

Precipitation Rate Controls on Foraminiferal Geochemistry

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The concentration of trace elements in the calcite tests of foraminifera reflect the physical and chemical conditions of the ocean in which they form. These trace elements are used as palaeoceanographic proxies for past ocean conditions, and have been instrumental in developing our understanding of Earth climate. Proxy relationships are rooted in knowledge of seawater chemistry and trace element incorporation into synthetic calcite, which predict connections between ocean conditions and foraminiferal chemistry. However, foraminiferal test chemistry frequently deviates from these expected relationships. These deviations are often attributed to the role of biology in mineralisation (the 'vital effect'), but the underlying mechanisms for this remain unknown.

The Ca and C chemistry of seawater are primary factors in CaCO₃ biomineralisation processes, and the trace element content of foraminifera. However, because the crystal growth environment is isolated from external seawater by biological processes, separating the relative importance of biological controls and seawater chemistry has proved challenging.

We present the trace element and isotopic chemistry of *Orbulina universa* cultured under a matrix of DIC and Ca concentrations, which allows us to separate the influences of saturation state, DIC and CO₃²⁻ concentration on foraminiferal geochemistry. We interpret the resulting test chemistry patterns in context of proposed models of foraminiferal biomineralisation. Both DIC and Ca exert a significant influence on all measured trace elements, that is inconsistent with Rayleigh reservoir effects¹, specific ion transport into a closed environment², and bulk shell growth rate effects. Patterns in the data are best explained by kinetic crystal precipitation rate effects³, whereby precipitation rate is linked to seawater chemistry, and decoupled from bulk shell growth rate. This suggests that kinetic effects could exert an important influence on the incorporation of many trace elements in foraminifera, and may need to be taken into account when interpreting proxy records spanning large excursion in Ca or C seawater chemistry.

¹ Elderfield et al (1996) doi:10.1016/0012-821X(96)00105-7

² Nehrke et al (2013) doi:10.5194/bg-10-6759-2013

³ DePaolo (2011) doi:10.1016/j.gca.2010.11.020