Review of: "Soil core study indicates limited CO2 removal by enhanced weathering in dry croplands in the UK"

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Potential competing interests: No potential competing interests to declare.

The reviewed paper investigated enhanced rock weathering (ERW) in the core soils taken from dry croplands in UK. These soils were treated with crushed basalt and were exposed to natural weathering condition for a period of 14 months within columns. In the core, the soil dissolution was sampled in 10-20 cm intervals to understand the fate of dissolution products with respect to soil depth. The data, mechanism, methods, and conclusions drawn from this study are critically discussed for potential scaling up of basalt application to soils for CO_2 drawdown. Key review research analysis/directions/reviews are enumerated as follows:

1. The idea of studying the soil core to investigate the formation of carbonates due to the application of crushed basalt is a positive research endeavor to mimic the geochemical complexity of soil environments. The takeaway from the investigation is beneficial to the research community in understanding that even high application of crushed basalt (100 t basalt ha^{-1}) can result, under the "dry" conditions studied, in limited drawing down of atmospheric CO_2, 5 to 25 times slower than previously modelled assessments in literature. This indicates that not all silicate minerals are suitable for ERW in every type of cropland/climate, and it is important to consider the choice of those silicates having demonstrated fast weathering capability under the conditions of application.
2. The use of the term "dry croplands" in this study should have been more accurately classified as to show how dry the cropland simulated in this study was. The text mentions the measured rainfall (columns were only naturally watered, though extra water was added to enable sampling) and compares it to the mean rainfall of the UK, but from a global perspective it is not as clear what a "dry" land would be defined elsewhere. The reader is left not knowing under what rainfall levels basalt would or would not be suitable for deployment of ERW. An opportunity for clarification is also missed in terms of correlating the particle size of the crushed basalt to the weathering rate measured, and if finer basalt would enable basalt application in drier climates, and again how dry that could be to achieve acceptable results.
3. The idea of using undisturbed soil cores to simplify the complexity of soil environment and address the limitations of laboratory experiments is worthy. It is also a more scientific approach as compared to the field studies, which are difficult to replicate, monitor and control. The idea of using Rhizon samplers at 10 cm depth interval of the soil core is novel and unique in the field of ERW and improves objective understanding, as it allowed the samples of soil solution collected at repeated intervals for geochemical analysis without disrupting the structure of soil core. The data from these samplers helped to exemplify that under low water fluxes, monitoring of dissolved alkanility at the end of the

column would not capture in the short-term the progress of the weathering reaction. The paper assumed that the conclusions drawn from this study are representative of field-scale enhanced weathering, but there can be limitations to such an assumption such as the difference of CO_2 partial pressure and fluid drainage between core and field studies. Also, when pedogenic carbonate formation and TIC are assessed with the core study, it would be more representative of the field one. The conclusions drawn from this study could be more certain if cores from various fields having a variety of soil types, climate and hydrological conditions are assessed and compared. Having these further trials would help in overcoming the knowledge gaps and simplifying the geocomplexity of soils to a better extent.

4. Another research direction would be to compare the application of various silicate minerals to the soil core study such as olivine, basalt, serpentine, clinopyroxene, orthopyroxene, amphibole, and minerals found in steel slags having faster weathering rates. It would help in assessing the feasibility of scaling up the ERW pathway of negative emissions technologies with the best options.
5. The effects of undissolved basalt (and other silicate minerals) accumulation on soil compositions and the fate of these undissolved silicate minerals need to be studied for repeated application. A research question would be that of how capable an already treated soil would be for another/repeated application of silicate minerals to capture atmospheric CO_2 and would there be any adverse effects on the fertility of croplands looking at a long run?
6. A conclusion about SiO_2 polymerization is made at the end of first paragraph on page 5, whereby it is posed that SiO_2 polymerization in basalt minerals retards dissolution as compared to fast-weathering olivine. The authors also suggest that slower than modeled weathering rates could be explained by the formation of secondary minerals that sorb ions. However, the study lacks direct evidence of either of these mechanisms. The data acquired from the Rhizon samplers suggest removal from solution of ions originating from the amended basalt, but it is not possible to know if these results in secondary minerals that prevent basalt weathering (i.e., passivate it), which would have to mean precipitation onto the basalt grains rather than heterogeneously in the bulk soil. This effect of SiO_2 polymerization should be studied further as a function of various fast weathering silicate minerals to have an in-depth understanding of their dissolution behavior under field-relevant conditions, particularly under a range of water fluxes.
7. The carbon dioxide removal CDR rate discussed in section 4.5 indicates important set of information on the development of research methodology by authors over the period. The natural water flux is far less than the irrigation water fluxes, and it becomes a limiting factor for weathering and dissolution. It is important to note here that any upscaling feasibilities of mineral carbonation should be made keeping in view the lower limit of dissolution (which is with natural cycles of watering through rain). Also, it is mentioned in the last sentence of first paragraph of section 4.5, where authors refer to some previous investigations, that the net draw down potential of enhanced weathering is estimated to be reduced by 10% to 30% by incorporating the subsequent emissions released from mining, transport, and comminution, which must be made part of the scaling up feasibility. Keeping all this in view will restrain the scientific community from overstating the potential of enhanced weathering of basalt and other silicate minerals, thereby reinforcing the approach of “net-zero” operations.
8. Despite indication of the formation of pedogenic (i.e., secondary) carbonates in the cores, as stated at the end of the Results section based on the depletion of alkaline earth metal ions towards the bottom of the column, soils were not characterized for total inorganic carbon (TIC) content. Keeping with the theme of drier croplands, literature shows that

such soils are richer in TIC. What is the impact of omitting the quantification of pedogenic carbonate accumulation in the column from the CO_2 drawdown calculation, which was based solely on soluble alkalinity measurement? Could be 1%, 10%, or 200%, but without the data it is not possible to know.

Declaration of potential competing interests

Prof. Rafael M. Santos is Scientific Advisor of Everest Carbon, a company commercializing ERW technologies and carbon credits.