# Coupled roles of ocean ventilation and the marine ecosystem in the deglacial rise of $CO_2$

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The changes in atmospheric $CO_2$ concentrations associated with the Quaternary glacial-interglacial cycles have proven remarkably difficult to explain. However it is widely thought that ocean chemistry played a major role, most importantly via the sequestration of carbon in the deep sea by the ocean's biological pump. Compilations of oxygenation proxies [1] and nitrogen isotopes [2] show that the deep ocean became better oxygenated over the deglaciation, while the polar oceans accumulated pools of unused nitrate, both of which are consistent with a weakening of the biological pump. The compilations also suggest that the biological pump weakened rapidly during the early deglaciation, contributing predominantly to the initial rise of $CO_2$ between 17.5 and 14 ka, consistent with inferences based on carbonate ion reconstructions [3] and the carbon isotopic composition of atmospheric $CO_2$ [4]. A comparison of data and model simulations supports the view that the early deglacial weakening of the biological pump arose from a double-whammy of decreasing iron fertilization and increasing deep ocean ventilation. The abrupt increase of deep ocean ventilation is suggested to have arisen following the emplacement of a salty abyssal water mass during the obliquity minimum prior to 25 ka, which became unstable and initiated deep convection in the Southern Ocean at about 17.5 ka. This deep convection released heat that rapidly warmed the southern hemisphere and dampened the supply of dust from terrestrial sources, explaining the simultaneous decline of iron fertilization to the Southern Ocean surface. According to this scenario, biology and physics played intertwined roles in the early deglacial weakening of the biological pump. The subsequent, late deglacial sources of $CO_2$ to the atmosphere probably included the removal of alkalinity by accelerated carbonate burial [3], possibly amended by enhanced volcanic outgassing of $CO_2$ in response to isostatic adjustment [5].

[1] Jaccard & Galbraith (2012), *Nature Geoscience* **5**, 151-156 [2] Tesdal *et al*, (2013), *Biogeosciences* **10**, 101-118 [3] Yu *et al* (2010), *Science* **330**, 1084-1087 [4] Schmitt *et al* (2012), *Science* **336**, 711-714 [5] Huybers & Langmuir (2007), *Earth and Planetary Science Letters* **286**, 479-491