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Boron-CO_2 workshop: Testing and extending the limits of the foraminiferal boron proxy for seawater pH and atmospheric CO_2 reconstructions

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Atmospheric carbon dioxide (CO_2) is the key driver of global temperatures over geological time, but calculating the exact sensitivity of Earth's climate to CO_2, and hence the trajectory of anthropogenic climate change, requires accurate quantification of past CO_2. Determining past CO_2 and fluxes among Earth's carbon reservoirs is difficult, particularly prior to ice-core records of the last 800 kyrs. Attempts have been made to compile multi-proxy atmospheric CO_2 proxy data through time (Foster et al. 2017; Hönisch 2021; Rae et al. 2021) which have gained considerable traction, including in the Intergovernmental Panel on Climate Change reports (IPCC 2021). However, many of these compilations can include inaccuracies and apparent contradictions arising from differing assumptions and auxiliary inputs used when translating proxy data to CO_2. To move forward as a community, ensuring the robustness of future CO_2 data contributions and reducing noise in a crucial dataset, such inconsistencies must be minimized, and uncertainties systematically accounted for (Fig. 1).

The importance of the boron isotope CO_2 proxy

Amongst proxies for past atmospheric CO_2 reconstruction, boron isotopes have become one of the most well-established, and are increasingly recognized for their accuracy and precision (IPCC 2021). Boron isotopes have gained this reputation for two reasons: firstly, they can replicate atmospheric CO_2 during periods where ice-core estimates are available for comparison (Chalk et al. 2017), and secondly, their methodological basis is now reproducible and accurate by different laboratories (Gutjahr et al. 2020) based on community-led efforts to standardize analytical data generation. As yet, however, no analogous consensus has emerged on how we obtain CO_2 estimates from boron isotopes. This area has seen a great many advances: in constraining and calculating seawater temperature and boron isotope composition, in deriving the necessary second carbonate system parameter, in how "vital effects" (i.e. biological modifications to the proxy) are accounted for, in dealing with changing seawater chemistry, and in how uncertainties are measured and propagated. As a result of this rapidly changing landscape, many studies are now mutually inconsistent in their guiding assumptions, and old data need updating with new methods, or even replacing or omitting where their inclusion no longer adds value.

A community-led consensus

To address these issues, we organized a virtual series of workshops between 2021 and 2022, culminating in a PAGES-supported workshop in Bergen, Norway, in September 2022. Our aims were to critically evaluate the approaches used, discuss how to expand the horizons of the boron-CO_2 proxy, and build an internally consistent compilation of long-term pH and CO_2 change that provides reliable, accurate and future-proof (where possible) constraints on past climate. Several important observations were developed over the course of these workshops, most notably that:

1) although not the main cause of inconsistent CO_2 values in the literature, differing data processing scripts utilized by the community can cause reconstructions to diverge over periods of changing seawater composition;

2) a consistent approach to "vital effects" is required to integrate different datasets; and

3) there are critical time periods where data density is poor, such as the Paleocene, Oligocene, and Miocene.

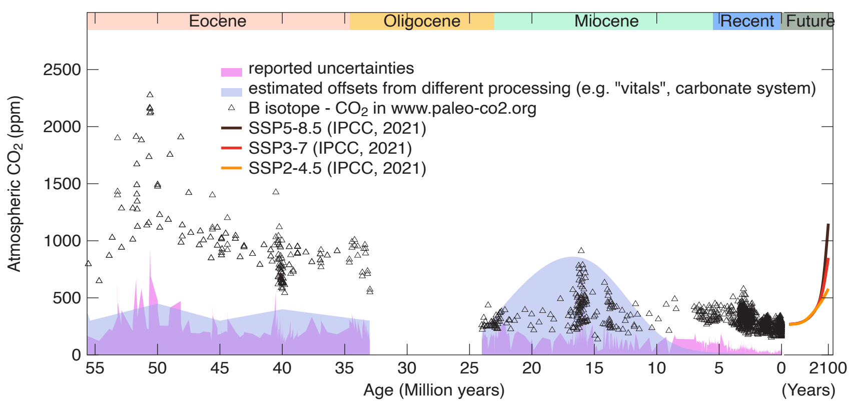

Figure 1: Representation of the magnitude of offsets and uncertainties in boron-CO_2 estimates in the literature. Future emission scenarios are depicted with lines (IPCC 2021).

Already, these workshops have streamlined cross-platform, community-tested scripts, incorporating recent developments in carbonate and seawater chemistry (Hain et al. 2015). We interrogated the unknowns of the proxy and best-practice approaches, for example the treatment of "vital effects", impact of seawater major ion chemistry, and assumptions about the auxiliary data required for converting pH to CO_2. Two periods – the Miocene and the Eocene – were identified as having the largest discrepancies in CO_2 estimates, thus providing effective test cases for developing consensus in boron-derived CO_2 processing.

Alongside resolving internal inconsistencies within the community, our workshop aimed to look outwards, and foster exchange with the broader community, toward data-model integrations and constraining past carbon cycle-climate interactions and Earth's climate sensitivity. Finally, we demonstrated the need for, and sowed the seeds of, closer collaboration and coordination within the international boron isotope community. Results of these efforts arising from the online and in-person PAGES meetings are already appearing in a dedicated special issue of *Paleoceanography and Paleoclimatology*, which is open for submissions. Results will also be synthesized in a forthcoming boron-CO_2 compilation paper.

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REFERENCES

Chalk TB et al. (2017) Proc Natl Acad Sci 114: 13114-13119

Foster GL et al. (2017) Nat Comm 8: 14845

Gutjahr M et al. (2020) Geostand Geoanal Res 41: 59-75

Hain MP et al. (2015) Glob Biogeochem Cycles 29(5): 517-533

Hönisch B (2021) Paleo-CO2 data archive (Version 1). Zenodo

IPCC (2021) Climate Change 2021: The Physical Science Basis. In: Masson-Delmotte V et al. (Eds). Cambridge University Press, 2391 pp

Rae JWB et al. (2021) Annu Rev Earth Planet Sci 49: 609-641

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