A general model for carbon isotope fractionation in eukaryotic phytoplankton

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The carbon isotopic composition of organic matter preserved in marine sediments provides a window into the global carbon cycle through geologic time, including variations in atmospheric CO_2 levels. Traditional models for interpreting isotope records of marine phytoplankton assume that these archives primarily reflect kinetic isotope discrimination by the carbon-fixing enzyme RubisCO. However, some *in vivo* and *in vitro* measurements appear to contradict this assumption, indicating that significant questions remain regarding the mechanistic underpinning of algal isotopic signatures, including the role of carbon concentrating mechanisms (CCMs). Here, we present a general model for explaining photosynthetic carbon isotope fractionation (ε_P) in prominent eukaryotic phytoplankton groups. The model proposes that a nutrient- and light-dependent step upstream of RubisCO is a kinetic barrier to carbon acquisition and therefore represents a significant source of isotopic fractionation. The model is able to reproduce existing chemostat and batch culture datasets. The primary implications are that RubisCO is predicted to exert minimal isotopic control in nutrient-limited regimes but becomes influential as growth becomes light-limited. This framework enables both environment-specific and taxon-specific isotopic predictions. By refining the mechanistic understanding of marine photosynthetic carbon isotope fractionation, we may begin to reconcile existing datasets and reexamine Phanerozoic isotope records—including the resulting CO_2 reconstructions—by emphasizing the influence of different types of resource limitation on photosynthetic carbon acquisition.