THE WORLD-CLASS REE DEPOSIT TANBREEZ, SOUTH GREENLAND: ITS SIZE AND STRUCTURE

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Abstract

The Tanbreez ore deposit is a highly fractionated ortho-magmatic Zr-Nb-Ta-REE deposit in the southern part of the 1.13Ga old Ilímaussaq intrusive complex in South Greenland. The commodities are hosted in the zirconosilicate mineral eudialyte, occurring concentrated in kakortokite at the floor of the exposed intrusion. The kakortokite sequence is outcropping over an area of 5 x 2.5 km and has a total thickness of 335 m. A conservative estimate specifies the resource to more than 4 billion tons. Linear correlations between ZrO_2 and individual REE indicate that eudialyte is by far the main REE bearing mineral in kakortokite. Estimated average grades are 1.75% ZrO_2, 0.18% Nb_2O_5 and 0.6% total REO, of which heavy REE make up 30% (including yttrium).

Introduction

Many of the metals used in today's technology such as REE are enriched in alkaline and carbonatitic intrusive complexes. The rare earth market is dominated by China. Therefore there is a concern outside China about supply of these elements. This has launched an exploration activity for these elements all over the world. Greenland, which is known for its alkaline igneous provinces, has been the focus for the industries REE exploration for the last 10-15 years.

The Ilímaussaq alkaline complex in southern Greenland host several mineral deposits one of which is Tanbreez, a world class REE deposit. The anagram, Tanbreez, is based on the major elements (Ta-Nb-REE-Zr) contained in the deposit. Moreover, there are elevated concentrations of the elements Hf and Y. Uniquely; all the commodities are contained in the mineral eudialyte, which is a rock-forming mineral in the agpaitic nepheline syenite kakortokite.

Rimbal Pty Ltd, the Australian owner of Tanbreez Mining Greenland A/S, holds an exploration license since 2001 over the deposit and has invested the last 13 years in understanding and testing the deposit. The previously existing knowledge, dating as far back as 1880's, included drilling and mapping programs and extensive metallurgical test programs carried out by former license holder has contributed to the present knowledge of the deposit

In this contribution we describe the structure and thickness of the kakortokite (ore host sequence) and its contact relationships to the rocks surrounding it. Furthermore, we show the geochemical correlation of REE and Zr in kakortokite, including an estimate on the overall size of the deposit.

Geological Setting

The Meso-Proterozoic Gardar Province in South Greenland contains 10 intrusive complexes that range in composition from alkali granite to nepheline syenites and gabbroic dikes. These rocks intruded the 1.9 Ga old Julianenhåb granite basement that is unconformably overlain by sandstones and basalts of the Eriksfjord formation[1, 2].

The alkaline to agpaitic Ilímaussaq intrusion has been dated at 1.13 ± 0.05Ga (Sm-Nd mineral isochron[3]) and belongs to the younger Gardar event. The intrusion is 17 km x 8 km in size and at least 3 km thick. The composite intrusion is cut by the Tunulliarfik Fjord (Fig 1). The geology of the Ilímaussaq intrusive complex has been described as a succession of three main phases that crystallized at about 3-4km depth[4,5,6] .

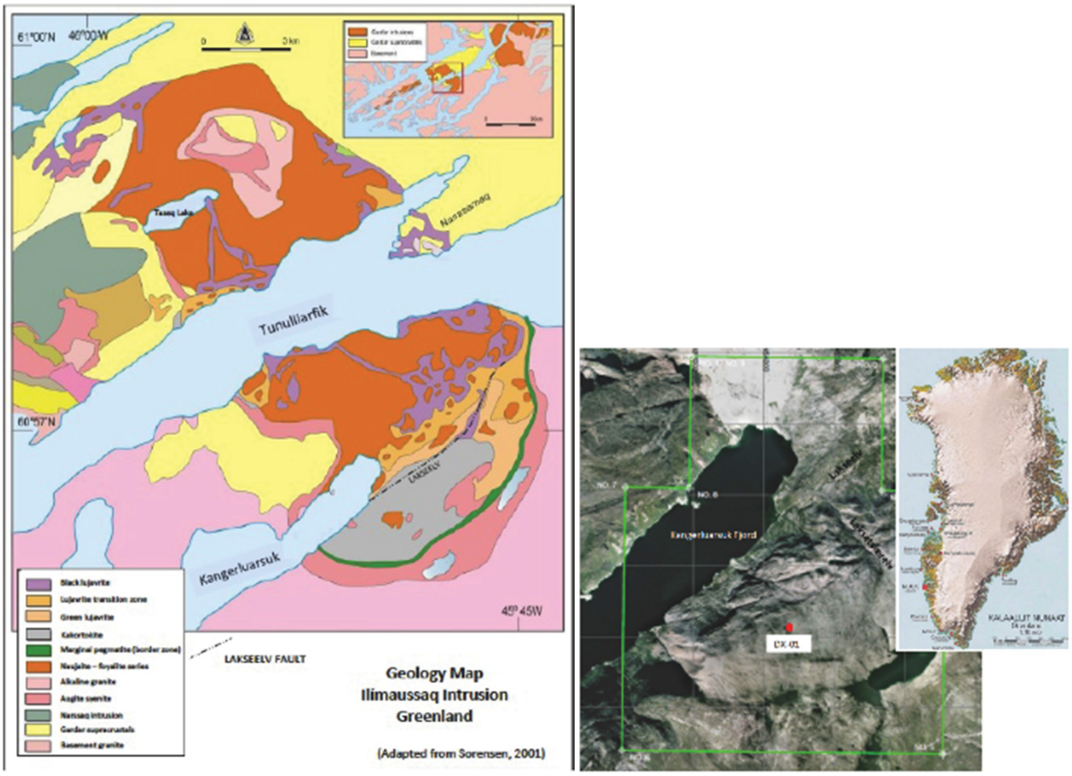

Fig. 1A) Geological map of the Ilímaussaq intrusion. **B)** Satellite image of the southern part of the intrusion with the exploration license area in green. Also shown is the drill hole location of the stratigraphic hole in the central part of the kakortokite.

Phase 1 is an outer ring dyke of augite syenite, which partly rims the complex to the west, east and south and is up to 1 km wide. The augite syenite also overlies the intrusive complex.

Phase 2 is alkali granite and quartz syenite in the roof zone of the complex.

Phase 3 consists of peralkaline rocks, evolving into the dominant agpaitic nepheline syenite of the complex. This phase can be subdivided into a:

Roof sequence that crystallizes from the roof downwards, forming the following succession of rocks downwards: pulaskite, foyaite, sodalite foyaite and naujaite (Fig. 1 naujaite-foyaite series). The three first mentioned rock types occur as a thin, but persistent cover of part of the complex on both sides of the Tunulliarfik Fjord (Fig 1a). The naujaite is by far the thickest unit of the roof sequence with a thickness between 600 m and 800 m[7].

Floor sequence solidifying upwards. The floor sequence consists of a rhythmically layered rock called kakortokite.

Intermediate series that is sandwiched between roof and floor series, consisting of different types of lujavrites.

The kakortokite contains a significant amount of the mineral eudialyte, and hence, is enriched in zirconium, rare earth elements, niobium and tantalum. The kakortokite sequence is regarded as the host of a world-class, multi-element deposit.

The structure of the kakortokite body

Kakortokite and lujavrite constitute the lower sequence of the stratified intrusion where kakortokite is overlain by lujavrite. The exposed thickness of the two rock types is nearly 1000 m[8]

The kakortokite has been subdivided into three parts[8]. From bottom to top:

- Lower layered kakortokite (LLK) (approx 209 m thick)
- Slightly layered kakortokite (SLK) (approx 35 m thick)
- Transitional layered kakortokite (TLK) (approx 40 m thick).

All planar elements are locally parallel and the combined structure recalls a simple saucer shaped pattern with steep to vertical structures at the periphery, which rapidly turns into a general dip of 10-15 degrees for the main part of the kakortokite[8]. Steeper dips of the sequence occur just north of Lakseelv, but this is probably linked to drag associated with the Lakseelv Fault (Fig 1b).

The kakortokite sequence is exposed over an area of 5 x 2.5 km on the south side of the Kangerdluarsuk Fjord (Fig 1) and ranges from sea level up to about 400 m asl. The exposed area comprises 95% kakortokite and 5% related rocks, mostly syenite dykes and sills.

The Lower layered kakortokite and the Transitional Layered Kakortokite show subhorizontal layered structures, whereas the Slightly Layered Kakortokite sequence is a virtually unlayered grey and fine-grained kakortokite.

The spectacular layering in LLK is composed of black, red and white layers, depending on the amount of specific minerals. The black layers are rich in the mineral arfvedsonite and contain lesser amounts of eudialyte, alkali-feldspar and nepheline. The red layers are composed of eudialyte, with lesser amounts of arfvedsonite, alkali-feldspar and nepheline, whereas the white layers are composed of alkali-feldspar and nepheline with lesser amounts of arfvedsonite and eudialyte. Locally sodalite occurs as a significant mineral phase.

Conventionally, the three colored layers together form a unit. The exposed part of the kakortokite consists of 29 units labelled +1 to +17 and -1 to -11 above and below unit 0, respectively[9].

The layering can be recognized from a distance; however, in some cases the exact contacts between layers is not always clearly defined close up and in drill core due to more transitional contacts between the main mineral phases of the layers. There is some variation in thickness between the layers as well as in texture and grain size, which helps to identify some horizons. On average, a unit is about 10-13 m thick. There are, however, units that are not fully developed; in some cases black/red layers are very faint or missing. An average relative thickness of the individual layers is 1.5m for black, 1m for red and 10m for white layers[10]. In general, the eudialyte content (main host for Zr, and REE) of the black and white layers is slightly below 10vol%, whereas the eudialyte content of the red layers is around 30-40 vol%.

Following is a description of the contact relationships of the kakortokite sequence to the upper, lower, and marginal boundaries of the intrusion.

Boundaries of the kakortokite body

The upper boundary of the kakortokite sequence is a gradual and concordant boundary to the overlaying lujavrite sequence.

The lower boundary of the kakortokite is not exposed, which has led to speculations on the thickness of the kakortokite. Exploration drillings by Tanbreez Mining Greenland A/S in 2007 in the coastal area of Kangerdluarsuk near the southern boundary of the Ilímaussaq intrusion (Fig 1b) encountered a black to grey, porphyritic, fine grained rock with peppered sodalite in the matrix below the kakortokite. The rock contains 5-10 vol% subhedral to euhedral, poikilitic biotite grains 1-2 mm in diameter, and aggregates of aenigmatite, biotite and arfvedsonite in a groundmass of feldspar, nepheline and sodalite. Geochemically the rock composition is equivalent to a tephri-phonolite. During drill core logging this rock was temporarily call “Black Madonna” and that name will also be used throughout this paper. Black Madonna was found in 8 drill holes so far, but none of the drill holes has completely penetrated Black Madonna. The longest interval drilled in Black Madonna is 220 meter.

There is a reasonable good correlation of the contact between kakortokite and the massive occurrence of Black Madonna between the drill holes. It is apparent, that the top of Black Madonna is dipping towards the northwest. Based on the limited data it seems that Black Madonna has a dip similar to the layering of the kakortokite. This was corroborated by the depth of the occurrence of Black Madonna in the stratigraphic hole (DX-01) drilled in 2010 about 1.5 km east of the drillings in 2007 (Fig 1b). This further indicates that Black Madonna could lie under the entire kakortokite sequence. The contact between Black Madonna and the Lower layered kakortokite is well defined without been sharp. In the contact zone rounded inclusions of Black Madonna often 5-10 cm long occur in the layered kakortokite and it is not uncommon to encounter inclusions 50 m or more from the contact. However there is a clear decrease in number of inclusions away from the contact.

A rim of massive agpaitic nepheline syenite, which consists of the same minerals as the layered kakortokite sequence, characterizes the marginal borders of the kakortokite sequence. This led ref. 11 to describe the rocks along the rim as a not banded kakortokite.

The rim has also been referred to as marginal pegmatite by ref. 9, 12. Because the rim is a complex mixture of different eudialyte-bearing rock types, including pegmatite, a more appropriate name would be ‘border zone’ of the kakortokite. The border zone represents a transition between the layered kakortokite and the augite syenite ring dyke of the Ilímaussaq intrusion (Fig 1a). The border zone is about 150 m wide at sea level at Kangerluarsuk and decrease to about 50 m at an altitude of about 450 m. The zone is made up of eudialyte-bearing nepheline syenite, which shows a variation in texture from medium to coarse-grained massive rock The inner boundary of the border zone against the kakortokite is gradual over about 5-10 m where the layering becomes more subtle and turns into a massive agpaitic rock. The outer boundary of the border zone towards the augite syenite is subvertical, sharp and without a chilled margin. The border zone’s complex intergrowth of texturally different kakortokite like rocks is cut by a eudialyte poor pegmatite mainly containing feldspar, nepheline, sodalite, arfvedsonite and aegirine. The proportion of the pegmatite increases towards the augite syenite and at the same time it largely parallels the augite syenite. In the outer 10 m of the border zone they occur as a subvertical swarm of pegmatite locally associated with hydrothermal alteration. The pegmatite is the youngest member of the border zone and from an economical point of view, down grades part of the border zone and this part will most likely not be subject to mining.

Size of the kakortokite body

The exceptionally well-exposed kakortokite in combination with the subhorizontal structure of the sequence were used by ref. 9 to estimate the tonnage of the lower layered kakortokite. The calculation was based on detailed mapping of the 29 rhythmic units in the exposed part of kakortokite. Ref. 13 repeated the estimate based on the geological map: Southern part of the IlÍmaussaq Complex, South Greenland, 1:20000 published by Grønlands Geologiske Undersøgelse (1988). Ref. 9 and 13 measured 209m and 218 m, respectively for the total thickness of the lower layered kakortokite, which is within the expected uncertainty of this kind of survey. The volume of kakortokite was determined using a planimeter to measure the area on the map between the contours of the different rhythmic units.

Exploration drillings in 2007 showed that the lower contact of the kakortokite and Black Madonna occurs about 20 m below sea level on the coast of Kangerluarsuk (Fig 1), which means that 20 m should be added to the thickness measured on the surface. Assuming 214 m as the average for the layered kakortokite based on the previous studies, the total thickness becomes 234 m.

Subsequently, the stratigraphic borehole DX-01 (Fig 1b) was drilled in the central part of the kakortokite body in 2010, and shows a total thickness of the lower layered kakortokite of 269 m, which is 35 m more than the measured thickness on the surface. The difference in thickness cannot convincingly be explained by the uncertainty in the measurements, but is most probably related to structural conditions. This makes the correlation between numbered layers on the surface and the layering observed in drill cores difficult, except for correlation over short distances and involving kakortokite layers with very characteristic textures.

Previous estimates of the tonnage of the lower layered kakortokite west of Laksetværelv (Fig 1b) yielded 3.7 billion tons[9]. The estimate was based on the thickness of the lower layered kakortokite of 209 m, which is 60 m less than the thickness found in drill hole DX-01. The new estimate, using the thickness from DX-01, and using a linear interpolation from previous estimates would increase the tonnage to 4.7 billion tons. This number would increase even more if kakortokite of the slightly layered kakortokite, the transitional layered kakortokite and the border zone would be included.

Ore Grade

Resource assessments in earlier studies[9, 13] show a variation in ore grade of the lower layered kakortokite between 1.4% ZrO_2 to 1.9% ZrO_2. The average ore grades based on assay data from drillings from the area along Kangerluarsuk where the initial mining is planned is 1.75% ZrO_2, 0.18% Nb_2O_5 and 0.6% total REO including yttrium. The commodities are all contained in eudialyte, a Na-rich zirconosilicate mineral. Eudialyte is by far the most abundant Zr-bearing mineral in kakortokite, occurring in the black, white and red layers. The bulk rock data show close linearly correlation between ZrO_2 and Nb, Ta and light and heavy REO (Fig 2), which is a clear indication that eudialyte is the dominant REE-bearing mineral.

The distribution of the total REO in the ore (kakortokite) shows a quantity of 30.9% heavy REE (including Y) and 69.1% light REE (Fig 3). Investigations have shown that no or very little cryptic variation occurs in the minerals of kakortokite[10,14] , consequently, little change in the eudialyte composition is expected in ore and therefore the magnetic properties of eudialyte would remain the same for the benefit of the planed magnetic concentration of eudialyte . Importantly, drill core assays show elements like U and Th have background values (20ppm and 53ppm, respectively), which is an advantage in processing the ore.

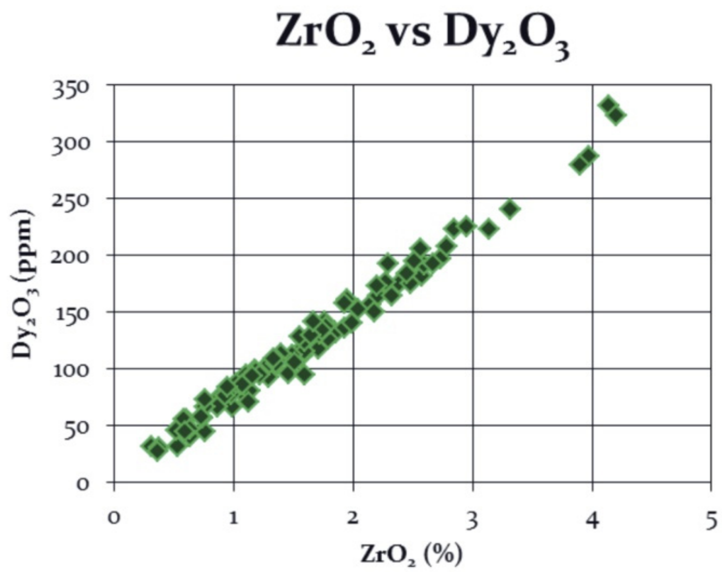

Fig. 2. Assay data showing good correlation between Zr and Dy as a representative of the REE.

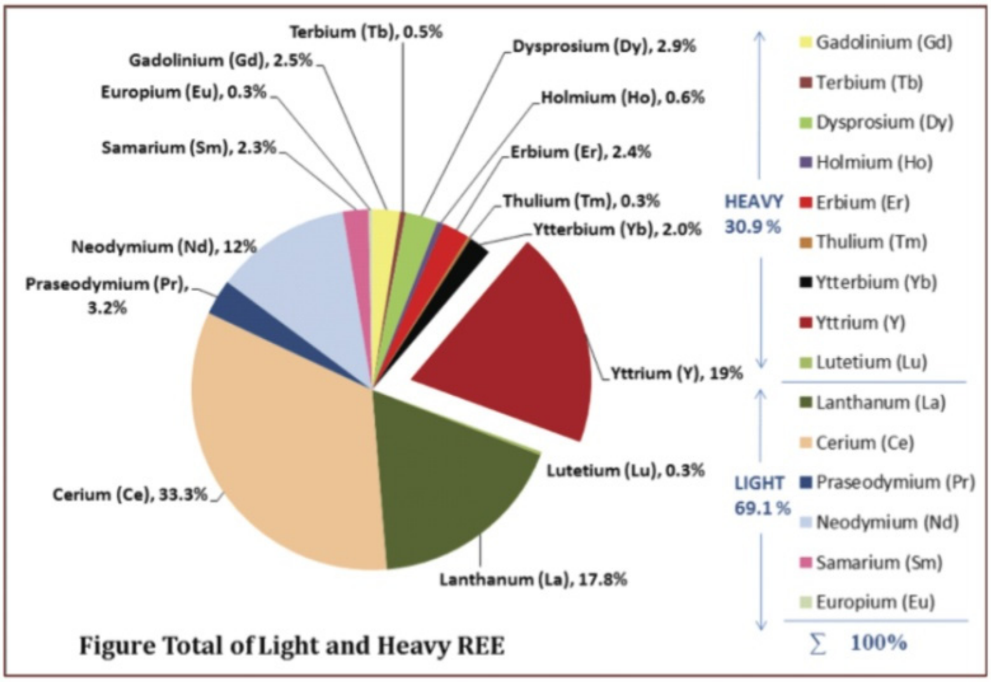

Fig. 3. Proportion of the different REE+Y found in the Tanbreez deposit

Conclusion

The Tanbreez polymetallic Zr-Nb-Ta-REE deposit is hosted in the Ilímaussaq intrusion in South Greenland. The ore body is made up of kakortokite that is characterized by rhythmically layered units of layers that are either dominated by feldspar, arfvedsonite and eudialyte, respectively. The kakortokite sequence is defined by gradual contacts to the overlying lujavrites and an unexposed (only encountered in drill cores) contact zone with numerous xenoliths to the underlying Black Madonna unit. The border zone contact to the augite syenite ring dike is well defined and the outer part of the zone cut by pegmatoid dikes.

Zr shows perfect correlations with REE in bulk rock analyses, which indicates that the main ore mineral is eudialyte. The thickness of the lower layered kakortokite sequence is a about 270m, and the volume of the ore body equals about 4.7 billion tons of ore. The average ore grade where the initial mining is planned is 1.75% ZrO_2, 0.18% Nb_2O_5 and 0.6% total REO. The proportion of HREE is up to about 30%.

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