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New Discoveries of REE-mineralization in the IlÍmaussaq Intrusion, South Greenland

Hans Kr. Schønwandt, Gregory B. Barnes
47 Labouchere Rd, South Perth, WA 6151, Australia

Abstract: A decade of continuous exploration on the IlÍmaussaq intrusion, South Greenland has resulted in discoveries of several new mineralization within the intrusive complex. The new mineralization is a contribution to the REE resources of the IlÍmaussaq intrusion and is common for mineralization associated with alkaline to peralkaline complexes. The new types of mineral occurrences, which occur in the southern part of the complex (south of Tunulliarfik) is described. 1) A Kvanefjeld type REE-U-Th deposit; 2) A large hydrothermal REE-deposit at Søndre Siorarsuit; and 3) High grade eudialyte zone associated with lujavrite sills. Some of these deposits have potential for hundreds of million tons of ore and are significant discoveries and underlines the impression that the intrusions stands out as having the most promising potential for REE deposits in Greenland and possibly in the western world.

Key words: IlÍmaussaq, agpaitic, REE-U-Th deposit, hydrothermal REE deposit, eudialyte replacement deposit, world class potential.

1. Introduction

The rare earth elements (REE) are in the exploration industry generally considered as the lanthanides and yttrium, which is a group of 15 chemically similar elements, which behave almost uniform during geological processes. They are generally divided into light (LREE) and heavy (HREE) rare earth elements, however the two groups are variably defined by different users, in this paper LREE consists of the elements lanthanum (La) to europium (Eu) and the HREE of gadolinium (Gd) to lutetium (Lu) plus yttrium (Y).

The REE market is presently dominated by China and consequently the western world must import most of its REE either as raw material or as REE-products such as magnets [1-2]. This has led to classification of the REE and especially the HREE as critical material with a significant risk of supply (EC 2014) which was clarified by the price peak in 2011. This scenario has launched an exploration activity for REE all over the world.

Alkaline to peralkaline complexes are known for their significant enrichment in REE and other high field-strength elements (HFSE). Greenland is known for its alkaline provinces and has for several decades been explored for HFSE, especially the IlÍmaussaq complex; South Greenland where two sizeable deposits has been located in nepheline syenite: Tanbreez (Killavaat Alannguat) and the Kvanefjeld (Kuannersuit) and its two satellite deposits.

The anagram, Tanbreez, is based on the major elements (Ta-Nb-REE-Zr) contained in the magmatic deposit, where eudialyte is the sole carrier of HFSE and is a rock forming mineral in kakortokite (agpaitic nepheline syenite).

The Kvanefjeld REE-U-Th deposit is hosted in different types of lujavrite (agpaitic and hyperagpaitic nepheline syenite) and is the result of processes involving both a volatile rich magma and a magma with a more moderate content of volatiles.

The continuous exploration on the IlÍmaussaq intrusion has lately revealed several new occurrences of mineralization including new type of mineralization for the intrusive complex. However, the mineralization found is common for mineralization associated with

Corresponding author: Hans Kr. Schønwandt, Ph.D., research fields: ore deposits, petrology, mineralogy. E-mail: Hank@mail.tele.dk.

this type of intrusive complexes. Three types of new mineral occurrences from the southern part (south of Tunulliarfik Fjord) of the complex will be described (Fig. 2):

1) REE-U-Th deposit of similar type as the Kvanefjeld deposit in the northern part of the IlÍmaussaq complex;

2) A large hydrothermal deposit with a vertical extent of more than 300 meters (The Søndre Siorarsuit deposit);

3) Eudialyte dominated zones associated with lujavrite sills (EALS).

2. Geological Setting

The IlÍmaussaq intrusion is a late member of the Mid-Proterozoic, alkaline Gardar province in South Greenland. It is dated at 1.13 +/- 0.05 Ga [3-5]. The intrusion has an ovoid shape with a size of 17 x 8 km and is at least 3 km thick. It intruded the 1.9 Ga old Julianehåb granite and the Mesoproterozoic sandstones-basalts of the Eriksfjord formation, which unconformably overlay the basement granite (Fig. 1).

The IlÍmaussaq intrusive complex (Fig. 2) has been described as a succession of three main phases [6-7]:

Phase 1 is the augite syenite, which occur as ring dyke and as roof of the intrusion. Phase 2 is alkali granite and quartz syenite in the roof zone and Phase 3 consists of peralkaline rocks, evolving into the dominant agpaitic nepheline syenite of the complex. Phase 3 can be subdivided into:

1) A roof sequence that crystallized downwards from the roof including the following succession of rocks pulaskite, foyaite, sodalite foyaite and naujaite of which naujaite is by far the thickest unit (600-800 m) [8];

2) Floor sequence which crystallized upwards and consists of a rhythmically layered rock, kakortokite;

3) Intermediate series that is sandwiched between roof and floor sequence consisting of different types of lujavrites.

The Tanbreez deposit make up the whole of the floor sequence (kakortokite), where eudialyte is a rock forming mineral and occur in sufficient amount in kakortokite to constitute a REE deposit [9].

The Kvanefjeld deposit is attached to the sandwiched lujavrite sequence and this sequence is only locally enriched enough in REE, U and Th to form a deposit.

3. REE-U-Th Deposit South of Tunulliarfik Fjord

One of the prominent features on the geological map of the southern part of IlÍmaussaq intrusion is the occurrence of black (arfvedsonite) lujavrite in the central part of the map with its dyke extension to WNW (Fig. 2). Black lujavrite from this area is known to have elevated uranium values [10] and was therefore part of the 1962 drilling program (drill hole VI) by the Danish authorities [11]. Drill hole VI showed the highest uranium concentration of all 1962 drill holes. This has been attributed to a structural culmination in the area of black lujavrite, which functioned as a collector of residual liquids enriched in uranium and REE [11].

To follow up on this indication of a possible Kvanefjeld type mineralization south of Tunulliafik, Tanbreez collected surface samples of black lujavrite in order to delineate and roughly characterize the mineralized area. Tanbreez finished in 2013 its surface sampling program of arfvedsonite (black) lujavrite and undertook at the same time an airborne magnetic and radiometric survey over its license south of Tunulliarfik fjord.

The uranium anomaly of the radiometric survey (Fig. 2) is about 280-hectares in size and coincide on the whole with the black (arfvedsonite) lujavrite in the central part of the map and the most eastern part of the lujavrite dyke. Subdividing the surface samples into two groups using a separation value of 200 ppm U_3O_8, will for the group > 200 ppm U_3O_8 roughly reflect the uranium anomaly area shown on Fig. 2 and thereby broadly define the surface of the mineralization found in drill hole VI. The group > 200 ppm U_3O_8, which include 251 samples, is a preliminary rough estimate of the grade of the arfvedsonite lujavrite hosted mineralization.

The sampled arfvedsonite lujavrite is the most dominant lujavrite within the uranium anomaly area, only a minor part consists of aegirine lujavrite. In contrast to this, a much more complex picture exist in the Kvanefjeld deposit where several varieties of lujavrite occur including arfvedsonite, aegirine, naujakasite, and acmite lujavrite as well as M-C-lujavrite (medium- to coarse- grained-lujavrite). While most lujavrites are agpaitic the naujakasite lujavrite, which is a prominent component of the Kvanefjeld deposit, is hyperagpaitic and represent a more highly evolved stage enriched in REE, U and Th compared to the ordinary lujavrite. Minerals in addition to naujakasite such as steenstrupine and villiaumite occur widespread in this hyperagpaitic rock.

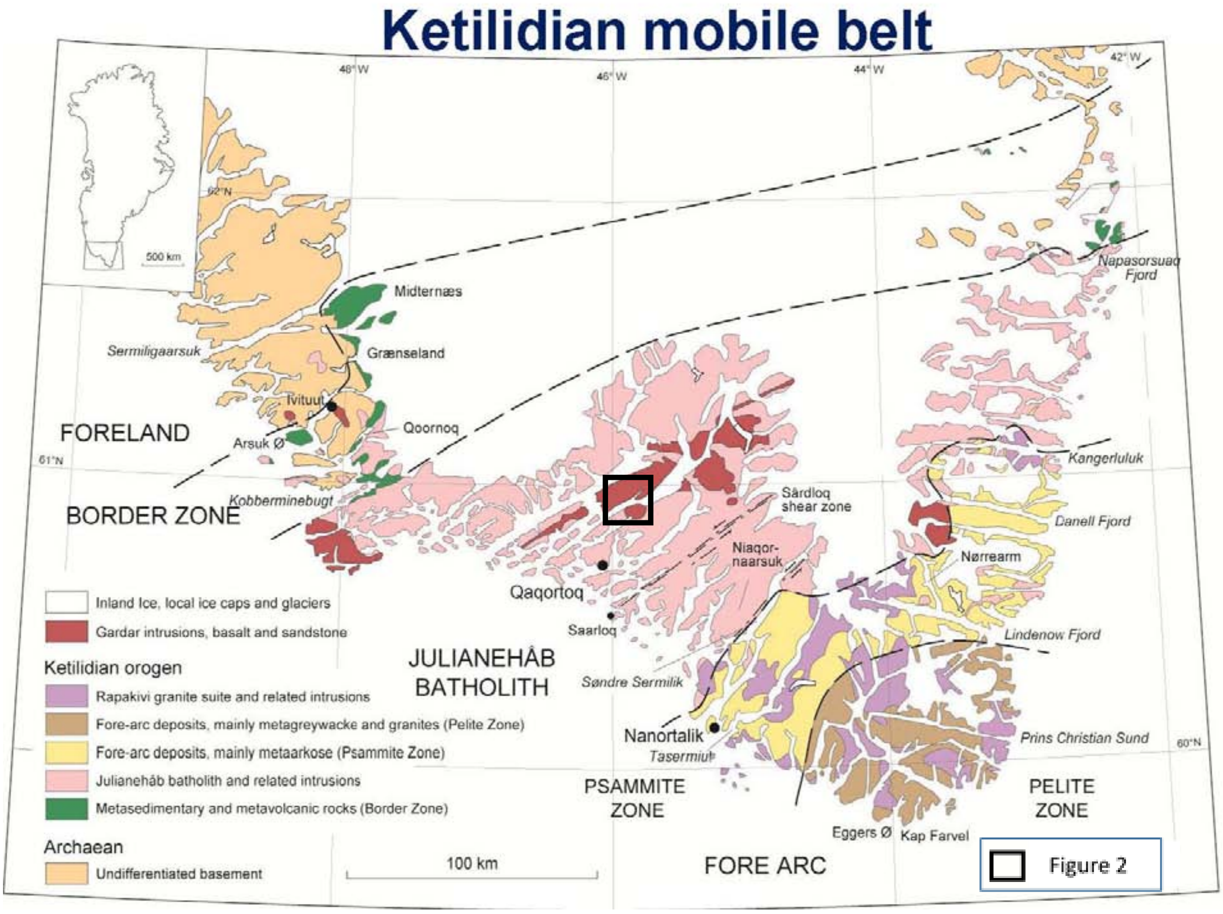

Fig. 1 Geological map of the Ketilidian Mobile Belt and the Gardar alkaline province in South Greenland (Adopted from Garde et al., 2002) [12].

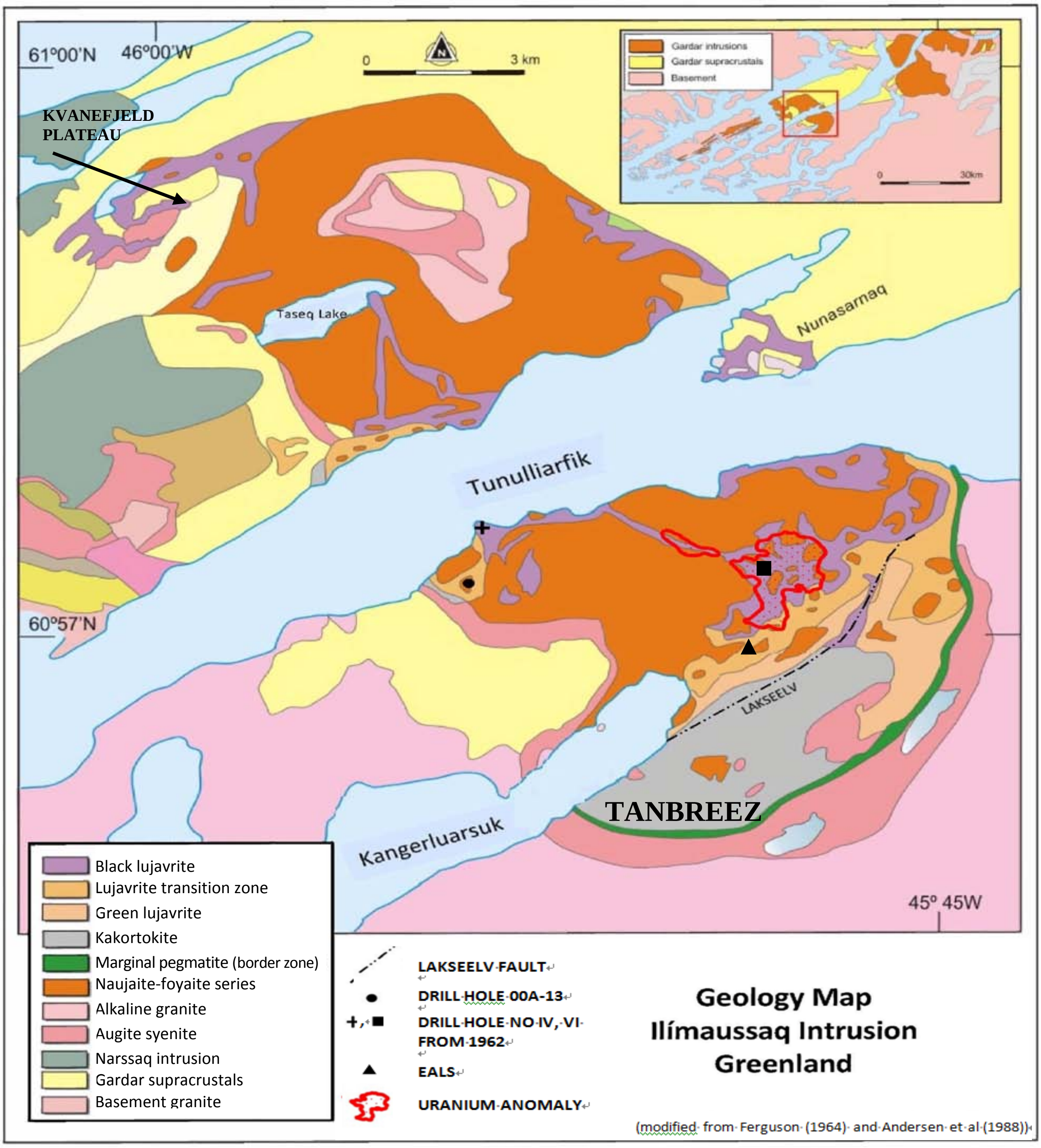

Fig. 2 Geological map of the IlÍmaussaq Complex, showing drill holes and other locations mentioned in the text (Modified from Ferguson (1964) [13] and Andersen et al. (1988) [15].

4. Geochemistry

The IlÍmaussaq complex follows the general trend of igneous complexes, that REE, U and Th is concentrated in the youngest component of igneous complexes [14]. The general or main mass of arfvedsonite lujavrite has an estimated amount of TREO of 9600 ppm (Table 1), which compared to 4600 ppm in the older kakortokite clearly shows the enrichment in the younger lujavrite.

However, the enrichment in the younger lujavrite is mainly due to an increase in LREO, which is reflected in that HREO make up 27% of the TREO in kakortokite (Tanbreez ore) and only 11% in the mineralized arfvedsonite lujavrite (Table 4 and Table 1).

Table 1 shows the amount of REO, U and Th in the black, arfvedsonite, lujavrite (column 1 and 2) and its mineralized counterparts (column 3, 4 and 5). Only where the mineralized black, arfvedsonite, lujavrite has a hyperagpaitic component and therefore the indicator minerals villiaumite and naujakasite is it straightforward to recognize the mineralized lujavrite. However, where the hyperagpaitic component is missing either radiometric measurements or assays is necessary to recognized and delineate the mineralization, as was the case of the mineralized, black, arfvedsonite, lujavrite south of Tunulliarfik.

5. The Søndre Siorarsuit Hydrothermal Deposit

As part of Tanbreez Mining's regional exploration work on its license 2010/24 (Tunulliarfik), which cover a great part of the southern part of the IlÍmaussaq complex, an exploration hole (00A-13), (Fig. 2), was drilled. The purpose was to test the presence of kakortokite underneath the exposed stratigraphy of the complex as shown on the sections together with the Geological Map at scale 1:20.000 [15].

The drill site was close to the Tunulliarfik Fjord and 400 m east of the augite syenite ring dyke and about 1 km south of a stratigraphic hole (no IV) drilled by the Danish state in 1962, as part of an uranium evaluation of the Ilimaussaq complex [11].

The stratigraphic hole (no IV) from 1962 started in weakly laminated fine-grained arfvedsonite lujavrite (black Lujavrite) which after 48 meter was replaced by 50 meter aegirine lujavrite (green lujavrite) which in turn was followed by 51 meters of arfvedsonite lujavrite and arfvedsonite-aegirine lujavrite and the hole finished in 51 meter aegirine lujavrite.

A similar section could be expected in the Tanbreez exploration hole (00A-13), before kakortokite would be encountered at a depth of approximately 200 meters.

6. Drill Core, 00A-13

Although bedrock close to drill site occurred as fresh the major part of the 327-meter long drill core consisted of intensely hydrothermally altered rocks. Only for some part of the altered rock is it possible to refer to a precursor. Moderate altered lujavrite only make up about 5% of the core whereas 55% of the core is interpreted as pervasive altered lujavrite (PAL). The remaining 40% of the core consists of altered naujaite (25%) and 15% of a presumed altered coarse-grained syenite (ACS) probably representing an overlooked or hidden rock unit of the complex. The altered naujaite is generally recognizable due to the characteristic poikilitic texture and the much coarser grained nature of the rock.

The ACS has a similar texture as the PAL and gives the impression of cutting the PAL, which will make the ACS the youngest rock in the drilled section.

In the following a preliminary petrographic description of the different rock types is given.

6.1 Altered Lujavrite and Naujaite

Arfvedsonite lujavrite occur as a fine-grained rock with anhedral, elongated altered arfvedsonite. Arfvedsonite, which has been replaced by chamosite/clinochlore (J. Nielsen pers. Com.), make up more than 50% of the rock whereas feldspar constitute about 30%. Both microcline and plagioclase occur, generally with the K-feldspar as the most altered. Some altered eudialyte grains are present replaced by very fine-grained catapeliite, nacareniobsite and some unidentified REE-minerals.

Aegirine lujavrite occur in the lower part of the core, where it occurs together with black lujavrite. Aegirine needles make up 5%-10% and provides a faint foliation. Centimeter big brownish poikilitic grains with feldspar chadacrysts characterize part of the green lujavrite. The brownish oikocrysts probably represents arfvedsonite now mainly replaced by chamosite/chlinochlore.

Hydrothermal processes do not destructively effect naujaite texture, since especially the pokilitic texture and the coarse-grained nature of the rock is preserved (Fig. 3). Coarse-grained alkali-feldspar, often pokilitic, dominates whereas plagioclase occur as smaller, lath shaped grains much less altered than the alkali-feldspar. Bright green epidote with minor piedmontite-allanite is a significant component of the alteration as is the fibrous nature of chamosite/chlinochlore replacing arfvedsonite.

6.2 Pervasive Altered Rocks

There are two types of pervasive altered rocks: A fine- to medium-grained and a more coarse-grained both of them leucocratic and with 5%-10% cavities or more. The fine- to medium-grained rock has locally a gradual contact to the less altered lujavrite and represents a pervasive altered lujavrite (PAL). The coarse-grained rock (ACS) cannot immediately be referred to a precursor of the complex and could therefore represent an overlooked or hidden coarse-grained syenite of the complex.

The texture of the PAL rock is hypidiomorphic and plagioclase is the dominant mineral occurring as 1 mm long lath (J. Nielsen pers. com). Ilvaite, which is the next most frequent mineral, occur partly as needle shaped grains and partly as centimeter-sized oikocrysts with chadacrysts of feldspar and epidote. The black oikocrysts on leucocratic background recalls the skin structure of dalmatian dogs (Fig. 4).

Feldspar is also the dominant mineral in the ACS rock with alkali-feldspar as equant, more altered, and coarser grained than the plagioclase, which occur as lath shaped grains. Ilvaite, which is a minor constituent, occur as lath shaped grains.

In both rock types epidote-piemontite-allanite occur as bright green to yellow brownish grains interstitial to feldspar and therefore often closely associated with cavities. Fibrous chamosite/chlinoclore, garnet, sphalerite and zircon occur as accessory minerals.

A characteristic feature of the pervasive altered rocks is the occurrence of hematite which in the PAL occur as veinlet's and breccia fillings whereas hematite generally occur as lens shaped crystals in the ACS (Fig. 4 and Fig. 5).

7. Geochemistry

A microprobe screening for REE on polished sections of the different rock types has shown, that most part of REE occur in grains showing a complex intergrowth of epidote-piedmontite-allanite. The preliminary REE assays of the different rock types is in Table 3.

PAL contain about 10% more TREO than the ACS. However, both rock types show the same relative amount of HREO (about 20%) as is also the case for the altered naujaite, but at a much lower level of TREO. The ilvaite-free endoskarn from Siorarsuit [16] differ somewhat since the HREO only make up about 14% of the TREO (Table 3).

In order to get a picture of element movement as a result of the hydrothermal process a comparison between the altered naujaite and Bailey et al (2001)'s [7] composition of a representative naujaite from the complex is made (Table 3). It is clear; that the altered naujaite is about 20% depleted in REO (e.g. CeO_2 from 1499 ppm to 1154 ppm) and Zn (from 505 ppm to 259 ppm) in relation to the representative naujaite.

According to Graser et al. [16], the endoskarn without ilvaite most likely represent altered naujaite. The absent of ilvaite in the altered naujaite is in accordance with the findings in the drill core. Graser et al (2007)'s assays show that the endoskarn is even more depleted in REO and Zn than the altered naujaite of the drill core (Table 3). However, there is a significant enrichment in Ca in both the endoskarn and the altered naujaite compared to the representative naujaite of Bailey et al. (2001) [7]. The mineralogical expression of the Ca enrichment is the wide spread occurrence of the epidote group minerals.

The precursor of PAL is lujavrite and as expressed above, both green (aegirine) and black (arfvedsonite) lujavrite occur in the section. However, it is not immediately possible to refer different sections of PAL back to green- or black-lujavrite.

Since there is a very big difference in REO content between the aegirine and the arfvedsonite lujavrite, it is not meaningful to compare Bailey et al (2001)'s [7] representative assays of these lujavrites with PAL (Table 3). Regardless of whether the PAL precursor is the one or the other lujavrite the available assays of HREO indicate, that the HREO is enriched in PAL compared to the representative lujavrite of Bailey et al (2001) [7]. This is however not the case for the ilvaite-free endoskarn from Søndre Siorarsuit and the altered naujaite (Table 3).

8. Eudialyte Zone associated with Lujavrite Sill (EALS)

High-grade mineralization of eudialyte occur locally where lujavrite intrudes naujaite. The eudialyte mineralization occur on the contact between lujavrite and the intruded naujaite. The most spectacular occurrences is found where lujavrite sill terminates (Fig. 6). At the nose of the sill, naujaite has been replaced by massive, pegmatitic eudialyte. Because most of EALS appear as sub outcrop, it is difficult to make a statement about the actual size of the mineralization, but the sub outcrop covers an area of about 5000 m^2 (Fig. 2). Similar occurrences have been located within an area of approximately 10 km^2 between the Kangerluarsuk fjord and the Tunulliarfik fjord.

The EALS, which has a sharp contact to lujavrite, is composed of about 50% or more of sub to euhedral eudialyte, up to several centimeter in diameter. Interstitial to eudialyte occur arfvedsonite, feldspar and sodalite (Fig. 6). EALS appear as a pegmatitic eudialyte zone.

9. Geochemistry

Table 4 presents mean of six large samples of massive EALS. For comparison is shown the mean of Tanbreez ore and a eudialyte rich representative sample from Norra Kärr in Sweden [17].

There is a clear relative increase in HREO in EALS compared to the Tanbreez ore, respectively 36% and 27% HREO of TREO.

Further, the relative amount of the individual HREO is approximately the same between in the Tanbreez ore and the EALS, which means that, the relative difference in REO mainly is due to enrichment of LREO in Tanbreez ore (kakortokite) compared to the pegmatitic, eudialyte rich zone (EALS).

The increase in HREO in EALS is followed by an increase in Nb_2O_5 content of approximately 30% based the proportion of zirconia in EALS and the Tanbreez ore.

The Norra Kärr sample show an impressive HREO content of 55% (Table 4). The relative amount of the individual HREO differ somewhat but not striking from the Tanbreez ore, however the most significant difference is the high amount of Y_2O_3 (4559 ppm) in the Norra Kärr sample. The high amount of HREO in Norra Kärr is not reflected in Nb_2O_5 content, which is low, compared to the Tanbreez ore.

Presently the tonnage of the pegmatitic eudialyte zone associated with lujavrite sill (EALS) is being investigated as a possible addition high-grade supplement ore to the Tanbreez mill and thereby increase the overall grade of the mill feed and at the same time keep the composition of HREO nearly constant.

10. Discussion

The three new REE deposit described above, are so different in style of mineralization that they will be discuss separately in the following.

10.1 REE-U-Th Deposit

According to Sørensen et al. (2011), the REE-U-Th deposit at Kvanefjeld is the result of a complex event of lujavrite magma intrusions involving anchieutectic crystallization of the lujavrite magma resulting in continuous release of volatile and residual elements to the upper part of the magma especially to dome shaped part of the magma chamber. This in connection with a tight roof cover are important elements in the formation of the mineralized lujavrites in the IlÍmaussaq complex [14].

Drill hole VI of the drilling campaign by the Danish authorities (Fig. 2) was located in a structural culmination of black, arfvedsonite, lujavrite. The drill hole show a general increase in U from bottom to top and the same is indicated for the few published Th assays [11]. This trend is in accordance with the suggested model for mineralized lujavrite [14]. However, the surface sampling by Tanbreez further shows that in this structural culmination area of lujavrite an enrichment of REO also occur *(Table 1*, column 5), which would be expected as a consequence of liquid fractionation suggested for the formation of the Kvanefjeld deposit [14].

Additionally it appears from *Table 1*, that the three mineralized lujavrite (column 3, 4 and 5) has a very similar grade. Table 1 further indicate that the mineralizing process has increased the TREO by 20% compared to the ordinary lujavrite. In case of U_3O_8 a threefold increase occurred.

With a depth of more than 100 meter of the mineralized lujavrite, as shown in drill hole VI, the 280-hectare uranium anomaly, indicate a global resource of probably hundred million tons or more of a Kvanefjeld type deposit south of Tunulliarfik fjord.

10.2 The Søndre Siorarsuit, Hydrothermal, REE Deposit

Graser et al (2008) report on a similar type of alteration along the border zone (marginal pegmatite) some 500 meter west of the drill site [16]. They classify the alteration as an endoskarn assemblage along fracture zones and not as a massive, pervasive alteration, as is the case in the drilled section. A recent visit to their locality has revealed that outcrop of PAL (pervasive altered lujavrite) with the characteristic dalmatian texture occur along the beach. However, this particular rock type is not dealt with by Graser et al. [16].

Although there is difference between endoskarn of Siorarsuit and the altered rocks of the drill core, both group of rocks presumably belong to the same hydrothermal system. This is primarily supported by the mineral assemblage, the geochemistry (significant enrichment of Ca) of the involved rocks which is unusual for the IlÍmaussaq complex and the occurrence of a unique rock type like PAL with Dalmatian texture in both localities.

Due to lack of outcrop between the drill site of 00A-13 and the outcrop along the beach, it is presumed that a horizontal distance of 400 m has been hydrothermally effected. Further, based on the poor out crop, which most likely is related to the hydrothermal alteration, an area of 10 hectare seems to be a reasonable estimate for the size of the affected area. That, combined with 327 m intensely altered drill core, would give a global resource of about 100 million tons.

Many alkaline complexes exhibit extensive hydrothermal alteration often closely associated with the most REE enriched part of the complex. This has triggered a debate of REE enrichment, is enrichment only caused by crystal fractionation or has hydrothermal process also played a role in forming the mineralization. Salvi et al (2005) has review the topic and concluded, that without a few exception such as the eudialyte bearing layers in the IlÍmaussaq and Lovozero complexes, most alkaline REE deposit originate from a combination of magmatic and hydrothermal processes [18].

In the model for the hydrothermal overprint on the primary magmatic mineralization, Salvi et al. (2005) present a two-fluid model. An orthomagmatic fluid enriched in REE, which component is deposited where mixing take place with a Ca-rich meteoric fluid [18]. The meteoric fluid, which has acquire Ca from the country rock, is responsible for the Ca-metasomatism and the creation of cavities in the upper part of the hydrothermal effected area.

Graser et al. (2008) also discuss the Ca-enrichment of the endoskarn and prefer the Ca source to be an external meteoric fluid [16]. However, they will not exclude that part of the Ca could be related to autometasomatic alteration of the magmatic rocks.

The Ca-metasomatism is important and for the IlÍmaussaq intrusion an unusual chemical phenomenon, which appear as a prominent characteristic of the deposit. The high relative content of HREO (20% of TREO) in this hydrothermal deposit is notable and is probably due to interaction between the hydrothermal fluid and a HREO rich source.

The drill core section of 00A-13 correspond in Salvi et al. (2005)'s fluid model [18], to the upper zone of the hydrothermal system, which is characterized by Ca-metasomatism and porosity. The porosity indicate that some depletion can be expected in this zone. Table 3 shows that REO is depleted from naujaite, whereas the situation for the lujavrite is more difficult because of the uncertainty of the precursor for PAL and ACS. However, some enrichment in HREO occur in the PAL and ACS rock units. According to the model, a more significant enrichment of REO can be expected below the porous, Ca-enriched zone, as is the case elsewhere e.g., Strange Lake, Canada.

Whether the two fluid model is valid for the Søndre Siorarsuit mineralization is yet to be seen. The occurrence, however, represent a target for a 100 million tons hydrothermal REE-deposit where HREO make up 20% percentage of TREO.

10.3 EALS, Eudialyte Zones Associated with Lujavrite Sills

The spatial relation between EALS and lujavrite sills is an important quality of EALS. However, only some lujavrite sills, which intrude naujaite, has EALS associated. It is unknown under which conditions formation of this special type of eudialyte deposit occur. Field relations indicate that naujaite is partly resorbed except for eudialyte, which seems to be redistributed and replace naujait at the front of the lujavrite sill.Consequently,it looks as if eudialyte of EALS is recrystallized naujaite eudialyte.

The REE content of naujaite and kakortokite correlate with ZrO_2 and as eudialyte is the most dominant ZrO2-bearing mineral in these rocks, eudialyte controls the REE budget [7]. The REE pattern of naujaite and kakortokite is very similar and reflects the pattern of eudialyte in the respective rocks. This means, that naujaite has the same change in REE pattern against EALS as in the case of the Tanbreez ore (kakortokite). This imply that naujaite is enriched in LREO compared to EALS and consequently in formation of EALS by recrystallizing naujaite eudialyte a loss of LREO take place.

EALS, Tanbreez ore (kakortokite) and naujaite only has background values of uranium and thorium, which is unlike the enrichment in lujavrite and its eudialyte. This support the assumption, that the eudialyte EALS is recrystallized eudialyte from naujaite because there is no chemical indication of involvement of uranium bearing eudialyte from lujavrite.

From a utilization point of view, this type of eudialyte mineralization is in addition to its high grade also interesting because of its relative amount of HREO, which is very similar to the Tanbreez ore and therefore can upgrade the Tanbreez ore without changing the relative composition of HREO.

11. Conclusion

After decades of exploration work it is still possible to reveal significant new REE-deposits in the alkaline IlÍmaussaq intrusion.

The model developed by Sørensen et al, 2011 for the Kvanefjeld mineralization matches the deposit defined by the uranium anomaly south of Tunulliarfik [14]. Grade and tonnage of the deposit south of Tunulliarfik is comparable to Kvanefjeld and the two satellite deposits north of Tunulliarfik. The structural culmination of the lujavrite, as pointed out in the model, is an important factor in connection with exploration for this type of mineralization in both the IlÍmaussaq intrusion and elsewhere.

The Søndre Siorarsuit occurrence is a new type of REE-deposit in the IlÍmaussaq intrusion, understood in the sense, that it represents a massive, hydrothermal event on the rocks and at a scale of several hundred meter and not just minor hydrothermal effects related to fractures and veins. Ca-metasomatism is important and for IlÍmaussaq intrusion an unusual chemical situation, which appear as a prominent characteristic of the deposit. The high content of HREO in this hydrothermal deposit is notable and probably due to interaction between the hydrothermal fluid and a HREO source.

The spatial relation between EALS and lujavrite sill's is an important but a not fully understood relation. Field relations and the geochemistry of EALS indicate that EALS is formed by redistribution and recrystallization of naujaite eudialyte. The high grade and the fact that the relative amount HREO is very similar to the Tanbreez ore make EALS and interesting contribution to the Tanbreez ore because it will increase the grade but not change the HREO pattern of the mill feed. The EALS deposit is with regard to tonnage order of magnitude smaller than the other two types referred to above. Economic use of this relative small REE-occurrence is only possible if ore can be delivered to a nearby existing mill.

Adding the two new deposits (Kvanefjeld type south of Tunulliarfik and Søndre Siorarsuit) to the known existing deposits (Tanbreez and Kvanefjeld and its two satellite deposits) in the IlÍmaussaq intrusion, will reinforce the impression that this intrusion stands out as having the most promising potential for REE in Greenland and possibly in the western world.

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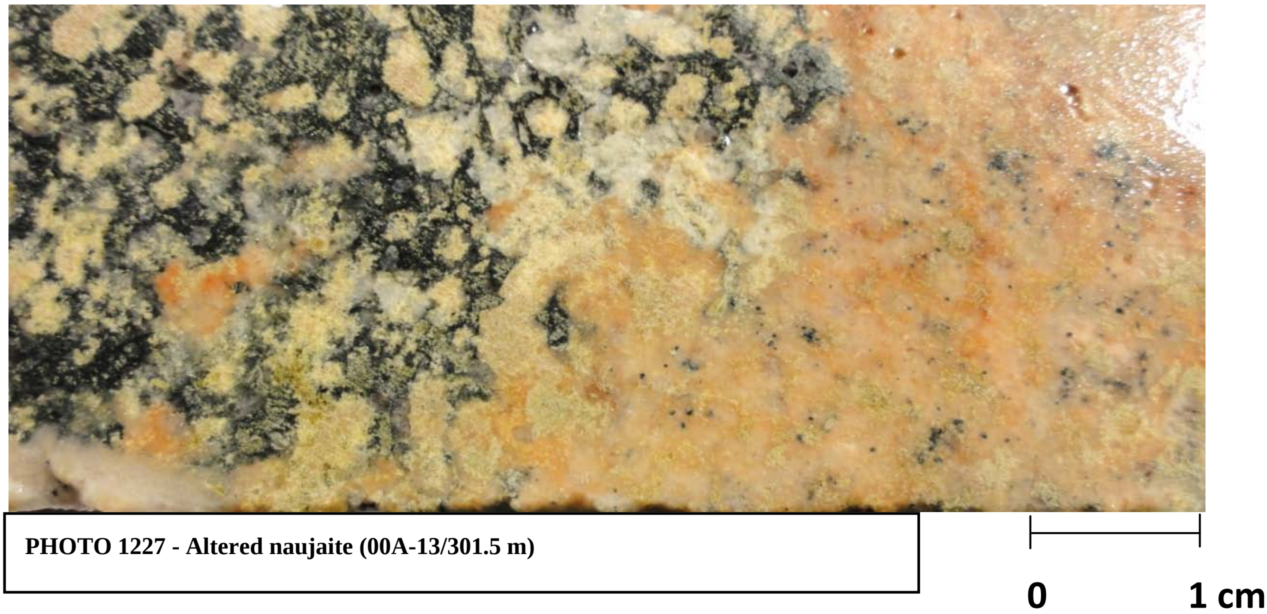

Fig. 3 Altered naujaite (00A-13/301.5 m).

PHOTO 1130 - (00A-13/7.5 m) Ilvaite (black), locally poikilitic, occurring partly as black spots recalls the skin structure of dalmatian dogs.

0 1 cm

PHOTO 1474 - (00A-13/231.0 m) Showing hematite veinlets and replacement of PAL

0 1 cm

Fig. 4 Pervasive altered lujavrite (PAL) with widespread occurrence of tiny cavities.

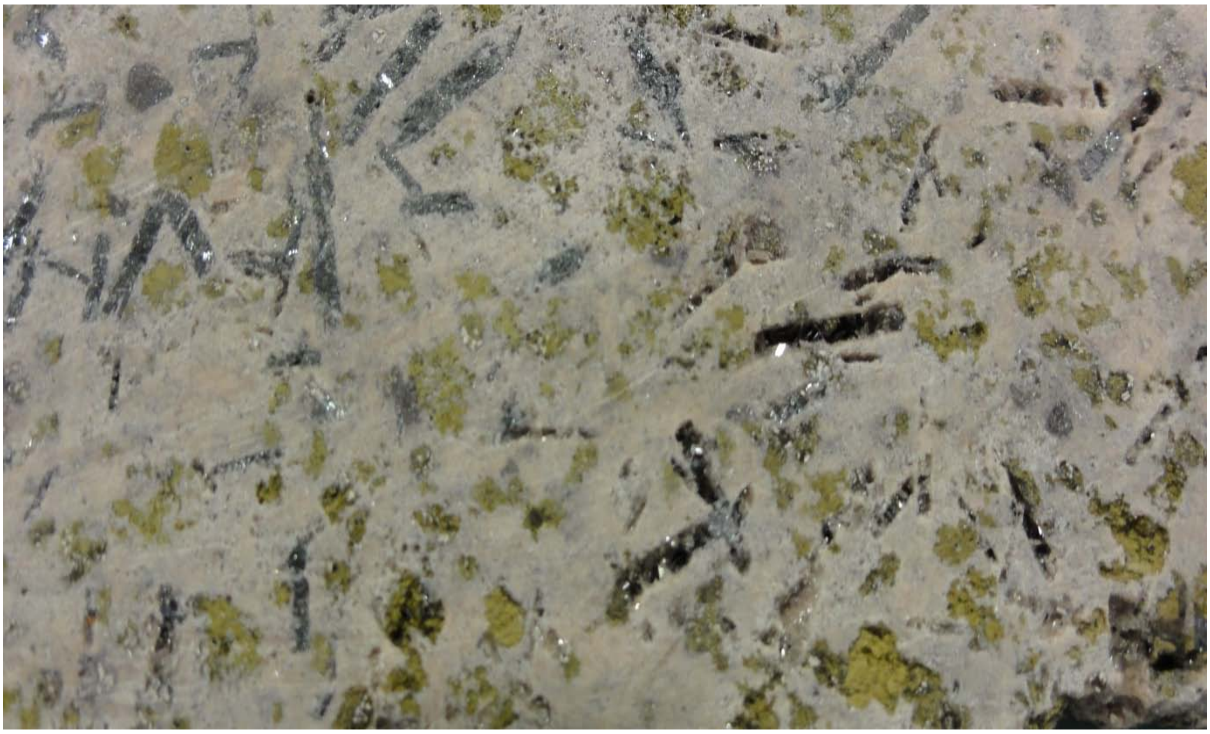

PHOTO 1468 - (00A-13/182.5 m) Hematite occur as lath shaped grains (presumably replacing ilvaite) in a matrix of feldspar and epidote-group minerals (bright green)

0 1 cm

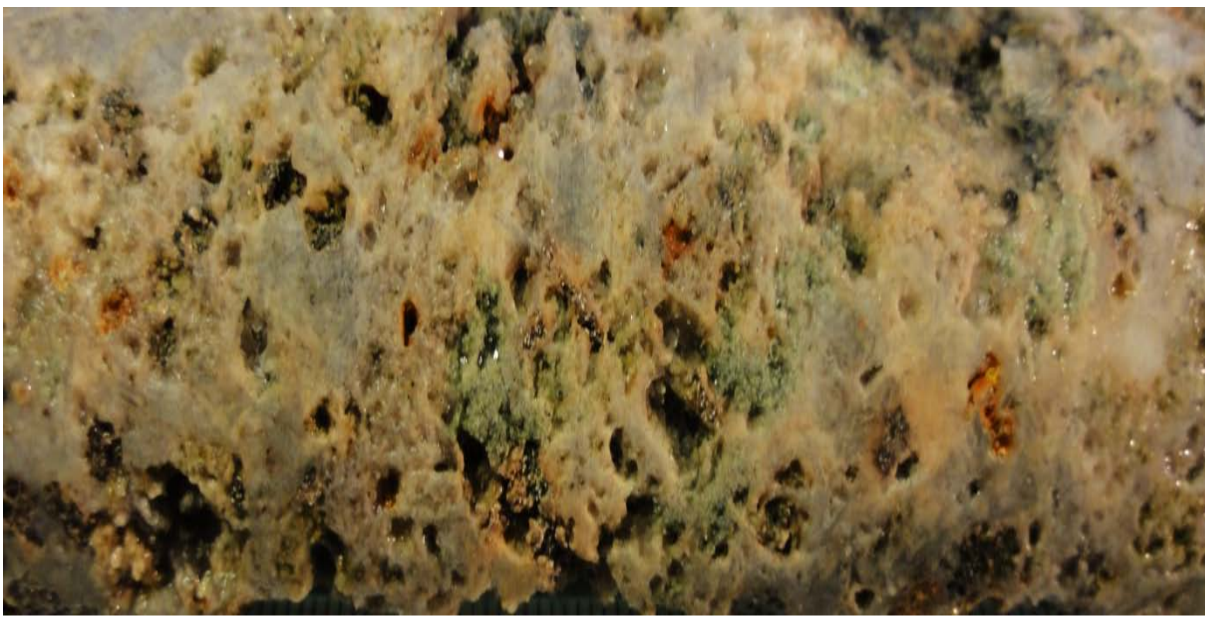

PHOTO 1185 - (00A-13/204.0m) Section showing a very coarse porosity with aggregates of epidote-piedmontite-allanite (bright green to red-brown)

0 1 cm

Fig. 5 Showing variation in what has been interpreted as altered coarse-grained syenite (ACS).

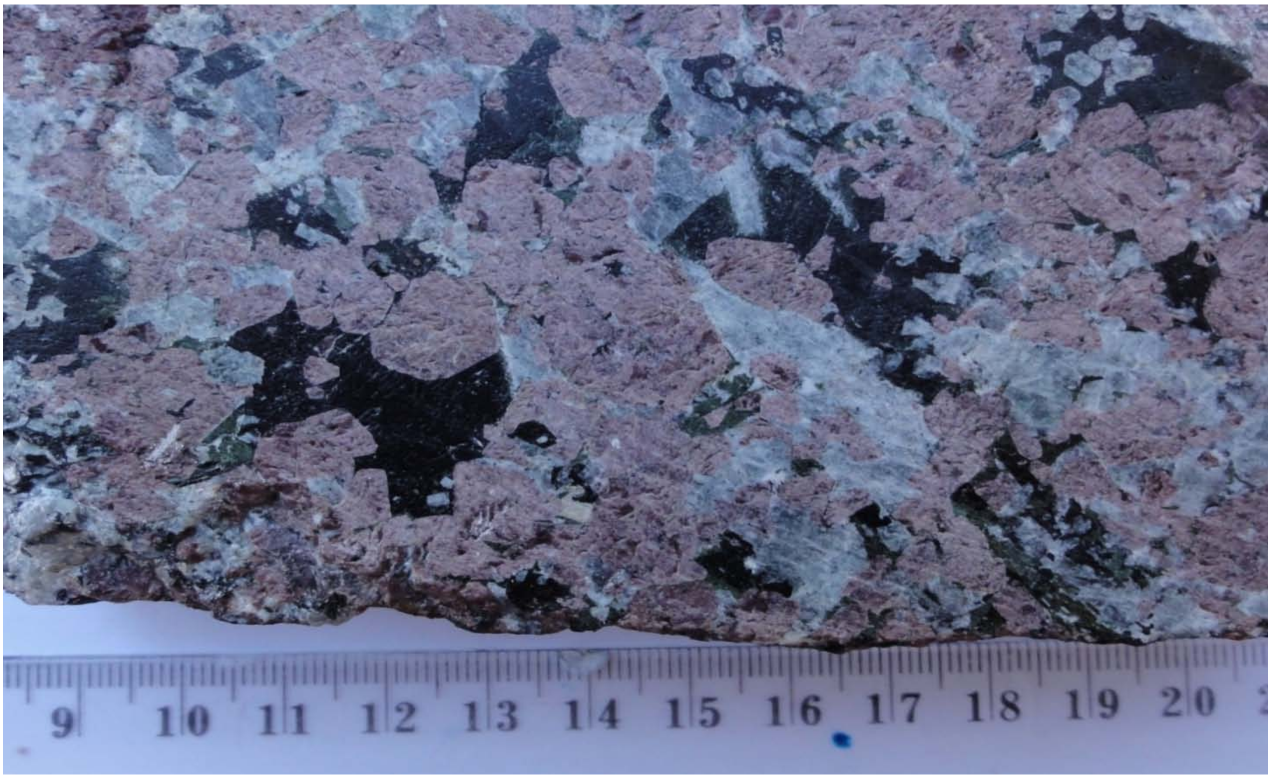

Fig 6 High grade pegmatitic eudialyte (red), EALS, with interstitial arfvedsonite (black) and feldspar/sodalite (white).

Table 1 Comparison of Arfvedsonite Lujavrite and its mineralised counterparts in the Ilímaussaq complex.

	Main Mass of Arfvedsonite Lujavrite	Representative Arfvedsonite Lujavrite	Kvanefjeld Cut Off 200 ppm U_3O_8	Satellite Deposit Sorensen 200 ppm U_3O_8 Cut off	Mean within Uranium Anomaly > 200 ppm U_3O_8
	See ref. [14]	See ref. [7]	See ref. [19]		
Y_2O_3 ppm	NR	815	955	932	943
Nb_2O_5 ppm	NR	714	NR	NR	1217
TREO ppm	9600*	NR	12100	11600	13342
% HREO of TREO	NR	NR	11.3	11.5	10.6
U_3O_8 ppm	118	146	310	344	343
ThO_2	114	73	NR	NR	370
Th/U	1	0.5	NR	NR	1.19

Notes: * The TREE has been converted to TREO by using 1.2 as a general factor for the whole group of REE; NR means "Not Reported".

Table 2 Analysis of Arfvedsonite Lujavrite from IlÍmaussaq Intrusion.

	Mean of Arfvedsonite Lujavrite within Uranium Anomaly			Drill Hole 55, 162.59M	Representative Arfvedsonite Lujavrite
	PPM	% of TREO	% of HREO	See ref. [14]	See ref. [7]
CeO_2	5926	44.4		4791	6191
La_2O_3	3649	27.4		3765	4328

(Table 2 continued)

	Mean of Arfvedsonite Lujavrite Within Uranium Anomaly			Drill Hole 55, 162.59M	Representative Arfvedsonite Lujavrite
	PPM	% of TREO	% of HREO	See ref. [14]	See ref. [7]
Pr_6O_{11}	541	4.1		NR	NR
Nd_2O_3	1598	12		1093	1831
Sm_2O_3	202	1.5		NR	264
Eu_2O_3	17	0.1		NR	20
Gd_2O_3	143	1.1	10.7	NR	NR
Tb_4O_7	4	0.2	1.7	NR	27
Dy_2O_3	128	1	9.1	NR	NR
Ho_2O_3	24	0.2	1.7	NR	NR
Er_2O_3	69	0.5	4.9	NR	NR
Tm_2O_3	10	0.1	0.7	NR	NR
Yb_2O_3	61	0.5	4.3	NR	217
Lu_2O_3	8	0.1	0.6	NR	NR
Y_2O_3	943	7.1	66.9	756	815
TREO	13342	-	-	-	-
% HREO of TREO	10.6	-	-	-	-
Nb_2O_5	1217	-	-	687	714
U_3O_8	343	-	-	112	146
ThO_2	370	-	-	87	73

Note: NR means "Not Reported".

Table 3 Analysis of rock types and its altered counterpart in the IlÍmaussaq Complex

		See ref. [7]			See ref. [16] Mean of N = 3	This Study, Mean of:		
		Naujaite	Aegirine Lujavrite	Arfvedsonite Lujavrite	Siorarsuit Ilvaite-free Assamblage	Altered Naujaite	ASC	PAL
%	CaO	1.7	0.8	0.4	5.5	6.8	4.76	5.6
PPM	CeO_2	1449	2162	6191	599	1154	3192	3427
	La_2O_3	690	990	4328	336	570	1635	1650
	Pr_6O_{11}	NR	NR	NR	70	134	337	380
	Nd_2O_3	629	798	1831	217	423	1150	1328
	Sm_2O_3	111	124	204	30	73	203	238
	Eu_2O_3	11	14	20	3	7	20	23
	Gd_2O_3	NR	NR	NR	29	61	166	197
	Tb_4O_7	18	21	27	4	11	29	34
	Dy_2O_3	NR	NR	NR	18	59	156	185
	Ho_2O_3	NR	NR	NR	3	13	33	39
	Er_2O_3	NR	NR	NR	9	35	69	103

(Table 3 continued)

		See ref. [7]			See ref. [16] Mean of N = 3	This Study, Mean of:		
		Naujaite	Aegirine Lujavrite	Arfvedsonite Lujavrite	SiorarsuitIlvaite-free Assamblage	Altered Naujaite	ASC	PAL
PPM	Tm_2O_3	NR	NR	NR	1	9	12	14
	Yb_2O_3	43	67	47	8	32	78	88
	Lu_2O_3	6	8	7	1	4	10	12
	Y_2O_3	585	771	815	126	381	1016	1211
	TREO				1454	2966	8106	8929
	% HREO of TREO				14	20	19	21
	Zn	505	846	2570	169	259	4207	2354

Note: NR means "Not Reported".

Table 4 Comparison of Tanbreez Ore with EALS and A Representative Eudialyte rich Ore Sample from NorraKärr, Sweden.

	TANBREEZ			EALS			NORRA KÄRR		
	ORE GRADE	% OF TREO	% OF HREO	ORE GRADE	% OF TREO	% OF HREO	A Eduialyte Rich	% OF TREO	% OF HREO
	PPM			PPM			Representative		
							Sample PPM		
CeO_2	1602	34.4%		7315	31.4		2487	21.1	
La_2O_3	850	18.3%		3355	14.4		1024	8.7	
Pr_6O_{11}	180	3.9%		789	3.4		318	2.7	
Nd_2O_3	603	13.0%		2840	12.2		1330	11.3	
Sm_2O_3	121	2.6%		593	2.5		104	0.9	
Eu_2O_3	12	0.3%		59	0.3		44	0.4	
Gd_2O_3	110	2.4%	8.6	656	2.8	7.5	414	3.5	6.4
Tb_4O_7	22	0.5%	1.7	134	0.6	1.6	81	0.7	1.3
Dy_2O_3	148	3.2%	11.5	861	3.7	10.0	520	4.4	8.0
Ho_2O_3	32	0.7%	2.5	196	0.8	2.3	120	1.0	1.9
Er_2O_3	98	2.1%	7.6	631	2.7	7.15	349	3.0	5.4
Tm_2O_3	14	0.3%	1.1	94	0.4	1.1	53	0.5	0.8
Yb_2O_3	98	2.1%	7.6	590	2.5	7.1	343	2.9	5.5
Lu_2O_3	13	0.3%	1.0	81	0.3	1.0	43	0.4	0.7
Y_2O_3	750	16.1%	58.4	5128	22	61.3	4559	38.7	70
TREO	4653			23322			11783		
% HREO of Total TREO	27%			36%			55%		
Nb_2O_5	1905			7815			1300		
ZrO_2	17100			57717			22300		

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