Universiteit Utrecht

Faculty of Geosciences
Earth Sciences

Olaf Schuiling & Poppe L. de Boer
R.D.Schuiling@uu.nl; P.L.deBoer@uu.nl

Mitigation of CO_2 emissions by stimulated natural rock weathering – fast weathering of olivine in high-energy shallow seas

Human CO_2 emissions (2014): 36 GT

Natural CO_2 emissions: 0.5 – 1 Gt

In order to restore the balance, natural rock weathering must be greatly stimulated

Annual consumption of hydrocarbons (in oil equivalents): 10 km³

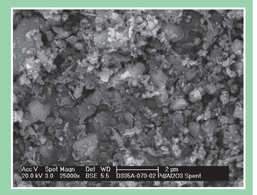
This can be compensated by stimulated weathering of 7 km³ olivine

Experiment: A week shaking of olivine in fresh water on a top table rotary shaker; water becomes milky by suspended olivine particles, and grains are rounded; pH rose to above 9.

Lab experiment

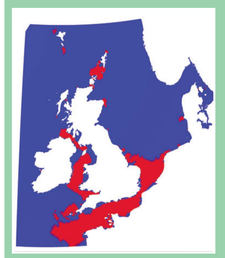
on shaking table ...

... after 1 week



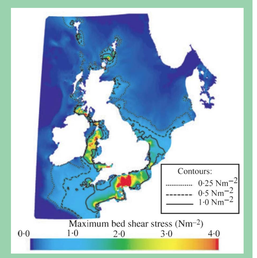
Fine-grained olivine produced during a week of shaking

In large parts of the Southern North Sea and the Irish sea tidal current velocities are sufficient to transport gravel (bed shear stress 1-4 Nm^{-2});
As in the above experiments olivine grains will weather well and increase the pH.
A 1 cm thick carpet of olivine grains spread out over a high-energy area of 35,000 km² (~15% of the area in red in the left-hand-figure) would be sufficient to compensate CO_2 produced during a year by fossil fuel burning in France, Belgium, The Netherlands, Ireland and the UK.



Bed shear stresses capable of transporting gravel (red)

Observed gravel in North European shelf seas



Maximum bed shear stress (Nm^{-2})

(From: Mitchell et al. (2012) Modelling tidal current-induced bed shear stress and palaeocirculation in an epicontinental seaway: the Bohemian Cretaceous Basin, Central Europe. Sedimentology **57**, 359-388)

$(Mg,Fe)_2SiO_4$ (**olivine** *) + 4 $H_2O \rightarrow$ 2 $(Mg, Fe)^{2+}$ + 4 OH^- + H_4SiO_4

followed by 4 OH^- + 4 $CO_2 \rightarrow$ 4 HCO_3^-

CO_2 is consumed, and Mg^{2+}, Fe^{2+}, H_4SiO_4 and HCO_3^- are produced.

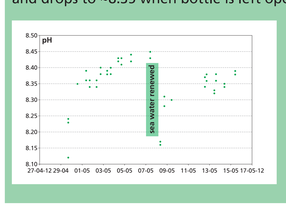
The reaction of serpentine is similar:
$Mg_3Si_2O_5(OH)_4 \rightarrow 3\ Mg^{2+} + 6\ OH^- + 2\ H_4SiO_4$

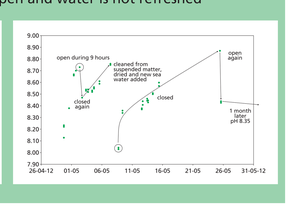
followed by 6 OH^- + 6 $CO_2 \rightarrow$ 6 HCO_3^-

* Minable olivine consists, with minor variations, of 0.92 Mg_2SiO_4 (forsterite) and 0.08 Fe_2SiO_4 (fayalite)

See movies
Flume video 1
Flume video 2
Flume video 3

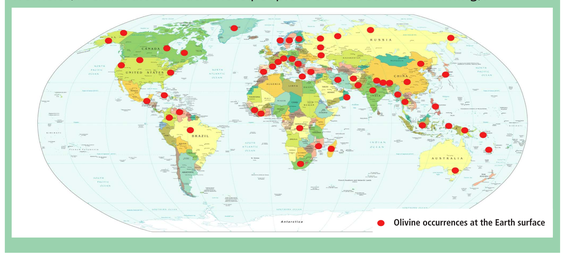
Erlenmeyer experiment with sea water
In an open bottle pH rises to ~8.4 (left) In a closed bottle pH rises to ~8.9 (right) and drops to ~8.35 when bottle is left open and water is not refreshed



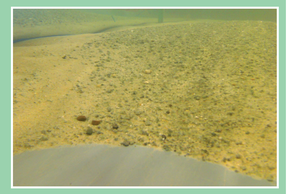


Some 1000 megacarriers would be needed to continuously carry olivine from mining areas to nearby high-energetic seas for the compensation of worldwide CO_2 emissions

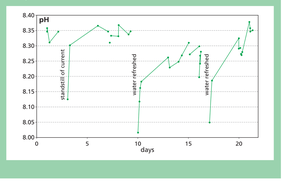
Olivine-rich occurrences
Based on Norwegian mine-employment data this would require 1.5 million mine workers (in China alone much more people are involved in coal mining).

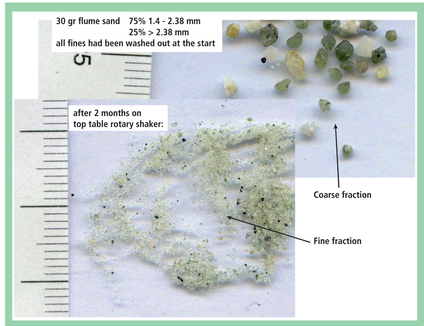


Experiments with olivine in a large recirculating flume; when water flows and olivine is transported, pH rises from 8-8.05 to ~8.3; pH drops to ~8.1 when current is stopped.



Coarse sand with ± 30% olivine, current velocity ~40-60 cm/sec





Production of fine olivine fraction after some weeks on shaking table

One such hole every few years; or *better* ***many small holes***

Quantity of olivine needed to compensate the global CO_2 emissions ≈ 7 km³ each year
cf. amount of fossil fuels mined annually (in oil equivalents) ≈ 10 km³ per year
Bingham Canyon Mine, Utah, U.S.A. ≈ 25 km³

The total volume of one such hole every few years or of many small ones to be spread over many shallow-marine locations world-wide.

Spreading of olivine in high-energy shelf seas can counteract human CO_2 emissions and ocean acidification against a price well below that of CCS and other methods.

In the reaction: $Mg(Fe)_2SiO_4$ (olivine) + 4 $H_2O \rightarrow$ 2 $Mg(Fe)^{2+}$ + 4 OH^- + H_4SiO_4
followed by 4 OH^- + 4 $CO_2 \rightarrow$ 4 HCO_3^-, CO_2 is consumed,
and Mg^{2+}, Fe^{2+}, H_4SiO_4 and HCO_3^- are produced.

Contrary to the paradigm that olivine weathering in nature is a slow process, flume experiments mimicking high-energy shallow marine environments show a fast reaction, consuming CO_2 and raising the pH at short notice. This must be because under immobile conditions a silica coating develops and retards or stops the reaction. In high-energy shallow marine environments such silica coatings are abraded so that the chemical reaction can continue. When kept in motion also large olivine grains and gravels rubbing and bumping against each other and against other sediment grains weather quickly. The experiments also show that fine micron- to silt-sized olivine particles are produced, and that the chemical reaction is fast.

The chemical weathering of 7 km³ olivine would be needed on a yearly basis in order to compensate the human CO_2 emissions. This seems very much. It is, however, of the same order of magnitude as the volume of fossil fuels (in oil equivalents ~10 km³) that are burnt annually. Olivine is readily available at the Earth' surface on all continents, and past mining efforts show that such volume of 7 km³ is exceeded by existing mines; e.g. the Bingham Canyon open pit mine in Utah has an excavated volume of 25 km³. Hydrocarbons, on the other hand, are commonly retrieved with great efforts, from great depths, and often at remote locations.

The annual spreading of large amounts of olivine (and/or serpentinite) in high-energy shelf seas where coarse sand and gravel can be transported, will counteract human CO_2 production by fossil fuel burning and ocean acidification against a price well below that of other methods; order of US$ 10.- per ton CO_2.

For example part of the continental shelf between the Shetland Isles and France, that is the Southern Bight of the North Sea, the English Channel and the Irish Sea, is covered with sand waves and in and around the English Channel an area of well over 100,000 km² experiences bed shear stresses capable of transporting gravel. A volume of 0.35 km³ coarse olivine grains, one cm thick, when applied to an area of 35,000 km² where gravel can be transported (or a thinner layer over a larger area), thus would compensate 5% of a year's worldwide CO_2 emissions. This 5% exceeds the combined annual CO_2 emissions of the adjacent countries, the United Kingdom, France, The Netherlands, Belgium and Ireland, which together are responsible for about 4% of the world's CO_2 emissions.

This is a far safer and cheaper approach than CCS. Moreover, contrary to CCS, adding olivine to the marine system, in areas where it weathers fast is an effective way to counteract ocean acidification. Bio-limiting nutrients brought into the system, Si and Fe, will moreover stimulate primary productivity thus trapping even more CO_2.

Can they help?
Weathering in the intestines of lugworms: acceleration 2 to 3 orders of magnitude that is 100 – 1000 times faster ...

Lugworm, *Arenicola marina*

... so not only high-energy environments needed.

Needham et al. (2006) Sediment indigestion by worms and the production of bio-clays: a study of macrobiologically enhanced weathering and early diagenetic processes. *Sedimentology* 53, 567-579

Layout: C&M - Faculty of Geosciences - ©2013 (8604)