Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.34827

Protocol sensitivity in exchangeable cation measurements for enhanced weathering

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Enhanced Weathering (EW) is a proposed carbon dioxide removal (CDR) strategy in which soils are amended with silicate minerals to generate alkalinity and enhance oceanic CO_2 drawdown. Several measurement, reporting, and verification (MRV) frameworks quantify carbon removal using mass balance approaches that assume exchangeable base cations in excess of control soils reflect silicate weathering and potential CDR. However, exchangeable cation measurements are operationally defined and extraction protocols vary widely across studies. As a result, quantification of exchangeable cations in amended soils requires careful assessment and standardization. Here we used an unweathered olivine feedstock to assess the potential variability in measured exchangeable cations. As stoichiometrically charge-balanced crystalline solids with negligible permanent structural charge, silicate minerals should demonstrate negligible cation exchange capacity.

First, we conducted a laboratory intercomparison of 1M ammonium acetate extractions using two olivine size fractions and two filtration pore sizes to investigate protocol reproducibility. For an olivine powder with a D90 of 207 µm, we measured an apparent cation exchange capacity (CEC; sum of Ca, K, Mg, Na) of 1.52 ± 0.04 meq / 100 g using a 0.45 µm filter and 2.09 ± 0.04 meq / 100 g using a 2.7 µm filter. This apparent CEC arises from partial feedstock dissolution and the passage of fine particles through the filtration setup. We then varied shaking, incubation time, rinses, and centrifugation and evaluated their effect on measured base cation concentrations in the collected leachates. Introducing vertical shaking prior to filtration increased the apparent CEC by 39%. Combining vertical shaking with an extended incubation time (30 min to 24 h) increased the apparent CEC by 166%, relative to the 0.45 µm filter base case.

Our findings demonstrate that without standardized extraction and analytical procedures, exchangeable cation measurements cannot provide consistent constraints on potential CDR. Reactive transport models increasingly use operational cation exchange measurements to constrain cation retention, the surface proton reservoir (SPR) and alkalinity loss throughout the soil column following EW deployment. Establishing reproducible analytical definitions is therefore essential for providing robust constraints for both mass balance quantification and mechanistic reactive transport modeling of EW systems for CDR quantification.