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Short communication

Coastal spreading of olivine to control atmospheric CO_2 concentrations: A critical analysis of viability. Comment: Nature and laboratory models are different

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The conclusion of Hangx and Spiers (2009), commenting on Schuiling and Krijgsman (2006), that in the coastal zone up to 2100 years may be needed for 300 μ olivine sand to be chemically weathered under the uptake of CO_2 grossly understates the uptake rate in natural settings, where flora, fauna and physical processes accelerate the weathering of olivine.

Since some 3 billion years the surface of the Earth has been colonised by biota which stimulate chemical weathering. The sharp decline in atmospheric CO_2 during the Devonian (416–359 Ma BP) is ascribed to the colonisation of the continents by deep-rooted trees (Berner, 1992). Mycorrhizal fungi living in symbiosis with plant roots actively extend into the soil and forage for nutrients by altering minerals through acidification and by the release of low-molecular weight organic chelators (Landeweert et al., 2001; Taylor et al., 2009), to the extent that, e.g. olivine grains (from nearby sources) are not commonly found in soils (Wilson, 2004).

In the coastal zone, grain-to-grain collisions, due to waves and currents, polish reaction-inhibiting Si-rich olivine-surface layers which – under static laboratory conditions – limit the reaction rate. A simple laboratory experiment, in which olivine grains in a closed volume of water are shaken continuously, shows a 4–8% decrease in olivine weight within 1 week, while the pH rises to 9.6 within a few days (authors' unpublished results). Collisions and scraping of the dissolving olivine grains thus enhance the reaction so that it is faster than theoretically predicted on basis of the dissolution kinetics of olivine in (sea)water. This explains why easily weatherable minerals like olivine are commonly absent or underrepresented in the lower reaches of rivers dissecting olivine-bearing source terrains.

In the coastal zone, sediment feeders such as the lugworm (*Arenicola marina*) are active. They feed on sand grains, up to 2 mm in diameter (Cadée, 1976), for bacteria and diatoms. Passage of sand grains through the animal's digestive system may accelerate olivine weathering by 2–3 orders of magnitude (cf. Needham et al., 2006; Worden et al., 2006). Of course lugworms do not rework the complete coastal zone continuously, and this extreme acceleration factor cannot be extrapolated over the full coastal zone. Admixtures of olivine to intertidal areas where lugworms and other sediment feeders are active, may have a positive feedback whereas silica (liberated during olivine weathering) often is a limiting nutrient for the growth of diatoms which in their turn serve as food for sediment feeders.

Chemical weathering of the Deccan Traps shows CO_2 consumption rates of $0.58–2.54 \times 10^6$ mol/km^2/year (Dessert et al., 2001). Dissolved solid concentration in river waters, induced by basalt weathering on the Island of Réunion indicate CO_2 consumption rates of $1.3–3.4 \times 10^6$ mol/km^2/year (Louvat and Allègre, 1997). Such values are equivalent to the consumption of up to 130 ton CO_2/km^2/year. In mine dumps of crushed ultramafic rocks, consumption of more than 4000 ton CO_2/km^2/year has been measured (Wilson et al., 2009).

In analogy to these natural processes, deep ploughing in humid tropical areas with an ultramafic subsurface and spreading of olivine and other crushed (ultra)mafic rock material over agricultural land will contribute to a reduction of CO_2 levels and, in addition, serve as Mg fertilizer. When used in agriculture in warm humid climates, it can, when carbon credits are applied, sup-

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port the income of farmers in developing countries. Distribution of olivine and other ultramafic rocks in high-energy coastal systems will counteract atmospheric CO_2 increase and acidification of the marine environment, a serious treath indeed (Orr et al., 2005; Hoegh-Guldberg et al., 2007).

Certain olivine occurrences indeed contain fibrous serpentine minerals, asbestos (Hangx and Spiers, 2009), and others do not. Olivine is used nowadays, instead of quartz sand, in sand blasting in order to prevent silicosis. This would not be done in case of asbestos admixtures. If needed, technological advances may offer possibilities to neutralize or remove asbestos, e.g. by separation based on specific gravity (asbestos ~1.6 versus olivine ~3) and other treatment.

The energy penalty, i.e., the CO_2 produced by the extra fuel to be burnt for mining, grinding, transport and distribution of olivine is about 4% of the amount of CO_2 captured. Estimates about the energy penalty of CCS (a Faustian Bargain? Spreng et al., 2007) differ, and upstream and downstream consumption, and energy costs of infrastructure are not generally included in such estimates. An additional energy consumption of 25% on a life cycle analysis basis, which might be difficult to achieve (Page et al., 2008; House et al., 2009), requires one additional power plant for every four in use. A significant increase in coal consumption in case of very large-scale CCS deployment will lead to a substantial additional need for coal, and to a lesser extent for natural gas and oil. Even if fuel resources will turn out to be sufficient in the long run, the energy penalty associated with CCS deployment will raise energy prices and price volatilities. This, in turn, may impact adversely the economics and politics of hydrocarbon-rich and hydrocarbon-importing countries (Jansen and Seebregts, 2010; pp 1656–7).

The olivine option, in the coastal zone and on the land, is a cost-effective way to counteract the increase of CO_2 level in the atmosphere, at the same time mitigating ocean acidification. The volume of olivine needed for the neutralisation of human fossil fuel burning is ~7 km^3/year, that is about 1 m^3/human. This is a large amount indeed, but comparable to the volume of fossil fuels which mankind burns annually, expressed in oil equivalent ~10 km^3/year, i.e., ~1.4 m^3/human. Olivine is produced in open pit mines, while hydrocarbons are often retrieved from kilometres depth in often remote areas.

Olivine weathering is a natural process that takes time, years to decades when applied to suitable environments. Contrary to CCS, the effect is not instantaneous, but in the course of the coming decades in which society will continue to produce CO_2 and to be threatened by continued greenhouse warming, the annual addition of large volumes of olivine to suitable environments will counteract the rise of CO_2 level of the atmosphere and the acidification of ocean waters.

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