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Carbon isotope shifts in CO_2-mineral equilibria: new elements to solve the sources of natural fluids

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The origin and transport of deeply-sourced CO_2, released in volcanically and tectonically active regions, are a key research theme in earth science, which is also of particular importance for geo-hazard mitigation (volcanic eruptions and earthquakes). Furthermore, Earth's long-term climate depends on the stability (source-and-sink) of atmospheric CO_2, in which the CO_2 inputs to the atmosphere are consumed in equivalent amount by surface sinks (e.g., carbonate precipitation).

In this scenario, the isotopic composition of CO_2 emitted from Earth interior provides critical insights into its origins. Traditional models assume that CO_2 maintains its initial isotopic signature as it migrates through the crust, primarily relying on binary mixing between sources. However, CO_2 is not a passive tracer as, degassing, interactions with crustal rocks and aquifer can significantly shift $\delta^{13}C$ values of the deep sourced CO_2 that move to the atmosphere. These processes complicate conventional geochemical interpretations and highlight the need to account for CO_2-rock equilibria to solve the sources of CO_2 in continental setting.

This study examines how CO_2-rock interactions modify the isotopic composition of CO_2 in continental systems. By analyzing equilibrium reactions between CO_2 and carbon-bearing minerals under varying temperature-pressure conditions and CO_2/mineral volume ratios, we show that these interactions can drive significant shifts in $\delta^{13}C$-CO_2 values, complicating source attribution when using standard mixing models.

Our results show that $\delta^{13}C$-CO_2 values can shift significantly (up to more than 10‰), depending on environmental conditions. These variations highlight the importance of including CO_2-mineral equilibria in geochemical models that rely on mixing processes. Without accounting for these reactions, CO_2 source interpretations may be misleading. The findings emphasize the need to incorporate CO_2-mineral equilibria into geochemical frameworks to improve the accuracy of CO_2 source interpretations and to use multidisciplinary model that constrain rock-type and P-T conditions at depth.

It results crucial in the use of the carbon isotopes of CO_2 in monitoring natural fluids to solve the relationship between fluids and earthquakes nucleation as well to define the contribution of CO_2 from volcanic and active seismic regions to the budget of CO_2 in atmosphere.