Palaeogeography, Palaeoclimatology, Palaeoecology 465 (2017) 395–406

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Changes of shell microstructural characteristics of *Cerastoderma edule* (Bivalvia) — A novel proxy for water temperature

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ARTICLE INFO

Article history:
Received 15 June 2015
Received in revised form 15 September 2015
Accepted 28 September 2015
Available online 8 October 2015

Keywords:
Microstructure
Bivalve shell
Prism size
Prism elongation
Temperature proxy
Scanning electron microscopy

ABSTRACT

Shells of bivalves potentially provide an excellent archive for high-resolution paleoclimate studies. However, quantification of environmental variables, specifically water temperature remains a very challenging task. Here, we explore the possibility to infer water temperature from changes of microstructural characteristics of shells of the common cockle, *Cerastoderma edule*. The size and elongation of individual microstructural units, i.e., prisms, in the outer shell layer of seven three to five year-old, specimens collected alive from the intertidal zone of the North Sea near Texel, The Netherlands, and Schillig, Germany, were measured by means of automatic image processing. Growth patterns (circatidal, ciralunidian and fortnightly increments and lines), shell oxygen isotope values and mark-and-recovery experiments were used to place the shell record in a precise temporal context. Irrespective of the locality and ontogenetic age, size and elongation of the prisms increased non-linearly with water temperature. Small ($0.12 \pm 0.05\ \mu m^2$) and round prisms (elongation: 2.42 ± 0.31) were formed at temperatures of ca. 10 °C (late April), whereas larger ($0.33 \pm 0.11\ \mu m^2$) and more elongated prisms (3.26 ± 0.28) occurred during hot summer (ca. 22 °C). No clear-cut or consistent correlation existed between microstructural characteristics and growth rate as well as a variety of other environmental variables such as salinity, chlorophyll a and turbidity. Based on these findings, a model was constructed from three shells at Texel that enables reconstruction of water temperature with a precision of 1.7 ± 1.0 °C from prism size and elongation: $SST = 9.02 + 17.25\ P_s + 1.10\ P_e$. This model was successfully tested at four shells from Schillig. The new temperature proxy can be of particular interest for paleoclimate studies in nearshore settings when non-recrystallized *C. edule* shells are available. Future studies are required to verify our findings and check if other species with the same and different microstructures show similar relationships with water temperature.

1. Introduction

Bivalve mollusks serve as sensitive, high-resolution recorders of past environmental change (Jones, 1983; Marchitto et al., 2000; Richardson, 2001). Information on seasonal and inter-annual change of temperature, salinity, food availability and water quality is preserved in their shells in the form of variable growth rates and geochemical properties (Kennish and Olsson, 1975; Jones et al., 1986; Wefer and Berger, 1991). These data can be placed in a precise temporal context by using periodic shell growth patterns (Rhoads and Pannella, 1970; Evans, 1972; Goodwin et al., 2001). Furthermore, bivalves inhabit almost all aquatic environments, in particular shallow marine and coastal settings, and well-preserved fossil shells occur in sedimentary deposits, in particular the Cenozoic. Therefore, bivalve shells are being increasingly utilized in paleoclimatic and paleoenvironmental analyses (Schöne and Gillikin, 2013). Most of such studies focused on the reconstruction of sea surface temperature (SST) because of its coupling to a variety of other climate parameters.

One of the most frequently used proxies for water temperature in bivalve sclerochronology is the oxygen isotope value of the shell carbonate ($\delta^{18}O_{shell}$). However, $\delta^{18}O_{shell}$ is a dual proxy that simultaneously records changes of temperature and the oxygen isotope composition of the ambient water, $\delta^{18}O_{water}$, which is correlated to salinity. To reconstruct temperature from $\delta^{18}O_{shell}$ values, the other variable ($\delta^{18}O_{water}$ or salinity) during shell formation must be known. This information is typically not available for ancient environments and currently not possible to infer from bivalve shells. Temperature reconstructions based on $\delta^{18}O_{shell}$ are particularly challenging in coastal and intertidal areas because of large salinity fluctuations and associated variations of $\delta^{18}O_{water}$ (Gillikin et al., 2005a). Variable shell growth rates can potentially provide information on water temperature. In many poikilothermic animals, faster growth occurs in warmer waters. However, shell growth of bivalves is also controlled by food availability and quality (Ansell, 1968; Witbaard et al., 1997) and depends on preserved energy reserves from previous years (Yan et al., 2012). Therefore, the temperature information recorded in variable increment widths is often

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http://dx.doi.org/10.1016/j.palaeo.2015.09.051
0031-0182/