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Origin, Timing of Magmatism, and Critical Metal Enrichment in the Alkaline Ferroan Granites of North Central Nigeria

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The transition from subduction-related magmatism during Pan-African orogeny to post-tectonic anorogenic alkaline magmatism in north-central Nigeria was driven by reactivated deep-seated lineaments during the Mesozoic era. Notably, the anorogenic ring complexes in this region are renowned for hosting economically valuable metals, including Mo, Nb, REE, Sn, Y, Zn, and Zr. A comprehensive understanding of the primary enrichment processes within selected complexes and their geological constraints is imperative for future exploration and development. Recent studies employing mineralogical, geochemical, isotope analysis, and zircon trace element geochemistry techniques have revealed a pattern of decreasing age from north to south (ca 214 to 141 Ma) and significant enrichment of critical metals. The alkaline granite magma and associated fluids originate from the lower crust with contributions from the upper mantle, as indicated by zircon Hf(t) values ranging from 10.06 to - 4.38. These granites are classified as A-type granites that mainly comprise peraluminous biotite granites and peralkaline amphibole-bearing granites, characterized by high differentiation and hypersolvus mineralogy containing columbite, fluorite, pyrochlore, and topaz accessories. Geochemical signatures indicate varied redox conditions during their formation spanning from log FMQ = -1.1 to +3.0. The ore-bearing minerals reveal two distinct types with varying composition and alteration stages. Primary ore grains, enriched in critical metals, form synchronously with the development of the fluid phase during crystallization in the oversaturated alkaline rocks. Subsequent hydrothermal alteration stages exhibit changes in composition and microstructure, reflecting ore-metal mobilization processes. The granites exhibited significant enrichment of key elements such as Nb (562–1568 ppm), ΣREE (1330-2244 ppm), Y (215-2390 ppm), and Zr (72-3070 ppm) but these enrichments are transitional compared to world-class deposits. The concentration of Sn and Mo within peraluminous biotite granites is attributed to sodic-potassic alteration or greisen-related mineralization processes. Conversely, Nb and REEs are primarily enriched in peralkaline amphibole-bearing granites, facilitated by Na-rich hydrothermal fluids. The presence of fluorine plays a crucial role in retaining these metals in the peralkaline melt until the late magmatic stage, where minerals such as pyrochlore, and REE-bearing minerals crystallize.