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Interactive comment on “A reappraisal of the vital effect in benthic foraminifera on Mg/Ca ratios: species specific uncertainty relationships” by J. C. Wit et al.

Anonymous Referee #3

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GENERAL COMMENTS

The Mg/Ca ratio of foraminiferal calcite is an established proxy for water temperature. The existence of species-specific differences in the Mg/Ca vs. temperature relationship is suggested to reflect "biological effects". Surprisingly, only few attempts have been made so far to further constrain and quantify biologically controlled Mg/Ca variability between specimens of the same species or between chambers of the same individual. However, it is this type of variability that ultimately limits the accuracy of temperature reconstructions based on benthic foraminiferal Mg/Ca, at least in cases where temperature seasonality is absent and salinity and pH of the ambient water can be considered

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constant. The present study addresses the above type of variability using the best possible approach. All known external factors forcing shell Mg/Ca are controlled in this culturing experiment, and the composition of both individual chambers and individual shells are measured using laser ablation ICP-MS. A temperature calibration is derived and error sources are quantified to the possible extent. The results are an asset to our understanding of the Mg/Ca temperature proxy. I appreciate the complete documentation of the data provided in the tables.

The manuscript has some shortcomings. The authors should make sure that the background information necessary for understanding the aims of the study and the Discussion is provided in the Introduction. It is important for the reader to know right from the beginning where the authors are heading to. Surprisingly, the Introduction underates the significance of this study. The Discussion is very long compared with the other parts of the manuscript, but too brief where things start getting complex (section 4.3). As it stands section 5 is largely detached from the author's results and should be shortened. Although the paper is about the vital effect, no clear definition of this term is provided. In some places it is the species specific offset in Mg/Ca between the shell calcite and inorganic calcite precipitated in thermodynamic equilibrium, in other places it is also the inter- and intrashell variability. The authors may consider using the more causative term "metabolic effect" throughout.

MAJOR COMMENTS

The revised introduction should include the following points:

- Provide a brief overview on the environmental controls on foram shell Mg/Ca, i.e., primarily temperature, but also salinity, carbonate system parameters, and seawater-Mg/Ca. It is the multitude of environmental factors influencing Mg/Ca that makes this culturing experiment under controlled conditions so important.
- Provide a more extensive overview of the literature where metabolic effects have been suggested to influence Mg/Ca. How is the metabolic effect expressed, and how is it

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distinguished from environmental forcing? This includes between-species differences, ontogenetic trends, between-shell, and between-chamber variability. Give a brief explanation on the proposed mechanism, but more concrete than what is stated in lines 4-6, p. 4955.

- Based on the above review a clear definition of the metabolic effect is required for the purpose of this study.

- Special attention might be given to endobenthic forams. When migrating through the sediment the ambient pore water chemistry may change, particularly in organic-rich sediments where the pH close to the sediment-bottom water interface can be quite acidic. This leads to the question whether (in forams from sediment samples) between-chamber and between-specimens differences in Mg/Ca are due to metabolic effects or whether they reflect the changing micro-environment. Again, this is why this culturing experiment is needed.

- Explain why it is important to quantify the metabolic effect on Mg/Ca. How much does it potentially bias paleo-reconstructions? This topic forms a major part of the Discussion and is the primary motivation for this study, so more details are required here.

- Explain how the experiment presented here addresses the above questions.

Discussion, Section 4.3

P. 4955, L. 21-P. 4956, L. 15; Eqs. 4 and 5: Reword using short and clear sentences. Provide a step-by-step explanation of how Eqs. 3-5 were derived, either in this paragraph or in the appendix. Where does the factor of 0.33 come from? $2 \cdot 16.3\%$ as suggested in the caption of Table 4? The fundamental principle is that Mg/Ca is exponentially dependent on temperature. This means at a given sensitivity a relative (%) uncertainty in Mg/Ca will always translate to the same absolute ($^{\circ}\text{C}$) uncertainty in T. This should be mentioned. Clarify that "sensitivity" is the exponential constant

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of the Mg/Ca versus temperature calibration. Equation 5, Table 4, Figure 6 and L. 14 of the text are inconsistent. Using the sensitivity from Eq. 2 (0.045) and 94 specimens Eq. 5 yields an uncertainty of 0.76 °C instead of 1.0 °C as written in the text. $0.33/(\text{SQRT}(94)*0.045) = 0.76$. This value is in line with Table 4, but not with Fig. 6 – the latter indicates a value of 1 (for *B. marginata*), consistent with the text, but not with the table.

Discussion, Section 5

The first paragraph is necessary as it compares the calibration obtained by the authors with existing calibrations. The proposed relationship between nutrients and Mg/Ca is interesting and worth being presented here, but it should be done in a way leaving the details to future studies. The authors should establish the link to the primary topic of the manuscript by emphasizing that their hypothesis is consistent with the metabolic influence on Mg/Ca. The following parts should be removed: P. 4957, L. 29-P. 4958, L. 13 P. 4959, L. 16-L. 28 Shorten P. 4960, L. 1-L. 11

SPECIFIC COMMENTS

Throughout

To improve clarity the authors should introduce terms to describe the Mg/Ca of individual chambers, individual shells, and the average of all shells grown at the same temperature. These terms should be used consistently throughout the manuscript. The same applies to reconstructed temperatures and temperature errors, and to the actual (set) temperatures of the experiments.

Abbreviations should be written out where they first occur (T, DIC, F, Mg/Ca_{sw}, ...).

Title

"species specific" implies the comparison of multiple species, but only *Bulimina marginata* is investigated here. "uncertainty" – of what?

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Methods

The slash is interchangeably used as mathematical operator (Mg/Ca) and comma (pH/DIC). It should be used for maths only.

What is the diameter of the laser beam, and how many spot measurements have been carried out for each foram chamber?

P. 4950, L. 7: Report the number of different temperature settings (8).

P. 4951, L. 8-9: It should be clarified that in this case Mg/Ca is variable over the thickness of the shell, in contrast to differences between chambers.

Results

Information on ontogenetic trends (or the lack thereof) should be added. Explain that "F" means the final chamber.

P. 4952, L. 24: Mg/Ca neither increases nor decreases with test size. Report the size range (300-600 μm based on Fig. 3).

Eq. 2: Constants and the associated errors must be in parentheses, otherwise the equation does not make sense. $\text{Mg/Ca} = (1.10 \pm 0.10) \cdot \exp((0.045 \pm 0.009) \cdot T)$ L. 26: This is a regression, not a correlation.

Discussion

P. 4952, L. 5: Move sentence to the Results section.

Section 4.2

Clarify the first sentence. The Results section states that there is no Mg/Ca increase with size, and Fig. 3 suggests there is no ontogenetic trend.

P. 4952, L. 22-24: Move before the last sentence of section 4.2. Changing from Mg/Ca to $\delta^{18}\text{O}$ and back to Mg/Ca is confusing.

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Section 4.3

P. 4953, L. 23: The subheading should be changed to more adequately reflect the content of section 4.3.

P. 4955, L. 4-20: The authors should clarify that the error of the calibration line is assumed to be zero.

L. 24-25: The text states that the error of the calibration line is 16%, but it seems that this number is actually the standard deviation of Mg/Ca at a given temperature setting.

P. 4956, L. 2: Clarify "different species" (each species?).

Section 5

First paragraph: Provide references for the calibrations.

Tables

Table 3: Make sure to explain all abbreviations including those in the footnotes. The letters a, b in the equations in the footnotes seem not to refer to the table columns annotated with a, b. This should be clarified.

Figures

Fig. 1 caption: reword last sentence "... rule out any instrumental cause for the Mg/Ca spikes observed in *B. marginata*."

Fig. 3: Explain F, F-1, ...

Figs. 4 and 7 captions: Provide references or refer to Table 4.

Fig. 5 caption: Explain #52 and 67.

Fig. 6 caption: "... based on an average Mg/Ca standard deviation ..." (insert Mg/Ca). "specimens", not "species". Use the same term for the axis label (specimens, not measurements).

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Fig. 6: As stated above the figure is consistent with the text (94 specimens are required for a 1 °C temperature uncertainty in *B. marginata*), but inconsistent with Eq. 5 (that gives 54 specimens instead).

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