Threshold phenomena in the marine carbon cycle

DANIEL H. ROTHMAN[1]

[1]Lorenz Center, Department of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA 02139

John Hayes was deeply interested in the ways in which the isotopic composition of carbon in marine sediments reveals how the marine carbon cycle works. As he and others have made clear, each carbon isotopic excursion in the geochemical record has its own story to tell. Yet we also know that each event records a disruption of the same, albeit changing, Earth system. This talk addresses aspects of that common structure. I first review a database of 31 isotopic events throughout the Phanerozoic, and find that the size of isotopic excursions appears limited by the timescale over which they occur. Closer analysis reveals a characteristic limiting rate that acts as a threshold: events faster than the characteristic rate are associated with mass extinction. Moreover, the size and timescale of events decreases towards the present. I associate the latter effect with evolutionary changes in the marine carbonate cycle. But what sets the characteristic rate? To investigate this question and others, I construct a simple dynamical-system model for the evolution of total alkalinity and total dissolved inorganic carbon in the shallow ocean. The model predicts a route to runaway ocean acidification in which a steady state remains stable while being extraordinarily sensitive to a finite perturbation (as might occur, e.g., via an external source of carbon dioxide). When such a perturbation exceeds a threshold, an internal reorganization of the marine carbon cycle creates a transient surge of carbon followed by a return to the steady state, similar to the behavior of many carbon isotopic excursions. The rate of change of these events is bounded by the riverine influx of alkalinity, thereby indicating how a characteristic limiting rate might exhibit itself in the real carbon cycle. The threshold for the surge may estimated theoretically. When applied to the modern carbon cycle, results suggest that human activities will likely have exceeded the threshold some time in the present century