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

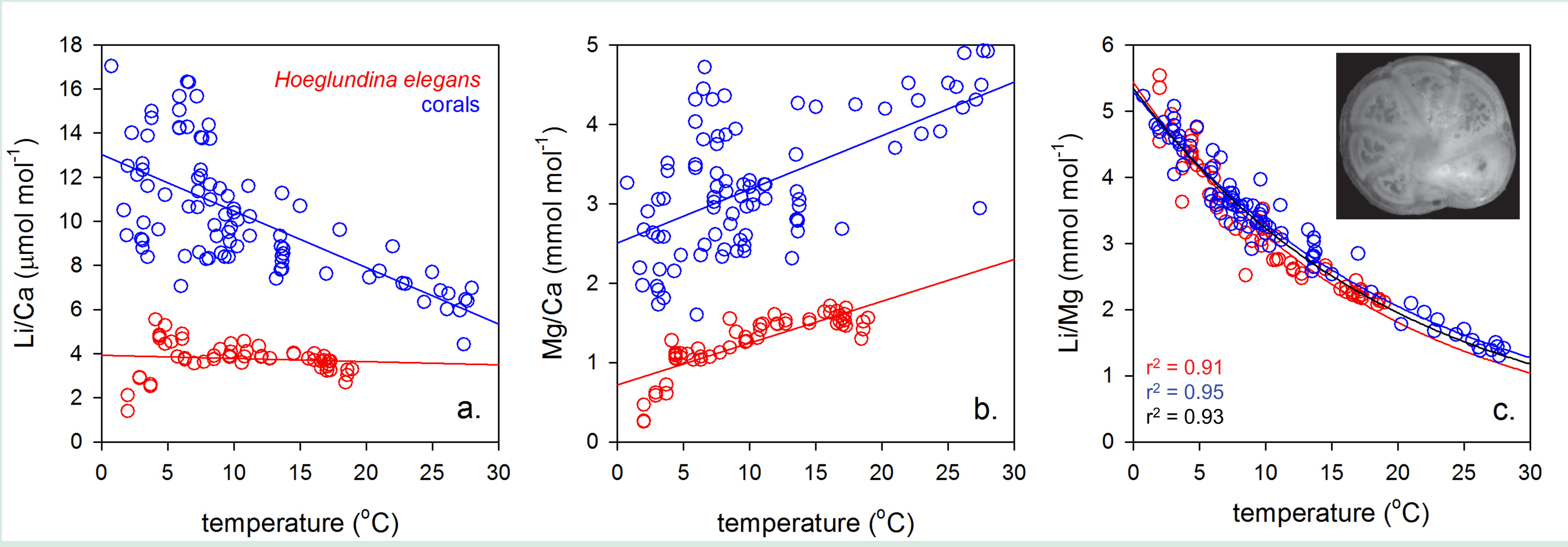
University of Colorado Boulder

Tom Marchitto[1], Shannon Valley[2], Jean Lynch-Stieglitz[2]

[1]University of Colorado, Boulder; [2]Georgia Institute of Technology

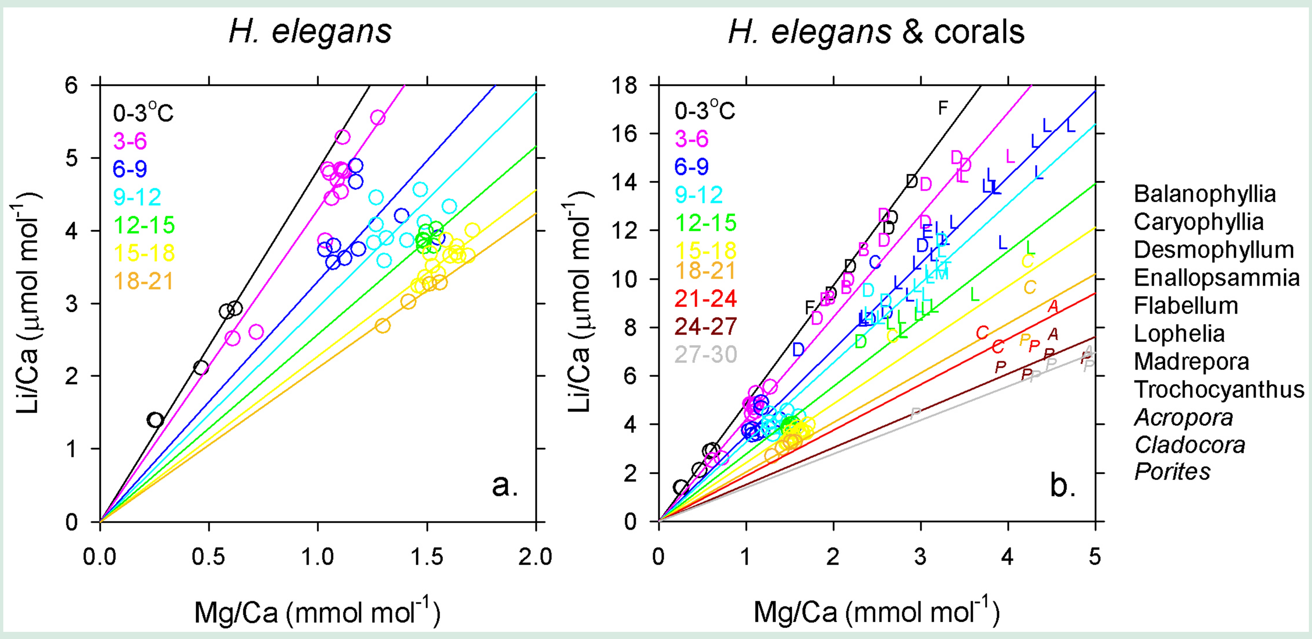
INSTAAR

Li/Mg reflects temperature in bio-aragonites



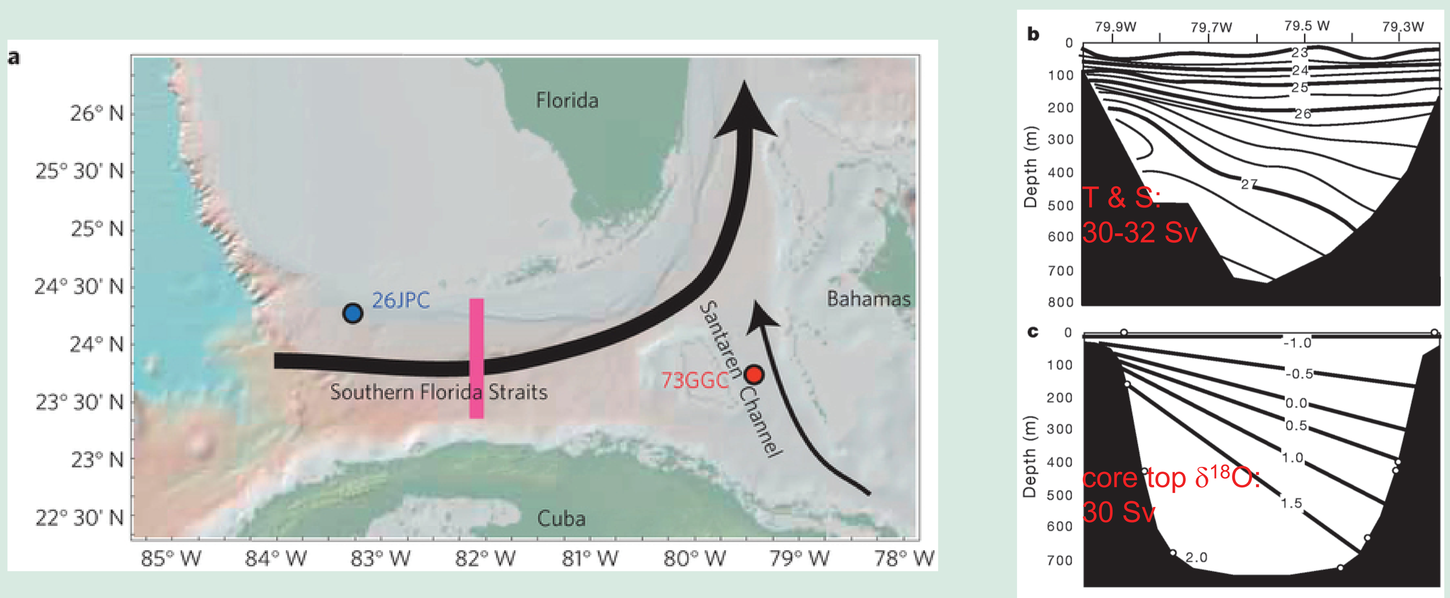
Neither Li/Ca nor Mg/Ca are well correlated with calcification temperature in the aragonitic benthic foraminifer *Hoeglundina elegans* (red). The same can be said for a wide range of coral taxa, both deep-sea and zooxanthellate, when considered as a whole (blue). However, the ratio **Li/Mg exhibits a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

Li/Mg is immune to biomineralization 'vital effects'



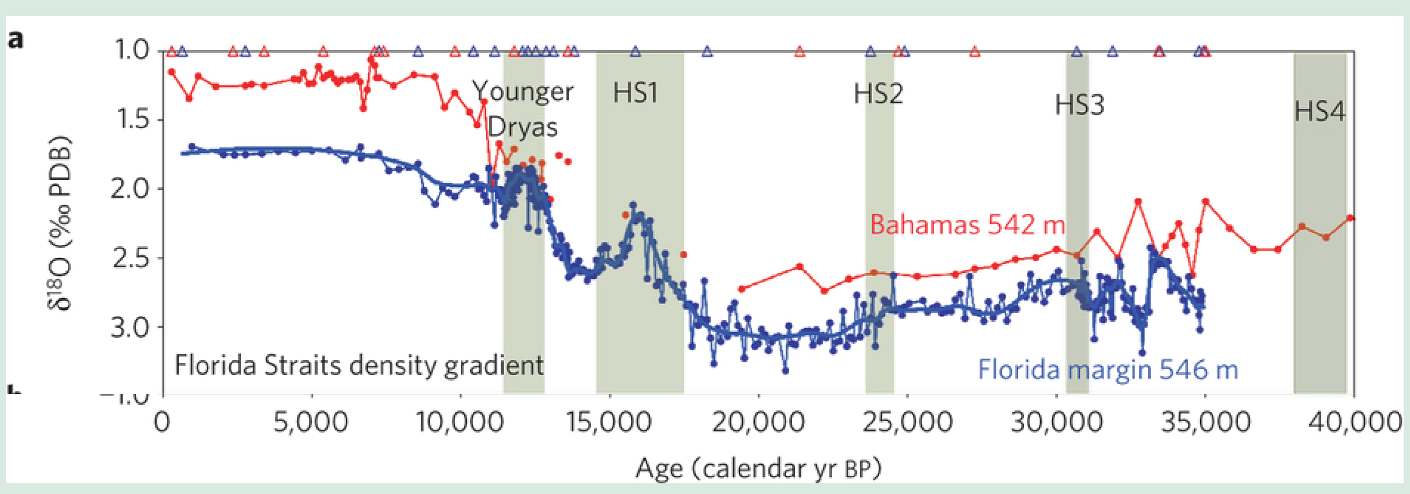
Here we plot Li/Ca vs. Mg/Ca, **color-coded in 3°C bins**, with best-fit straight lines forced through the origin. Those lines therefore represent **constant Li/Mg at a given temperature**, consistent with the previous figure. We suggest that the slopes of those lines (i.e., the Li/Mg ratios) are controlled by **inorganic thermodynamics**, while the spread along those lines is due to **modification of the organism's internal calcification pool**. Chemistry moves toward the origin along these lines as **Ca^{2+} is pumped in**, assuming the Ca^{2+} pump is essentially impervious to both Li^+ and Mg^{2+} due to their small ionic radii. Chemistry moves away from the origin along these lines as aragonite is precipitated, following **Rayleigh fractionation** with negligible amounts of Li^+ and Mg^{2+} removed from the pool because K_{Li} and K_{Mg} are so small.

Paleo-AMOC in the Florida Straits



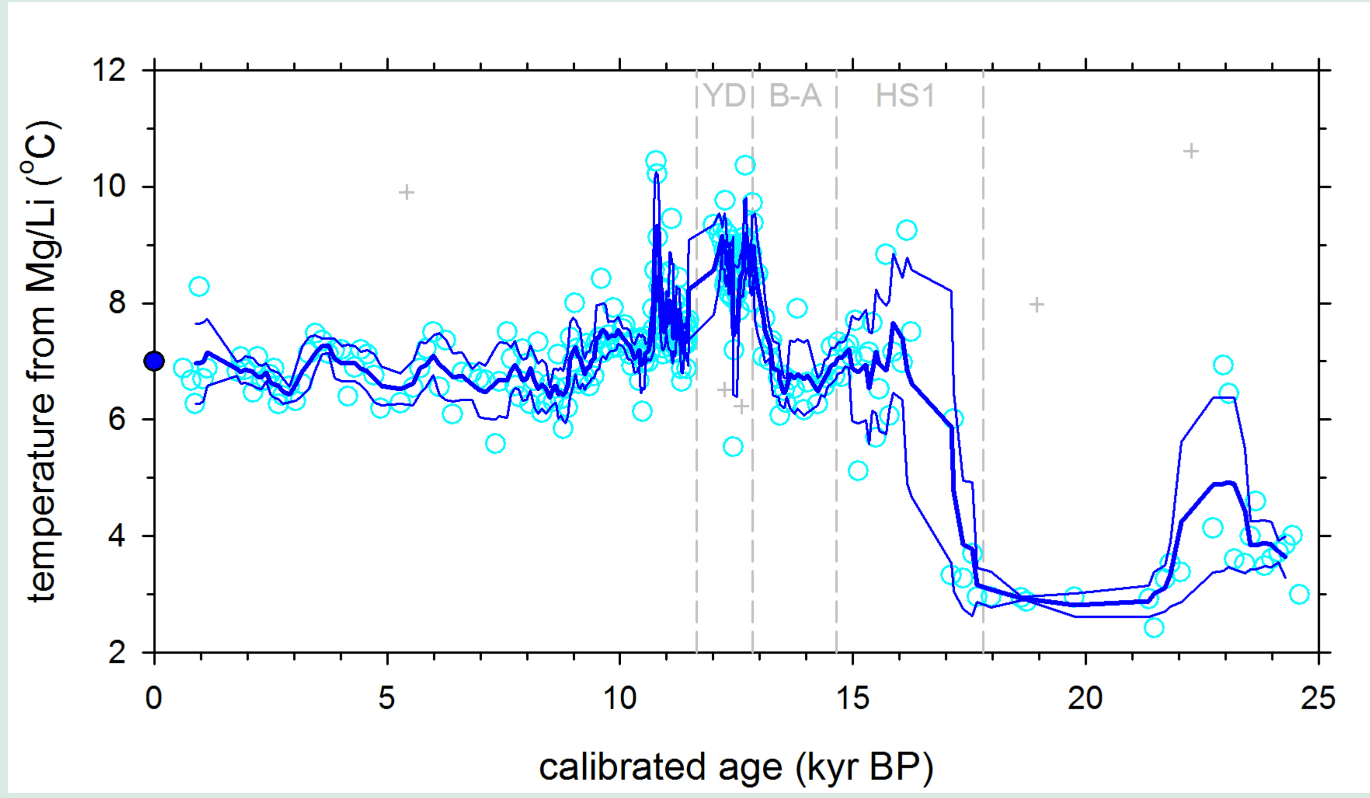
Lynch-Stieglitz et al. (1999) showed that the **geostrophic flow through Florida Straits** can be calculated using **benthic foraminiferal $\delta^{18}O$** from cores on each side of the Florida Current. This is because the cross-current pressure gradient is manifested as **horizontal density gradients**, 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 $\delta^{18}O$ because **$\delta^{18}O$ is a function of temperature and salinity**. Core top benthic $\delta^{18}O$ is consistent with hydrographic data in suggesting a geostrophic flow of ~30 Sv, of which **~13 Sv is tied to the AMOC**.

Evolution of the Florida Straits $\delta^{18}O$ gradient



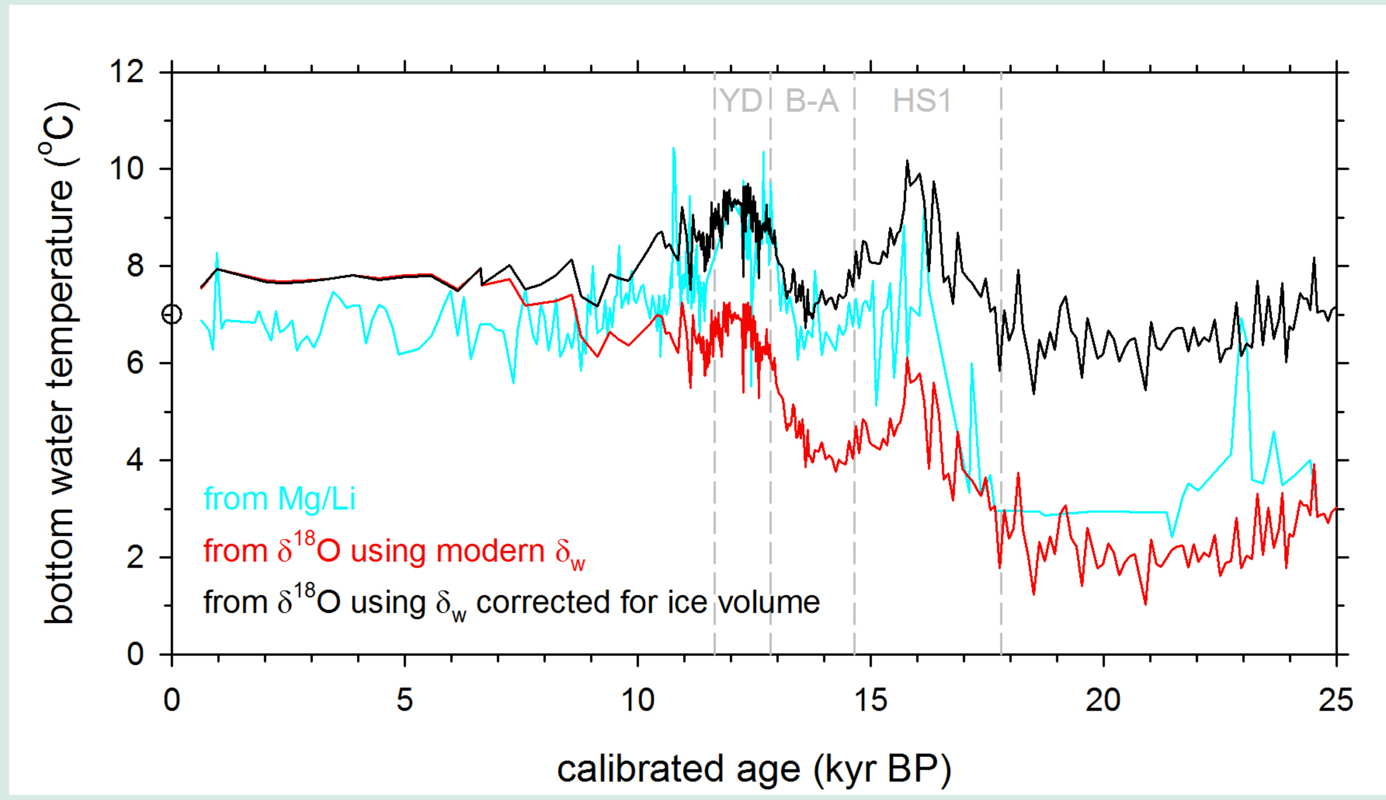
During the Last Glacial Maximum, the benthic $\delta^{18}O$-based density contrast between east (red) and west (blue) was slightly smaller than today, consistent with a somewhat weakened AMOC (Lynch-Stieglitz et al., 2014). **During Heinrich Stadial 1 and the Younger Dryas, the gradient appears to have largely collapsed**, suggesting a near-cessation of geostrophic transport through the straits. These collapses are mainly manifested as reduced density (lower $\delta^{18}O$) in the west; by analogy with modern conditions this implies **warmer and saltier (more subtropical) waters as isopycnals flatten**. However, because glacial-deglacial boundary conditions were different from modern, an **independent paleotemperature proxy (Li/Mg) is required** to partition the temperature and salinity components of the density ($\delta^{18}O$) signal.

Mg/Li confirms warming during HS1 and YD



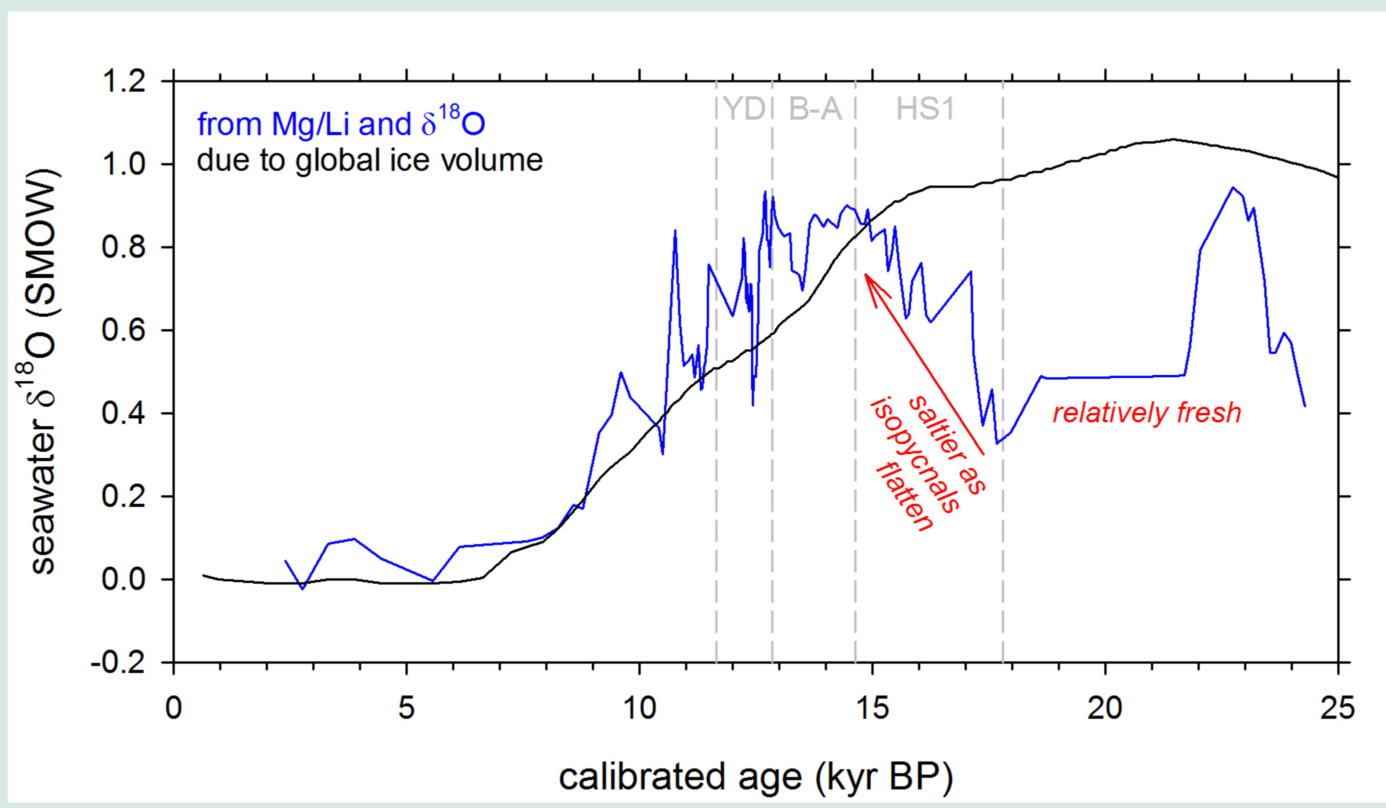
This is the **first downcore application** of the *H. elegans* Mg/Li paleotemperature proxy (note that we use Mg/Li here instead of Li/Mg because the former provides better precision and accuracy at the lower Mg/Ca and Li/Ca ratios found in *H. elegans*). **Reproducibility is excellent**, with a median 5-depth running standard deviation of <0.5°C, even including outliers (gray crosses) and sharp climate transitions. Bottom waters 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.

Comparison between Mg/Li and $\delta^{18}O$



Benthic foraminiferal **$\delta^{18}O$ can be converted into estimated temperature** by assuming seawater $\delta^{18}O$ has remained constant (red) or has evolved only due to global ice volume changes (black) (calibration from Marchitto et al., 2014). The **Mg/Li temperatures (cyan) are in good agreement** with ice-volume-corrected $\delta^{18}O$ back to mid-HS1, with very similar magnitudes of warming and cooling. During the LGM, Mg/Li temperatures fall closer to the uncorrected $\delta^{18}O$, suggesting that **glacial-age source waters experienced a smaller positive isotopic shift than the average ocean**. This implies that LGM source waters were **relatively fresh** in the context of an overall saltier ocean.

Record of salinity-related seawater $\delta^{18}O$



Finally we can derive a record of seawater $\delta^{18}O$ by combining the Mg/Li paleotemperatures with benthic foraminiferal $\delta^{18}O$ (blue, based on 5-depth running means of each record). During the **LGM seawater $\delta^{18}O$ was roughly 0.5‰ lighter than predicted** from the whole-ocean ice volume effect (black), suggesting *relative* freshening of cold source waters. **As bottom waters warmed during HS1 they also got saltier**, consistent with a more subtropical signature due to flattened isopycnals, but also likely reflecting a **late HS1 shift away from fresher glacial boundary conditions**. After HS1 seawater $\delta^{18}O$ 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 $\delta^{18}O$**

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

NSF
US CLIVAR AMOC Workshop, Boulder, May 2016