Cenozoic carbon cycle imbalances and a variable silicate weathering feedback

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Earth's long-term climatic stability, and its ability to recover from carbon cycle perturbations, is often attributed to a stabilizing negative feedback between silicate weathering and climate. However, direct evidence for the operation of this feedback over million-year timescales remains scarce. For example, the Cenozoic is a period of long-term cooling, declining pCO_2, and invariant solid Earth degassing rates; yet, past weathering fluxes—as calculated using marine isotopic proxies (*i.e.* $^{87}Sr/^{86}Sr$, δ^7Li, and $^{187}Os/^{188}Os$)—appear to increase during the Cenozoic, which is inconsistent with both past atmospheric pCO_2 records and carbon mass balance. Further, modern weathering fluxes are often most closely correlated with tectonic uplift. Here, we evaluate the existence of a negative feedback over the Cenozoic by using the major surface (ocean and atmosphere) reservoirs of carbon to determine the total allowable imbalance in the geologic carbon cycle, the corresponding silicate weathering flux, and the residence time of carbon with respect to silicate weathering.

We demonstrate that the imbalance in the surface carbon cycle has been minimal for the entire Cenozoic, implying the existence of a strong negative feedback between silicate weathering and climate. Only a sustained 0.5-1% increase in silicate weathering is necessary to explain the long-term decline of pCO_2 over the Cenozoic. This small change in the weathering flux corresponds to a two-fold decrease in the residence time of carbon. Rather than an appreciable increase in the silicate weathering flux, we suggest the long-term decrease of pCO_2 results from an increase in the strength of the silicate weathering feedback due to a rearrangement of tectonic-climate interactions. Thus, at constant degassing rates, a weak silicate weathering feedback results in high pCO_2. Increasing feedback strength reconciles the need for carbon mass balance with evidence for a strong correlation between uplift rates and weathering fluxes, and may explain why there are periods when the Earth system appears more sensitive to carbon cycle perturbations than at present, such as in the early Paleogene.