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Editorial: Development and novel applications of geochemical proxies in marine and terrestrial carbonate records

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Editorial on the Research Topic

Development and novel applications of geochemical proxies in marine and terrestrial carbonate records

Many marine and terrestrial carbonate deposits contain records of past climate and oceanographic conditions that span annual cycles to millions of years. Consisting of aragonite or (magnesian) calcite of biogenic or authigenic origin, they must accrete in regular increments to allow accurate dating of individual horizons. Advances in (micro) analytical and sampling techniques are unlocking records in new types of deposits, using novel geochemical proxies encompassing an ever-widening range of environmental variables, and going further back in time. We therefore felt that this Research Topic (RT) would be timely and informative.

In two papers, known proxies were retrieved from challenging, slow-growing organisms. Hetzinger et al. investigated specimens of high-Mg calcite coralline algae *Neogoniolithon hauckii* from the temperate Mediterranean Sea, associated with long *in situ* temperature records. High-resolution laser ablation (LA-)ICP-MS revealed Mg/Ca and Li/Ca cycles in distinctive annual banding with growth rates of 1.1–1.2 mm/y. Both display significant positive linear correlations with temperature. Hughes et al. report a 24-year isotope record from the bivalve *Astarte borealis*, a long-lived species that is difficult to drill with seasonal resolution. Secondary ion mass spectrometry (SIMS) yielded $\delta^{18}O_{shell}$ with sub-monthly resolution showing marked correlations with sea surface temperature (SST) and, after appropriate smoothing of the data, with *in situ* salinity and the North Atlantic

Oscillation (NAO) index. The authors propose that regional influences of the NAO on the Baltic temperature–$\delta^{18}O_{SW}$ correlation may render $\delta^{18}O_{shell}$ particularly sensitive to NAO variations and that SIMS analysis of long-lived bivalves may uncover such variations across the Holocene.

Four papers describe laboratory or field cultures to develop new proxies. Pacho et al. studied shell Na/Ca and K/Ca, potential proxies for seawater Ca content on geologic time scales, in laboratory cultures of benthic foraminifera *Amphistegina lessonii*, as a function of seawater K/Ca and temperature. The results suggest that K/Ca in the calcite increases with increasing $[K]_{SW}$ and does not depend on $(K/Ca)_{SW}$ at constant $[K]_{SW}$. However, due to a contrasting increase of Na/Ca in the calcite with $(Na/Ca)_{SW}$, constraining paleoceanic $[K]_{SW}$ and $[Ca]_{SW}$ may require both ratios. de Winter et al. exposed aragonitic cockles (*Cerastoderma edule*), calcitic oysters (*Ostrea edulis*), and polycrystalline mussels (*Mytilus edulis*) to a timed series of five dissolved Sr spikes in an outdoor mesocosm over a period of ~3 months. Shells were analyzed by LA-ICP-MS, to ascertain the presence of concomitant Sr/Ca peaks that could serve as recognizable time markers for use in extended growth rate experiments. All three species recorded Sr/Ca peaks that generally matched the applied spikes in dose size and timing, yielding Sr-derived growth records that were broadly consistent with growth curves based on direct size measurements. Brosset et al. analyzed Sr/Ca in the outer shell layer of *Arctica islandica* bivalves from two lab-based temperature studies (1.1–15°C) by LA-ICP-MS. The data show complicated relations between temperature, growth, and the area and elongation of biomineral units. Comparison with an earlier field-based study indicates that the Sr/Ca thermometer in lab-grown specimens is much more sensitive and that neither the calibration nor corrections for vital effects are transferable between the two. Sakata et al. grew many non-clonal colonies of Pacific massive (*Porites australiensis*) and branching (*Acropora digitifera*) corals in aquarium culture for 77 days at different temperatures (18, 21, 24, 27, 30°C). Calcification rates and photosynthetic efficiency were monitored and newly grown aragonite was analyzed for Mg/Ca, Sr/Ca, Ba/Ca, U/Ca, $\delta^{18}O$ and $\delta^{13}C$, using standard techniques. Moderate to strong negative linear correlations were found between temperature and Sr/Ca and $\delta^{18}O$ in both corals, and Ba/Ca in *A. digitifera* only, none showing a correlation with calcification rate. The authors conclude that both corals are promising targets for paleotemperature studies. Conversely, U/Ca showed a negative linear correlation with calcification rate in *A. digitifera*, but no consistent dependence on temperature. No correlation with either temperature or calcification was found for Mg/Ca and $\delta^{13}C$.

In two papers, existing proxies are applied to samples from the distant past. Ichimura et al. obtained $\delta^{18}O$ records of well-preserved fossil aragonite bivalves from the mid-latitude paleo-Pacific to investigate SST seasonality during the middle Cretaceous "supergreenhouse" climate. Assuming an invariant Cretaceous $\delta^{18}O_{SW}$ value of −1‰ (*vs.* VSMOW), the $\delta^{18}O_{shell}$ records of two species reflect temperatures of 28–35°C with a seasonal range of 7°C. These are higher than in modern mid-latitudes (e.g., 4.8–22.1°C) but with smaller seasonality, more similar to modern subtropical conditions and consistent with an ice-free Arctic and the existence of the Bering Land Bridge at that time. Jacobi et al. reconstructed SST from shallow and deeper dwelling species of planktonic foraminifera in a unique core from a North Pacific seamount above the carbonate compensation depth, to derive the position of the subarctic front (SAF) into the Pleistocene (600 ka BP). Calcite $\delta^{18}O$ and Mg/Ca reveal a sudden shift to colder SST around 280 ka BP, suggesting a southward SAF displacement that appears to be driven by a transition from sustained La Niña to El Niño-like conditions in the Pacific. Productivity, on the other hand, represented by sediment Ba/Ti ratios and by sediment Fe constraining dust input, appears to be driven by variations related to glacial–interglacial cycles.

Finally, Saenger et al. use a pseudo-proxy modeling approach, based on a large ensemble of linear inverse models, to determine whether SST distributions derived from Individual Foraminifera Analysis (IFA) is a potential proxy for Marine Heat Wave (MHW) events. With a bootstrapping algorithm, the model evaluates which MHW metric appears the most promising and then assesses what IFA sample size would be necessary to achieve a specific level of uncertainty for the MHW reconstruction, given the sedimentation rate. A case study for the Northeast Pacific indicates that cumulative MHW metrics with a 1σ threshold and 1-month duration yield the strongest transfer functions, independent of species, but that only sites with extremely high sedimentation rates allow MHW events to be predicted with uncertainties <20% for typical IFA sample sizes of 100–200 foraminifera.

We hope that readers of this RT will enjoy these papers and find inspiration for equally innovative research.

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Conflict of interest

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