Goldschmidt 2022 Abstract
https://doi.org/10.46427/gold2022.12189

Physical, Biological and Ecological Drivers of the Biological Carbon Pump in the Cenozoic

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Marine plankton sequester carbon from the atmosphere in the ocean interior via sinking particulate organic carbon (“the Biological Carbon Pump”), which in the modern ocean, acts to decrease the base-line atmospheric CO_2 concentration by 150-200 ppm beyond that expected solely from physio-chemical drivers of the marine carbon cycle. Conceptually, the amount of carbon sequestered is sensitive to how much carbon is produced by plankton ecosystems (export production); how much of that carbon reaches the deep ocean (sinking and remineralisation); and how long the carbon is stored in deep ocean for (ocean circulation). Features in the geological record such as a paucity of organic carbon in early Cenozoic sediments and long-term trends in the cell size and upper water-column ecology of fossilised plankton groups, alongside changes in paleogeography and climate, suggest that the Biological Carbon Pump and the carbon it sequesters from the atmosphere was variable across the Cenozoic.

Here I use a new trait-based plankton ecosystem model coupled to the Earth System model of Intermediate Complexity, EcoGEnIE, to make quantitative predictions of plankton ecology and the Biological Carbon Pump for time periods throughout the Cenozoic. EcoGEnIE resolves plankton ecosystems based on fundamental physiological constraints and resolves key feedbacks such as the impact of temperature and plankton cell size on organic matter sinking and degradation. The model is used to separate out and identify the magnitude and direction of the individual impacts of changing climate, paleogeography, plankton ecology, and organic matter fluxes. Overall, the model predicts a long-term increase in export production by plankton ecosystems across the Cenozoic. However, the carbon sequestered by the Biological Carbon Pump is strongly constrained by environmental factors such as changes in ocean circulation (via climate and paleogeography) and ocean temperatures (via metabolic rates) whereas changes in plankton ecology have a lesser impact. The model predictions are compared against a new long-term record of the vertical gradient of $\delta^{13}C$ during the Cenozoic as a proxy for the Biological Carbon Pump.