Goldschmidt 2024 Abstract
https://doi.org/10.46247/gold2024.23485

The sources of economic carbonatites through time

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Carbonatites are currently enjoying something of a renaissance largely due to increasing awareness that these rocks are among our best sources of critical metals. The dominant paradigm dictates that economic mineralization in carbonatites forms only after protracted magmatic differentiation and post-magmatic overprinting by fluids. There are indications, however, that some mantle sources are more conducive to the formation of economic carbonatites than others, which means that not all carbonatites were born equal with respect to metal budgets.

We interrogate a global database for the radiogenic and stable isotope compositions of carbonatites through the past 3 billion years. In Sr-Nd-Hf isotope space, the carbonatite data array develops between a well-defined moderately depleted endmember, reminiscent of prevalent mantle, and a range of enriched isotopic components. The enriched components are highly heterogeneous and may represent metasomatized mantle lithosphere or various types of recycled sediment located within the convecting mantle. The database suggests further that Phanerozoic and Precambrian carbonatites from continental shields were derived from similar mantle sources that comprise mixtures of moderately depleted and enriched components. In contrast, carbonatites from collision zone settings tend to have extremely enriched Sr-Nd-Hf isotopic compositions not known from the global OIB record. This uniquely enriched ‘mantle’ flavour is best interpreted as an undispersed, discrete sedimentary carbonate component recycled into the shallow mantle beneath active collision zones, where its melting products mix with deeper sourced alkaline magmas.

Temporal evolution diagrams for the neodymium, hafnium, sulphur and boron isotope data suggest that recycled crustal components in the mantle sources of carbonatites became increasingly common after 1 Ga, possibly linked to Earth’s transition into a modern plate tectonics regime at lower geotherms. Establishing of colder subduction mechanisms with time promoted deeper levels of lithosphere transfer into the convecting mantle, including a more effective introduction of volatiles and sediments into the deep Earth. We therefore suggest that it is no coincidence that the richest rare-earth element deposits occur in alkaline rock and carbonatite districts located in Proterozoic mobile belts and Phanerozoic collision zones, where their upper mantle sources may have received a much larger contribution of fertile components from recycled crust.