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A global database of carbon and oxygen isotopes for the last deglaciation

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The PAGES Data Stewardship Scholarship (DSS) contributed towards the completion of the first version of a database of carbon and oxygen isotopes from benthic foraminifera in deep-ocean sediment cores.

The Ocean Circulation and Carbon Cycling (OC3) working group (pastglobalchanges.org/science/wg/former/oc3) started in 2014. OC3 brought together researchers with a scientific question: What global changes can explain variations in ocean carbon and oxygen isotope ratios ($\delta^{13}C$ and $\delta^{18}O$) in benthic foraminiferal samples from deep-sediment cores? Of particular interest was the transition between the Last Glacial Maximum (LGM, 23–19 kyr BP) and early last deglaciation (19–15 kyr BP), where a first increase in atmospheric CO_2 from glacial values (~180 ppm) is observed in ice-core data (Petit et al. 1999). $\delta^{13}C$ from tests of benthic foraminifera in deep-ocean sediment cores is used in paleoceanography as a tracer for past deep-water mass structure (Curry and Oppo 2005). $\delta^{18}O$ from the same samples is used as a tracer for deep-water temperatures and $\delta^{18}O$ of sea water (Lynch-Stieglitz et al. 1999). Despite relatively large amounts of existing data, the use of stable isotopes in paleoclimate research is hindered by several issues, such as:

1) formatting differences among sites;

2) differences in the methodologies used to calculate age models and/or;

3) offsets due to different species used to measure stable isotopes, and species-specific corrections included in some data.

The OC3 community established standards to homogenize benthic foraminifera isotope data and age models from different sources. In 2021, OC3 was granted a DSS from PAGES, which enabled us to finish the database product in early 2023. The database is available at zenodo.org/records/10391267, and a description paper was published (Muglia et al. 2023). It includes 287 globally distributed coring sites (Fig. 1). A *csv* file format was chosen, which makes the files both machine- and human-readable. A quality check on the data and age models was performed before their inclusion in the database. To be able to resolve the rapid changes associated with the last deglaciation, we only include data with temporal resolution of 1 kyr or better (Fig. 1). Stable isotope data from the genus *Cibicidoides* were preferred. The choice minimizes offsets from contemporaneous $\delta^{13}C$ of dissolved inorganic carbon in the overlaying bottom water. A toolbox written in Python calculates time slices, selects data by its time resolution, and plots data in time series, map, or vertical section formats. It is available in the database repository.

One important goal of OC3 is to quantify age-model uncertainties. For this purpose, we included different age models for sediment cores, if multiple age-model approaches were available. This enables an evaluation of the sensitivity of the reconstructed time evolution of benthic foraminiferal $\delta^{13}C$ and $\delta^{18}O$, with respect to different age models. We found that offsets in time series of isotope ratios obtained from using different age models are typically smaller than the uncertainties in those age models. This suggests that the direction of changes in stable isotope ratios may be captured, irrespective of the age-model approach used. Due to its global coverage and high temporal resolution, the OC3 database allows scientists to reconstruct a four-dimensional picture of changes in $\delta^{13}C$ and $\delta^{18}O$ through the last deglaciation. The database is useful for modelers to compare with computer simulations of the deglacial state, and for paleoclimatologists to study past deep-ocean and carbon-cycle changes. The database structure can also be used as a template for compilations of other paleoceanographic data in the future.

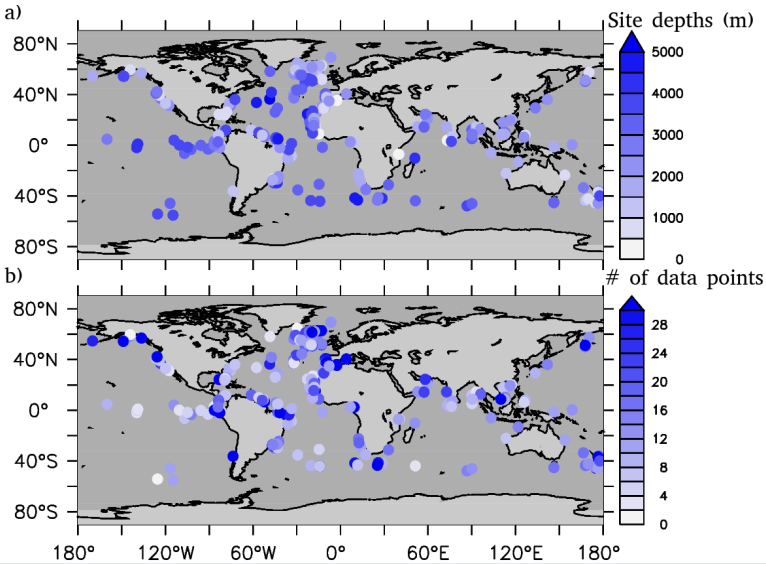

Figure 1: (A) Positions and depths (in m) of all sites included in our database. **(B)** Number of data points at each site in the 21–15 kyr BP time interval. Figure modified from Muglia et al. 2023.

Future plans

The OC3 database is an ongoing project, with updates and additions performed as new coring sites and age models are published in the literature, or provided by our collaborators. The database will be combined with visualization tools of PaleoDataView (marum.de/Dr.-stefan-mulitza/PaleoDataView.html). In addition, we plan to translate the database into formats compatible with the LinkedEarth initiative.

Benthic foraminifera $\delta^{13}C$ and $\delta^{18}O$ are useful, but limited, tracers for deep-ocean characteristics. Expanding the database with other paleo-tracers, such as radiocarbon ages, Pa/Th or Neodymium, will provide a more complete picture of the ocean in past-climate scenarios. For this reason, in a future project, the database will be expanded to include these tracers.

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