Resolution and Fidelity of Oxygen Isotopes as Paleotemperature Proxies in Bivalve Mollusk Shells: Models and Observations

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Bivalve mollusks are biological chart recorders: their shells contain a record of environmental conditions in the form of geochemical variation. However, these records are often incomplete. Growth cessations and/or changing growth rates can reduce the range and resolution of the recorded environmental conditions.

To investigate the effects of these variables on geochemical profiles, stable oxygen isotope ($\delta^{18}O$) profiles were modeled using several growth parameters. Two sets of profiles were calculated: one with constant daily increment widths, the other based on the annual pattern of daily increment width variation observed in the northern Gulf of California bivalve mollusk Chione cortezi. *In both sets of models, multiyear $\delta^{18}O$ profiles were calculated assuming that the bivalve shell grows continuously throughout its life. Other profiles were calculated to simulate an ontogenetic decrease in growth rate by decreasing the growth period, daily growth rate, or both. Altering the growth period simulates the effects of thermal thresholds, above or below which no shell material is deposited. Decreasing the daily growth rate results in lower annual shell growth rates while keeping the growth period constant. Combining the two provides a more accurate representation of bivalve shell growth in many subtropical and temperate species.*

In addition to the modeling exercise, the shell of a Chione cortezi *that lived in the northern Gulf of California was sampled in two ways. First, low-resolution (300 micron) samples were recovered from the entire growth profile along the axis of maximum shell height (umbo to the commissure). Second, high-resolution (50 micron) samples were taken from regions of the shell representing winter growth from late in the bivalve's life.*

Modeling results and observations indicate that the fullest range of environmental conditions only is reflected in the earliest years of growth; profiles from successive years have reduced amplitudes, sample resolutions, or both. Variation of intra-annual growth rate in models simulating continuous growth can produce cuspate $\delta^{18}O$ profiles that mimic shutdowns. More detailed sampling in later stages of ontogeny can reconstruct a fuller range of environmental conditions. Finally, within-shell trends in isotopic amplitudes and averages may reflect decreases in growth rate rather than environmental fluctuations. Therefore, particular care should be taken when interpreting inter-annual isotope profiles from long-lived species.

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INTRODUCTION

Accretionary hard parts are valuable sources of environmental information (Jones, 1983; Wefer and Berger, 1991). Bivalve mollusks in particular are an important source of geochemically archived environmental information. However, the growth of bivalves rarely is constant and growth cessations are common (e.g., Jones and Quitmyer, 1996). These growth halts prevent bivalves from archiving continuous and complete records of environmental conditions.

The rate and timing of bivalve shell growth is controlled by temperature (Pannella and MacClintock, 1969; Kennish and Olsson, 1975; Jones et al., 1978, 1989), salinity (Koike, 1980), age and reproductive cycle (Hall et al., 1974; Sato, 1995), tidal cycle and intertidal position (Berry and Barker, 1975; Lutz and Rhoads, 1980; Ohno, 1989), and nutrient availability (Coe, 1948). However, temperature appears to be the dominant factor controlling intra-annual growth rates (Goodwin et al., 2001; Schöne et al., 2002). Growth cessations occur when temperatures exceed the thermal tolerances of individual organisms (Jones and Quitmyer, 1996). Furthermore, when temperatures approach but do not exceed the thermal tolerances, growth rates and sub-annual growth increments are reduced (Goodwin et al., 2001). Thus, the proportion and resolution of recorded environmental conditions are affected by the duration of growth periods and/or changing growth rates.

Here the influence of growth-period duration and variation of growth rates on inter-annual geochemical profiles is investigated. Using a simple model of environmental conditions, two sets of stable oxygen isotope ($\delta^{18}O$) profiles were calculated, one with constant daily increment widths and the other based on the annual pattern of daily increment width variation, from the northern Gulf of California bivalve mollusk *Chione cortezi*. In each set of models, a series of profiles reflecting various intra- and inter-annual growth patterns was calculated. First, a profile in which the full range of environmental conditions was represented was calculated. This model was designed to simulate a $\delta^{18}O$ profile from an organism that grows continuously throughout its ontogeny. Second, profiles were modeled with various ontogenetic declines in growth rate, which is a feature of many bivalve mollusks (e.g., Appleyard and Dealteris, 2001; also see King, 1995, for a general discussion). This decrease in growth rate was modeled in three ways: (1) the growth period (i.e., the number of days of shell deposition) was shortened through the bivalve's life; (2) the width of daily growth increments was decreased while keeping the growth period constant; and (3) both the growth period and daily increment widths were decreased through ontogeny.

These modeled $\delta^{18}O$ profiles reveal how different styles

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