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Microstructures in shells of the freshwater gastropod *Viviparus viviparus*: A potential sensor for temperature change? ☆

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ABSTRACT

Mollusk shells contain a plethora of information on past climate variability. However, only a limited toolkit is currently available to reconstruct such data from the shells. The environmental data of some proxies (e.g. Sr/Ca ratios) is obscured by physiological effects, whereas other proxies, such as $\delta^{18}O$, simultaneously provide information on two or more different environmental variables. The present study investigates whether microstructures of the freshwater gastropod *Viviparus viviparus* provide an alternative means to reconstruct past water temperature. Cold and highly variable temperature regimes resulted in the precipitation of highly unordered first-order lamellae of simple crossed-lamellar (XLM) structures if new shell formed from scratch. However, during stable and warm conditions, well-ordered first-order lamellae were laid down irrespective of pre-existing shell material. Homogeneous first-order lamellae also formed during times of cold and highly variable temperatures if the new shell was deposited onto existing shell material with well-ordered first-order lamellae. The growth front seems to contain instructions for building specific microstructure variants, irrespective of environmental conditions. However, if this template is missing, the animal forms a deviating microstructure. Under extremely stressful situations (e.g. removal from habitat, calcein staining, extreme temperature shifts), the gastropod precipitates an evolutionarily older microstructure (irregular simple prisms) rather than XLM structures. These shell portions were macroscopically described as disturbance lines. In addition, repetitive, presumably periodic growth patterns were observed, which consisted of gradually changing third-order lamellae between consecutive faint, organic-rich growth lines. These growth patterns were probably controlled by intrinsic biological clocks and exhibited a two-daily periodicity. The results of this study may provide the basis for using changes in the microstructure of shell sections as a new sensor (environmental proxy) for past water temperature.

1. Introduction

Mollusk shells are becoming increasingly recognized as powerful tools for paleoclimate reconstructions [1–3]. During growth, ambient environmental conditions are recorded in the shells in the form of variable geochemical properties [4,5] and variable growth rates [6,7]. Since mollusk shell formation occurs periodically (tidal cycles, diurnally, annually), environmental proxy data can be precisely temporally aligned. Such data are essential to validate and optimize numerical climate models and identify forcing mechanisms operating within the Earth system (e.g. Ref. [8]).

However, it still remains extremely challenging to obtain quantifiable environmental data, specifically paleotemperature from mollusk shells. The only well-accepted proxy for temperature in mollusks, $\delta^{18}O_{shell}$, is a dual proxy that simultaneously records temperature and the oxygen isotope signature of the ambient water ($\delta^{18}O_{water}$). To reconstruct past water temperature from $\delta^{18}O_{shell}$ values, $\delta^{18}O_{water}$ (or salinity) must be known, which is rarely available for ancient environments. Attempts have been made to infer water temperature from other physicochemical properties such as Mg/Ca and Sr/Ca ratios [9,10], Δ_{47} values [11], $\delta^{44/40}Ca$ values [12] and growth patterns [13–15]. However, vital effects typically result in a strong biological filtering of the temperature signal in these proxies [16]. For example, Sr/Ca and Mg/Ca values of mollusk shells remain far below that of the ambient water, and their relative changes are not always linked to temperature shifts [17–20]. The sensitivity of the Δ_{47} clumped isotope thermometer is much lower

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