

Multi-element ratios to define estimation domains: Kvanefjeld REE-U-Zn deposit

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Introduction

Kvanefjeld is the flagship orebody of Greenland Minerals and Energy Ltd's (GMEL) Northern Ilimaussaq Specialty Metals Project. The project contains the world's largest Mineral Resource of rare earth elements reported according to the standards of the JORC Code or NI 43-101, and one of the world's largest uranium resources. Mineral Resources are given in TABLE 1. Prefeasibility work on the project was completed in 2012, and feasibility studies are underway.

The host rock for Kvanefjeld mineralisation is lujavrite – a form of nepheline syenite unique to the Ilimaussaq Complex in southern Greenland. The lujavrite occurs in a shallow dipping layer from about 250 m to over 500 m in thickness and extends laterally for several kilometres. The other main rock type in the area is naujaite, also a nepheline syenite. The visual contrast between the dark lujavrite and the lightly coloured, non-mineralised naujaite makes it easy to identify the contacts of mineralisation in core or during mapping. A challenge for GMEL was to identify higher grade zones within the lujavrite that could be accessed at the start of the mining schedule, to improve the economic viability of exploiting a large but essentially low-grade orebody. Delineating zones of common chemistry and ore mineralogy were also of importance, for focussing metallurgical studies and guiding the choice of processing methods.

Early work to establish criteria for subdividing the lujavrite, based either on core logging or statistical analysis of uranium and rare earth element (REE) grades, yielded inconclusive results. Initial resource estimations for Kvanefjeld were based on a single estimation domain, resulting in smoothing of local grade variability.

Classification	Tonnes (Mt)	TREO* (%)	U ₃ O ₈ (ppm)	Zn (%)
Indicated	437	1.1	274	0.22
Inferred	520	1.1	272	0.25

*Total Rare Earth Oxide (lanthanide series plus yttrium)

TABLE 1: Mineral Resources for Kvanefjeld and satellite deposits, as of June 2012, reported at a 150 ppm U₃O₈ cut-off.

Database and Methodology

An alternative approach to domain definition became possible because of the detailed geochemical data collected for the deposit. Since acquiring the project in 2007, GMEL had made substantial additions to the drill hole database, including reassaying historical core and broadening the suite of analyses to cover 14 rare earth elements, yttrium, uranium, zinc and 23 other elements. From the 47,000 m of diamond drilling for the deposit, about 16,000 one metre samples have been analysed for the full set of elements.

The suitability of various elements, singly or combined, for defining estimation domains was tested using Leapfrog software for 3D visualisation, and Isatis for statistical analysis.

Results

An intriguing feature emerged from the statistical analysis of lujavrite composite grades: scatterplots of hafnium or zirconium to any of the heavy rare earth elements show five distinct clusters. This pattern was clearest when hafnium (Hf) was plotted against ytterbium (Yb) (FIGURE 1). The same trait is evident from the five peaks on the histogram of Hf to Yb ratios (FIGURE 2).

The clusters on the scatterplot were used to code the lujavrite composites into five groups, allowing separate statistical and spatial analysis of each group. The key results from this analysis were:

- For each group, the corresponding REE and U_3O_8 grades have a roughly normal distribution, compared to the more complex distribution that is characteristic of the combined lujavrite composites. FIGURES 3 and 4 show how flagging the cluster in the scatterplot one at a time resolves the multi-peak U_3O_8 histogram into simpler, single-peak distributions.
- Spatially, the composite groups have some scatter and overlap, but overall each group appears to form a layer, with boundaries broadly parallel to the overall lujavrite contacts (FIGURE 5).
- Combining the statistical and spatial characteristics, the five groups correspond to five lujavrite layers that have distinct REE and U_3O_8 grades. The mean grades of each layer successively decrease down through the stack of layers.

A group code based on the identified clusters in FIGURE 1 was assigned to the drill hole data and this information was imported into 3D modelling software. From the boundaries of each group, wireframes were constructed of the domain contacts.

Conclusion

The Hf to Yb ratio was adopted as a geochemical marker for dividing the lujavrite into five layers which became the resource estimation domains. The clusters in FIGURE 1 were interpreted as zones that are spatially coherent and statistically distinct enough to justify defining hard estimation boundaries based on these geochemical characteristics.

Of particular importance are the upper two layers, which will be accessed first by mining. The mean Total Rare Earth Oxide (TREO, sum of lanthanide series grades plus yttrium) grade of these layers is about 50%

greater than the lower layers, and uranium grades are also higher. The improved domain definition meant that these higher grade zones were not obscured by the influence of lower grades during estimation. Ongoing studies of Kvanefjeld by GMEL have further characterised the mineralogy and geochemistry of the estimation domains, and shown these domains to be internally consistent and separated by clear boundaries.

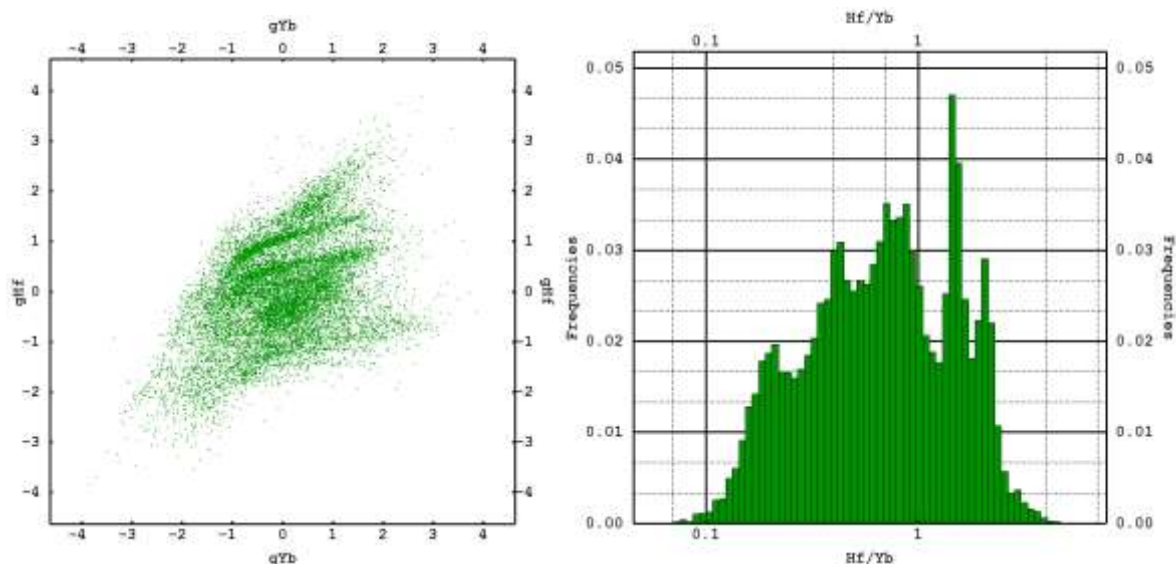


FIGURE 1: Scatterplot of Gaussian-transformed Hf and Yb. **FIGURE 2:** Histogram of Hf/Yb

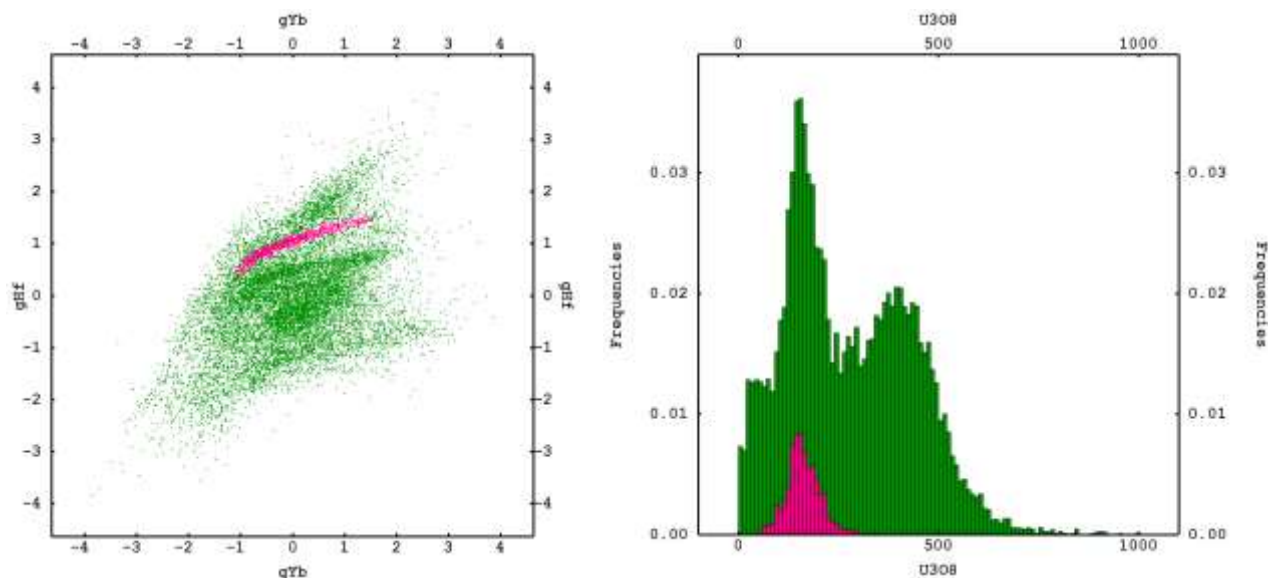


FIGURE 3: Group 2 highlighted on (A) scatterplot of Hf and Yb, and (B) histogram of lujavrite U₃O₈ grades.

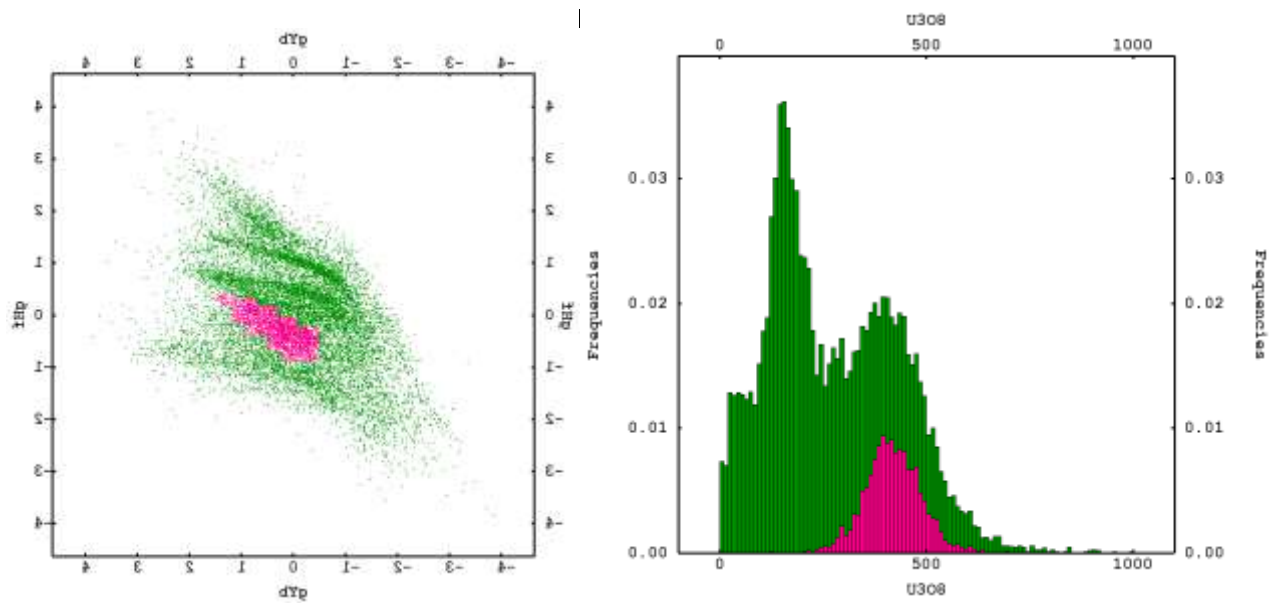


FIGURE 4: Group 4 highlighted on (A) scatterplot of Hf and Yb, and (B) histogram of lujavrite U_3O_8 grades.

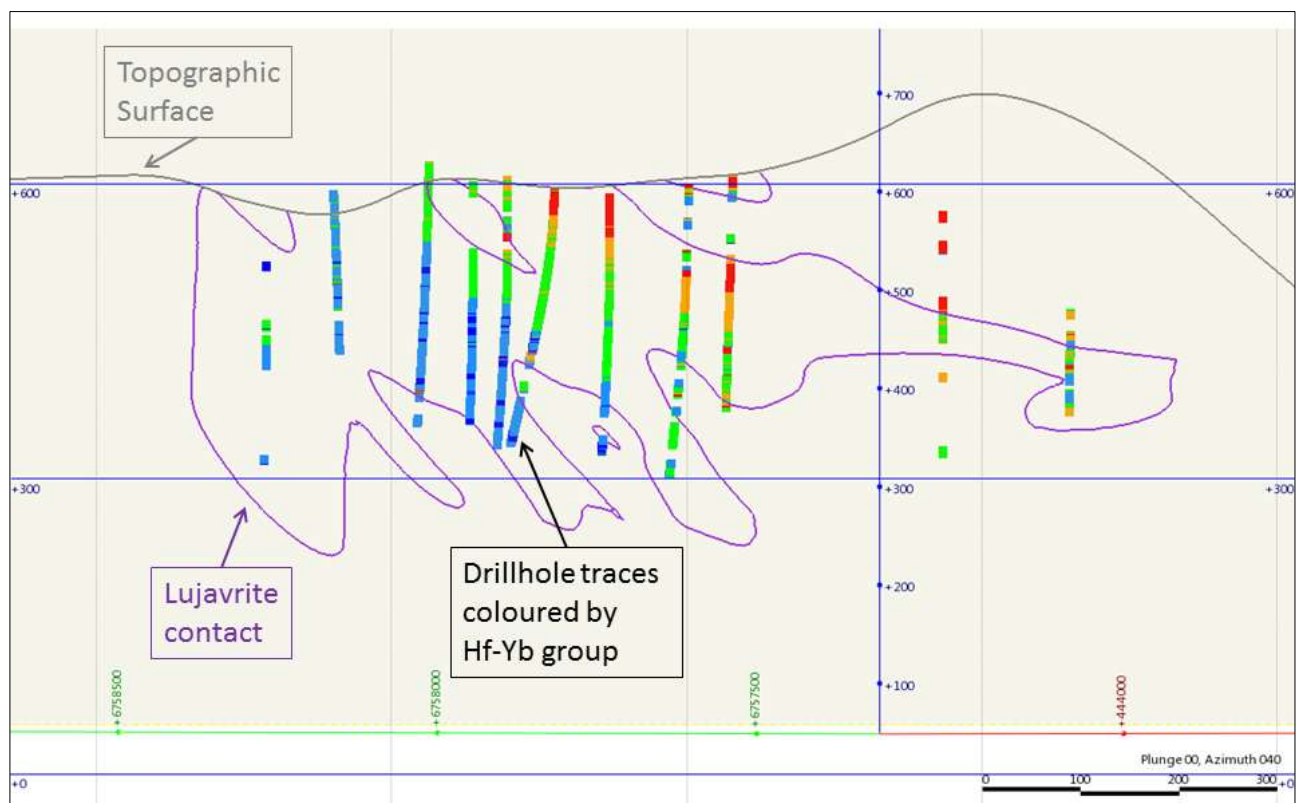


FIGURE 5: Cross section showing lujavrite contact and Hf-Yb coding