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Evaluation of runaway precipitation and trace metals release during ocean alkalinity enhancement with olivine sand

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Ocean alkalinity enhancement (OAE) using olivine sand has been proposed as a carbon dioxide removal strategy. However, secondary minerals precipitation may trigger self-accelerating “runaway” feedback processes that influence both alkalinity persistence and trace-metal mobility. In this study, we evaluate runaway precipitation dynamics and associated trace-metal risks using standardized batch (ISO 21268-2), column leaching tests (ISO 21268-3), and a magnetic stirrer leaching test, combined with geochemical reaction modeling. These approaches were applied to investigate olivine dissolution, carbonate and hydroxide precipitation, and the associated release of trace metals under ambient conditions relevant to OAE deployment.

Model simulations predict runaway precipitation of aragonite, calcite, and dolomite, consistent with the observed decreases in seawater Mg and Ca concentrations during batch experiments. This rapid mineral formation consumes alkalinity and shortens its effective lifetime. Trace metals of potential ecological concern such as Mn, Ni, Cr and Co were detected in leachates, whereas Cr and Co were relatively low. Notably, Mn and Ni concentrations declined over time in both standard batch and column leaching tests, indicating scavenging by newly formed mineral phases as alkalinity increased or adsorption onto mineral surfaces. In contrast, this phenomenon did not occur in the magnetic stirrer leaching test.

Overall, these results demonstrate that runaway precipitation is a key and underappreciated process controlling both the efficiency of olivine-based OAE and the timing and magnitude of trace-metal release. Recognizing and quantifying this behavior is essential for the responsible assessment and deployment of OAE strategies.