Pulsed phytoplankton turnover in the Southern Ocean forced by stepwise Antarctic cooling

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Abstract

The Southern Ocean accounts for about 25% of total oceanic uptake of atmospheric carbon dioxide and more than 10% of anthropogenic carbon dioxide uptake since the start of the industrial revolution, via direct solubility effects and the biological pump (Arrigo et al. 2008, Deppler and Davidson 2017). The biological pump and food webs are based critically on phytoplankton that generate approximately 50% of global primary productivity. How phytoplankton communities in the Southern Ocean will respond to polar amplification of global warming remains unclear, although there is growing evidence of biogeographic, community and adaptive changes in the living flora (e.g., Boyd et al. 2015).

Here we report the results of high-resolution analysis of turnover (speciation rate plus extinction rate) of diatom species in the Southern Ocean over the past 25 million years. Results are based on quantitative biostratigraphic analysis of highly vetted fossil occurrence data from 34 drill cores from the Southern Ocean and Antarctic margin, which have been age-calibrated using a conservative subset of available paleomagnetic and radiometric date constraints (Crampton et al. 2016).

We find that turnover is highly pulsed and identify six major episodes of elevated turnover (>0.5 extinctions per lineage million years), as well as a number of lesser turnover events (see figure). All the major events and some of the lesser turnover pulses are coincident with cooling of southern high-latitude climate, growth of Antarctic ice sheet across continental shelves, and expansion of sea ice across the Southern Ocean. We infer that past times of phytoplankton turnover occurred when a warmer-than-present climate was terminated by a major period of glaciation that caused loss of open-ocean habitat and extinction of non-ice-adapted diatoms. Our results suggest that these phytoplankton communities are tolerant of "baseline" variability on glacial-interglacial timescales, but are sensitive to large, step-wise changes in mean climate state.

Important questions remain unanswered. In particular, we do not yet know to what extent species turnover in the phytoplankton affects the food chain and the wider ocean ecosystem. Also, past turnover has been in response to cooling – it is not clear how the phytoplankton will respond to rapid warming in the Southern Ocean in coming decades and centuries.

Keywords: diatoms, Miocene, Pliocene, phytoplankton

References

Arrigo, K.R., van Dijken, G.L., Bushinsky, S., 2008. Primary production in the Southern Ocean, 1997-2006. Journal of Geophysical Research, 113, C08004, doi:10.1029/2007JC004551.

Boyd, P.W., Lennartz, S.T., Glover, D.M., Doney, S.C., 2015. Biological ramifications of climate-change-mediated oceanic multi-stressors. Nature Climate Change 5, 71-79, doi: 10.1038/NCLIMATE2441.

Crampton, J.S., Cody, R.D., Levy, R., Harwood, D., McKay, R., Naish, T.R., 2016. Southern Ocean phytoplankton turnover in response to stepwise Antarctic cooling over the past 15 million years. Proceedings of the National Academy of Sciences of the USA, 113(25), 6868-6873, doi: 10.1073/pnas.1600318113.

Deppeler, S.L., Davidson, A.T., 2017. Southern Ocean phytoplankton in a changing climate. Frontiers in Marine Science, 4(40), doi: 10.3389/fmars.2017.00040.