Improved constraints on deep sea temperatures from Li/Mg in biogenic aragonites, with a paleo-AMOC application in the Florida Straits

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Li/Mg reflects temperature in bio-aragonites

Neither Li/Ca nor Mg/Ca are well correlated with calcification temperature in the aragonitic benthic foraminifer H. elegans (red). The same can be said for a wide range of coral taxa, both deep-sea and biohermals, when considered as a whole (blue). However, the ratio Li/Mg exhibits a strong anticorrelation with temperature in both groups. Furthermore the two Li/Mg temperature regressions are indistinguishable. We suggest that this Li/Mg similarity is a manifestation of inorganic chemistry shining past the usual complications of biominalization.

Li/Mg is immune to biominalization ‘vital effects’

Here we plot Li/Ca vs. Mg/Ca, color-coded in 3°C bins, with best-fit straight lines forced through the origin. Those lines therefore represent constant Li/Mg at a given temperature, consistent with the previous figure. We suggest that the slopes of those lines (i.e., the Li/Mg ratios) are controlled by inorganic thermodynamics, while the spread along those lines is due to modification of the organism’s internal calcification chemistry. Potential chemistry moves toward the origin along these lines as Ca²⁺ is pumped in, assuming the Ca²⁺ pump is essentially impervious to both Li⁺ and Mg²⁺ due to their small ionic radii. Chemistry moves away from the origin along these lines as an aragonite is precipitated, following Rayleigh fractionation with negligible amounts of Li²⁺ and Mg²⁺ removed from the pool because K₁ and K₂ are so small.

Palo-MOC in the Florida Straits

Lynch-Stieglitz et al. (1999) showed that the geostrophic flow through Florida Straits can be calculated using benthic foraminiferal δ¹⁸O from cores on each side of the Florida Current. This is because the cross-current pressure gradient is manifested as horizontal density gradients, with waters at a given depth on the west side of the current being denser (colder and slightly fresher) than waters on the east side. Density in turn can be estimated using δ¹⁸O because δ¹⁸O is a function of temperature and salinity. Core top benthic δ¹⁸O is consistent with hydrographic data in suggesting a geostrophic flow of ~30 Sv, of which ~13 Sv is tied to the AMOC hydrographic data in suggesting a geostrophic flow of ~30 Sv, of which ~13 Sv is tied to the AMOC.

Evolution of the Florida Straits δ¹⁸O gradient

During the Last Glacial Maximum, the benthic δ¹⁸O-based density contrast between east (red) and west (blue) was slightly smaller than today, consistent with a somewhat weakened AMOC (Lynch-Stieglitz et al., 2014). During Heinrich Stadial 1 and the Younger Dryas, the gradient appears to have largely collapsed, suggesting a near cessation of geostrophic transport through the straits. These collapses are mainly manifested as reduced density (lower δ¹⁸O) in the west; by analogy with modern conditions this implies warmer and saltier (more fresher) glacial boundary conditions.

Comparison between Mg/Li and δ¹⁸O

Benthic foraminiferal δ¹⁸O can be converted into estimated temperature by assuming seawater δ¹⁸O has remained constant (red) or has evolved only due to global ice volume changes (black) (calibration from Marchitto et al., 2014). The LGM Mg/Li temperatures with ice-volume-corrected (IQC) δ¹⁸O were ~4°C colder during the Last Glacial Maximum, presumably reflecting colder source waters. Mg/Li confirms that the western density reductions during Heinrich Stadial 1 and the Younger Dryas were manifested as bottom warming due to flattening of isopycnals, with the Younger Dryas ~2°C warmer than modern.

Record of salinity-related seawater δ¹⁸O

Finally we can derive a record of seawater δ¹⁸O by combining the Mg/Li paleotemperatures with benthic foraminiferal δ¹⁸O (blue, based on S-depth running means of each record). During the LGM seawater δ¹⁸O was roughly 0.5‰ lighter than predicted from the whole-ocean ice volume effect, suggesting relatively fresher and colder source waters. As bottom waters warmed during HS1 they also got saltier, consistent with a more subtidal signature due to flattened isopycnals, but also likely reflecting a late HS1 shift away from fresher glacial boundary conditions. After HS1 seawater δ¹⁸O more closely tracks ice volume, suggesting the establishment of a temperature/salinity regime similar to modern.

CONCLUSIONS

The ratio between Li and Mg in biogenic aragonite reflects growth temperature and is insensitive to various ‘vital effects’ that plague other proxies.

A first application of this proxy in the benthic foraminifer H. elegans from a Florida Straits core shows good agreement with paired δ¹⁸O.

Both proxies are consistent with AMOC slowdowns during Heinrich Stadial 1 and the Younger Dryas.

H. elegans Mg/Li holds promise for reconstructing temperature and salinity regimes of the deep ocean during past climate states.

US CLIVAR AMOC Workshop, Boulder, May 2016