Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.37900

Stable strontium isotopes ($\delta^{88/86}Sr$) in Archean hydrothermal carbonates: forward modeling constraints on fluid mixing in Archean orgenic gold systems

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Stable strontium isotopes ($\delta^{88/86}Sr$), together with other isotopic compositions ($\delta^{18}O$ and $\delta^{13}C$) in carbonates, can be used to provide insights into mixing processes and precipitation dynamics in hydrothermal systems. However, the relative roles of fluid composition versus Sr isotope fractionation remain poorly constrained in ancient hydrothermal environments. Here, we apply forward geochemical modeling to carbonate $\delta^{88/86}Sr$ data from two Archean hydrothermal systems associated with orogenic gold mineralization in Québec, Canada: the Augmitto-Bouzan deposit and the Val-d'Or orogenic gold vein field. Previous radiogenic and stable isotope geochemistry studies of vein minerals from both locations suggest that the hydrothermal fluids resulted from mixing between two end-members: metamorphic and upper crustal sources. Our modeling integrates binary mixing between isotopically distinct fluid end-members and precipitation-controlled Sr isotope fractionation using the empirical relationship $\Delta^{88/86}Sr_{carbonate\text{-}fluid} = -1.2DSr - 0.05$ [1], where DSr is the carbonate–fluid partition coefficient. For Augmitto-Bouzan, modeled fluid mixing between crustal (Sr/Ca ≈ 2 mmol/mol; $\delta^{88/86}Sr \approx -0.30‰$) and metamorphic (Sr/Ca ≈ 6 mmol/mol; $\delta^{88/86}Sr \approx 0.55‰$) end-members reproduces the observed carbonate array, with $\delta^{88/86}Sr$ values from -0.28‰ to 0.48‰. Best-fit solutions indicate low DSr values and limited isotopic fractionation ($\Delta^{88/86}Sr_{carbonate\text{-}fluid} \approx -0.05‰$), suggesting that carbonate $\delta^{88}Sr$ is primarily controlled by fluid composition. The reconstructed fluid signatures yield slightly negative to moderately positive values, consistent with fluid mixing-dominated hydrothermal conditions and an upper crustal end-member that was isotopically lighter than the modern ocean ($\delta^{88/86}Sr \approx 0.4‰$). In contrast, Val-d'Or carbonates ($\delta^{88/86}Sr$ values from 0.39‰ to 1.05‰) require isotopically heavier end-members and display a broader range of Sr/Ca and DSr values. Modeled fractionation factors are significantly larger ($\Delta^{88/86}Sr_{carbonate\text{-}fluid}$ down to −0.45‰), indicating stronger kinetic control linked to precipitation rate and implying variable precipitation conditions superimposed on fluid mixing. These results demonstrate that combined forward modeling of fluid mixing and Sr isotope fractionation enables quantitative discrimination between different controls in Archean hydrothermal systems.

[1] AlKhatib, M., and Eisenhauer, A. (2017), Geochimica et Cosmochimica Acta 209, 296–319.