

## **Carbonatites: Evolution of high-grade REE mineralization and subsequent processes driving economic exploration**

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Carbonatites are igneous, carbonate-dominated rocks derived from the Earth's upper mantle and crust that are critically important due to their associated economic rare-metal mineralization. Although carbonatites have been the subject of scientific scrutiny for almost a century, many aspects of their origin and evolution, as well as their exploration remain understudied. Carbonatite-hosted rare earth element (REE) deposits have been exploited since the late 1940s and their impact on the market has grown substantially; they now contribute over half of the global REE production. Increased demand for innovative technologies, electronic devices, electric vehicles and renewable energy has created a steadily growing REE industry that requires continuously increasing supply of REE and other critical metals. As the market for REE continues to grow, carbonatites prove to have favorable aspects including simple REE mineralogy desired for current processing techniques, significant tonnages, and high grades (particularly in weathered and hydrothermally modified deposits) that allow them to be exceptional resources worthy of further research and investment. The post-magmatic behavior of REE minerals during deformation and metasomatic reworking is one significant aspect of carbonatite petrogenesis that has direct implications for the economic potential of these rocks. Carbonatites and associated primary ore mineralizations mostly are composed of mineral phases that are highly unstable and easily soluble in the shallow crust or under near-surface conditions. It has been increasingly recognized that secondary processes such as regional fluid flow, weathering or regional low-grade metamorphism often overprint the primary textural, geochemical and mineralogical composition of the carbonatites. These processes, however, not only result in the remobilization or re-precipitation of economically important elements (REE, Nb, Ta, Th and U) but they also modify the original isotope patterns of the primary minerals and fluid inclusions. Due to the unique and often simple mineralogical composition of carbonatites, these secondary processes can often remain

unrevealed, or are barely detectable for rocks which pretend to represent an unmodified carbonatite at hand specimen scale. The current research is focused to this topic to better understand the factors that allow carbonatites to be economically viable and favorable production targets.

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