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Effect of CO_2 on coccolithophorid calcification, past, present, and future

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The calcite production of coccolithophores plays a key role in the ocean carbon cycle through ballasting of organic carbon, but may be affected by future changes in CO_2 and ocean conditions. From our cellular process models ACTI-CO and CaSri-CO, we show how stable Ca and C isotopes in coccolith calcite elucidate the carbon and Ca allocations to calcification and how these allocations change under different CO_2 concentrations. From our culture study across the modern diversity of strains of Gephyrocapsa and E. huxleyi we show that coccolith thickness variations are an excellent indicator of cellular calcification per surface area or PIC/POC, which can be used to ascertain the variation in cellular calcification to CO_2 changes in the past. In modern culture experiments, cellular process modeling of carbon isotopes reveals that calcification and photosynthesis compete for intracellular bicarbonate allocation. At low CO_2, photosynthesis is prioritized, and less bicarbonate is allocated to calcification. In response to decreasing atmospheric CO_2 over the last 15 Ma, coccolithophorids decreased allocation of bicarbonate to the calcification beginning at about 8 Ma. This shift in carbon allocation was accompanied by major changes in the degree of calcification, as estimated from the evolution of coccolith thickness in the dominant Noelrhabdaceae coccoliths. Likewise, Ca isotopes in coccoliths suggest a change in the efficiency of Ca allocation to calcification at this time. The results suggest that on evolutionary timescales, within the full diversity of the natural ocean population, periods of high CO_2 and low pH do not correspond to decreased cellular calcification.