



## **The geochemistry of carbonatites revisited: Two major types of continental carbonatites and their trace-element signatures**

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There have been several attempts to systematize the geochemistry of carbonatites, most recently by Samoilov (1984), Nelson et al. (1988), Woolley and Kempe (1989), and Rass (1998). These studies revealed a number of important geochemical characteristics that can be used to track the evolutionary history of these rocks, distinguish them from modally similar metamorphic parageneses, and aid in mineral exploration for rare earths, niobium and other resources commonly associated with carbonatites. Important breakthroughs in the understanding of carbonatite petrogenesis and numerous reports of new carbonatite localities made in the past two decades lay the ground for a critical re-assessment of the geochemistry of these rocks. A new representative database of whole-rock carbonatite analyses was compiled from the post-1988 literature and various unpublished sources. The database contains 820 analyses encompassing calcio-, magnesio- and ferrocarnatites from 174 localities (ca. one-third of the total number of carbonatites known worldwide) reduced to ca. 350 analyses following the approach of Woolley and Kempe (1989). Carbonatites emplaced in oceanic settings (e.g., Cape Verde), ophiolite belts (e.g., Oman), or those of uncertain tectonic affinity (e.g., El Picacho in Mexico) were not included.

Two major types of continental carbonatites can be distinguished on the basis of their geological setting and trace-element geochemistry: (1) carbonatites emplaced in rifts and smaller-scale extensional structures developed in stable Archean cratons or paleo-orogenic belts, and (2) carbonatites emplaced in collisional settings following the orogenesis. In both settings, the most common and best-studied type of carbonatite is calcite carbonatite (predominantly intrusive with a small percentage of extrusive occurrences), which accounts for 62% of the analyses included in the database. Both types of carbonatite are typically associated with alkaline silicate lithologies (meleigites, nepheline syenites, etc.), but those associated with type-1 rocks are typically Na-rich and silica-undersaturated, whereas type-2 carbonatites are associated with K-rich silica-saturated to undersaturated syenites. Type-1 carbonatites are notably different from their type-2 counterparts in showing higher abundances of high-field-strength elements (HFSE = Ti, Zr, Hf, Nb, Ta), Rb, U and V, but lower levels of Sr, Ba, Pb, rare-earth elements, F and S. Key element ratios are also different in the two carbonatite types; in particular, Rb/K, Nb/Ta, Zr/Hf and Ga/Al values are consistently higher in type-1 samples. Notably, some element ratios (e.g., Co/Ni and Y/Ho) are very similar in both groups. Type-2 carbonatites commonly show a  $^{13}\text{C}$ -depleted signature relative to the "primary carbonatite" range (Deines, 1989).

The observed differences in geological setting and geochemistry indicate the existence of two distinct carbonatite sources in the subcontinental lithosphere: amphibole-bearing lherzolite producing type-1 rocks (cf. Chakhmouradian, 2006), and subducted oceanic crust (rutile-bearing eclogite?) yielding type-2 melts depleted in HFSE, but enriched in light carbon, large-ion-incompatible elements, F and S.

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