THE MOTZFELDT OF THE IGALIKO NEPHELINE SYENITE COMPLEX, SOUTH GREENLAND – *A MAJOR RESOURCE OF REE ELEMENTS*

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Abstract

The Motzfeldt Centre (1,273 ± 6 Ma) is one of four major alkaline centres belonging to the Igaliko complex, part of the Mid-Proterozoic Gardar province of South Greenland. The Centre covers an area of approximately 150 km^2 with excellent 3-dimensional exposure. The Motzfeldt Centre is made up of multiple intrusions of syenite. The syenites were emplaced as two main igneous phases into the Proterozoic Julianehåb batholith and the unconformably overlying Gardar supracrustal rocks. The apparent intrusion mechanism was a combination of block stoping, ring fracture and partial ring dyke formation. The oldest igneous phase, the Motzfeldt Sø Formation, underwent an extreme in situ differentiation, which resulted in the formation of peralkaline residues rich in volatile and incompatible elements. The peralkaline residues gave rise to a complex of late peralkaline sheets of microsyenite and pegmatite, and pervasive hydrothermal alteration with associated Th-U-Nb-Ta-Zr-REE mineralization which increases in the intensity towards the margins, and especially towards the roof of the intrusions.

The highest enrichment of REE and Y and the relative enrichment of HREE are confined to the peralkaline sheet complex in the roof zone of the intrusion. The volumes of the peralkaline microsyenite with 0.6 – 1.1% TREO is huge and can be estimated to a minimum of 80 million tons.

Introduction

High-field-strength-elements (HFSE) such as Zr, Hf, Nb, Ta, Y, REE, Th and U are often enriched in alkaline rocks where a substantial volume of the world's strategic reserves of these elements are found. The mid-Proterozoic Gardar province in South Greenland (Fig. 1) representing the products of repeated rift-related alkaline magmatism9,10 in the Proterozoic Ketilidian (1,900 -1,700 Ma) and Archaean rocks9,10 during the period ~ 1,300 – 1,1406,7,8 Ma. There are approximately ten major intrusive complexes of alkaline rocks of Gardar-age in southern Greenland. The intense enrichment of the HFSE-elements in the agpaitic intrusive units of Ilímaussaq intrusion has been known and evaluated since 197115. The extensive mineralisation of the HFSE-elements in the

Motzfeldt Centre of the Igaliko Complex was discovered in late 1970's4 and Centre has been a target for geological mapping and exploration for Nb and Ta 13,14.

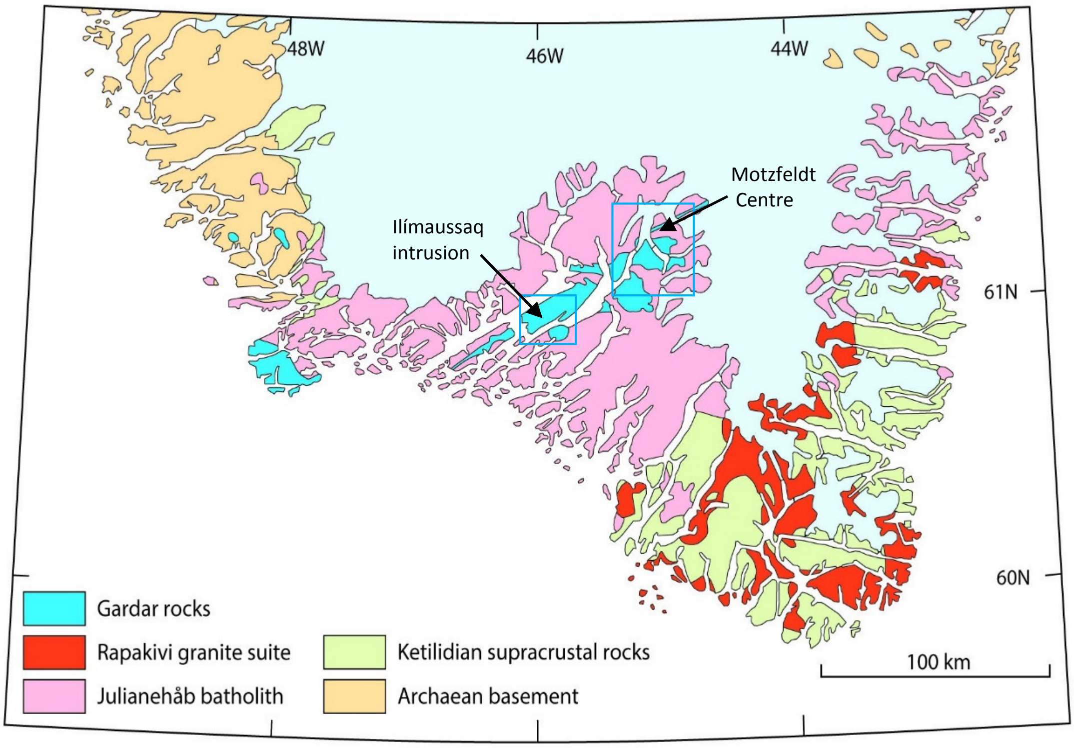

Figure 1: Geological sketch map of South Greenland[1]. The location of the Igaliko Complex, Motzfeldt Centre and Ilímaussaq intrusion is highlighted.

Geology of the Motzfeldt Centre

The Motzfeldt Centre (Fig. 2) appears to be a classic example of central-type alkaline complexes which developed which developed through the successive emplacement of syenite guided by combination of ring fractures and block subsidence.

The syenite units of the main igneous phase originally comprised a circular body about 18 km in diameter having a shape of "bell jar". The contact relationships between the syenites and the syenites/basement rocks in indicate that the emplacement of the syenites took place passively via permissive stoping.

The Motzfeldt Sø Formation (MSF) is the oldest unit of the centre and now occupies its outer part. The MSF has been divided into two major concentric zones: namely inner Nepheline syenite and outer altered syenite. No evidence of these zones as separate intrusions has been found. The MSF hosts a conspicuous sheet complex of pegmatite/aplite and peralkaline lujavrite and peralkaline microsyenite.

The Flinks Dal Formation (FDF) occupies the core of the MRS and includes three major intrusions of phonolitic composition.

The present exposure of syenites is an intricate combination of faulting an topography. The Centre was affected by two major sets of vertical or nearly vertical faults, one striking NE-SW (older) and another approximately E-W (younger). The fault sets display both vertical and horizontal component.

The younger E-W striking faults are characterised by movements in sinistral sense. The Flinks Dal Fault (Fig. 2) traverses the whole centre with a horizontal component of about 6 km.

The present altitude of the Eriksfjord Formation/basement unconformity provides a means to evaluate the magnitude of the vertical movements along the faults. The Flinks Dal Fault has the most dramatic downthrow of a minimum of 600 metres to the north.

The Motzfeldt Sø Formation – mineralisation of HFSE-elements

The texturally and mineralogically highly variable units of the Motzfeldt Sø Formation (Fig. 3) contain exceptionally high concentrations of Th, U, Nb, Ta, Zr and REE and volatile components such as F and H_2O. Within the inferred roof zone (fig. 4) the diversity of rock types is most extreme with the highest enrichment of HFSE.

The rock types of the MSF, their mineralogical and chemical characteristics manifest and extreme internal differentiation of the phonolitic (?) magma. Along with the progressive crystal fractionation the incompatible elements and volatile components were increasingly concentrated at the top of the chamber. The build-up of the volatiles must have affected the physical and chemical properties of magma/fluid. The peralkaline magma was able to dissolve large amounts of volatiles[12] and there may have been a gradual transition into a hydrothermal fluid. The formation of the peralkaline sheet complex could be related to a formation of such a fluid phase.

The MSF and the peralkaline sheets complex are characterised by the pervasive hydrothermal alteration associated with the subsolidus evolution of the MSF. The textural relationships of the minerals indicate that the migration involved a continuous readjustment (precipitation/leaching) of the mineral phases with the proceeding hydrothermal activity. The proceeding hydrothermal activity was accompanied by the relative and absolute enrichment the HFSE.

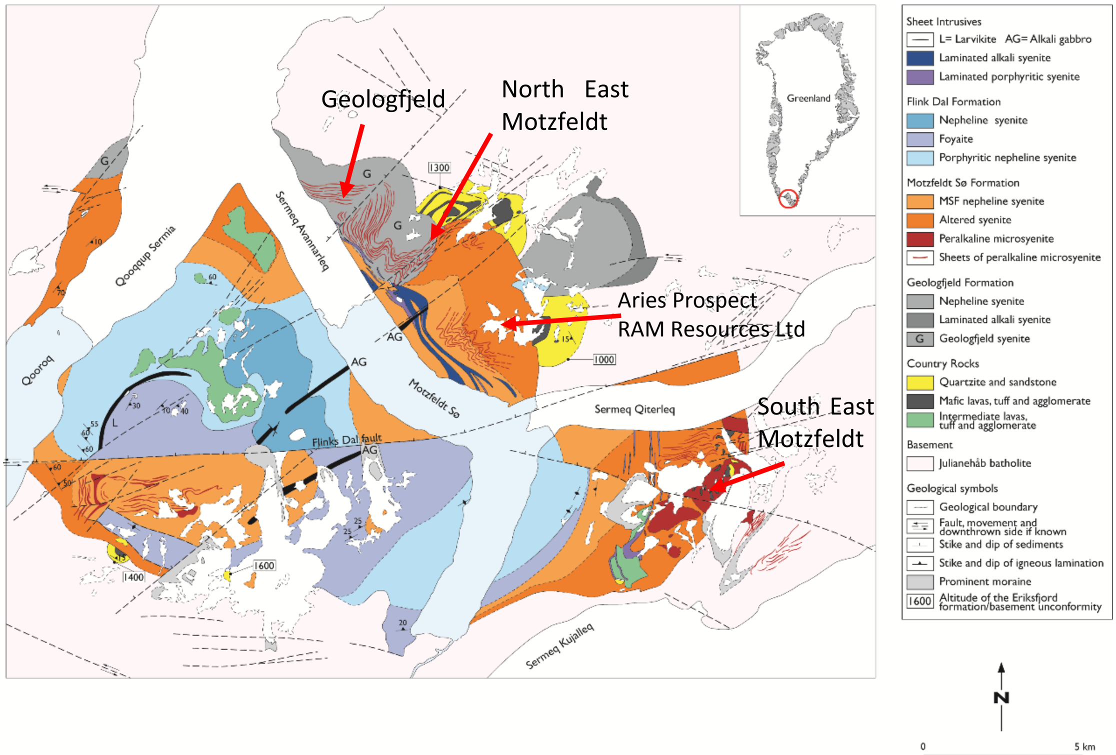

Figure 2: Geological map of Motzfeldt alkaline centre (after Bradshaw[2]; Jones[3]; Tukiainen & al.[4]). The great numbers of dykes, predominantly alkali trachytes of the late-Gardar dyke swarm are omitted for the sake of clarity. The localities referred in the text are highlighted:

The extent and the intensity of the Th-U-Nb-Ta-Zr-REE mineralisation are well outlined by the high resolution airborne gamma spectrometer survey[4].

The mineralogy of the HFSE in the MSF is complex. The REE are dominantly hosted by REE–carbonates, pyrochlore, monazite and eudialyte (table 1.)

The peralkaline sheet complex was sampled in selected mineralised localities as vertical profiles traversing from 20 to 200 metres of ground with a sampling density of reconnaissance character (table 2.).

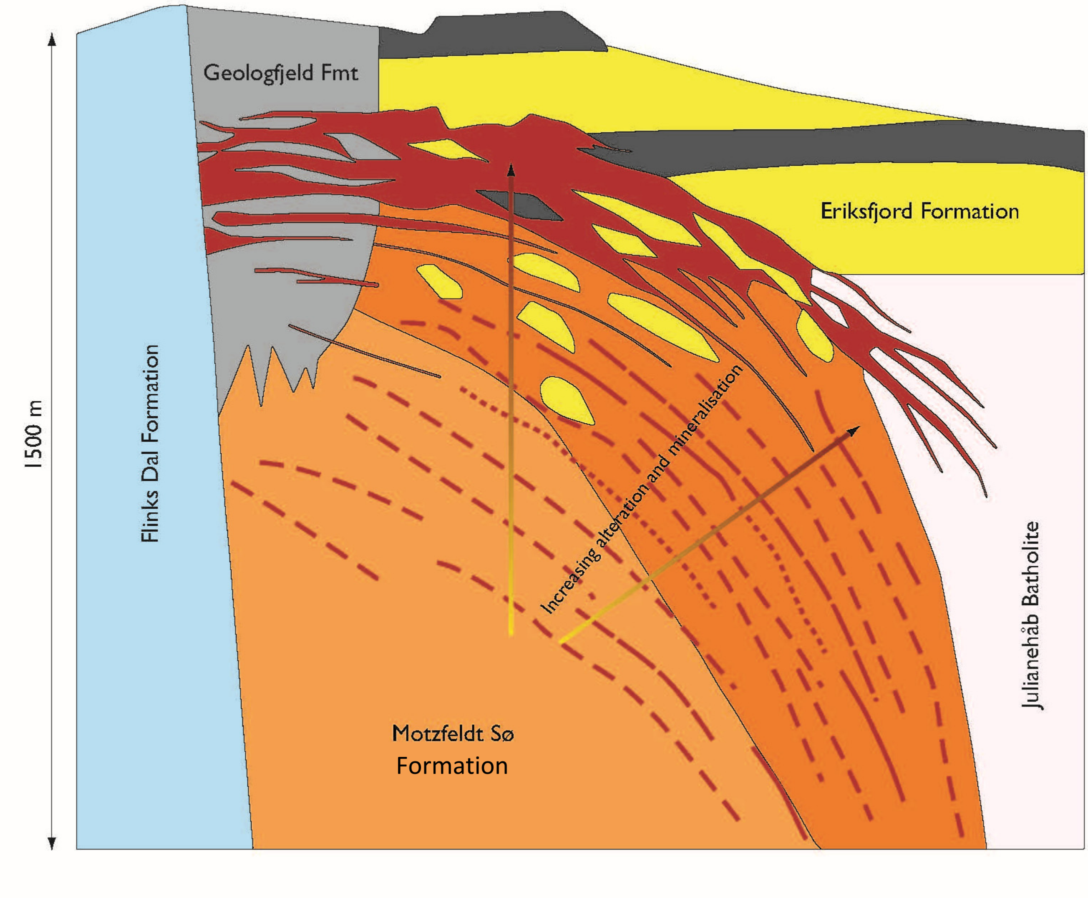

Figure 3: Schematic cross section of the Motzfeldt Sø Formation, explanation of colours same as in Fig. 2

Reserve estimates

The peralkaline sheet complex

The peralkaline sheet complex of the Motzfeldt Centre constitutes a huge reserve of Zr in the class 1-2 % ZrO_2. The extent and the intensity of the Th-U-Nb-Ta-Zr-REE mineralisation is well outlined by the high resolution airborne gamma spectrometer survey. Within the inferred roof-zone, the diversity of rock types is most extreme and roof zone hosts the highest concentrations of HFSE and REE. Large portions of the roof-zone are preserved in North and South East Motzfeldt containing 0.6 - 1.5 % TREO covering 4 and 6 km^2 of ground, respectively. Assuming that only the topmost 50 meters of peralkaline sheet complex is of interest, the rock volumes in this category are c. 1250 Mt containing 0.6 - 1.5 % TREO corresponding to 75 – 187 million tons of contained REO, respectively.

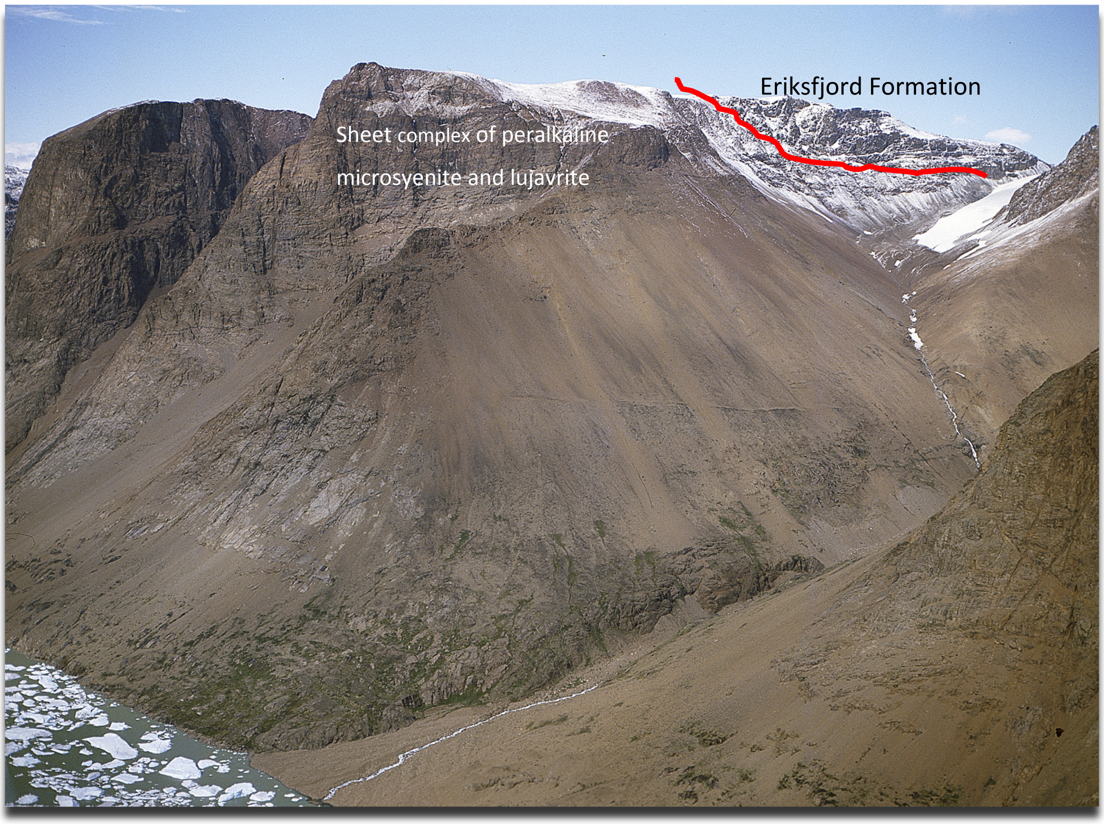

Figure 4: The peralkaline sheet complex of lujavrite and microsyenite in North Motzfeldt. The water table of the lake is 162 metres a.s.l., the mountain top is 1500 metres a.s.l. The MSF roof zone below the Eriksfjord Formation indicated with red colour.

The MSF altered syenite

The enrichments of pyrochlore in the MSF altered syenite have been assessed for their economic potential for Ta and Nb. The Aries Prospect of the Ram Resources Limited (Fig. 1) with an exploration potential of 200 – 500 Mt @1800-2200 ppm Nb_2O_5 , 130-160 ppm Ta_2O_5 and 3000-5000 ppm TREO contained both in Pyrochlore (4-6 % TREO) and REE-carbonate (70 % TREO)

The extraction of Ta and Nb from pyrochlore may also yield significant quantities U, Th, Zr and LREE.

Table 1: Dominant minerals for Nb-Ta-REE-Zr-Y-U in the MSF (Tukiainen[11], *1988)*

Peralkaline sheet complex								
Mineral	**Nb_2O_5**	**Ta_2O_5**	**REE_2O_3**	**ZrO2**	**Y_2O_3**	**UO_2**	**ThO_2**	
Pyrochlore	**54.78**	**1.42**	**16.1**	**1.04**	**-**	**6.88**	**0.13**	**Altered syenite**
Columbite	**68.13**	**0.8**	**-**	**-**	**-**	**-**	**-**	**Altered syenite**
Bastnaesite			**70.0**					**Altered syenite**
Zircon				**46.3**	**2.53**			**Altered syenite**
Thorite					**0.7**	**5.53**	**50.58**	**Altered syenite**
Monazite			**63.5**				**3.3**	**Altered syenite**
Eudialyte	**2.47**	**-**	**5.68**	**12.21**	**-**	**-**	**-**	**Lujavrite, unaltered**
Altered Motzfeldt Sø Syenite								
Pyrochlore	**47.39**	**6.04**	**6.04**	**1.03**		**3.48**	**0.34**	**Altered syenite**
Zircon				**65.05**	**2.0**	**0.1**	**0.37**	**Altered syenite**
Monazite			**64.2**				**4.2**	**Altered syenite**

Table 2: Content of the HFSE-elements in selected mineralised localities of the peralkaline sheet complex of the Motzfeldt Sø Formation

Locality (Map 2)	**∑Ce_20_3,La_2O_3, Nd_2O_3**	***Y_2O_3%***	**U ppm**	**Th ppm**	**ZrO_2 %**	**Nb_2O_5 %**	**Ta_2O_5%**
Geologfjeld	**0.1 – 0.3 % Max. 0.9 %**	**0.06 - 0.1 %**	***100 – 500***	**100 – 600**	**0.6 – 1.5 Max. 2 %**	**0.2 – 0.6 % (Max. 1 %)**	**0.01 – 0.03 %**
North East Motzfeldt	**0.4– 1.1 % Max. 2 %**	***0.02-0.05 %***	***100 – 200 Max. 1400***	**200-300 Max. 1900**	**0.9 – 1.5 Max. 2 %**	**0.2 – 0.5 % (Max. 1 %)**	**0.005 – 0.01%**
South East Mozfeldt	**0.2 – 0.4 % Max. 1 %**	***0.012-0.12%***	***200 - 866***	**300-4936 Max.9000**	**1.0 – 1.3 Max. 2 %**	**0.2 – 0.3 % Max. 1 %**	**0.01 – 0.03 %**

Conclusions

The magmatic differentiation of the Motzfeldt Sø formation resulted in the formation of peralkaline rocks with the exceptional enrichment of HFSE (Th-U-Nb-Ta-Zr, Y-REE) towards the margins and especially towards the roof of the intrusion.

The preserved inferred topmost roof-zone of the intrusion in North East and South East Motzfeldt is likely to host a reserve of c. 1250 Mt with the TREO content varying from 0.6 - 1.5 % TREO.

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