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Experimental investigation of multiple industrial wastes for geochemical carbon dioxide removal strategies

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Negative emission technologies that can potentially reduce CO_2 concentrations in the atmosphere are becoming more urgent, requiring evaluations of different CO_2 removal (CDR) strategies. One approach is geochemical CDR, whereby minerals dissolve in a reaction with CO_2 and water to form alkalinity, or precipitate to form carbonate minerals, stabilised by Ca^{2+} and Mg^{2+} cations. Industrial waste by-products, such as mine tailings, quarry cuttings, fly ashes and glassy slags, have been pinpointed for their geochemical CDR potential based on a number of physical and chemical advantages over natural systems. However, critical uncertainties remain regarding which materials are appropriately reactive, and at what dissolution rates. Furthermore, rigorous experimental studies on by-product reactions with CO_2 are generally lacking. Here, we investigate the reactivity of a range of by-products with CO_2 and water.

The sample set includes materials from mines of differing geological settings (copper, diamond, nickel, olivine, aluminium, ilmenite, borax and fluorite tailings), slag derived from smelter operations, coal-fired power plant-derived fly ashes, SO_2 processing by-products and marble quarry cuttings. Olivine dunites, kimberlites and marble cuttings were identified as the main cation sources, while ilmenite and select Cu tailings also showed notably high cation release. Borax tailings, olivine dunite, fly ashes, ilmenite tailings and red muds showed the highest Si-derived dissolution rates, comparable to rates typically achieved in favourable CDR materials (e.g., mafic rocks). Dunites, kimberlites, red muds and ilmenite tailings showed both the highest cation release concentrations and favourable dissolution rates. Ni sulphide, kimberlite, ilmenite and dunite tailings also showed secondary carbonate precipitates, based on PHREEQC modelling.

Industrial by-product generation could provide a massive untapped resource for geochemical CDR opportunities, based on the promise shown by chemically and mineralogically suitable materials, and also the huge tonnages of material generated annually. While cation release and dissolution rates of some by-products show similar promise to rocks utilised in geochemical CDR pilot schemes, there is still a need to accelerate reactions to achieve near-complete dissolution on human-relevant timescales (decades or faster).

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