Mineral carbonation and the KISS principle

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Abstract
The Earth emits annually between 0.5 and 1 Gt of CO2, among others by volcanoes. Before the industrial revolution this was captured by the weathering of basic silicates, turning CO2 into bicarbonate in solution. These bicarbonate solutions are then carried by rivers to the oceans, where the CO2 is returned to the rock record as solid carbonates (limestones and dolomites). The burning of fossil fuels has dramatically increased the emission of CO2 to more than 30 Gt/yr., and weathering reactions cannot cope with this, so the CO2 levels in the atmosphere are rising. The balance can be restored by mineral carbonation. The recipe is simple and straightforward:

-select an abundant material that weathers easily (olivine or serpentine)
-mine and mill this material
-spread it in a favorable climate for weathering

One should follow the KISS principle (Keep It Simple, Stupid), and leave the weathering to nature. Instead, many researchers try to develop techniques to speed up the carbonation. This costs extra energy and money, by which mineral carbonation is pricing itself out of the market.

Introduction
Rising CO2 levels probably cause a climate change, and are definitely causing ocean acidification, because that is a straightforward consequence of a higher CO2 pressure in the atmosphere. The Earth has experienced larger fluctuations of CO2 levels in the past, and larger sea level changes, but evidently never with a human population of 7 billion people, of whom a significant proportion lives close to sea level. It is generally admitted that something must be done to stop a further rise of CO2 in the atmosphere. Solutions are sought in energy saving, developing alternative energy sources, or capture of CO2 in a sustainable way. Reduction of emissions is much talked about, but so far barely with effect. This is part of the "global climate stalemate". Western industrialized nations propose obligatory reduction percentages, but for the emerging economies (China, India, Brazil, South Africa) their economic development has priority, for which cheap and abundant energy is a prime requirement. As these countries also possess large coal deposits, their choice is obvious.

Speed of weathering
There is no need to speed up the reaction, as olivine grains of 100 μm weather and capture CO2 in a few years in a suitable climate. Extrapolation of abiotic experiments seems to suggest that weathering is not fast enough. Outside the laboratory the role of biotic factors like mycorrhizal fungi on land or lugworms on tidal flats has been demonstrated, which speed up the weathering reaction by factors of ten to almost one thousand. Crushed serpentinite mine tailings in a fairly unfavorable climate in British Columbia are known to weather fifty times faster than basaltic tuffs in even the most favorable climate for weathering (Wilson et al. 2009).

It was stated in the literature that olivine grains on beaches would take 700 to 2200 years to weather. (Hangx and Spiers, 2009), but the authors had overlooked the fact that such grains are ground very effectively in the surf. In a simple experiment with olivine grains in an artificial surf it was shown that crushed angular olivine grains with a rough surface became rounded and smooth in one day, producing a milky opaque suspension of micron-sized olivine scrap. The pH of the water rose to 9.4, underlining the fact that such tiny slivers weather very fast. Because the surf acts as the world's largest and cheapest ball mill, beaches are an excellent environment for olivine weathering, where it has a direct effect on ocean acidification (Schuiling and de Boer, in prep.).

Summing up, there is plenty of evidence that once the olivine is mined and milled, olivine grains in several major environments will weather fast enough.

Olivine mining
For the global C-cycle it makes no difference where the CO2 is captured, as the atmosphere is a well mixed reservoir on the timescale of a few months. There is no need for nations or companies to capture their "own" CO2, as all molecules of CO2 are equal. Capturing and storing of CO2 from flue gases is too expensive. The separation step alone costs already considerably more than straightforward enhanced weathering.

The strategy for enhanced weathering relies for a large part upon olivine mined in the wet tropics. This material is milled and the grains are spread over the surrounding area. With large olivine mines that are strategically distributed to limit transport distances, the whole operation (mining, milling and transport) will cost around 10 Euro/ton of captured CO2 (Steen and Borg, 2002). Negative effects on the

environment are unlikely, because the same process has operated without a hitch throughout geological time.
Every mine has an impact on the local environment. For olivine mines, this impact can be considerably reduced in the following way. Most dunite complexes in the tropical zone are deeply weathered, and covered with a thick lateritic residual soil, from which major elements like magnesium or silicon are almost completely leached. Iron is relatively immobile, and so is nickel, causing these immobile elements to become enriched in the residual soil. The nickel content may rise to several %, making these laterites rich nickel ores which are mined or explored in a number of countries (a.o. Australia, New Caledonia, Indonesia, Philippines, Madagascar, Malawi, Cuba, Brazil). These nickel-rich weathering crusts are underlain by fresh dunite. This makes them favorable locations for olivine mining as well. No need to clear a new site, the infrastructure for mining is in place, and there is a population that depends on mining for their livelihood. Environmental damage is reduced, the lead time to start an olivine mine is shortened, mining costs are less and the miners can keep their job.

Conclusions

There is a clear case for enhanced weathering as the most cost-effective strategy for the removal of large quantities of CO2 from the atmosphere. This mineral carbonation process should not be burdened by needless additional technologies to speed up the reaction. One should adhere to the KISS principle (Keep It Simple, Stupid) because additional technologies cost energy, and add to the costs.
Enhanced weathering can be applied on farmland, plantations and forests, on beaches as well as on tidal flats. Collateral benefits are the addition of mineral nutrients to poor soils, increasing the productivity of acid soils, and helping to restore the pH of ocean water threatened by ocean acidification.