The Lanthanide Tetrad Effect as an Exploration Tool for Granite-related Rare Metal Ore Systems: Examples from Iberian Variscides

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The current technological evolution and energy transition policies amplify the dependence on a large number of metals, many of them with low recycling rates. This generates additional pressure on mineral exploration endeavors to search new primary resources for these strategic metals, which are often associated with highly-evolved muscovite-bearing peraluminous granites. Granite differentiation and related magmatic-hydrothermal ore-forming processes can be traced by elemental content ratios such as K/Rb, Sr/Eu, Y/Ho, Rb/Sr, Nb/Ta and Zr/Hf. The lanthanide tetrad effect ($TE_{1,3}$) is also a useful whole-rock geochemical fingerprint of granite differentiation. Its application as an exploration vector for granite-related mineralization in the Central-Iberian Zone (CIZ) is assessed in this work by examining the $TE_{1,3}$ variations along with those elemental ratios, and with the concentration of Sn, W, Nb, Ta, Li and fluxing elements. The U-Pb zircon dating and multi-elemental whole-rock geochemical characterization of the main plutons and late aplite-pegmatite dykes exposed across the Segura-Panasqueira Sn-W-Li belt (in CIZ) show that Cambrian-Ordovician and Carboniferous-Permian granite suites: (i) display different degrees of differentiation and metal-enrichment; and (ii) their compositional features compare well with data published for similar rocks from other Variscan segments. Increasing $TE_{1,3}$ (up to 1.5) co-varies with magmatic differentiation and metal-enrichment, and the Carboniferous-Permian granites are more differentiated, and metal specialized. The Argemela Li-Sn-bearing Rare Metal Granite (RMG) and the Segura aplite-pegmatite dykes deviate from this geochemical trend, displaying $TE_{1,3} < 1.1$, but also high P_2O_5 contents. The results obtained suggest that mineralized rocks related to Peraluminous-High-Phosphorous Li-Sn(-Nb-Ta) granite systems are typified by $TE_{1,3} < 1.1$, whereas those associated with Peraluminous-Low-Phosphorous Sn-Ta-Nb granite systems display $TE_{1,3}$ well above 1.1, reaching values as high as 1.7-2.1 in the case of the Penouta RMG (NW Spain).

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