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Carbonatite melt meets marble: a case study from Osongombo, NW Namibia

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Given their economic importance in green energy transition, carbonatites are intensely studied for their potential to carry significant amounts of critical elements (e.g., REE, Nb, F). While their mantle source has been generally accepted, many key aspects regarding their genesis remain unresolved. Upon emplacement, carbonatite melts can react with wallrocks to form *antiskarns*. A low-temperature (400-600°C) fluid exsolves during the transition from late-magmatic- to hydrothermal stages. This fluid can generate *carbothermalites*, which often contain significant amounts of REE minerals, sulfides, sulfates, fluorite and quartz [1]. Additionally, expelled alkali-rich fluids metasomatise wall-rocks and form fenites.

To investigate wallrock interaction between carbonatites and marbles, Osongombo was chosen as an ideal study site, where diverse carbonatitic dykes intrude Damara marbles. Carbonatite dykes vary in composition, including calcite, Fe-dolomite and ankerite + calcite, and sulfide-bearing ankerite carbonatites. Interaction zones (IZ) form in the marble, with calcite carbonatites exhibiting minimal IZ. Fe-dolomite calcite carbonatites show up to 1 cm wide IZ consisting of small euhedral Fe-dolomite with an increasing Fe-content towards the rims, and ankerite carbonatites display IZ up to 2 cm, characterized by clusters of Fe-dolomite and ankerite, which additionally form rims on dolomite from the marble. Primary carbonates in the Fe-dolomite carbonatite dyke [$Ca_{0.98}(Mg_{0.71}Fe_{0.25}Mn_{0.06})(CO_3)_2$] are compositionally similar to those from the corresponding IZ [$Ca_{0.98}(Mg_{0.74}Fe_{0.24}Mn_{0.04}Sr_{0.01})(CO_3)_2$] and the same applies to ankerite carbonatites ([$Ca_{1.00}(Fe_{0.47}Mg_{0.46}Mn_{0.07})(CO_3)_2$] and [$Ca_{0.99}(Mg_{0.52}Fe_{0.43}Mn_{0.05})(CO_3)_2$]). However, marble calcite (($Ca_{1.98}Mg_{0.02}$)CO_3) exhibits a strong compositional overprint in the IZ ($Ca_{1.97}(Mg_{0.01}Fe_{0.01}Mn_{0.01}Sr_{0.01})CO_3$), suggesting an influx of carbonatite-derived fluids into the marble (Figure 1).

Furthermore, a characteristic carbothermal assemblage observed in some of the carbonatites (apatite + baryte + REE-F-carbonates + quartz; Figure 2) implies the significance of fluids in element remobilization and enrichment in later stages. An increase of $aSiO_2$ is evidenced by reaction textures of sphalerite altering to willemite and thorianite to thorite.

These findings provide insights into the reactivity and elemental exchange of carbonatite melts observable even in a calcite marble, and indicate noticeable differences during the evolution from calcite to ankerite carbonatites, with a distinct late-stage carbothermal overprint.

[1] Mitchell, R.H. and Gittins, J., (2022) *Lithos* 430, 106861.