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Absolute temperature seasonality from skeletal carbonates—Techniques and limitations of oxygen- and clumped isotope analyses

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The carbonate skeletons of marine organisms are unique archives for high-resolution climate reconstructions. Well-preserved specimens potentially allow for seasonal to even daily scale variability reconstructions of climate and environment in deep time (pre-Quaternary), providing otherwise unavailable snapshots of climate variability during greenhouse periods (e.g. Steuber et al., 2005; Ivany et al., 2008; de Winter et al., 2017). However, uncertainties on past seawater compositions hamper use of the popular stable oxygen isotope ratio ($\delta^{18}\text{O}$) as proxy for paleotemperature reconstructions. The use of the independent carbonate clumped isotope (Δ_{47}) paleothermometer, which is insensitive to changes in seawater composition, on these promising fossil archives is complicated because of sample size limitations (Fernandez et al., 2017; Bernasconi et al., 2018).

In an attempt to circumvent these issues and use the $\delta^{18}\text{O}$ and Δ_{47} measurements jointly for accurate seasonal reconstructions of temperature and seawater isotope composition, we present a novel data reduction approach that combines Δ_{47} measurements of small (~100 μg) serially sampled aliquots to estimate summer and winter temperatures in mollusk shell records. When applied on Δ_{47} and $\delta^{18}\text{O}$ measurements in the same specimens, combined with accurate shell chronologies, this approach reconstructs seasonal differences in temperature and seawater composition in a coastal site from the Campanian (Late Cretaceous) high-latitudes.

To test the robustness of these reconstructions, we apply different approaches of combining $\delta^{18}\text{O}$ and Δ_{47} data on a wide range of simulated data representing various scenarios of variability in growth rate, temperature and sea water composition typical for the natural shallow marine environments of carbonate-producers. This approach tests how choices such as sampling resolution and the method of data collection and reduction influence the accuracy and reproducibility of (paleo)seasonality reconstructions in these scenarios.

Finally, we present preliminary data of $\delta^{18}\text{O}$ and Δ_{47} analyses on bivalve specimens grown under controlled temperature conditions that allow us to calibrate the techniques above for temperature reconstructions. Together, these investigations pave the way for accurate, high-resolution climate reconstructions in deep time. These reconstructions provide valuable information on the dynamics of greenhouse climates, against which climate models can be compared to improve predictions of future climate.

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