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Stable isotope (δ^{18}O and δ^{13}C) sclerochronology of Callovian (Middle Jurassic) bivalves (*Gryphaea* (*Bilobissa*) *dilobotes*) and belemnites (*Cylindroteuthis puzosiana*) from the Peterborough Member of the Oxford Clay Formation (Cambridgeshire, England): Evidence of palaeoclimate, water depth and belemnite behaviour

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ABSTRACT

Incremental δ^{18}O and δ^{13}C signals were obtained from three well-preserved specimens of *Cylindroteuthis puzosiana* and from three well-preserved specimens of *Gryphaea* (*Bilobissa*) *dilobotes* from the Peterborough Member of the Oxford Clay Formation (Cambridgeshire, England). Through-ontogeny (sclerochronological) δ^{18}O data from *G.* (*B.*) *dilobotes* appear to faithfully record seasonal temperature variations in benthic Callovian waters of the study area, which range from *c.* 14 °C to *c.* 17 °C (arithmetic mean temperature *c.* 15 °C). Water depth is estimated to have been in the region of *c.* 50 m, based upon comparisons between these data, previously published non-incremental sea surface δ^{18}O values, and a modern analogue situation. Productivity in Callovian waters was comparable with that in modern seas, based upon δ^{13}C data from *G.* (*B.*) *dilobotes*, with ^{13}C depletion occurring during warmer periods, possibly related to an interaction between plankton blooms and intra-annual variations in mixing across a thermocline. Incremental δ^{18}O data from *C. puzosiana* provide temperature minima of *c.* 11 °C for all specimens but with maxima varying between *c.* 14 °C and *c.* 16 °C for different individuals (arithmetic mean values *c.* 13 °C). Temperatures for late ontogeny, when the *C. puzosiana* individuals must have been living close to the study site and hence the analysed specimens of *G.* (*B.*) *dilobotes*, are closely comparable to those indicated by the latter. However, for significant portions of ontogeny *C. puzosiana* experienced temperatures between *c.* 2 °C and *c.* 3 °C cooler than the winter minimum as recorded by co-occurring *G.* (*B.*) *dilobotes*. Comparisons with modern seas suggest that descent to a depth of *c.* 1000 m would be necessary to explain such cool minimum temperatures. This can be discounted due to the lack of deep waters locally and due to estimates of the depth tolerance of belemnites. The most likely cause of cool δ^{18}O signals from *C. puzosiana* is a cosmopolitan lifestyle including migration to more northerly latitudes. Mean δ^{13}C values from *C. puzosiana* are comparable with those from *G.* (*B.*) *dilobotes*. However, the incrementally acquired data are highly variable and probably influenced by metabolic effects. The probable identification of migratory behaviour in *C. puzosiana* calls into question the reliability of some belemnite species as place-specific palaeoenvironmental archives and highlights the benefits of adopting a sclerochronological approach.

1. Introduction

Belemnite rostra have been widely used as a source of stable oxygen (δ^{18}O) and carbon (δ^{13}C) isotope signals for the reconstruction of Mesozoic climatic and oceanographic conditions (e.g. Price et al., 2000; Price and Mutterlose, 2004; Nunn et al., 2009; Wierzbowski and Joachimski, 2009; Nunn and Price, 2010; Price, 2010; Price et al., 2011; Alberti et al., 2012; Price et al., 2012). This is because (1) they are widely considered to record oxygen isotope ratios in equilibrium with ambient oceanic water, although there are suspicions that metabolic effects may influence carbon isotopes (Wierzbowski, 2004; McArthur et al., 2007; Price and Page, 2008; Žák et al., 2011), and (2) their robust form and low-magnesium calcite composition is believed to be resistant to diagenesis, thus preserving original isotope ratios (Rosales et al., 2004; Wierzbowski and Joachimski, 2009; Price et al., 2012).

Despite their apparent suitability, there have been some concerns regarding the utilization of data from belemnites when reconstructing environmental evolution through geological time. This is because firstly, signals are likely to be obtained from different assemblages of belemnite species at different geological times, and could therefore represent

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