# Accelerated marine carbon cycling forced by tectonic degassing over the Miocene Climate Optimum

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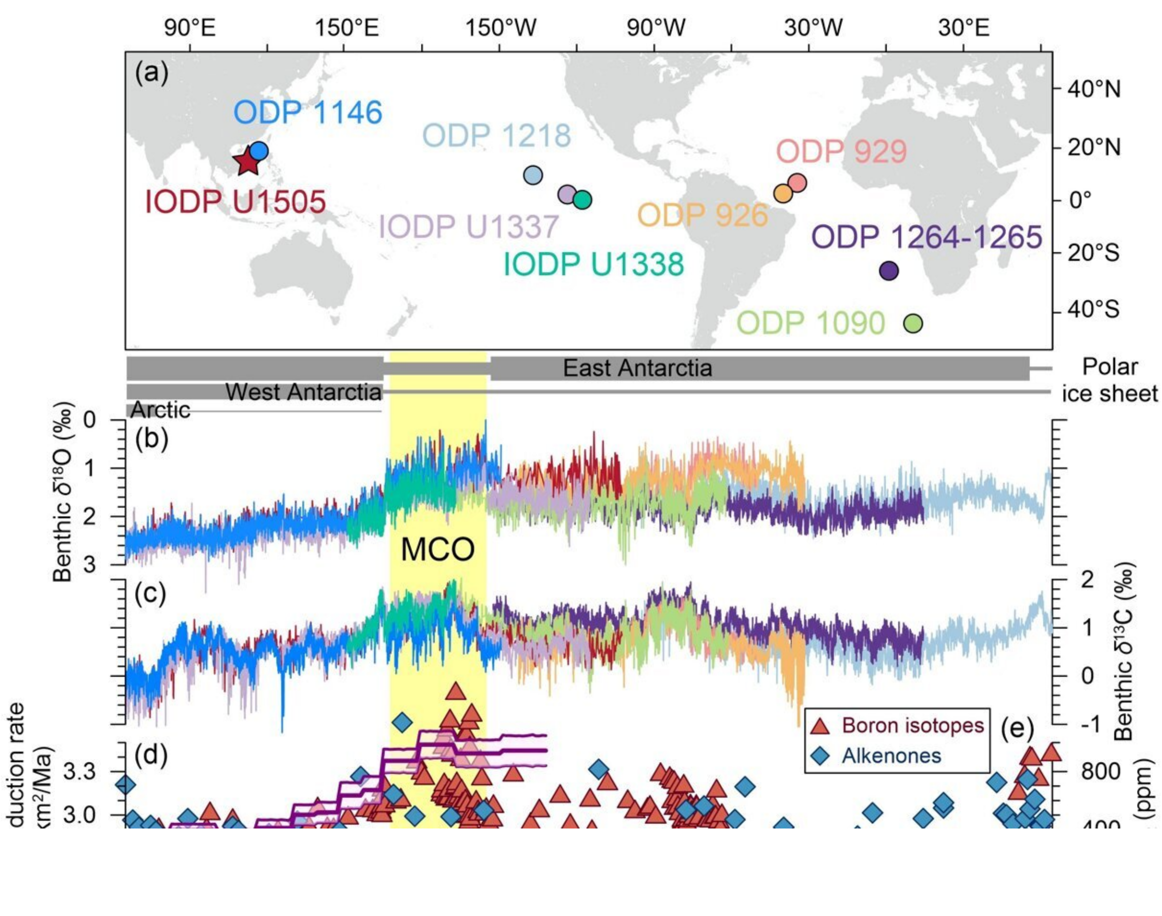
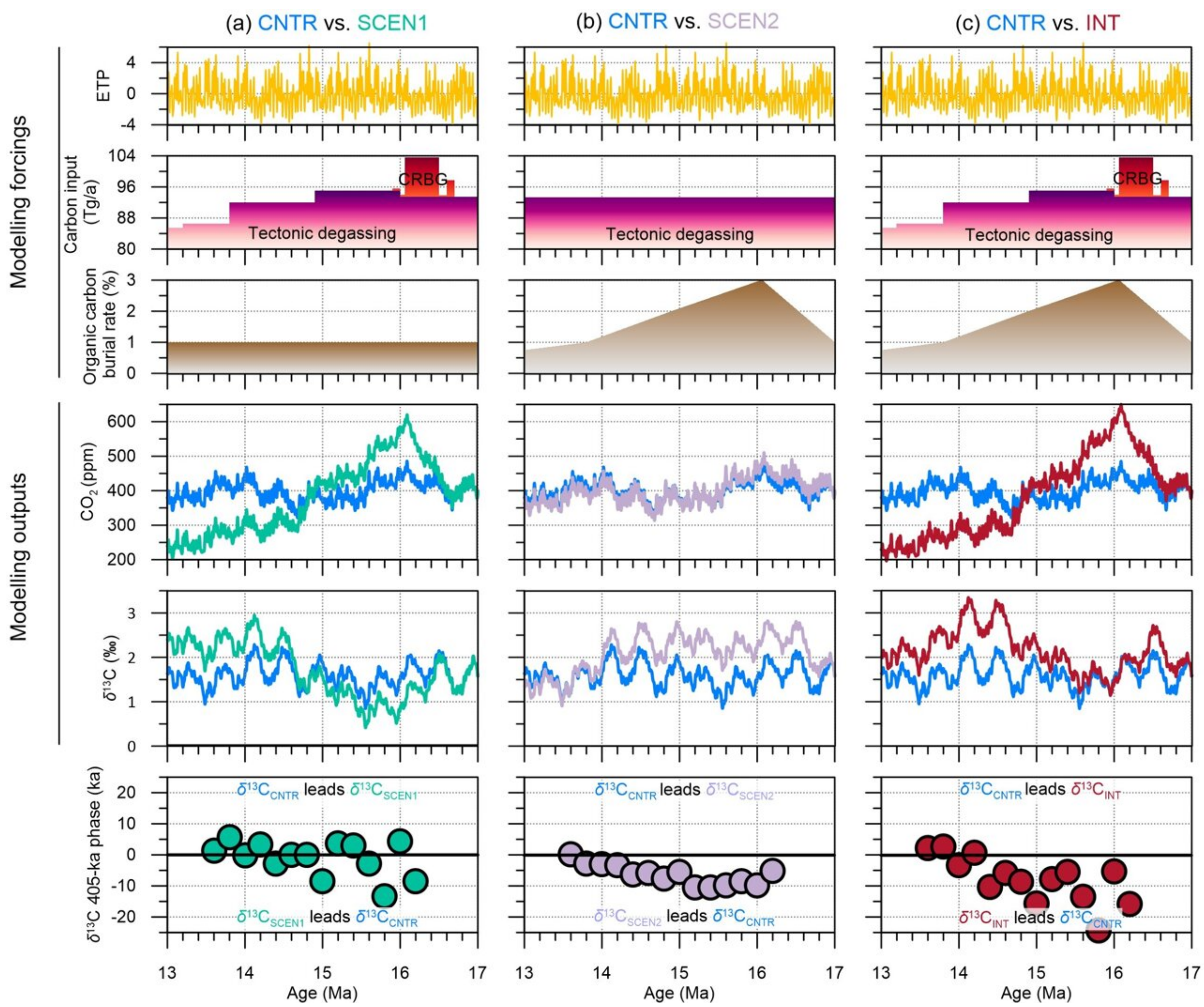



(a) Locations of the sites discussed in this study, highlighting the new IODP Site U1505 (red star). (b and c) Overview of the benthic $\delta^{18}O$ and $\delta^{13}C$ records with the evolution of the polar ice sheets (gray shadow). (d) Global ocean crust production rates with 95% confidence intervals. (e) Reconstructed atmospheric $CO_2$ levels derived from boron isotope and alkenone. The occurrence of the Columbia River Basalt Group (CRBG) is shown by an orange rectangle (f and g) Eccentricity sensitivity of benthic $\delta^{18}$O and $\delta^{13}$C ($S_{ecc}$-$\delta^{18}$O and $S_{ecc}$-$\delta^{13}$C) from selected IODP/ODP sites. (h) Evolutive phase relationship between $\delta^{18}$O and $\delta^{13}$C records in the 405-ka bands. Only results with a coherence >0.6 are presented. Positive and negative phase relationships indicate that $\delta^{18}$O leads and lags $\delta^{13}$C, respectively. Yellow shading marks the period when $\delta^{13}$C leads $\delta^{18}$O during the MCO. Credit: *Science Bulletin* (2024). DOI: 10.1016/j.scib.2023.12.052

In a recent publication in *Science Bulletin*, a multidisciplinary team of authors from Tongji University, the Second Institute of Oceanography (Ministry of Natural Resources), the Institute of Earth Environment (Chinese Academy of Sciences), and Utrecht University reports for the first time that massive carbon inputs from volcanism and seafloor spreading have impacted the orbital phase relationships between carbon cycle and climate change.

Past changes in climate and carbon cycle have been documented by the stable isotope composition of benthic foraminiferal oxygen and carbon, as they are proxies for climate-cryosphere and carbon transfers between the ocean and other reservoirs, respectively. In addition, the global climate-cryosphere changes and the marine carbon cycle were significantly regulated by Earth's orbital eccentricity, obliquity, and precession, with the 405,000-year cycle having a particularly pronounced effect.

When Earth was glaciated by unipolar ice sheets at Antarctica over the Oligocene and Miocene, about 34 to 6 million years ago, variations in the global climate-cryosphere and the marine carbon cycle exhibited almost in-phase behavior on eccentricity timescales.

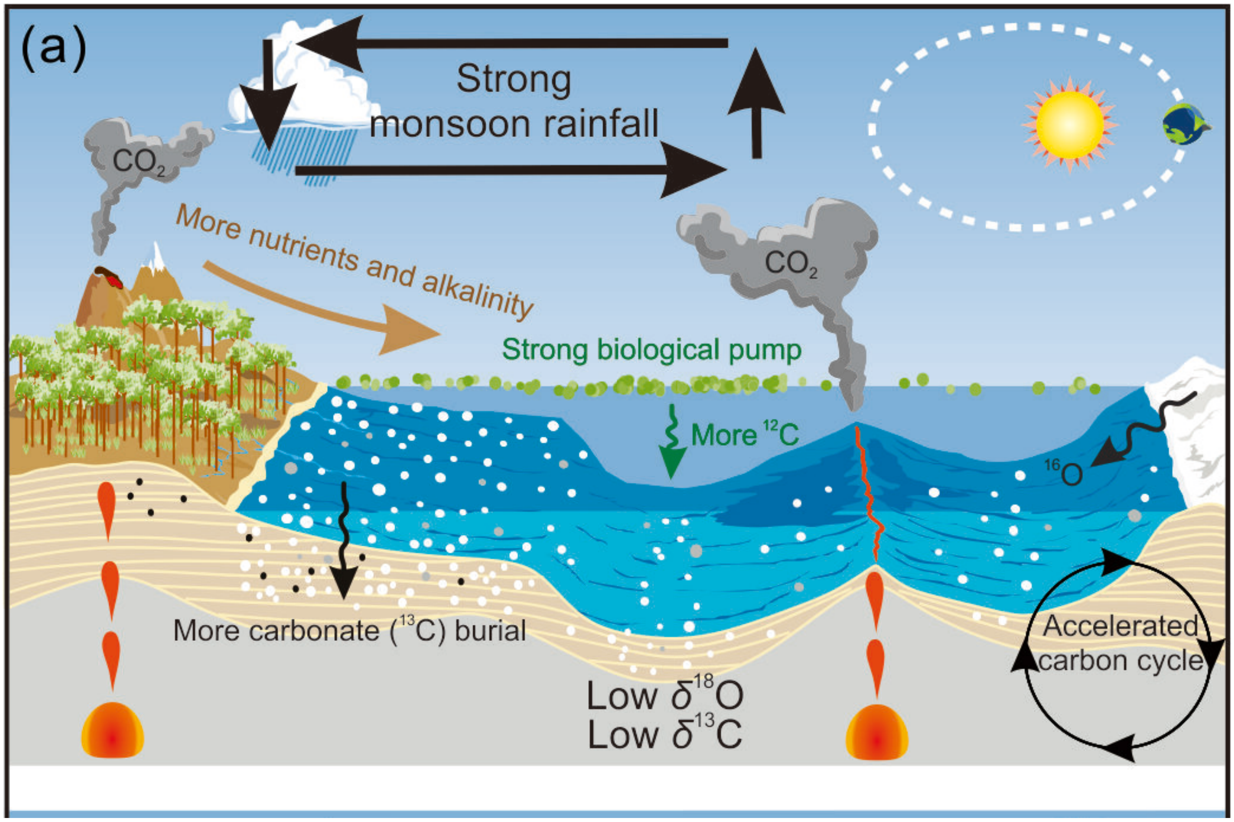



(a) Comparison between the CNTR and the SCEN 1, (b) the CNTR and the SCEN 2 and (c) the CNTR and the INT. Modeling forcings include changes in the ETP, the tectonic degassing carbon input (Tg=$10^{12}$g), and the fraction of buried organic carbon. Model outputs presented here are atmospheric $CO_2$ concentrations and the $\delta^{13}$C of dissolved inorganic carbon in bottom waters. The evolutive phase relationship between the $\delta^{13}C_{CNTR}$ and the $\delta^{13}C_{SCEN1/SCEN2/INT}$ at the 405-ka cycle is shown. Credit: *Science Bulletin* (2024). DOI: 10.1016/j.scib.2023.12.052

On this basis, a moderate but noticeable phase lag of the marine carbon cycle relative to climate-cryosphere changes of about 19.2 thousand years was observed. This phase lag was attributed to the relatively long residence time of carbon in the ocean.

However, through time-evolutive phase analysis of new and published high-resolution benthic foraminiferal oxygen and carbon isotope records across the global ocean, the authors find that variations in the marine carbon cycle led the climate-cryosphere by an average of about 17 thousand years during the Miocene Climate Optimum from around 17 to 14 million years ago.

This corresponds to the occurrence of the Columbia River Flood Basalt and the rapid global seafloor spreading, a period when massive amounts of deep-sourced carbon were released into the atmosphere.




(a) Eccentricity maxima can cause a shrinkage of the Antarctic ice volume and an increased $^{16}O$ (isotopically light oxygen) transfer to the ocean. Simultaneously, enhanced monsoons and continental weathering can transport more alkalinity and nutrients to the ocean, releasing more $^{12}C$-enriched carbon into the deep sea. (b) During eccentricity minima, the opposite processes occur. Therefore, benthic $\delta^{18}O$-$\delta^{13}C$ interactions are nearly in phase at eccentricity cycles. (c) Cross-spectral coherence and phase angles between parallel $\delta^{18}O$ and $\delta^{13}C$ records from IODP/ODP sites 1146, U1337, U1338 and U1505 for the MCO interval, and they show that variations of benthic $\delta^{13}C$ lead those of $\delta^{18}O$ in the 405-ka bands. In general, the relatively long residence time of carbon in the deep ocean facilitates a lead of benthic $\delta^{18}O$ relative to $\delta^{13}C$. The MCO greenhouse effect is likely to have accelerated the response of marine carbon cycle to eccentricity forcing, generating the $\delta^{13}C$-lead-$\delta^{18}O$ scenario. Credit: *Science Bulletin* (2024). DOI: 10.1016/j.scib.2023.12.052

Further sensitivity analyses and model simulations suggest that the elevated atmospheric $CO_2$ concentrations and the resulting greenhouse effect strengthened the low-latitude hydrological cycle during the Miocene Climate Optimum, accelerating the response of the marine carbon cycle to eccentricity forcing via enhanced chemical weathering and organic carbon burial.

Hence, tropical climate processes played a dominant role in regulating the marine carbon cycle when Earth's climate was in a warm regime.

This study provides a robust case for linking long-lasting tectonic events to orbital-scale changes in the Earth's surface system.

**More information:** Fenghao Liu et al, Accelerated marine carbon cycling forced by tectonic degassing over the Miocene Climate Optimum, *Science Bulletin* (2024). DOI: 10.1016/j.scib.2023.12.052

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