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Lower Jurassic belemnites as indicators of palaeo-temperature

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ABSTRACT

In order to test the validity of palaeo-proxy records in belemnite calcite, four species of belemnite have been compared for Mg/Ca, Sr/Ca, Na/Ca, $\delta^{18}O$ and $\delta^{13}C$. They are *Acrocoelites* (*Acrocoelites*) *subtenuis*, *Acrocoelites vulgaris*, *Simpsonibelus dorsalis* and *Youngibelus simpsoni*. The specimens derive from 25 m of Lower Toarcian strata in Yorkshire, UK, that represent a period of ≈400 kyrs.

Compared to *Acrocoelites vulgaris*, the species *Acrocoelites subtenuis* and *Youngibelus simpsoni* are less positive in $\delta^{13}C$, less negative in $\delta^{18}O$, and have broader compositional ranges. In all four species, $\delta^{13}C$ correlates negatively with $\delta^{18}O$ but the regression line for *Simpsonibelus dorsalis* is displaced 1.5‰ to more positive values of $\delta^{18}O$. In all species, Mg/Ca does not correlate with $\delta^{18}O$ whilst, excepting in *S. dorsalis*, Sr/Ca correlates well, suggesting that Sr/Ca in Early Toarcian belemnites, but not Mg/Ca, may be a useful recorder of palaeo-temperature. Compositional differences between species reflect biofractionation, habitat differences, or both, and confirm that element/Ca values in belemnite calcite, if usable as palaeo-environmental proxies, must be interpreted at species level.

For each of the species *Acrocoelites subtenuis* and *Acrocoelites vulgaris*, indistinguishable compositional ranges and inter-element relations exist in two populations, one from specimens collected from 25 m of strata that encompass ≈400 kyrs; the other for specimens collected from a single level in the section that is interpreted to represent a period of no more than a few weeks of time. The similarity suggests that at least some belemnite species inhabited environmental niches that remained unchanged in character, if not necessarily location, over substantial periods of time.

1. Introduction

The oxygen isotopic composition of belemnite calcite is presumed to reflect both calcification temperature and the isotopic composition of the seawater in which the belemnites lived (Urey et al., 1951; Saelen et al., 1996; Podlaha et al., 1998; Bailey et al., 2003 and many others). Following Chave (1954), the Mg/Ca, and later the Sr/Ca, of belemnite calcite has also been used as a palaeo-temperature proxy (Berlin et al., 1967; Yasamanov, 1981; Bailey et al., 2003; Nunn and Price, 2010). Such interpretations assume that the composition of belemnite calcite reflects calcification under equilibrium conditions (for $\delta^{18}O$; see Saelen et al., 1996 for a discussion) or, perhaps with biological bias, the Sr/Ca and Mg/Ca of ambient seawater. That the assumptions are not wholly wrong is suggested by the existence of reasonable negative correlations in some belemnite populations between $\delta^{18}O$ and either Sr/Ca or Mg/Ca, or both (McArthur et al., 2000; Bailey et al., 2003; Rosales et al., 2004a; McArthur et al., 2007a,b). If these palaeo-proxies work, they may be used in combination to estimate palaeo-temperatures and polar ice-volume (cf. Dwyer et al., 1995; Lear et al., 2000) in deep time.

Interpreting the composition of belemnite calcite in terms of palaeo-environment is hampered by a poor knowledge of vital effects, which probably introduce noise into the environmental signal belemnites may carry (McArthur et al., 2007b; Wierzbowski and Joachimski, 2009), and of inter-species differences in habitat, which might confuse interpretation of undifferentiated belemnites. In addition, by analogy with modern cuttlefish (but see caveats in Dutton et al., 2007), belemnites probably were mobile, and so experienced a range of environmental conditions during growth: such changes might be reflected in intra-rostral compositional variations that would compromise palaeo-environmental interpretation of specimens analysed in bulk, or after indiscriminate sub-sampling e.g. those of Podlaha et al. (1998) or McArthur et al. (2000).

Such confounding factors make it difficult to establish whether or not compositional variations within a belemnite population collected through a section represent real signals of environmental conditions and change. Nevertheless, it is worthwhile trying to understand which palaeo-proxies, in which belemnite species, provide useful palaeo-environmental information and which do not.

To address some of these issues, McArthur et al. (2007b) reported the bulk compositional range, and the range of intra-rostral, micro-compositional, variation, for two species of Early Toarcian belemnites, *Acrocoelites vulgaris* and *Acrocoelites subtenuis*. The specimens were interpreted to represent the regurgitated stomach contents of a marine predator and so an instant of Toarcian time in which both species lived

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in the same sea. The compositional range of *A. vulgaris* was small, whilst that of *A. subtenuis* was large. The differences were interpreted as showing that *A. vulgaris* occupied a restricted environmental niche, whilst *A. subtenuis* ranged more widely and had a more cosmopolitan lifestyle. This study extends that of McArthur et al. (2007b) by reporting on the compositions of these two species, plus two others, *Simpsonibelus dorsalis* and *Youngibelus simpsoni*, from a 25 m-thick section of Lower Toarcian sediment preserved on the coast of Yorkshire, UK, that represents a period of ≈400 kyrs.

2. Sampling

Samples were collected at Saltwick Bay, near Whitby, on the coast of Yorkshire, UK (Fig. 1). The lithostratigraphy and biostratigraphy of the Lower Toarcian sediments in the study interval are detailed in Howarth (1963; redrawn in McArthur et al., 2008 to include chemical profiles). Samples derive from the 25 m of strata upward from the base of Bed 43 to the lower part of Bed 51 of Howarth (1963) and so bracket his Bed 48 (the Ovatum Band), that yielded the specimens studied by McArthur et al. (2007b). Exposure on this coastal section is 100% and sampling levels were accurate to ±20 cm. The interval encompasses the upper half of the *Harpoceras falciferum* Zone and the lower part of the overlying *Harpoceras bifrons* Zone. Later, alternate, zonal/subzonal designations are *Harpoceras serpentinum* for *H. falciferum*, and *Harpoceras laticosta* for *Dactylioceras commune* (Page, 2004): the older names are retained here to provide a link to previous literature. A duration of ≈400 kyrs for the study interval has been derived by Sr-isotope stratigraphy (McArthur et al., 2000, 2008).

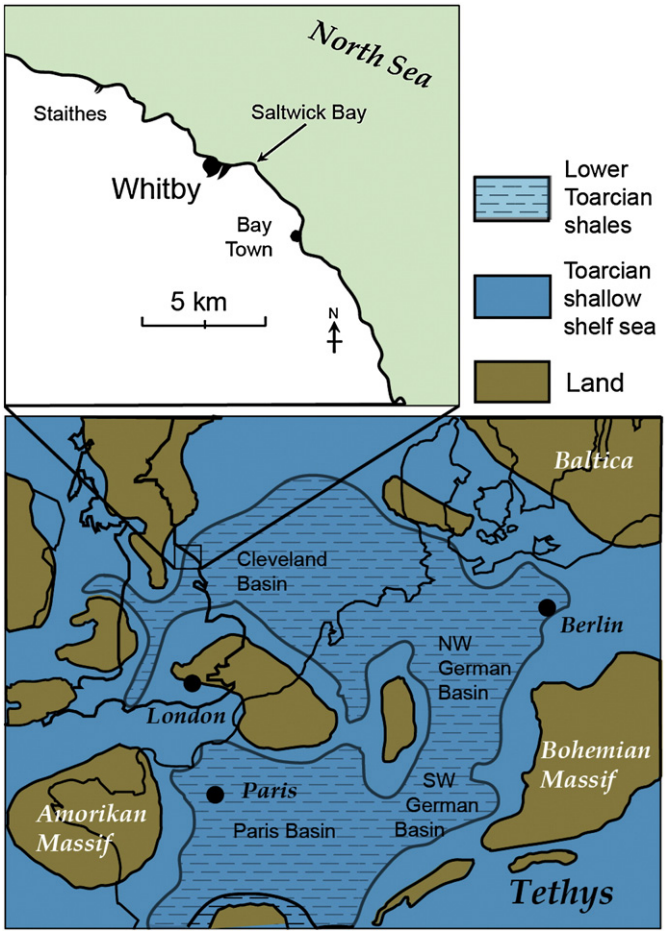

Fig. 1. Simplified sampling locality maps. Arrow denotes Saltwick Bay, Yorkshire, UK. Maps are after Schwark and Frimmel (2004).

3. Palaeo-environments

The interval studied here was a time when the early Toarcian epicontinental seaway of northwestern Europe evolved from an unrestricted setting, through a phase of restriction and black shale (up to 20% TOC) development, and back to an open-shelf setting. The lower half of the section studied here was laid down as restriction eased; the upper half was laid down when restriction had all but vanished. As a consequence, faunas show a degree of restriction through much of the section studied (Harries and Little, 1999) because water-mass restriction led to intermittent euxinia (Saelen et al., 1996; McArthur et al., 2008; refs therein). The beds immediately underlying the studied interval comprise the *falciferum* Subzone and were laid down during the time of severest restriction and almost permanent euxinia (*ibid*). During the intervals of restriction, episodic oxygenation events permitted brief colonization by benthic and pelagic forms, including belemnites (Rohl et al., 2001; Schmid-Rohl et al., 2002). Beds overlying the study interval were deposited under unrestricted conditions.

The sampling undertaken from the Toarcian of Yorkshire therefore represents snapshots in time during which the condition generally unfavourable for life had been briefly (and intermittently) interrupted (Little and Benton, 1995; Rohl et al., 2001; Schmid-Rohl et al., 2002; McArthur et al., 2008; Caswell et al., 2009). Belemnites (and other fossils) therefore flourished in the seaway of northwestern Europe only during these brief events of mixing and oxygenation, and so captured a record only of conditions during those brief events. In effect, belemnites, having lived only a couple of years, captured brief events that were not representative of the long-term oceanic conditions represented by the sediment in which they are buried. The sediments in which the belemnites now reside carry a different record; that of conditions when macrofauna were absent from most of the water column.

4. Samples

The four species presented here, with numbers of specimens in parentheses, are *Acrocoelites* (*Acrocoelites*) *subtenuis* (24), *Simpsonibelus dorsalis* (10), *Youngibelus simpsoni* (9) and *Acrocoelites vulgaris* (5). Typical examples of each species are shown in Fig. 2. The stratigraphic levels of the specimens are reported in Table 1 in metres above the base of the Toarcian.

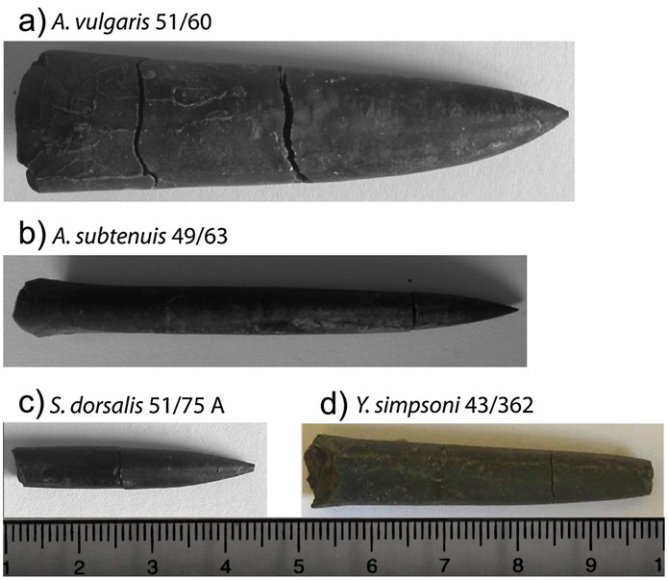

Fig. 2. Specimens of the studied four belemnite species from the Toarcian sediments of Yorkshire, UK, with sample numbers. Scale is in mm and cm. Apex missing from specimen shown in d).