The lanthanide tetrad effect as an exploration tool for granite-related rare metal ore systems: examples from Iberian Variscides

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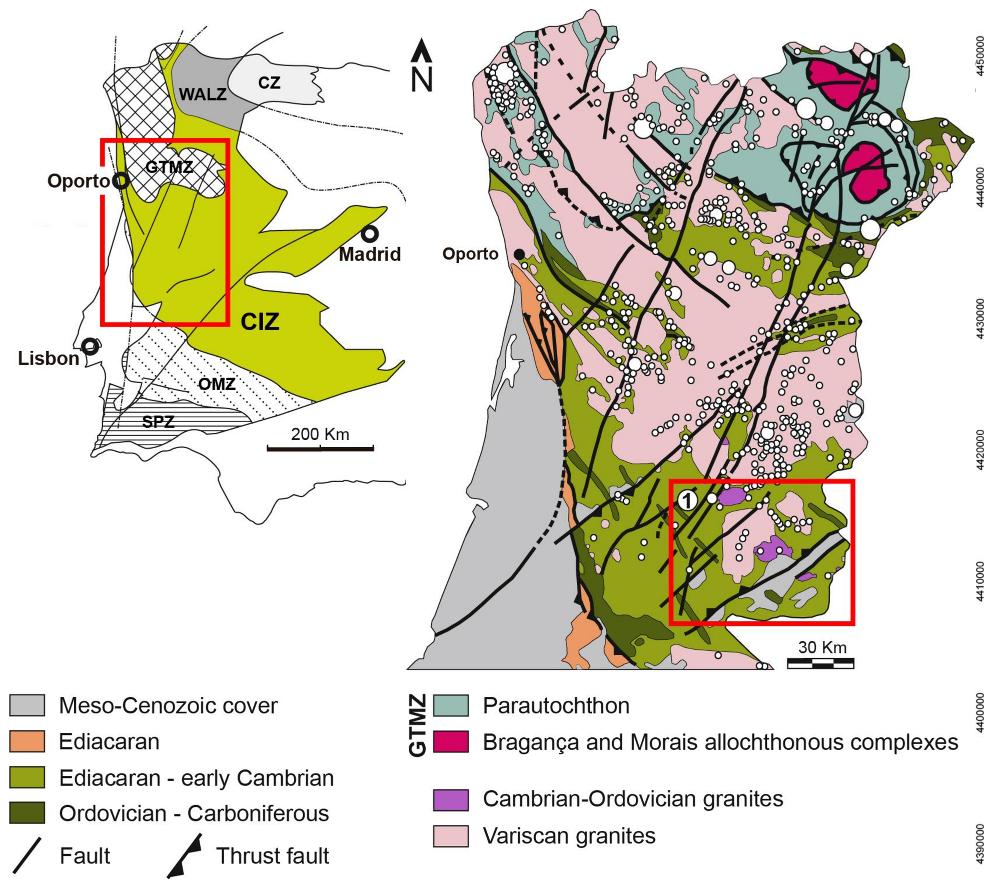
1. Motivation and setting

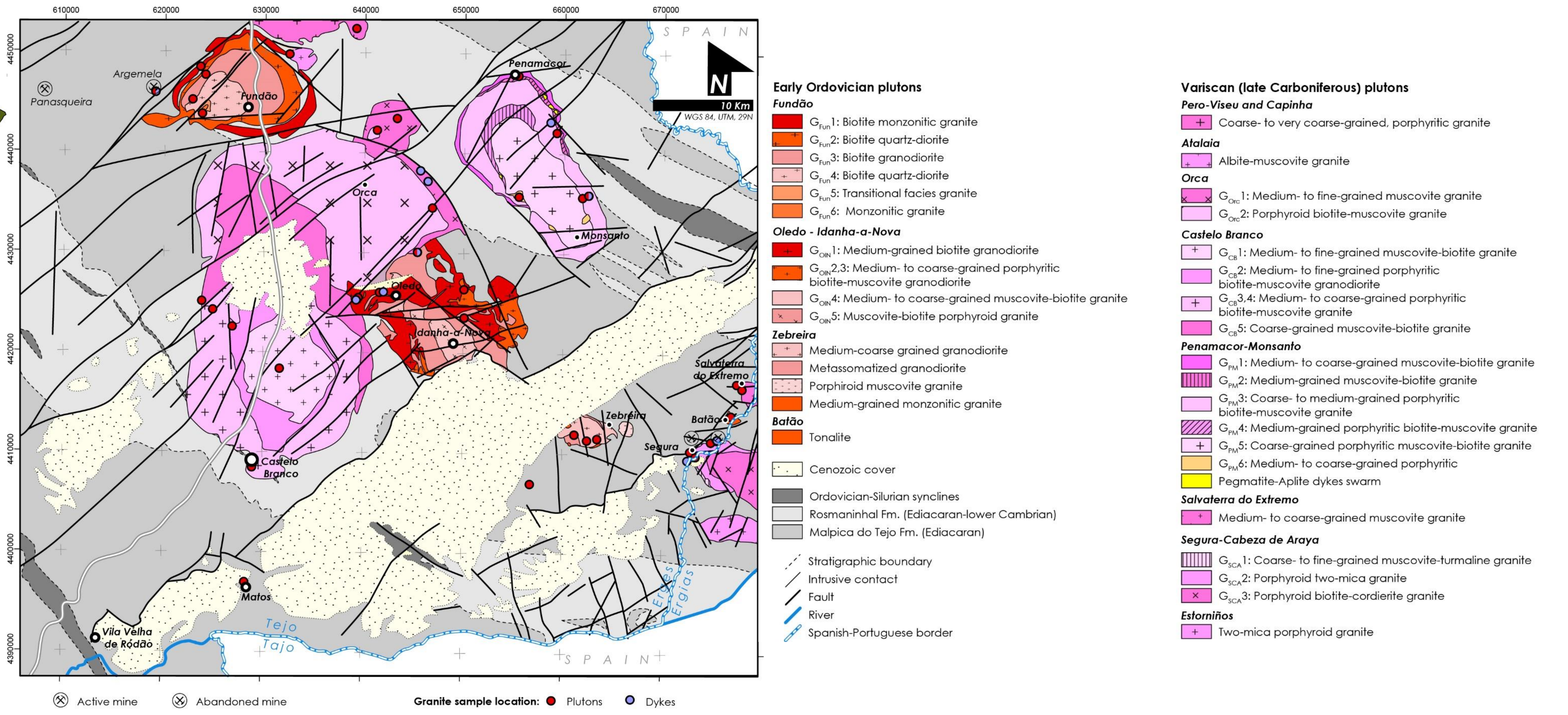
In this work we assess the application of the degree of the lanthanide tetrad effect (**$TE_{1,3}$**; Bau, 1996; Irber, 1999; Monecke et al., 2002) as an exploration vector for granite-related mineralization in the Central-Iberian Zone (**CIZ**).

This study focuses on the Segura-Panasqueira area (CIZ, Portugal), which is characterized by a siliciclastic (shale-greywacke) metasedimentary sequence, belonging to the Beiras Group, that hosts several voluminous granite bodies. Numerous mineral occurrences were recognized in this area, indicating significant metallogenic potential.

Granitic rocks representing two main regional magmatic events:

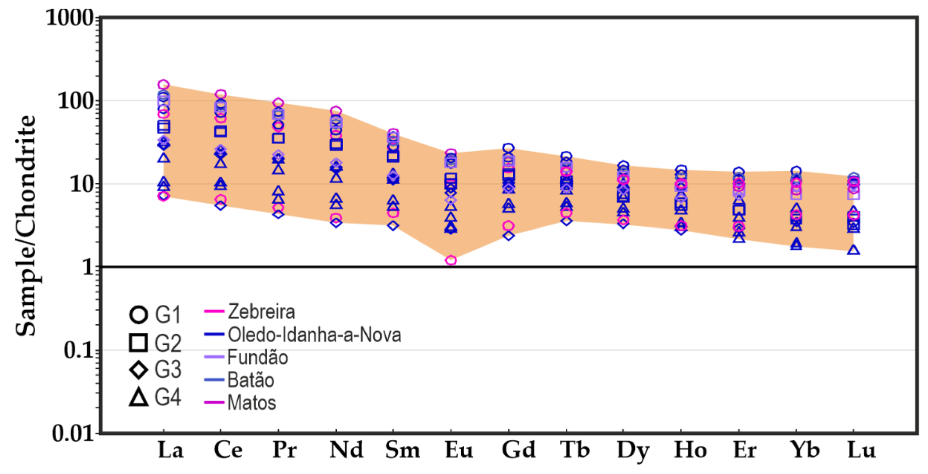
- **Cambrian-Ordovician (490-470 Ma)**
  - Zebreira, Oledo-Idanha-a-Nova, Fundão, Batão and Matos plutons and dykes;
- **Carboniferous-Permian (Variscan – 320-290 Ma)**
  - Castelo-Branco, Salvaterra do Extremo, Capinha, Segura, Atalaia, Orca, Penamacor-Monsanto plutons and dykes, and Zebreira porphyry;
  - Highly differentiated granite rocks that are key references for granite-related ore systems, such as the Panasqueira Granite, Li-Sn Argemela Rare Metal Granite, and the Li-Sn-bearing aplite-pegmatites dykes of Segura.

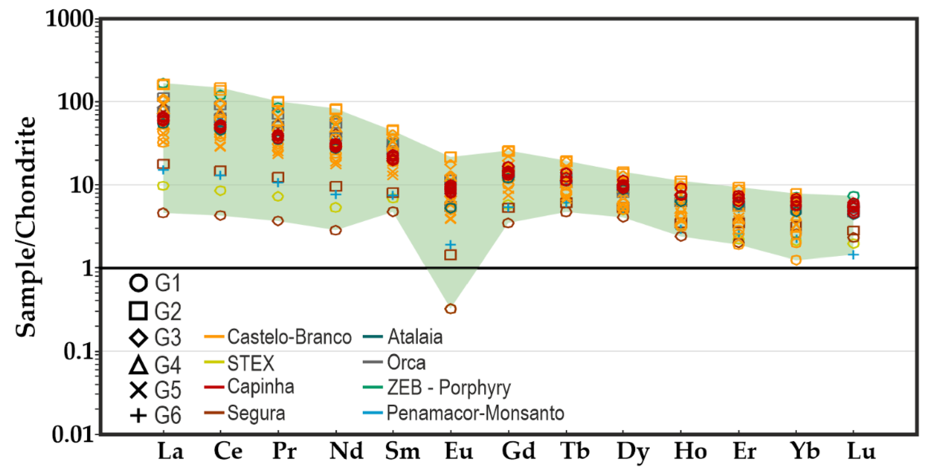




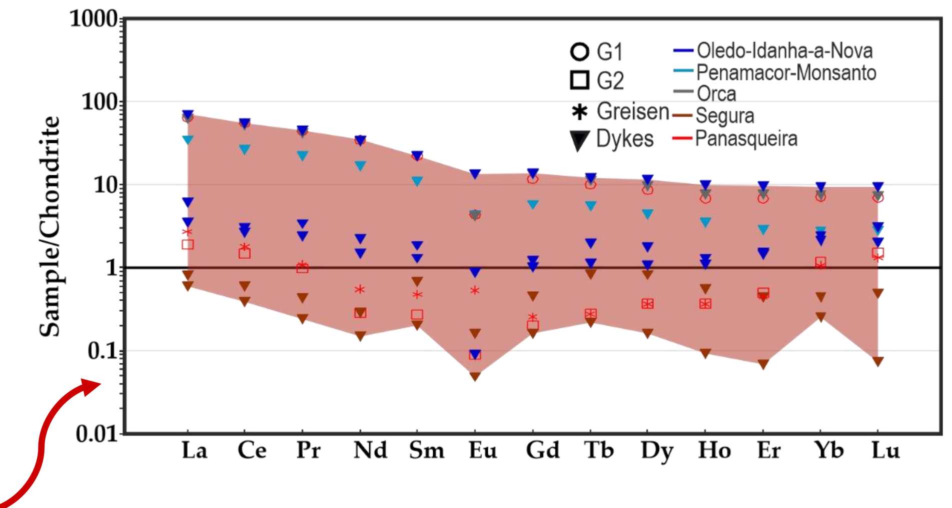
2. Whole-rock geochemistry

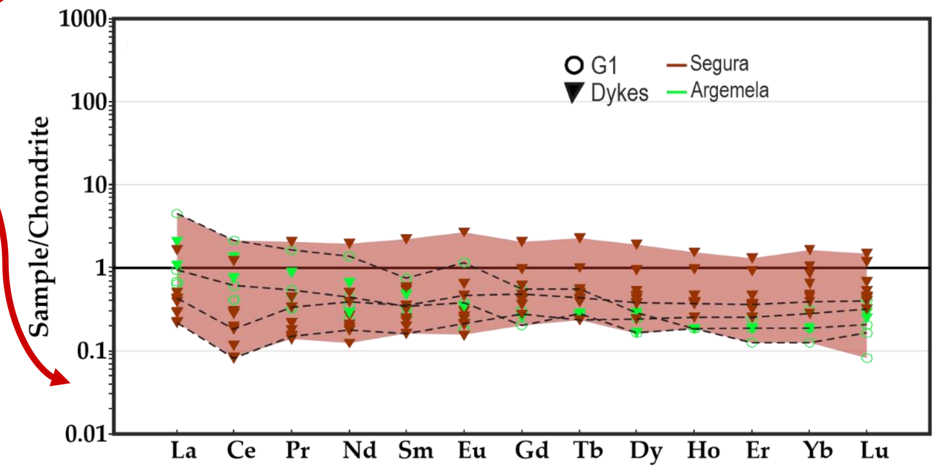
- Cambrian-Ordovician magmatism:
  - Weakly peraluminous I-type;
  - Bt/Bt>Ms tonalite to granodiorite;
  - Calcic to calc-alkalic series and magnesian granitoid rocks;
  - Diorite to normal granite compositions;
  - Volcanic arc granitoids;
- Variscan magmatism:
  - Highly peraluminous S-type;
  - Ms>Bt/Bt>Ms monzogranite to granite;
  - Calc-alkalic to alkali-calcic and magnesian to ferroan granites;
  - Strongly differentiated rocks;
  - Syn-collisional granites;
- Cambrian-Ordovician and Variscan magmatic events:
  - Wide REE concentration ranges, but similar patterns;
  - Negative sloped patterns, LREE enrichments relatively to HREE and negative Eu/Eu*;
  - Comparable $TE_{1,3}$ (0.95-1.20 for Cambrian-Ordovician; 0.99-1.30 for Variscan granites).





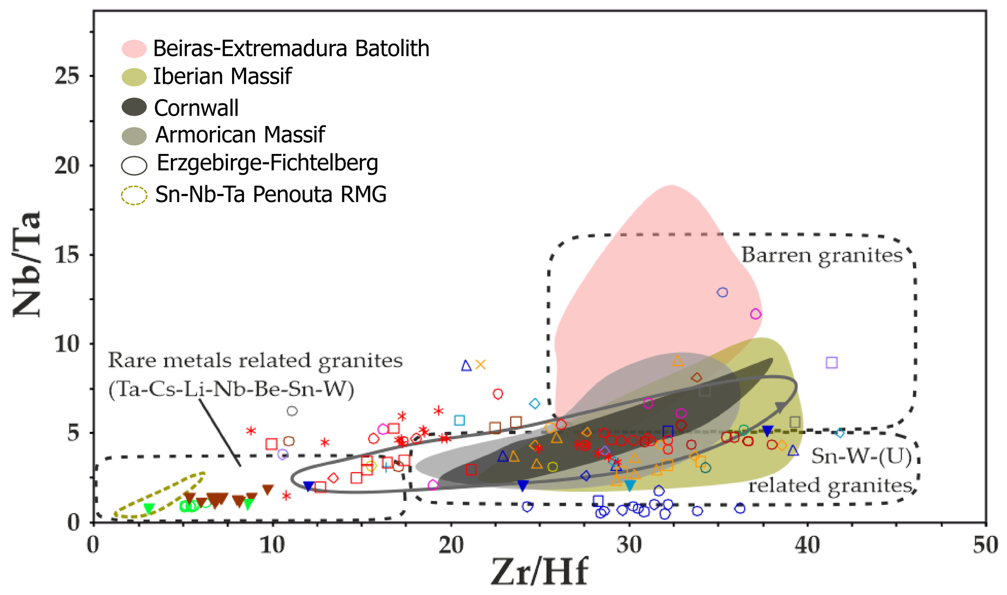
- Highly differentiated rocks:
  - Follow the typical S-type granites fractionation trend;
  - Plot in the leucogranites field, near the Rare Metal Granite composition;
  - Panasqueira greisen, Argemela Rare Metal Granite and aplite-pegmatite dykes from Argemela and Segura deviate from the general trend;
    - **M-type group (convex)** – Wide range of REE contents, negative sloped patterns, slightly flat HREE and pronounced Eu/Eu* anomalies -> $TE_{1,3}$ = 1.01-1.38;
    - **W-type group (concave)** – Low contents of REE, positively to negatively sloped patterns and tendentially positive Eu/Eu* -> $TE_{1,3}$ = 0.71-1.05.

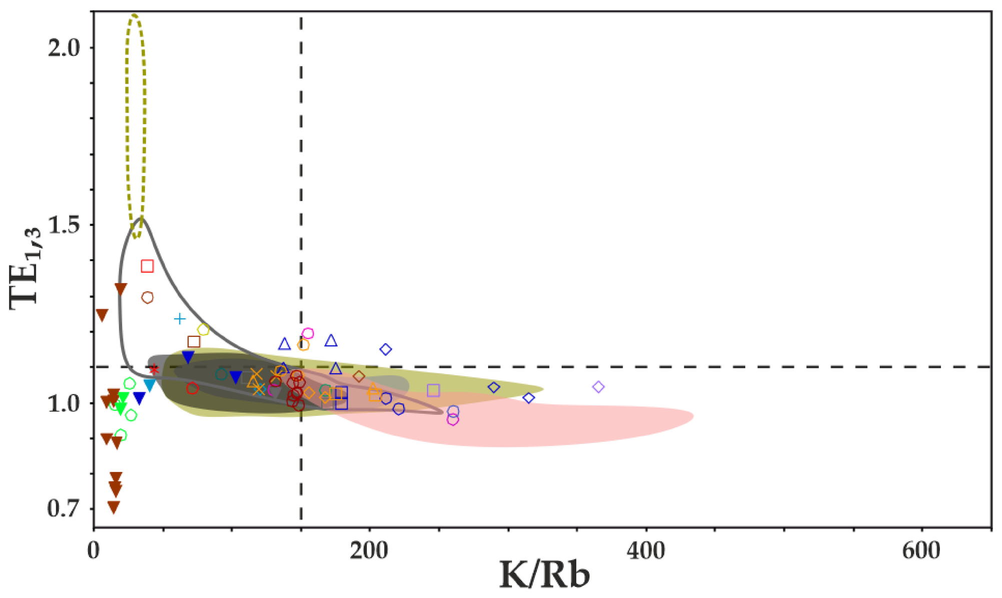


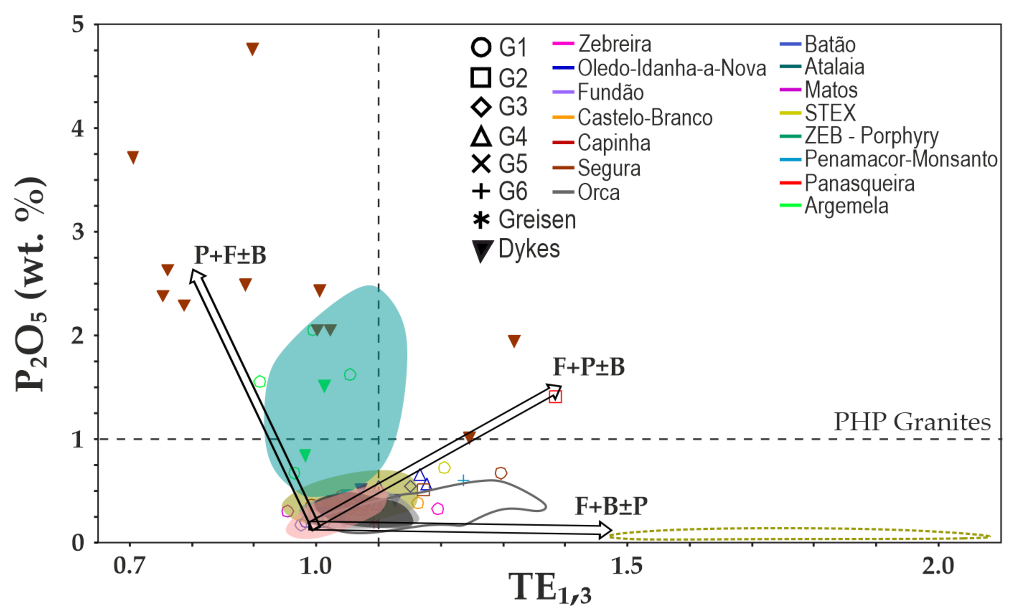


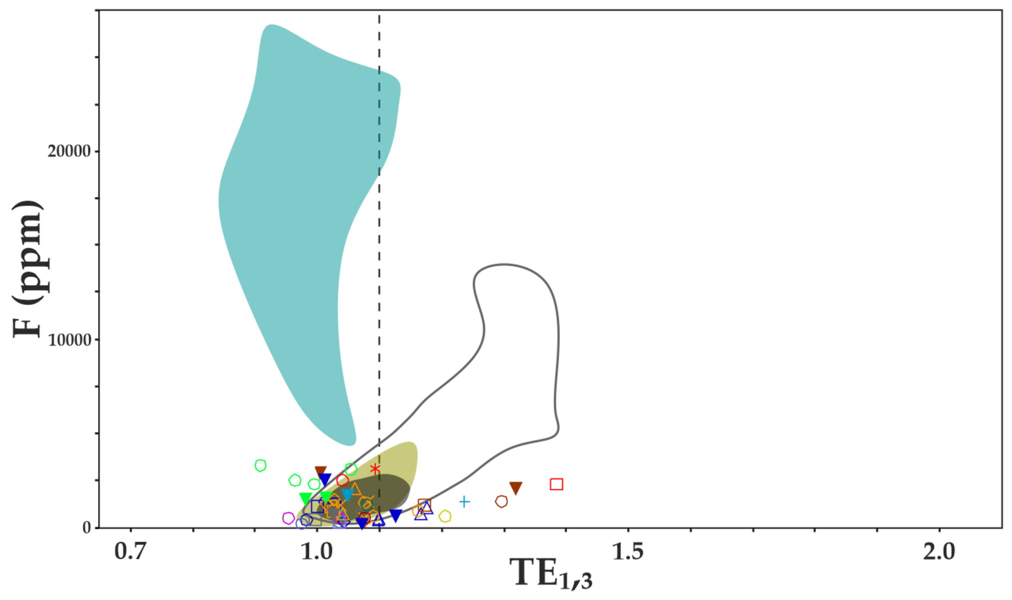
3. Granite differentiation, metal specialization and the $TE_{1,3}$ as an exploration vector

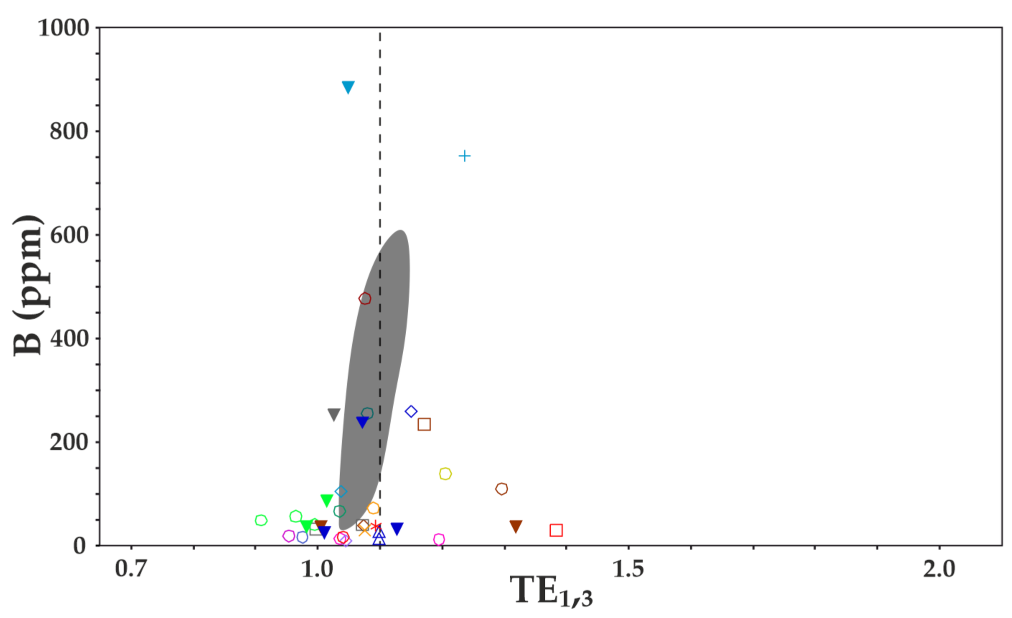
- Good compositional similarity with published data for similar rocks from other sectors of the Variscan belt;
- Clear correlation between different element ratios:
  - Weakly peraluminous Cambrian-Ordovician rocks are less evolved;
  - Highly peraluminous Variscan granites and dykes are strongly differentiated and significantly affected by magmatic-hydrothermal processes;
  - Variscan magmatism tend to be more fertile;
- Granite differentiation led to a progressive enrichment in granitophile elements (e.g., Sn, Li, Nb, Ta, Be, Cs);
- Increase in $TE_{1,3}$ values tend to co-vary with magmatic differentiation and metal enrichment:
  - Poorly differentiated Cambrian-Ordovician granites with the lowest $TE_{1,3}$ values (up to 1.2);
  - Variscan granites showing gradually higher $TE_{1,3}$ values (up to 2.1 – Penouta RMG);
  - Li-phosphate-bearing rocks deviate from this general trend, having no evidence of tetrad effect ($TE_{1,3}$ <1.1);
- **$TE_{1,3}$** values can be used to separate:
  - **P+F±B (P>F)** systems related to Li-Sn Peraluminous-High-Phosphorous granites and Li-phosphates-bearing pegmatite dykes ($TE_{1,3}$ <1.1);
  - **F+P±B (F>P)** systems related to W-Sn-Li Peraluminous-High-Phosphorous granites and lepidolite-bearing aplite-pegmatite dykes ($TE_{1,3}$ up to 1.4);
  - **F+B±P (F>B)** systems related to Sn-Ta-Nb Peraluminous-Low-Phosphorous granites ($TE_{1,3}$ up to 2.1);











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Acknowledgments:

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