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Leukoma antiqua (Bivalvia) - A high-resolution marine paleoclimate archive for southern South America?

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ABSTRACT

The Patagonian Sea in the SW Atlantic is one of the most productive marine ecosystems worldwide. Besides its economic relevance, this shelf sea serves as a major sink for atmospheric CO_2 and thus plays a major role in global climate. Despite that, the marine climate dynamics in that region remain barely known. Instrumental records only cover the last 30 years or so and high-resolution climate archives are currently not available. Here, we explore the possibility to obtain seasonally to inter-annually resolved paleotemperature data from shells of the bivalve mollusk, *Leukoma antiqua* collected alive from the shallow subtidal zone of the San Jorge Gulf. Results demonstrate that this species grows during summer and – at least at slow rate – during winter at this locality and records nearly the full seasonal temperature amplitude (monthly averages) in the form of $\delta^{18}O_{shell}$. Furthermore, isotope-based climate reconstructions will be limited to the first 15 years of life, because growth rates are sharply reduced afterward which aggravates sampling. The oldest studied specimen attained an age of 34 years. Annual, fortnightly and lunar daily increments can potentially be used to determine the timing and rate of seasonal shell growth and help placing the shell record into precise temporal context. However, due to interferences with the shell microstructure, sub-annual growth patterns were only occasionally well developed. In this study, the temporal alignment of the growth record was therefore largely achieved by forcing $T_{\delta18O}$ to match the shape of the instrumental temperature curve. In some years it was possible to validate such temporal alignments with fortnight increments. Shell growth rate is strongly linked to primary production which attains a maximum in spring. For yet unexplained reasons, shell formation occurs with an offset of almost −1‰ (−0.9 ± 0.3‰) from expected oxygen isotopic equilibrium with the ambient water. When this offset is adjusted for, $\delta^{18}O_{shell}$ can be used to compute past water temperature. Given the individual variability regarding $\delta^{18}O_{shell}$, it is advised to study a sufficient number coeval specimens to obtain more reliable information on the seasonal temperature range. Presumably, the overall life history and the isotopic offset is similar for *L. antiqua* specimens at other localities in southern South America. Since *L. antiqua* not only dominates modern nearshore benthic assemblages, but also occurs abundantly in Quaternary deposits along the Argentine Patagonian coast, this species can significantly contribute to a better understanding of natural baseline conditions and past climate dynamics in southern South America.

1. Introduction

The Patagonian Sea in the SW Atlantic Ocean is one of the most productive marine ecosystems and one of the largest continental shelves (e.g., Longhurst et al., 1995; Carreto et al., 2007; Fernández et al., 2007; Dogliotti et al., 2014; Paparazzo et al., 2017; Fig. 1). Besides its economic relevance, this region serves as a major sink for atmospheric CO_2 with one of the highest uptake rates (Bianchi et al., 2005, 2009; Kahl et al., 2017; Orselli et al., 2018). Primary production in the Patagonian Sea is particularly strong near the numerous oceanic fronts at which water masses of different properties meet (Acha et al., 2004). From West to East, Carreto et al. (1995) distinguishes (1) the coastal

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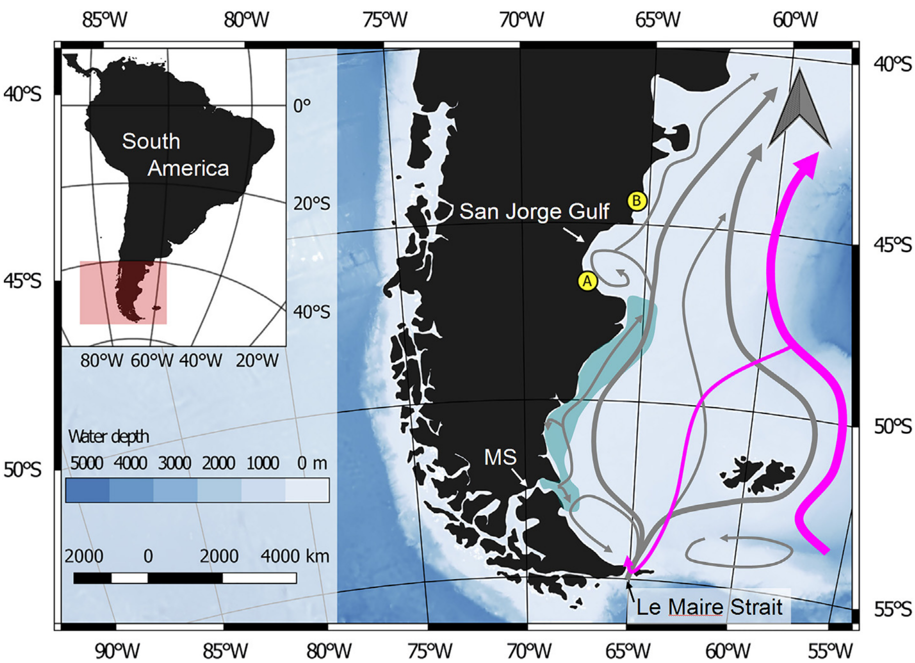

Fig. 1. Map showing localities at which living specimens of *Leukoma antiqua* were collected for the present study (A; sample ID = 2013-PAT3; see also Fig. 2) and for a previous study by Schellmann and Radtke (2007) (B). Major currents of the Patagonian shelf (grey) largely derive from the Cape Horn Current. The western boundary current (Malvinas/Falkland Current), a branch of the Antarctic Circumpolar Current, is depicted in purple. Waters from the latter flow as bottom currents (thin purple line) onto the Patagonian shelf and upwell through the Le Maire Strait. Fresher waters (Magellan Plume, green) deriving from the Magellan Strait (MS) are diluted as they move northward. At the southern tip of the San Jorge Gulf, the remainders of these waters are deflected offshore and can be traced up to ca. 42°S (references see Section 1). Origin of the map: gridded bathymetry data ("GEBCO 30 arc-second global grid of elevations") from the website www.gebco.net. Configuration of currents based on Matano et al. (2010). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

regime (comprising the upper 30 to 50 m) that is well mixed throughout the year by strong semidiurnal macrotides and westerly winds, (2) the tidal front, (3) the subantarctic shelf waters system which is stratified between spring and fall, and (4) the thermohaline shelf-break front that separates the shelf waters from the cooler, more saline and nutrient-rich Malvinas/Falkland Current (Kahl et al., 2017). Patagonian shelf waters mainly derive from the Cape Horn Current (Bianchi et al., 2005, Fig. 1), i.e., subantarctic waters that move around the southern tip of South America in eastward direction largely driven by the Westerlies. The West Wind Drift belt, in turn, is meridionally modulated by the Southern Annual Mode (also known as Antarctic Oscillation) which exhibits a statistically significant quasi-decadal variability of 8 to 16 years (Yuan and Yonekura, 2011). A poleward shift (= positive Southern Annual Mode) of the West Wind Drift belt results in increased poleward heat transport and increased kinetic energy of the ocean currents. In addition, deeper waters of the Malvinas Current upwell through the Le Maire Strait onto the Patagonian shelf and are then advected northward by westerly winds (Matano et al., 2010; Fig. 1). Relatively fresh waters enter the Patagonian Shelf from the Magellan Straits (Bogazzi et al., 2005; Lucas et al., 2005; Palma and Matano, 2012). The extension of the so-called Magellan Plume (Fig. 1) can be traced as far north as 42°S. However, near the southern tip of the San Jorge Gulf (ca. 47°S) the lower salinity waters are deflected offshore and separated from subantarctic waters by the Southern Patagonian Frontal System (Bogazzi et al., 2005). Therefore, the majority of the San Jorge Gulf (Fig. 1) and coastal areas further north are dominated today by subantarctic waters with a fairly stable salinity.

Knowledge of the complex oceanography of the Patagonian Shelf has benefitted a lot from remote sensing, direct measurements of water properties during research cruises, data collected at meteorological stations, and numerical simulations. However, the seasonal to interannual marine climate variability prior to the short instrumental era (30 years; Garreaud et al., 2013) remains largely unknown, because high-resolution marine proxy data are currently not available. Such data are required to constrain the natural baseline conditions, place ongoing changes in the area into a broader historical context and predict possible future changes. Shells of bivalves and gastropods can potentially provide respective paleoclimate data. However, only very few sclerochronological studies were conducted in southern South America, mainly along the coasts of Peru and Chile (Lazareth et al., 2006; Thébault et al., 2008; Gosselin et al., 2013) and the Beagle Channel (limpets: Colonese et al., 2012), but to our best knowledge only once on the Patagonian Shelf (Yan et al., 2012).

Here, we explore the possibility to obtain highly resolved temperature data from a combined analysis of shell growth patterns and stable oxygen isotope signatures of the shallow infaunal bivalve mollusk, *Leukoma antiqua* (King, 1832), previously assigned to the now-unaccepted genus *Protothaca*. *L. antiqua* not only dominates benthic faunal assemblages of modern nearshore (intertidal and shallow subtidal) environments in the Atlantic and Pacific Oceans (Carcelles, 1950; Carcelles and Williamson, 1951; Clasing et al., 1994; Rios, 1994; Urban and Tesch, 1996; Reid and Osorio, 2000); it also occurs abundantly in sedimentary strata along the Argentine Patagonian coast that formed during past warm intervals, in particular, the Mid-Holocene as well as MIS 5, 7, 9 and 11 (Feruglio, 1950; Aguirre, 2003; Aguirre et al., 2008, 2009, 2011; Schellmann and Radtke, 2007, 2010; Schellmann et al., 2008). In the present study, we conducted a detailed analysis of the timing and rate of shell formation of *L. antiqua* and investigated how faithfully the oxygen isotope data of its shell record changes of ambient water temperature. Through the use of multiple coeval specimens, we also addressed reproducibility aspects.

2. Material and methods

On 6 April 2013, several dozen specimens of *L. antiqua* were collected alive at low tide by apnea diving in ca. 3 m water depth in the shallow subtidal ESE of Caleta Olivia, Argentina (Golfo San Jorge; 46°29′23.10″S, 67°28′28.61″W; WGS84 datum; locality name: diving school "Cadace", Fig. 1). Bivalves were eviscerated immediately after collection and rinsed with seawater. At the same site, water samples were taken (in ca. 1 water depth) in 30 ml glass vials for the analysis of salinity (determined with a Schott handylab pH/LF12) and the stable oxygen isotope value of the water ($\delta^{18}O_{water}$) (Table 1).

2.1. Shell collection and preparation

Seventeen bivalves were arbitrarily chosen for subsequent analysis (Table 2). One valve of each specimen (again, arbitrarily left or right valves were chosen) was mounted on a Plexiglas cube with fast-curing plastic welder. To protect the shell during cutting, the inner and outer