Review of: "Mineral stabilities in soils: how minerals can feed the world and mitigate climate change"

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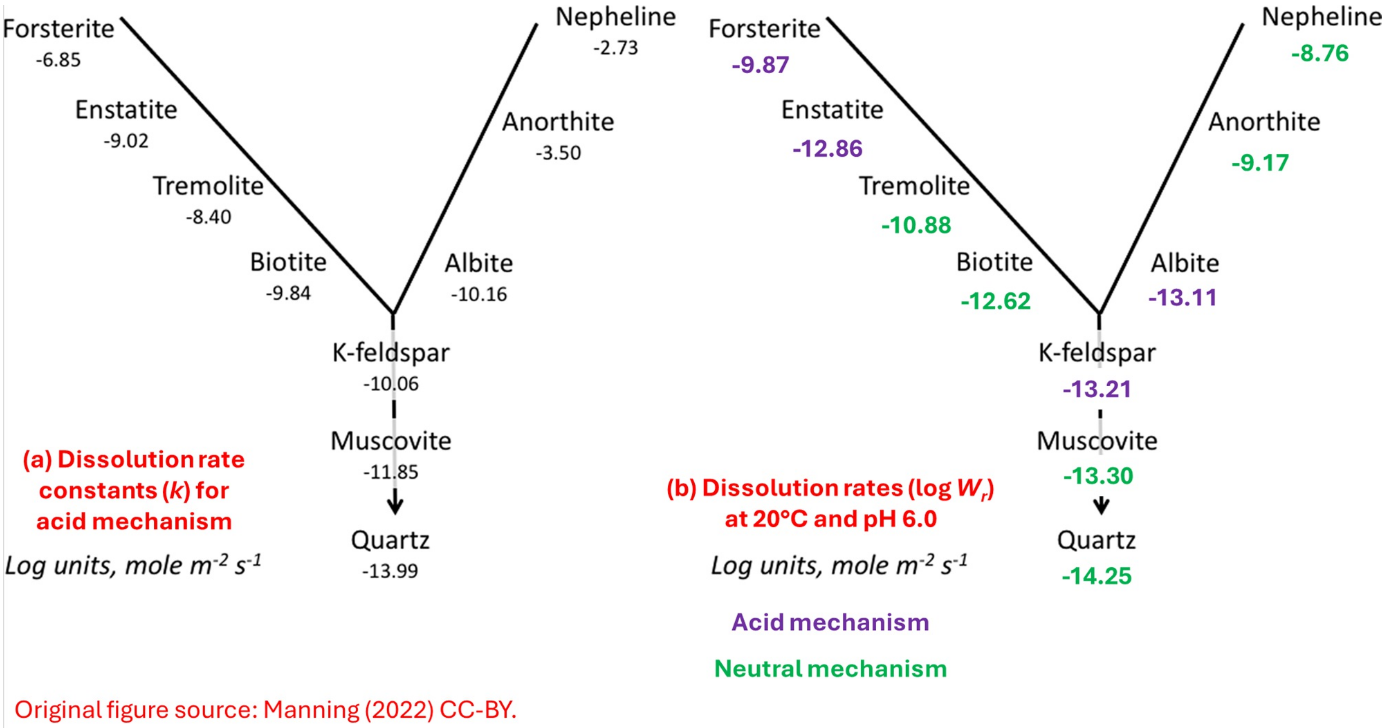
Enhanced rock weathering (ERW) is potentially a climate change mitigation wedge, and the current state of the science is leading to increasing deployment of this technology in croplands, pasture lands, and forested lands. The article by Manning (2022) is a literature review that aimed to cover the mineral weathering aspects of ERW by compiling relevant literature available at the time of writing. Mineral weathering is a mature science, so it is not surprising that the review included papers spanning over a century, from 1922 until 2022.

The review covers several aspects of geochemistry and some aspects of mineralogy, including:

- ΔG_{rxn} (Figure 1) of several weathering reactions (Table 1);
- The expected solubility of Si and Al as a function of pH (Figure 2);
- Mineral weathering data in Figure 3 and Table 2 (**which contains a critical mistake, to be discussed below**);
- SEM images exemplifying the microbial role during weathering in soils (Figure 4);
- A schematic illustration of the oxygen and carbon isotope compositional range of soil carbonates (Figure 5); and
- A unique analysis of the expected silicon release from silicate weathering (rock-forming minerals in Figure 6 and clay minerals in Figure 7) compared to the expected Si intake of wheat during a crop season.

The review article by Manning (2022) is timely and largely useful for researchers and practitioners involved in ERW. However, as it contains one important mistake, the rest of this post-publication review will focus on rectifying this.

Below is the main issue found in Manning (2022). The original Figure 3 (and corresponding values also shown in Table 2) showed values that were reported to be “mineral dissolution rates”, in log units. However, those values are in fact mineral dissolution rate **constants** (in log units), which we can term k. The values of log k are meant to be used in equations developed by Palandri and Kharaka (2004) to first calculate log A values, and then calculate log W_r values, where W_r is the “mineral dissolution rate”. In fact, W_r is a function of pH and temperature, so W_r values can be readily calculated for conditions expected to be found in soils, while k being a constant, actually represents a theoretical weathering rate at pH of 0 (zero) and 25°C. Manning (2022) actually realizes this later in the review, when presenting the data of Figures 6 and 7, but when presenting Figure 3 and Table 2, which are more likely to be used by readers, the correct terminology and meaning of the presented values is missing. To rectify this, I have reproduced Figure 3 below, with the original figure on the left, now clearly indicating that those are log k values for the acid mechanism, and a modified figure on the right, where the values are calculated log W_r's based on pH of 6.0 and temperature of 20°C and using the most appropriate mechanism (more on this explained later). While the order of the values still largely matches the order of the Goldich Stability Series (except for enstatite, tremolite and biotite being slightly out-of-order), the magnitude of the differences is very large. Most notably in the case of anorthite, wherein its k value is the second-highest of the series and is more than 6 orders-of-magnitude greater than that of K-feldspar, whereas its W_r value is far closer to that of forsterite and tremolite and is 4 orders of magnitude greater than that of K-feldspar. For comparison, the log W_r of wollastonite under the same conditions is –7.93, based on the acid mechanism.



A point of clarification about the modified figure above is that the logW_r values reported are the greatest values between those calculated based on the "acid mechanism" and the “neutral mechanism,” as reported in Palandri and Kharaka (2004), and also discussed in Manning (2022). This approach is taken since there is a significant discontinuity between the two mechanisms around the typical pH range of cropland soils (~5.5-7.5), where for some minerals, one of the mechanisms predicts an unreasonably low W_r value. More on this is discussed in Haque et al. (2023), wherein weathering rates for several minerals are graphed as a function of pH and temperature based on the two mechanisms.

A final point of discussion on the difference between k and W_r can be made based on the following sentence found in Manning (2022): “Basaltic glass has a corresponding dissolution rate of –3.30 (expressed as log moles m^{-2} s^{-1}; Lewis et al., 2021).” In fact, the value of –3.30 is correctly reported in Lewis et al. (2021) as a “rate constant” for the acid mechanism, and a value of –11.85 for the neutral mechanism (it is out-of-scope of this post-publication review to confirm that these values were correctly used in that study). However, Lewis et al. (2021) incorrectly cites the source of these values as coming from Palandri and Kharaka (2004), as that source does not contain values for basaltic glass and the only similar value is the log k of muscovite being –11.85 for the acid mechanism. Hence, it is unclear if those values for basaltic glass are valid, and even if so, how to use them since the activation energy and pH correction factor are missing for the acid mechanism. Moreover, even if the neutral mechanism does not require a pH correction factor and without the activation energy it is still possible to calculate log W_r at 25°C to be simply –11.85, it is uncertain what mol unit the equation uses. The values calculated from the data of Palandri and Kharaka (2004) are meant to be in terms of per mol of mineral. But basaltic glass is not a mineral with a known molecular formula; it is an amorphous phase, so what a "mol" of basaltic glass weathering may be is not trivial to know; it could be per mol of Ca, per mol of Si, per mol of a normalized chemical formula based on chemical composition, or something else.

In summary, when it comes to weathering rates, care is needed with sources of data, meaning of data, and units of data to avoid errors that can lead to scientific confusion about "mineral stabilities in soils," as the article of Manning (2022) is titled. Manning (2022) is still an excellent source of information about the other topics it covered.

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