REE deposits vary, and the ages cover a wide span. A brief introduction to these known deposits follows.

The Gardar province hosts three large REE deposits: Kvanefjeld, Kringlerne and Motzfeldt Sø

The Meso-proterozoic Gardar province in South Greenland is designated as a cra-

tonic rift province consisting of sandstones, and a variety of volcanic and plutonic igneous rocks. The plutonic rocks are alkaline to peralkaline and are hosted within the Ilímaussaq intrusion (1160 Ma). The Ilímaussaq intrusion is largely implaced by block subsidence and formed by three pulses, of which the third formed a layered series of nepheline syenites. The Ilímaussaq intrusion is generally enriched in the elements U, Th, Nb, Ta, Be, Zr, Li, F, Zn and REE, and hosts two REE deposits e.g. Kringlerne (dominated by the kakortokite bottom cumulates) and Kvanefjeld (dominated by lujavrites). The Gardar

province also includes the Igaliko Nepheline Syenite Complex, hosting the Motzfeldt Sø REE deposit.

Kvanefjeld

The Kvanefjeld multi-element deposit, located a few kilometers north of Narsaq, South Greenland, is an accumulation of various igneous rocks and supracrustals from the roof of the Ilímaussaq intrusion. Additionally rocks from the early phases of the alkaline intrusion are also included, forming blocks and sheets within the later agpaite magma. The bulk of the REE (as well as U and Th) is associated with the



View of the Narsaq Valley, Kvanefjeld and gravel road to the former test mine.
Photo: Greenland Minerals and Energy A/S.

lujavrite rocks hosting disseminated steenstrupine, which is the primary mineral host of both REEs, U and Th. The deposit also contains zinc, occurring mainly as disseminated sphalerite in the lujavrite, and fluorine hosted in the mineral villiaumite (NaF). The Kvanefjeld deposit has previously been explored for the potential of U and Th.

The Kvanefjeld REE deposit is dominated by Ce (approx. 40%), La (approx. 25%), Nd (approx. 15%), Y (approx. 10%), Pr (approx. 5%) and the remaining HREE accounts for about 5%.

Greenland Minerals and Energy A/S has reported the following resource estimate figures (based on 150 ppm U_3O_8 cut-off):

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

TREO, 404 ppm U_3O_8 (0.05% heavy REO, 0.12% Y_2O_3)

Kringlerne

The multi-element deposit at Kringlerne is hosted in the lower cumulates of the layered agpaitic nepheline syenites, referred to as kakortokite, and is situated near the

townships of Narsaq and Qaqortoq in South Greenland. The kakortokite cumulates form a total of 29 cyclic, and regular layers, with a total thickness of about 200 m, made by units composed of black syenite (arfvedsonite dominated), reddish syenite (eudialyte dominated) and whitish syenite (feldspar dominated) rocks. The



The characteristic layering of the Karkortokite at the Kringlerne multi-element deposit. Note the campsite in the lower left part of the image as scale. Photo: TANBREEZ Mining Greenland A/S.



Drill core logging at the Motzfeldt Sø camp in 2011. Photo: Ram Resources Ltd.

mineral eudialyte (Greek for 'easily dissolved') is enriched in Ta-Nb-REE-Zr-Y and this is the main exploration target for REE by the licensee, Rimbal Pty Ltd. The kakortokites have been investigated for decades focusing in particular on Zr, Y, Nb, and REE.

Current work by Rimbal Pty Ltd indicates a resource of no less than 1,000 Mt grading 2% ZrO_2 , 0.25% Nb_2O_5 , 0.5% REO, 0.1% Y_2O_3 and 0.025% Ta_2O_5 . The distribution of light and heavy REEs in eudialyte is reported to be 88% and 12% respectively.

Motzfeldt Sø

The Motzfeldt Sø REE deposit is part of the Motzfeldt Centre, which in turn is part of the Igaliko Nepheline Syenite Complex. Pyrochlore accumulations in the Motzfeldt Sø syenite show significant grades of Tantalum. The estimated resource based on investigations carried out by GEUS in

the 1980s is 600 Mt grading 120 ppm Ta. High grade zones carry up to 426 ppm Ta. Additionally an Nb resource of at least 130 Mt grading 0.4-1.0% Nb_2O_5 is known. The deposit is regarded as a 'low grade-large tonnage' type of resource.

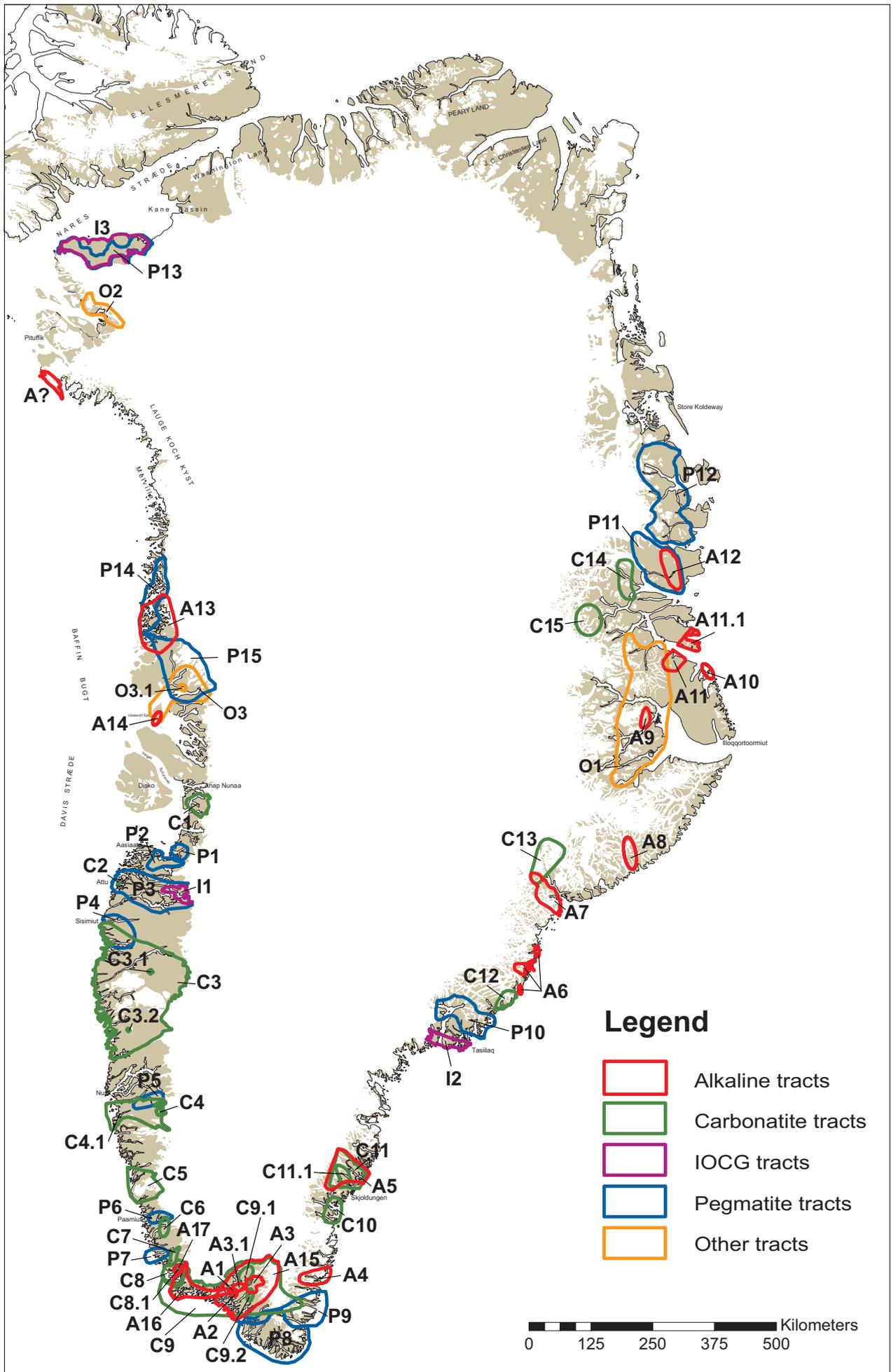
Ram Resources Ltd. is currently investigating the intrusion for REEs. The 2010 work indicates that the known Ta-Nb mineralisation is only weakly correlated with the REE mineralisation. In the central part of the intrusion, where the richest Ta-Nb mineralisation is found, the lithology is predominantly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

Sarfartoq

The Sarfartoq carbonatite complex (564 Ma) is well exposed, situated on the transition zone between the Archaean craton and the Palaeoproterozoic Nagsugtoqidian mobile belt. The host rocks are granodioritic gneisses. The complex was discovered by GGU in 1976 on the basis of a regional airborne radiometric survey and later fieldwork. Subsequently, the complex has been the target of various exploration campaigns focusing on diamonds, P, Nb and REE.

The central core zone of the complex is surrounded by a series of ring-like layers or dykes, containing innumerable intrusive

Map showing the areas (tracts) used for the REE potential assessment workshop, grouped according to the type of geological environment of relevance to REE deposits.

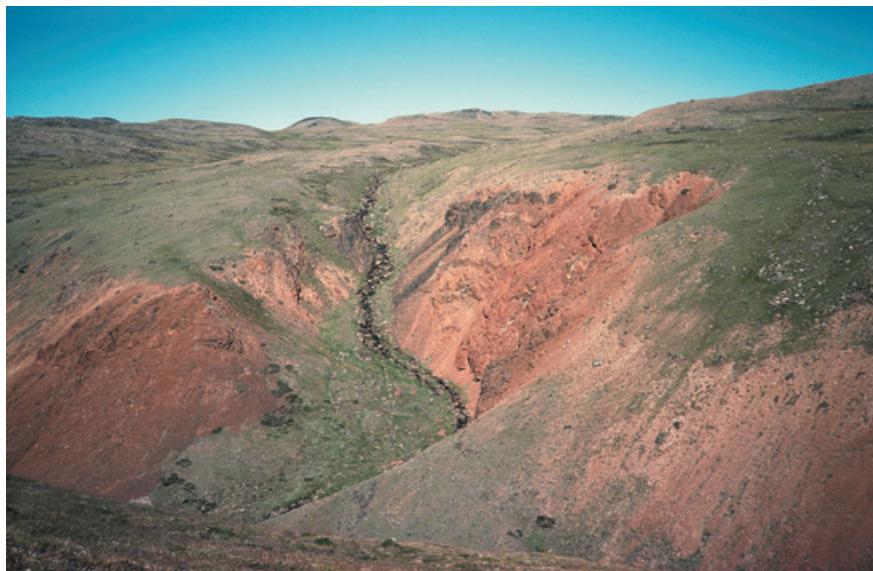


carbonate breccia veins. Substantial fenitisation occurs around the core. Mineralisation of Nb and REE has been recorded from separate zones in the outer fenitised zone. The REE minerals are correlated with thorium and are mainly bastnasite, synchysite and monazite.

In 2010 Hudson Resources reported an NI 43-101 compliant resources estimate result over the ST1 site in the northern part of the complex: 14 Mt inferred resources averaging 1.53% TREO at a cut-off grade of 0.8% TREO. The REE distribution is 45% Ce, 20% La, 25% Nd, 6% Pr, 2% Sm, and approx. 2% Gd, Dy and Y.

Qaqarsuk

The Qaqarsuk carbonatite complex (165 Ma), situated 60 km east of Maniitsoq, West Greenland, intruded the Archaean gneiss complex, along with kimberlite dykes and alkaline intrusions. The composition of the carbonatite varies from sövite to rauhaugite.



View towards the well exposed outcrop at the ST1 site, part of the Sarfartoq carbonatite complex. The slope is c. 200 m high.

Outcropping of vertical to subvertical, early stage carbonatite sheets of the Qaqarsuk carbonatite complex. Photo: NunaMinerals AIS.





Aerial view of the Tikiusaaq carbonatite complex with carbonatite sheets and fenites (yellowish areas) exposed in north walls of the gully. The extent of the gully is c. 1-1.5 km. Photo: NunaMinerals A/S.

In 2010 NunaMinerals A/S initiated REE exploration within the carbonatite. The main potential appears to lie in the core of the complex concealed in carbonate veins, and the company reports the average grade for a 1.5 km² area as 2.4% TREO, mainly hosted in ancylite (Sr-REE-carbonate); the mineralisation is LREE dominated with 50% Ce, 27% La, 16% Nd, and 5% Pr. The REE-mineralised veins are generally less than one metre thick.

Tikiusaaq

The Tikiusaaq carbonatite, discovered by GEUS in 2005 by using regional stream sediment data and regional airborne geophysical data, consists of massive dolomite-calcite carbonatite sheets intruded along a ductile shear zone at approximately 158 Ma. The carbonatite is later

intruded by carbonate-rich ultramafic silicate dykes. NunaMinerals A/S initiated exploration of the Tikiusaaq carbonatite in 2010, and focussed on the aeromagnetically defined 'carbonatite core'. REEs are typically enriched in the latest phases of carbonatite magmatism, and the main REE mineral is ancylite (Sr-REE carbonate). REE-enriched carbonatite surface samples containing up to 9.6% TREO (predominantly LREE), have been found in an area of anomalous thorium counts. The REE distribution is 47% Ce, 33% La, 12% Nd, 4% Pr and 4% other REEs. High phosphate grades (up to 8.5% P₂O₅) were returned from surface samples within the magnetic core of the carbonatite.

A recent interpretation of radiometric and magnetic data indicates a separate body about 750 m long and 100 m wide and

that the extension of the carbonatite dykes continues to a depth of at least 500 m.

The Niaqornakassak and Umiammakku Nunaa REE deposits

The Niaqornakassak (NIAQ) REE deposit in central West Greenland was discovered by Avannaa Resources Ltd. in 2007 and in 2009, an extension of the deposit was discovered on the Umiammakku Nunaa (UMIA) peninsula 7 km along strike from the NIAQ site. The two deposits are jointly named 'Karrat'.

Work conducted by Avannaa Resources Ltd. in 2010 on the NIAQ and UMIA deposits included diamond drilling and collecting 13 mini-bulk samples. The REE accumulation is hosted in an amphibolite unit of the Palaeoproterozoic Karrat Group. Strike length of NIAQ is 1.5 km but open

at both ends. The tabular NIAQ ore body has been found at a maximum elevation of 56 m above sea level and down to 168 m below sea level; the thickness varies between approx. 10 m and 33 m. The NIAQ bulk samples indicate an average of TREO of 1.36%, of which the average HREO content is approx. 13%. Preliminary resource estimates of the NIAQ body are 26 Mt. The REE are mainly hosted by bastnasite, monazite and allanite related to hydrothermal agents within the mineralised sequences. Very limited work has been undertaken on the UMIA body. Based on three drill holes the TREO of the UMIA deposit is in the range of 0.08 - 0.12%.

Milne Land REE deposit

The Mesozoic Milne Land paleoplacer was discovered in 1968 by Nordisk Mineselskab A/S in connection with a heavy minerals concentrate sampling programme and an airborne radiometric survey. The placer is in the basal part of the Charcot Bugt Formation, and the most anomalous locality, "Hill 800" in Bays Fjelde, is around 500 m in diameter and 40-50 m thick. The heavy minerals are hosted by a 20 m thick basal sandstone. The potential resources REE, Ti and Th are mainly hosted in monazite.

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

Conclusions

Based on the conclusions of the recently conducted workshop at GEUS, South Greenland is believed to have the largest potential for hosting new REE deposits,

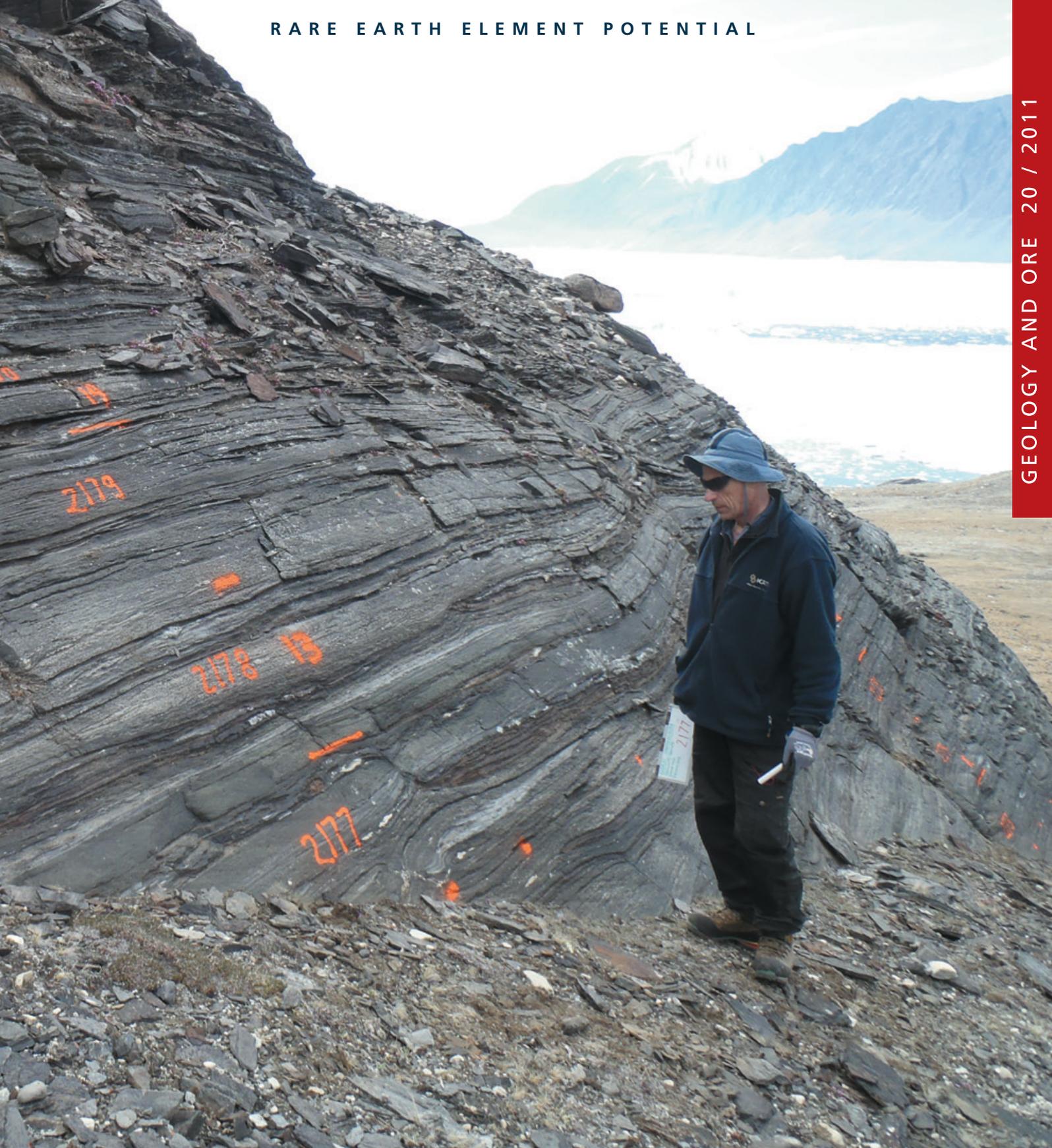


aside from of the known deposits at Kvanefjeld and Kringlerne. Among the more promising areas are around the Grønvedal-Ika carbonatite and the Qassiarsuk carbonatite.

West Greenland is highly prosperous for carbonatite related REE deposits.

Among the known deposits are Sarfartoq, Qaqarsuk and Tikiussa. Of these, Tikiussa were only recently discovered in 2006.

In the more remote and less investigated areas of Greenland, the Kap Simpson alkaline intrusion in central East Greenland and the Skjoldungen Alkaline Province in



Geological mapping and sampling of the NIAQ REE deposit in 2010.
 Photo: Avannaa Resources Ltd.

South East Greenland are believed to have a good potential for hosting new REE deposits.

Several of the known deposits are already covered by exploration licences and extensive exploration and drilling is currently being carried out on several

licences to move the projects towards exploitation stage. Greenland has thus responded to the increased global demand and has a possibility to become a major exporter of rare earth elements.



View of the NIAQ and UMIA REE deposits. The distance between the two deposits is 7 km.
Photo: Avannaq Resources Ltd.

Key references

- Grice, J. D., Gault, R.A., Rowe, R. & Johnsen, O. 2006:** Qaqarssukite -(Ce), a new barium-cerium fluorocarbonate mineral species from Qaqarssuk, Greenland. *Canadian Mineralogist* **44**, 1137-1146.
- Harpøth, O., Pedersen, J.L., Schönwandt, H.K. & Thomassen, B. 1986:** The mineral occurrences of central East Greenland. *Meddelelser om Grønland. Geoscience* **17**, 138 pp.
- Knudsen, C. 1991:** Petrology, geochemistry and economic geology of the Qaqarssuk carbonatite complex, southern West Greenland. *Monograph Series on Mineral Deposits* **29**, 110 pp.
- Secher, K. & Larsen, L.M. 1980:** Geology and mineralogy of the Sarfartôq complex, southern West Greenland. *Lithos* **13**, 199-212.
- Secher, K., L. M. Heaman, Nielsen, T.F.D., Jensen, S.M., Schjøth, F. & Creaser, R.A. 2009:** Timing of kimberlite, carbonatite, and ultramafic lamprophyre emplacement in the alkaline province located 64°–67°N in southern West Greenland. *Lithos* **112S**: 400-406.
- Steenfelt, A. 2001:** Geochemical atlas of Greenland – West and South Greenland. *Danmarks og Grønlands Geologiske Undersøgelse Rapport* **2001/46**, 39 pp. + 1 CD-Rom.
- Steenfelt, A., Schjøth, F., Sand, K.K., Secher, K., Tappe, S., Moberg, E. & Tukiainen, T. 2007:** Initial assessment of the geology and economic potential of the Tikisaaq carbonatite complex and ultramafic lamprophyre dykes. *Mineral resource assessment of the Archaean Craton (66° to 63°30'N) SW Greenland Contribution no. 3. Danmarks og Grønlands Geologiske Undersøgelse Rapport* **2007/64**, 53 pp. + 1 DVD.
- Sørensen, H. 2001:** The Ilimaussaq alkaline complex, South Greenland: status of mineralogical research with new results. *Geology of Greenland Survey Bulletin* **190**, 167 pp.
- Sørensen, H. 2006:** The Ilimaussaq Alkaline Complex, South Greenland – an Overview of 200 years of research and outlook. Contribution to the mineralogy of Ilimaussaq no. 130. *Meddelelser om Grønland. Geoscience* **45**, 70 pp.
- Sørensen, L. L., Kalvig, P., Hanghøj, K. 2011:** Rare earth element potential in Greenland. Reporting the BMP/GEUS mineral resource assessment workshop 29 November - 1 December 2010. 2. revised version. *Danmarks og Grønlands Geologiske Undersøgelse Rapport* **2011/80**, 30 pp. + 1 DVD.
- Tappe, S., Steenfelt, A., Heaman, L. M. & Siminetti, A. 2009:** The newly discovered Jurassic Tikisaaq carbonatite-aillikite occurrence, West Greenland, and some remarks on carbonatite-kimberlite relationships. *Lithos* **112S**, 385-399.
- Tukiainen, T. 1988:** Niobium-tantalum mineralisation in the Motzfeldt Centre of the Igaliko Nepheline Syenite Complex, South Greenland. In Boissonnas, J. & Omenetto, P. (ed) *Mineral Deposits within the European Community*. SpringerVerlag Berlin & Heidelberg, 230-246.

Usage of the term rare earth element (REE) in this magazine is restricted to 16 elements including Y, La, and the lanthanides.

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



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Front cover photograph

Front cover photograph: Hudson Resources Inc. drilling for REEs at its ST19 target which is part of the Sarfartôq carbonatite complex. Photo: Hudson Resources Inc.

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