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An intractable climate archive — Sclerochronological and shell oxygen isotope analyses of the Pacific geoduck, *Panopea abrupta* (bivalve mollusk) from Protection Island (Washington State, USA)

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ABSTRACT

Annual growth increment patterns of cardinal teeth (CT) of *Panopea abrupta* (Conrad) can reportedly provide information about past climate variations. However, little is known about the intra-annual timing and rate of shell growth necessary to interpret such records. In addition, it remains unclear whether actual temperatures can be reliably inferred from $\delta^{18}O$ values of geoduck {goo'e-duk} shells. This study compared high-resolution environmental records (hourly to monthly resolved temperature, bi-weekly to monthly $\delta^{18}O_{water}$ and salinity data) with temperatures reconstructed from oxygen isotope values of the outer shell layer ($T\delta^{18}O_{OSL}$) and cardinal tooth portions ($T\delta^{18}O_{CT}$) of different contemporaneous specimens alive at the same locality. Results indicate that shell growth mainly occurred between March/April and November/December with a maximum during May–August. This finding must be considered when comparing the "annual" growth increment width chronologies to environmental parameters. In addition, intra-annual $\delta^{18}O_{shell}$ values require the calculation of weighted averages instead of arithmetic means. During ontogeny, the duration of the growing season remained nearly unchanged; an important finding for paleoclimate studies based on inter-annual growth patterns. Seasonal shell growth was strongly correlated with temperature (R=0.93, R^2=0.86, p<0.0001). Presumably due to individual differences in the exchange rate between the extrapallial fluid (EPF) and the ambient water, the outer shell layer of some specimens formed out of oxygen isotopic equilibrium, particularly during summer (high growth rates, increased ^{18}O depletion of the EPF). This resulted in a $T\delta^{18}O_{OSL}$ difference of up to 2 °C among different specimens. In addition, a bias was observed in different specimens toward daytime or nighttime temperatures, particularly during summer. Such a bias may be related to individual differences in the physiological activity at ultradian time-scales or to elevated predation pressure. More importantly, CT portions (= inner shell layer) formed in isotopic disequilibrium with the ambient water. Typically, reconstructed temperatures differed by more than 3–4 °C from actual water temperatures. Within specimens, $T\delta^{18}O_{OSL}$ and $T\delta^{18}O_{CT}$ were offset by ca. 2 °C. Some $T\delta^{18}O_{CT}$ also exhibited unexplained inter-annual trends, so that $T\delta^{18}O_{CT}$ among specimens varied by up to 4 °C. Given the $\delta^{18}O_{shell}$ inconsistency between and among shells, a small seasonal temperature amplitude barely exceeding 4 °C and the error bars of $T_{\delta 18O}$ of geoducks at this setting on the order of ±2 °C (error bars of the paleothermometry equation+variable $\delta^{18}O_{water}$ values+precision error of the mass spectrometer), the geochemical record of a single *P. abrupta* may not serve as a suitable paleoclimate archive. A reliable approximation to paleotemperatures may only be achieved by exclusively sampling the outer shell layer of multiple contemporaneous specimens, so that the $T\delta^{18}O_{OSL}$ variance among shells can be quantified.

1. Introduction

Skeletons of many aquatic organisms function as recorders of environmental and climate change. Particularly, long-lived bivalve mollusks such as *Arctica islandica* (Linnaeus), *Cucullaea raea* Zinsmeister, *Margaritifera margaritifera* (Linnaeus), or *Panopea abrupta* (Conrad) are increasingly used to reconstruct climate variations prior to anthropogenic forcing in the North Atlantic or North Pacific, respectively (Marchitto et al., 2000; Schöne et al., 2003; Buick and Ivany, 2004; Schöne et al., 2004a,b; Strom et al., 2004; Schöne et al., 2005a; Strom et al., 2005; Wanamaker et al., 2007). Such data is relevant because knowledge of natural low frequency climate oscillations (e.g., the Pacific Decadal Oscillation, PDO, or the El Niño/

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