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Carbonatite-silicate complexes and their critical metals: A unified theory.

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Features of carbonatite complexes that need explaining are why they commonly host ultramafic rocks, including dunites, pyroxenites and glimmerites, why these rocks are intruded by ijolites and, in turn, by nepheline syenites, and why the carbonatites show a close spatial association with phoscorites. We also need to explain why these complexes are unusually enriched in the critical commodities, niobium, the REE and phosphate. The widely accepted explanation for the different rock-types is that they are the result of the fractionation of carbonated olivine nephelinite magmas that crystallise cumulates of olivine and clinopyroxene to form dunites and clinopyroxenites, and evolve through ijolitic and nepheline syenitic compositions to produce carbonatitic magmas. Experimental data, however, show that such fractionation to carbonate liquids is only possible at pressures > 3 GPa, i.e., that carbonatites cannot form by fractional crystallisation in the crust. We propose a unifying theory that we believe explains the various rock types present in carbonatite complexes and also the economic concentrations of niobium, the REE and phosphate in these complexes. According to this theory, the ultramafic rocks are the products of metasomatic reactions between the carbonatitic magmas and the feldspathic gneisses that host the complexes. These reactions consume magma, leaving behind a residue enriched in incompatible components, which crystallises to form banded carbonatite (alternating carbonate and silicate-apatite-magnetite-pyrochlore layers) and/or phoscorite, concentrating niobium to economic levels. These processes are accompanied and succeeded by the release of aqueous-carbonic fluids that fenitise the gneisses. The REE partition preferentially into these fluids to form economic concentrations of REE in the carbonatites and fenites. In addition to carbonatite-induced metasomatism, interaction of the carbonatitic magmas with the host rocks causes them to melt. The melting is restricted initially to the proximal, fenitised gneisses, generating alkaline silicate magmas that intrude the ultramafic rocks, forming ijolites, but with time the melting extends into the unaltered gneisses, to produce magmas of nepheline syenite composition that intrude the earlier-formed ultramafic rocks and ijolites. This unified theory satisfactorily explains the origin of the various rock types that make up carbonatite complexes and the processes that concentrate their critical commodities to economic levels.