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Editorial: Enhanced weathering and synergistic combinations with other CDR methods

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Editorial on the Research Topic
Enhanced weathering and synergistic combinations with other CDR methods

1. Introduction

Weathering of silicate minerals stabilizes climate on geologic time scales by consuming carbon dioxide (CO_2) (Walker et al., 1981; Berner et al., 1983). Artificially enhancing weathering rates on land by crushing and spreading silicate mineral-bearing rocks is a promising carbon dioxide removal (CDR) technology (Hartmann et al., 2013) that exploits acceleration of these natural weathering reactions with potential to scale to gigatons of CDR annually when deployed on croplands (Strefler et al., 2018; Beerling et al., 2020). Over the past 1.5 decades, research interest on Enhanced Weathering (EW) has increased with research foci including process modeling of the CDR potential of nations (Beerling et al., 2020; Kantzas et al., 2022), capacity of rivers and oceans to transport sequestered CO_2 (Kohler et al., 2010; Zhang et al., 2022; Kanzaki et al., 2023), field trials aiming to understand the performance of this technology in agricultural systems under real world conditions (Haque et al., 2020; Larkin et al.), and the requirement for robust monitoring, reporting and verification (MRV) of CDR. The collection of papers in this Research Topic focuses on the application of EW on land and in the oceans and the resulting feedback mechanisms and potential co-benefits.

2. Overview of publications in this Research Topic

Out of the 11 publications in this Research Topic, some deal with fundamental factors controlling mineral dissolution kinetics. Fuhr et al. used a batch reactor to investigate dissolution of sand-sized olivine-rich rocks in artificial seawater. They showed an unexpected decline in total alkalinity (TA), which they attributed to authigenic clay mineral formation exceeding olivine dissolution. Amann et al. investigated the role of partial pressure of CO_2 (pCO_2) and mineral grain size on CO_2 uptake in a series of column experiments. In most columns, they observed a fourfold increase in CO_2 uptake when comparing saturated vs. ambient pCO_2. Interestingly, while the absolute CO_2 uptake was highest with smallest grain size, the CO_2 uptake normalized per reactive surface area was highest with coarser grains. Pogge von Strandmann et al. compared olivine weathering in soil cores at 4–19°C and showed that the olivine dissolution rate was two orders of magnitude lower at the lower temperature. Since many laboratory or greenhouse studies investigate mineral weathering at relatively high ambient temperatures, this finding has important implications when translating small-scale experiments to larger-scale settings.

Other studies investigated the co-benefits of EW in relation to various aspects of soil quality at a range of spatial scales. te Pas et al. compared the potential of five different silicates for both CO_2 sequestration and soil quality improvements. They showed that while wollastonite and olivine had the highest CDR potential, columns amended with the latter mineral also exceeded nickel (Ni) groundwater threshold values in their leachates. Furthermore, most treatments produced a net carbon loss due to enhanced losses of organic carbon (OC). This highlights the need to investigate both inorganic carbon (IC) and OC dynamics in EW experiments to fully understand CO_2 sequestration at multiple timescales, a common finding in this Research Topic (e.g., Almaraz et al.; Janssens et al.). Vienne et al. investigated co-benefits of EW in a mesocosm experiment growing potato in so far understudied alkaline soil. Besides finding no negative impact of basalt amendment on potato yield despite higher soil aluminum and Ni availability, the study also showed reduced nitrogen leaching for the basalt-amended treatments. The authors additionally used a 1-dimensional reactive transport model (RTM) to estimate CO_2 sequestration during the experiment. Combining mesocosm experiments with RTMs allows assessment of the underlying processes of EW and CO_2 sequestration on timescales exceeding the duration of experiments (Kelland et al., 2020).

A couple of perspectives in this Research Topic had a broader look at factors that should be considered in the upscaling of EW. To address the abovementioned heavy metal release resulting from EW, Suhrhoff investigated whether phytoremediation strategies can prevent the accumulation of Ni and chromium in soils. He proposes the use of either hyperaccumulating plants in crop rotation strategies, or accumulating plants with a high biomass production, as a way of preventing long-term heavy metal contamination. Janssens et al. looked at the use of EW in combination with biochar amendment and OC sequestration in soils suffering from low fertility and water retention capacity. They argue that these CDR technologies do not only result in negative CO_2 emissions, but also in negative erosion, through improving soil structure and increasing both cation and anion exchange capacities. Their work highlights that combined applications of CDR technologies may synergistically contribute to multiple Sustainable Development Goals (SDGs) (Beerling et al., 2018).

EW requires long-term field trials investigating its performance on working lands under a wide range of environmental and agronomical settings. Larkin et al. present for the first time the results of such a field trial in a tropical environment using TA export, thereby accounting for possible lower CDR due to either carbonate mineral dissolution or silicate mineral dissolution with acids other than CO_2. They show higher CDR in one of the three catchments in their study design, likely due to EW of silicate minerals in this catchment. Almaraz et al. conducted a literature review on the use of mineral amendments as a CDR technology, as well as methodologies used to studying mineral weathering by both geologists and agronomists. Their work highlights the need for both groups to collaborate in interdisciplinary projects and involve stakeholders. Besides large-scale field trials of EW, a low-cost method for MRV of CO_2 removal in such settings is required. Acknowledging that TA can be used to track CO_2 removal due to mineral weathering, Amann and Hartmann propose such a method. Their work shows linear correlations between electrical conductivity (EC) and TA both in column experiments and at the catchment scale. These promising results for using EC as a proxy for CO_2 sequestration will need further calibration with a range of both abiotic and biotic factors.

While the studies in this Research Topic mostly focused on EW of silicate rocks, also enhancing carbonate mineral weathering may contribute to CDR because of its relatively high mineral dissolution rates. However, reprecipitation of carbonate minerals before the produced TA reaches the ocean fully reverts CO_2 capture. To investigate this potential reprecipitation (Knapp and Tipper) conducted a modeling study in almost 150 river basins. They show that the key factor controlling the efficacy of carbonate weathering for CDR is riverine transport of the weathering products, and not the capacity of soils to dissolve carbonate minerals.

3. Conclusion

The publications in this Research Topic offer guidance on possible future directions of EW research, ranging from fundamental mineral dissolution kinetics to practical applications in naturally heterogenous fields. A unified, synchronized global research agenda to develop a robust MRV framework, and to understand if and how EW and its interaction with other CDR-methods might contribute to the significant CDR-necessities to stabilize climate within this century, is urgently necessary.

Author contributions

MH wrote the draft, with input from JH, SV, and DB. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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