

Magmatic to metasomatic processes in the genesis of volcanic-intrusive alkaline-carbonatite REE-HFSE deposits along the South Qinling Orogenic Belt, China

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The South Qinling orogenic belt hosts a spectrum of rare earth element (REE), niobium (Nb), and tantalum (Ta) deposits, including the Miaoya carbonatite-syenite REE-Nb deposit, Tianbao trachyte Nb deposit, and Tudiling/Wenjiawan trachyte-phyllite Nb-Ta deposits. These mineral systems share a common alkaline magmatic origin, with recent identification of extrusive carbonatites at Wenjiawan (REE-Nb-rich with monazite, bastnäsite, and columbite assemblages) providing critical insights into their magmatic-hydrothermal evolution.

The Wenjiawan extrusive carbonatites exhibit a matrix dominated by calcite-apatite and phenocrysts of altered Fe-oxides (magnetite-ilmenite) in association with quartz. Whole-rock trace element geochemistry demonstrates strong compositional affinity with Miaoya intrusive carbonatites, supporting a cognate magmatic source. Stable isotope analyses of calcite ($\delta^{13}\text{C} = -7.89$ to -9.1‰ ; $\delta^{18}\text{O} = 16.87$ - 18.87‰) reveal distinct geochemical signatures: moderately depleted $\delta^{13}\text{C}$ values compared to primary mantle carbonatites (likely attributed to magmatic degassing), while elevated $\delta^{18}\text{O}$ values suggest significant post-magmatic fluid interaction. Our integrated findings indicate that both Wenjiawan extrusive and Miaoya intrusive carbonatites originated from an Early Paleozoic REE-HFSE-enriched alkaline parental magma. Volatile exsolution processes during Wenjiawan's eruptive history potentially enhanced REE-HFSE concentration. Subsequent metasomatic overprinting also played an important role in REE remobilization and ore-grade mineralization. The South Qinling volcanic-intrusive complex thus encapsulates a dynamic interplay between mantle-derived alkaline magmatism and late-stage metasomatism, establishing a genetic framework for REE-HFSE mineralization in carbonatite systems globally.