REE DEPOSITS AND OCCURRENCES IN GREENLAND

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Abstract

The Greenland REE potential is considered excellent, consisting of three giant deposits and several smaller deposits in addition to favourable geological settings for undiscovered REE-occurrences. In South Greenland, the main REE occurrences are related to the Mesoproterozoic alkaline intrusions of the Gardar Province, including three world-class deposits: (i) Kvanefjeld and (ii) Kringlerne both hosted by the Ilímaussaq intrusion, and (iii) the Motzfeldt Sø deposit associated with the Igaliko Complex. In West Greenland, the REE occurrences are mainly related to carbonatite intrusions e.g. the Sarfartoq, Qaqarssuk and Tikiussaq intrusions, but some smaller occurrences also exist at Niaqornakavsak, Attu and Nassuttooq. In the Caledonian fold belt of East Greenland, occurrences are related to quartz veins in Bjørnedal, as well as a palaeoplacer deposit at Milne Land.

Introduction

Greenland comprises several large REE deposits in various geological settings. The largest deposits are hosted in peralkaline intrusions related to the Gardar Province in South Greenland, including the deposits around Kvanefjeld, Kringlerne, and Motzfeldt Sø. Additionally, three carbonatite deposits are known from the West coast, and quartz veins in Bjørnedal and one palaeoplacer deposit (Milne Land) are located in East Greenland (Figure 1). An overview of the REE-deposit types and main REE-minerals are listed in Table 1. Additionally, Greenland holds potential for undiscovered REE deposits related to carbonatite magmatism, alkaline intrusions, pegmatite settings, IOCG mineralising systems, and palaeoplacer environments[1,2].

South Greenland

The Mesoproterozoic Gardar province in South Greenland is an intracratonic rift province of sandstones, and a variety of volcanic and plutonic igneous rocks of alkaline and peralkaline affinity. Of the intrusions in the province, the most important economic REE deposit include the Ilímaussaq intrusion (1160 Ma), and the Igaliko Nepheline Syenite Complex (1273 Ma), hosting the Kvanefjeld and Kringlerne REE deposits, and the Motzfeldt Sø REE deposit, respectively. In addition, the Gardar province also encompasses the minor REE carbonatite occurrence at Grønnedal-Ika.
The Ilímaussaq intrusion is largely emplaced during block subsidence and formed by three pulses, of which the third pulse formed a layered series of nepheline syenite, enriched in REE, U, Nb, Ta, Zr, Zn and F. The Ilímaussaq intrusion covers an area of 8 km x 17 km and hosts two world class REE deposits: (i) Kvanefjeld, an intermediate

series sandwiched between roof and floor series, which consist mainly of lujavrites, and (ii) Kringlerne, the bottom cumulates of kakortokite.

The Kvanefjeld multi-element deposit is an accumulation of igneous rocks from the central part of the Ilímaussaq intrusion. The bulk of the REE and the U is associated with lujavrite rocks containing disseminated steenstrupine, lovozerite and an unnamed mineral species. Greenland Minerals and Energy Ltd. (GME) has been the license-holder since 2007, and reports[3] the indicated JORC compliant resources of Kvanefjeld to be 437 Mt ore grading 1.1 % TREO, hence containing 4.8 Mt TREO (0.18 Mt HREO), 263 Mlbs U_3O_8, and 1 Mt Zn. In addition, they have located and assessed two other lujavrite bodies in the vicinity, the Sørensen Zone and Zone 3. However, the proposed mining project is focused on the Kvanefjeld deposit. The deposit will be exploited as an open pit mine, with ore beneficiation at an adjacent plant, extracting sphalerite by flotation followed by hydrometallurgical leaching of steenstrupine and recovery of the uranium and REE. GME anticipate annual production to be in the range of 3 Mt ore resulting in 33,000 ton TREO (equivalent to 3,400 ton Nd_2O_3 and 300 ton Dy_2O_3), 1.8 Mlbs U_3O_8 and 6,636 ton Zn. The feasibility report is in progress.

The Kringlerne multi-element deposit is hosted in agpaitic kakortokite, and consists of a total of 29 exposed cyclic layers with a total thickness of about 200 m, made up by arfvedsonite dominated kakortokite, eudialyte dominated kakortokite, and a nepheline-feldspar dominated kakortokite. Eudialyte, the main economic mineral, is enriched in REE-Zr-Nb-Ta. TANBREEZ is the current license-holder, and they report[4] the inferred JORC-compliant resource to be at least 4,300 Mt grading 0.65 % TREO, 0.2 % Nb_2O_3 and 1.8 % Zr_2O_5 equaling 28 Mt TREO. Their proposed mining project involves an open pit mine near the fjord, hauling the ore to a nearby beneficiation plant, where they will produce three products: (i) eudialyte concentrate (REE, Nb, Zr); (ii) feldspar concentrate, and (iii) arfvedsonite concentrate, all to be shipped for further processing and/or use outside Greenland. Planned annual production is set at[5] 500,000 ton ore, equal to 3,250 ton TREO (equivalent to 400 ton Nd_2O_3 and c. 90 ton Dy_2O_3) and 9,000 ton Zr_2O_5. The feasibility report is in progress.

The Motzfeldt Sø REE deposit is part of the Motzfeldt Centre, which in turn is one of the intrusions of the Igaliko Nepheline Syenite Complex. It contains extensive U-Nb-Ta-Zr-REE mineralisation[6,7]. Significant Ta-Nb-enriched zones relate to altered syenite, minor pegmatite and diorite dykes and high grade REE intersections are related to pegmatites at depth. Presently, RAM Resources Ltd. has licensed the area and reports[8] a resource estimate of 340 Mt grading 0.26 % TREO, 0.19 % Nb_2O_3, 0.012 % Ta_2O_3 and 0.46 % ZrO_2. A scoping study is in progress.

West Greenland

West Greenland possesses a number of carbonatite associated REE deposits intruded between Neoproterozoic and Jurassic. The most important of those, in terms of REE resources, are Sarfartoq, Qaqarssuk, and Tikiussaq. These carbonatites are located in southern West Greenland intruded into the Archaean basement of the North Atlantic

Craton. In addition, West Greenland hosts minor REE occurrences at Niaqornakavsak, Attu and Nassuttooq.

The *Sarfartoq carbonatite* intrusion is located on a Precambrian thrust zone and intruded 560 ± 13 Ma ago[9,10], during the opening of the Iapetus Ocean. The host rock consists of orthogneiss with schlieren of amphibolite. The complex has an ellipsoidal shape and covers about 90 km², of which 15 km² are intrusive carbonatites. The core of the complex consists of rauhaugite with schlieren of sövite and beforsite dykes, surrounded by a Na-type fenite zone with aegerine- and pyrochlore-bearing rocks. The carbonatite contains REE-bearing minerals in veinlets of dolomite and REE-carbonatite and in shear zones with thorium, uranium, K-feldspar alteration and limonitisation[11]. The most common REE-minerals are synchysite and zhonghuacerite, which are relatively enriched in LREE[12], most notably Ce, La and Nd. Furthermore, ancylite, burbankite and Sr-REE barite were observed[13]. Hydrothermal activity caused an enrichment of niobium in the carbonate veins and shear zones, which have been drilled in the past. Hudson Resources Ltd. currently holds the license of the area and reports resource estimates that include indicated NI 43-101 compliant resources of 5.9 Mt averaging 1.8 % TREO and an additional inferred resource of 2.5 Mt averaging 1.6 % TREO, based on a 1 % cut-off grade[12,14].

The *Qaqarssuk carbonatite* (Qeqertaasaq) complex consists of carbonatite ring-dykes that are elliptical to semi-rectangular in shape and intruded into the Archaean basement at 165.7 ± 1.9 Ma[9,10]. The carbonatite covers an area of 15 km² and is surrounded by fenitised basement. The ring-dykes consist of sövite, olivine-sövite, and dolomite carbonatite. They are cut by late-stage sövite veins, REE-carbonatite veins, ferrocarbonatite and lamprophyre dykes[15]. The sövites contain increasing amounts of silicate minerals and inclusions of fenitised basement away from the centre of the complex. The fenites are composed of albite, alkali amphibole, and alkali pyroxene[16]. The major REE minerals in the complex are ancylite, burbankite, huanghoite and qaqarssukite. NunaMinerals A/S holds the license for the area and report[17] that surface sampling and trenching have yielded up to 13.2 % TREO within the late-stage carbo-hydrothermal REE veins, and that drilling demonstrated that the REE veins are up to 4.5 % TREO. Metallurgical flow sheets are currently being defined.

The Late Jurassic *Tikiusaaq carbonatite complex* was discovered in 2005[18]. The presence of the carbonatite was predicted by a study of regional stream sediment geochemistry and aeromagnetic data. The complex consists of a central intrusive carbonatite surrounded by a fenite zone with carbonatite and aillikite dykes, and the main REE-mineral is bastnaesite. The exposed carbonate 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. Both magmas have common origin within carbonated upper mantle source[19]. The 165-150 Ma carbonatite intruded during the opening of the Labrador Sea. Apart from REEs, the carbonatite complex hosts P, Nb and Ta. The highest grade REEs are associated with a thorium anomaly. NunaMinerals A/S holds the license for the area and reports up to 9.6 % TREO in a carbonate float[17].

The *Niaqornakavsak REE deposit* was discovered in 2007 by Avannaa Resources who still holds the license of the area. The mineralisation is hosted in Early Proterozoic metasediments and metavolcanic of the Karrat Group, situated in the Karrat Isfjord region. The mineralisation is a lithological distinct horizon of banded carbonates within an amphibolite unit. The horizon strikes 1.5 km and dips 32 degrees. The mineralised body is estimated to contain tens of millions tons of ore. Drill intersections indicate that TREO+Y typically varies between 0.8 and 1.5 wt. % with some layers containing up to 1.9 wt. % with an average of 1.03 wt. %. The REE´s are mainly hosted by bastnaesite, monazite, allanite and other REE silicates[20]. The Niaqornakavsak bulk samples indicate an average TREO+Y of 1.36 wt. % of which the average HREO+Y content is 13.06 %. A metallurgical analysis and flow sheet development is in progress.

East-Greenland

In the Caledonian fold belt of East Greenland, a couple of occurrences exist in quartz veins in Bjørnedal, in a palaeoplacer deposit at Milne Land and in an alkaline intrusion in the Gardiner Complex.

Nb-REE-bearing types of mineralisation occur in *the Kap Simpson complex in Bjørnedal on Traill Ø.* The mineralisation occurs in course-grained quartz veins intruding Jurassic/Cretaceous shales, siltstone and sandstones. The veins are up to 30 m long and 15 cm wide and contain minor amounts of Nb and REE-bearing minerals columbite, euxenite, samarskite, fergusonite, monazite and bastnaesite. Selected samples contain up to 3.2 % Nb and 3 % REE, but the average content is not reported[21].

In East-Greenland, the Jurassic placer deposit on *Milne Land* is forming another source for REEs. The deposit, placed within the Mesozoic basins in central East Greenland, formed during the opening of the North Atlantic Ocean. The placer consists of heavy mineral-bearing arkosic sandstones and breccias that are rich in zircon, monazite, Ti-minerals and garnet. The units forms the lowermost 20 m of the Charcot Bugt Formation, which rests unconformably on Mesoproterozoic migmatic granite. The best outcrops occur on Hill 800, where these sedimentary rocks are 40-50 m thick and are more than 500 m in diameter[9,22]. CGRG Ltd. currently has the license for the area and is exploring for Mo-Zr-REE-Ti.

Conclusion

The Greenland REE potential is considered excellent including several known deposits, as well as favourable geological settings for undiscovered REE-occurrences such as alkaline intrusions, pegmatite settings, carbonatites and IOCG mineralising systems. Currently, two giant deposits that have reached advanced stage of development, plan to enter operation before 2018.

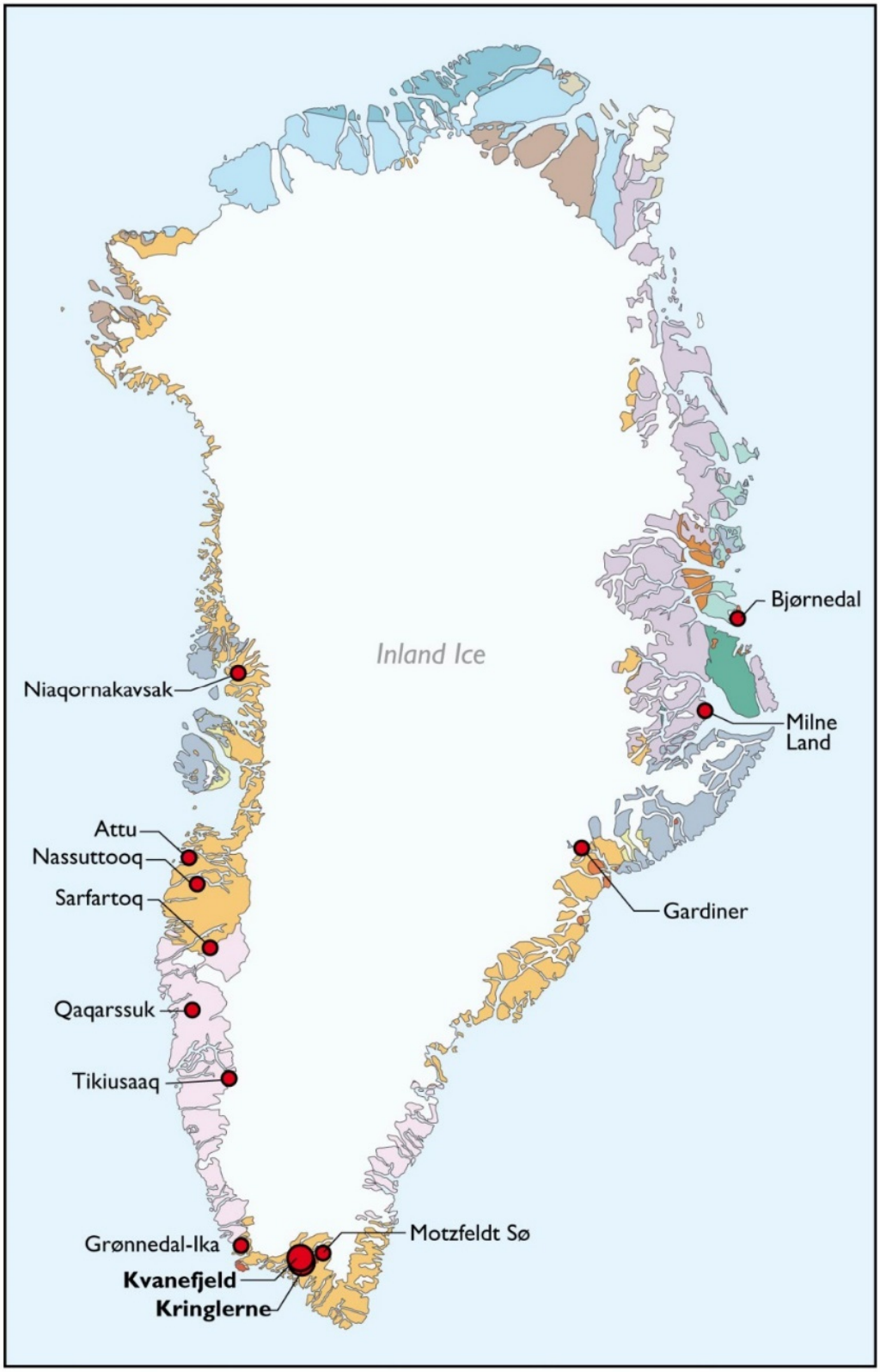

Figure 1: Known REE deposits/occurrences in Greenland

Table 1: Deposit types and REE-minerals of the Greenland REE-occurrences

Occurrence	REE-deposit type	Main REE minerals	Chemical formula
Attu	Granitic	Allanite	$(Ce,Ca,Y,La)_2(Al,Fe3+)_3(SiO_4)_3(OH)$
Bjørnedal	Granitic	Euxenite Samarskite Fergusonite Monazite Bastnaesite	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$ $(YFe3+Fe2+U,Th,Ca)_2(Nb,Ta)_2O_8$ $REENbO_4$ $(Ce,La)PO_4$ $(Ce,La,Y)CO_3F$
Gardiner	Alkaline	Perovskite Apatite	$CaTiO_3$ $Ca_5(PO_4)_3(F,Cl,OH)$
Grønnedal-Ika	Carbonatite	Bastnaesite	$(Ce,La,Y)CO_3F$
Kringlerne	Alkaline	Eudialyte	$Na_{15}Ca_6(Fe,Mn)_3Zr_3SiO(O,OH,H_2O)_3(Si_3O_9)_2(Si_9O_{27})_2(OH,Cl)_2$
Kvanefjeld	Alkaline	Steenstrupine Lovozerite	$Na_{14}REE_6(Mn,Fe)_3(Th,U,Zr)(Si_6O_{18})_2(PO_4)_7{\cdot}3H_2O$ $Na_2CaZrREE(H_4Si_6O_{18})H_2O$
Milne Land	Palaeoplacer	Monazite	$(Ce,La)PO_4$
Motzfeldt Sø	Alkaline	Pyrochlore, Bastnaesite, Monazite Eudialyte	$(Na,Ca)_2Nb_2O_6(OH,F)$ $(Ce,La,Y)CO_3F$ $(Ce,La)PO_4$ $Na_{15}Ca_6(Fe,Mn)_3Zr_3SiO(O,OH,H_2O)_3(Si_3O_9)_2(Si_9O_{27})_2(OH,Cl)_2$
Nassuttooq	Granitic	Monazite	$(Ce,La)PO_4$
Niaqornakavsak	Carbonatite?	Bastnaesite Monazite Allanite	$(Ce,La,Y)CO_3F$ $(Ce,La)PO_4$ $(Ce,Ca,Y,La)_2(Al,Fe3+)_3(SiO_4)_3(OH)$
Qaqarssuk	Carbonatite	Ancylite Burbankite Huanghioite Qaqarssukite	$Sr(Ce,La)(CO_3)_2(OH)H_2O$ $(Na,Ca)_3(Sr,Ba,Ce)(CO_3)_2$ $BaCe(CO_3)_2F$ $Ba(Ce,REE)(CO_3)_2F$
Sarfartoq	Carbonatite	Synchysite Zhonghuacirite	$Ca(Ce,La,Nd,Y)(CO_3)_2F$ $Ba_2(Ce,La,Nd)(CO_3)_3F$
Tikiusaaq	Carbonatite	Monazite	$(Ce,La)PO_4$

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