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# Increased chemical weathering 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

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In the reaction: $Mg(Fe)_2SiO_4$ (olivine) + 4 $H_2O$ 2 $Mg(Fe)_2^+$ + 4 $OH^-$ + $H_4SiO_4$, followed by 4 $OH^-$ + 4 $CO_2$ 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 show a fast reaction, consuming $CO_2$, and raising the pH at short notice. Only under static conditions a silica coating develops that retards the reaction. In high-energy shallow marine environments such silica coatings are abraded so that the chemical reaction can continue. When kept in motion even large olivine grains and gravels, rubbing and bumping against each other and against other sediment grains, weather quickly. Experiments show that fine micron- to silt-sized olivine particles are produced, and that the chemical reaction is fast.

The chemical weathering of 7 $km^3$ olivine is needed on a yearly basis in order to compensate the human $CO_2$ emissions. This seems much, but is of the same order of magnitude as the volume of fossil fuels (in oil equivalents $\sim$10 $km^3$) that are burnt annually. Olivine is readily available at the Earth' surface on all continents, and such volume of 7 $km^3$ is exceeded by existing mines; e.g. the Bingham Canyon open pit mine in Utah has an excavated volume of 25 $km^3$. Hydrocarbons, on the other hand, are commonly retrieved with great efforts, from great depths, and often at remote locations.

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 $km^2$ experiences bed shear stresses capable of transporting gravel. A volume of 0.35 $km^3$ coarse olivine grains, one cm thick, when applied to an area of 35,000 $km^2$ where gravel can be transported (or a thinner layer over a larger area), 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, together responsible for about 4% of the world's $CO_2$ emissions.

This is a 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. It brings bio-limiting nutrients, Si and Fe, into the system that will stimulate primary productivity thus trapping even more $CO_2$.