Geochemistry of *Nummulites* as a proxy for the Eocene paleotemperature evolution in the Southern North Sea Basin: an Ypresian test case

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The early Eocene period is characterized by sudden and brief climate variations, recognized as short-term hyperthermals, which are superimposed on the gradual warming trend that culminated in the Early Eocene Climatic Optimum (EECO). The regional environmental conditions during these periods of varying temperature and sea level under greenhouse conditions are recorded in the Ypresian (56 - 47.8 Ma) sediments in Belgium. Here we present the shallow marine temperature evolution towards the EECO based on the geochemical composition of nummulites. These larger benthic foraminifera (LBF) are absent in the clayey Orchies Member of the Kortrijk Formation (Fm.) but appear abruptly as monospecific assemblages in the aftermath of a hyperthermal, suggesting an environmental threshold. The lowermost incursion, represented by *Nummulites involutus* (Baccaert, 2017), is recorded in the nearshore fine sands of the Mons-en-Pévèle Fm. (nannoplankton zones NP11-12). Renewed deposition of a basin-wide clayey unit (Aalbeke Member of the Kortrijk Fm.) marks the regional disappearance of this species. This pre-EECO LBF fauna is replaced by *Nummulites aquitanicus* in the Egem sands of the Hyon Fm. (zone NP12), which represents renewed deposition in a broad shallow marine embayment during the EECO. We hypothesize that these LBF dispersals into the North Sea Basin are controlled by pulses of northward migration during warmer periods and by species-specific environmental thresholds.

At the moment, nummulites are still an underutilized source of detailed paleoclimate data, despite their potential as high-resolution archives of annual to seasonal temperature variations (Evans et al., 2013). These temperature reconstructions are based on the Mg-incorporation into the calcareous tests, by using the Mg/Ca (mmol/mol) ratio and a recently proposed Mg/Ca_{LBF}-temperature calibration (Evans et al., 2018). The use of Mg/Ca as a paleotemperature proxy solves the limitations of traditional oxygen isotope paleothermometry, which depends on two unknown values: temperature and regional $\delta^{18}O_{sw}$. We tested the effect of a) preservation (dissolution and recrystallization), b) natural variability and c) cleaning methods on the geochemical record of LBF to assess their potential as a paleotemperature proxy.

Nummulites within the Mons-en-Pévèle and Hyon Formations occur regularly in outcrops, but are also common in drill cores. Our geochemical analyses and SEM observations of different preservation states indicate that taphonomic alterations by partial dissolution and recrystallization resulted in significantly lower Mg/Ca and Sr/Ca ratios, which renders unrealistically low temperatures. This post-depositional decrease in the Mg-content is a general feature of the tested outcrop material. Nonetheless, the majority of analyzed specimens retrieved from the Kester core (Mons-en-Pévèle Fm.) and the Ampe section (Hyon Fm.) show reliable Mg/Ca data (range of 60 to 85 mmol/mol) with higher Sr/Ca content (> 1.75 mmol/mol). These results indicate a gradual increasing trend of the mean annual temperature, starting from 15°C (pre-EECO) to > 30°C during the peak of the EECO (Fig. 1).

To estimate the size-dependent effect on the geochemical signal of individual specimens, we used a set of well-preserved nummulites derived from a single layer, thus excluding any taphonomic alteration and paleoclimate variations. Our results indicate that smaller specimens (radius < 2.5 mm) show a natural variability in their mean temperature signal. Larger specimens represent periods of continuously higher seawater temperatures and partially overlap with the observed variability within the smaller ones. This can bias the temperature reconstructions to higher values if the dimensions of individual specimens are not taken into account. Geochemical cleaning steps are widely used to remove elements that are related to contamination by detrital particles, organic matter, and iron- and manganese-rich oxyhydroxide coatings on the test surfaces. Traditional foraminiferal cleaning protocols were applied, which include multiple ultrasonication steps, and additional oxidative and reductive cleaning methods. The results indicate that Mn/Ca and Fe/Ca, two commonly used indicators of contamination, can be successfully removed with the oxidative and reductive cleaning methods. However, these more intensive and hazardous procedures are avoidable as no significant effect on the Mg/Ca-signal of the calcareous tests was detected.

Based on these observations, we conclude that the geochemistry of nummulites can be applied as a proxy for the Eocene paleotemperature evolution within the North Sea Basin. Further integration of high-resolution geochemical data of all nummulites-bearing levels with other biotic, geochemical and lithological data will give an explanation for the collapse of one species and its replacement by another on a NW European scale, linking their distribution and evolution to the Eocene climate development.

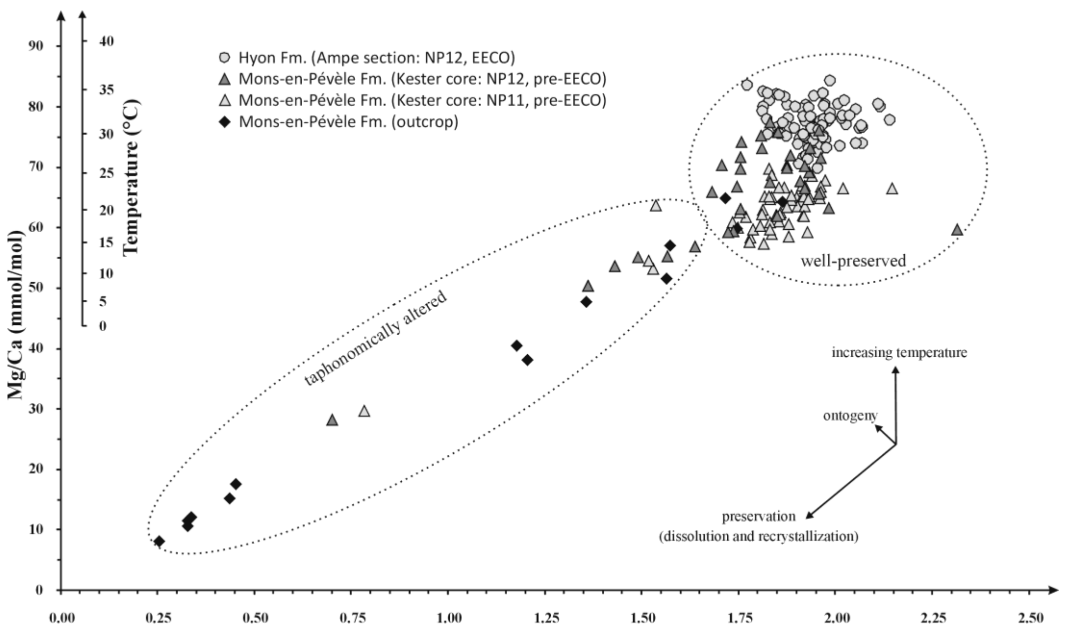

Figure 1. Sr/Ca – Mg/Ca element data and the approximate trajectories of different processes impacting Mg/Ca and Sr/Ca content in nummulites.

References

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