AN ABERRATION IN THE GLOBAL CARBON CYCLE 55 MILLION YEARS AGO: IMPLICATIONS FOR CARBON CYCLE FEEDBACKS

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ABSTRACT

Approximately 55 million years ago (Mya) at the boundary between the Paleocene and Eocene epochs (P-E boundary), the Earth experienced an extreme global warming event that persisted for several tens of thousands of years, and which triggered short- and long-term changes in marine and terrestrial ecosystems. Several lines of evidence suggest that the warming was caused by the sudden decomposition of marine methane hydrates which ultimately released >2000 gigatons of carbon (GtC) to the atmosphere. In theory, a large portion of this carbon would have been absorbed by the ocean, thereby lowering the ocean pH, and initiating a neutralization process involving the massive dissolution of seafloor carbonate. This process would enable the ocean to absorb and temporarily store additional carbon. Permanent sequestration of this excess carbon, however, would occur gradually through a number of negative feedback processes such as the burial of organic carbon. Quantitatively, the most important feedback should be the chemical weathering of silicate rocks, and eventual redeposition of carbonate on the seafloor. Here, I discuss the evidence used to constrain the magnitude of changes in ocean carbon chemistry 55 Mya, and implications for future carbon cycle feedbacks.

INTRODUCTION

An ancient global warming event, known as the Paleocene-Eocene thermal maximum (PETM), punctuated earth climate history ~55 Ma. Sea-surface temperatures increased by as much as 5°C in the tropics and 8 ºC in polar regions, while deep sea temperature increased by 5°C [*Kennett and Stott*, 1991; *Zachos et al*. 2003]. Several lines of evidence from near shore marine P-E boundary sections in mid-high latitudes indicate increased humidity and precipitation. This includes blooms of dinoflagellate *Apectodinium*; expanded clay-rich excursion layers dominated by kaolinite. The onset of this climate shift was particularly rapid, <several 10^3 years, and the impacts on the global biosphere significant, altering abundances and distributions of taxa, and the biotic evolution among organisms ranging from marine protists to terrestrial vertebrates [*Koch et al.*, 1992, *Kelly et al.*, 1996; *Bowen et al*., 2002; *Bralower*, 2002]. One of the most prominent biotic impacts was a major mass extinction of pelagic benthic protists.

Several lines of evidence suggest that a large amount of ^{12}C depleted carbon, most likely methane, was released to the atmosphere 55 Mya. This includes an abrupt, negative carbon isotope excursion (CIE) recorded in marine and terrestrial fossils [*Kennett and Stott*, 1991; *Koch et al.*, 1992]. To date, the most plausible mechanism for the sudden release of large quantities of methane into earth's surficial carbon reservoir is the catastrophic dissociation of sedimentary methane hydrate along continental slopes [*Dickens et al*., 1995]. It has been posited that gradual warming of the ocean destabilized the hydrates triggering a strong positive feedback loop, with initial warming driving additional decomposition. Other sources of carbon such as increased mantle CO_2 outgassing and geothermal heating of organic rich crust may have played an important role in initiating this process. Regardless of source, a massive influx of carbon into the ocean-atmosphere system would have elevated pCO_2 levels thereby decreasing the pH and carbonate ion concentration [CO_3^{2-}] of seawater, and the depth of the oceanic carbonate-saturation horizon [*Dickens et al*., 1995].

The transient nature (~120 – 220 kyr) of PETM warmth, rapid removal of ^{12}C from the ocean-atmosphere system, and resumption of carbonate sedimentation following the CIE all indicate that negative-feedback mechanisms within the global carbon cycle abated greenhouse climatic conditions [*Zachos et al.*, 2005]. A number of negative-feedback processes may have contributed to carbon sequestration including expansion of continental vegetation with increased terrestrial organic-carbon storage [*Beerling*, 2000] as well as elevated surface-ocean productivity with increased marine organic-carbon burial. However, quantitatively the most important feedback for permanently sequestering carbon and lowering atmospheric CO_2 levels is the acceleration of silicate-weathering reactions on land [e.g., *Dickens et al.*, 1995]. This weathering mechanism would slowly absorb CO_2 that was temporarily being stored in the ocean, and return bicarbonate and soluble cations into the ocean, thereby driving ocean-carbonate content toward saturation and enhancing carbonate production/preservation.

To constrain the timing and magnitude of changes in ocean carbon chemistry during this event, and to better understand the impacts on marine ecosystems, the Ocean Drilling Program (ODP) embarked on a series of expeditions to recover sediment cores spanning the P-E boundary from the Pacific and Atlantic ocean basins. In particular, a transect of 5 cores recovered from between 2.4 and 4.8 km water depth of the flank of Walvis Ridge in the south Atlantic has provided compelling evidence for ocean acidification. In each core, the P-E boundary is marked by a prominent clay layer, the thickness of which increases with depth [*Zachos et al.*, 2005]. The physical and chemical characteristics of this layer indicate that ocean pH dropped sufficiently to drive dissolution of carbonates at depths shallower than 1 km. The ocean pH than slowly recovered over 120,000 y. Moreover, toward the end of the recovery phase, it appears that the ocean may have become supersaturated leading to massive carbonate deposition. These findings support hypotheses that a large mass of carbon (>>2000 Gt) was released 55 Mya, and permanent sequestration of this carbon occurred gradually via the silicate weathering feedback. These results validate a class of global carbon cycle models which estimate the time-scale of recovery (return to pre-industrial conditions) from present and projected future emissions of anthropogenic carbon (~4500 GtC) to be over 100,000 y.

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