Global and Planetary Change 181 (2019) 102990

Contents lists available at ScienceDirect

Global and Planetary Change

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

Research article

Late Quaternary nearshore molluscan patterns from Patagonia: Windows to southern southwestern Atlantic-Southern Ocean palaeoclimate and biodiversity changes?

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ARTICLE INFO

Keywords:
Pleistocene
Holocene
P. antiqua
T. atra
Palaeoproductivity
ocean fronts
Mar Argentino

ABSTRACT

Varied approaches (palaeobiodiversity, palaeobiogeography, bioerosion, geochemistry) to unique Patagonian late Quaternary molluscan assemblages in the southwestern Atlantic, with ages especially from interglacial Marine Isotope Stage (MIS) 5e and MIS 1, provide large-scale and long-temporal palaeoenvironmental data for the southern SWA. Together with new patterns of $\delta^{18}O$ and $\delta^{13}C$ variations in modern, mid-Holocene, and Late to Middle Pleistocene shells of *Protothaca antiqua* (Bivalvia) and the coeval Pleistocene *Tegula atra* (Gastropoda), the overall sources of evidence illustrate possible responses to recent palaeoclimate and sea-ice changes around the southernmost SWA-western Antarctica, leading to modern conditions. For the mid-Holocene, the influence of the Hypsithermal is confirmed. In the northern Golfo San Matías, the highest $\delta^{18}O$ and $\delta^{13}C$ values support higher salinity and sea surface temperatures (SST), and a Golfo San Matías Front stronger than today. Lower $\delta^{18}O$ values in the northern Golfo San Jorge (GSJ) compared to the Late to Middle Pleistocene suggest warmer mid-Holocene waters, independently supported by thermally anomalous molluscan taxa, geographical shifts of areas of endemism and absence of *T. atra* (cold water proxy); overall higher $\delta^{13}C$ values compared to present suggest higher productivity. For the Late to Middle Pleistocene (particularly MIS 5e), highest $\delta^{13}C$ values (relative to modern and mid-Holocene trends) match with the location of tidal fronts and areas of maximum chlorophyll-a concentrations today. Accordingly, these fronts may have been already active and significantly intensified due to the prevailing climate conditions that included colder waters and stronger upwelling from the southern GSJ southwards. This is independently supported by palaeobiogeographical and bioerosion trends and the dominance of the cold water species *T. atra* during the Pleistocene, which is dispersed from the SE Pacific

Abbreviations: A, Argentinean malacological province; AAIW, Antarctic Intermediate Water; ACC, Antarctic Convergence Current (= WWW, West Wind Drift); AMOC, Atlantic Meridional Overturning Circulation; BC, Brazilian warm current; BMCZ, Brazil-Malvinas Confluence Zone (= BMC); CHC, Cabo de Hornos Current (cold); GSJ, Golfo San Jorge; GSM, Golfo San Matías; HC, Humboldt Current System (cold); M, Magellanean malacological province; MC, Malvinas/Falkland cold current (branch of the ACC); MIS, Marine Isotope Stage; MP, Magellean Plume (cold subantarctic nutrient-rich waters from the SEP); NGSJF, northern Golfo San Jorge Frontal System; NSAO, north of san Antonio Oeste; PC, Patagonian coastal cold current (Subantarctic shelf waters); PE, Polar easterlies; PF, Polar Front; SAF, Subantarctic Front; SASW, Subantarctic shelf waters; SAMW, Subantarctic Mode Water; SCOL, south of Caleta Olivia; SGSJF, southern Golfo San Jorge Frontal System; SO, Southern Ocean; SST, sea surface temperature; SSW, southern westerly winds

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https://doi.org/10.1016/j.gloplacha.2019.102990
Received 31 December 2018; Received in revised form 12 July 2019; Accepted 13 July 2019
Available online 19 July 2019
0921-8181/

into the SWA by rafting on kelps and whose occurrence is controlled by SST, light, winds, and nutrient concentration/productivity. Repeated, abrupt climate oscillations during the last glacial cycle with significant impact on SST, ice melting and surface-ocean stratification in the western Antarctica-Weddell Sea-Antarctic Circumpolar Current realm are so far the only available plausible explanations to account for the different mid-Holocene and modern patterns, and for the regional disappearance of *T. atra* after MIS 5e. Further palaeoceanographic research in this key area is needed to understand how all these mechanisms operated in the past, potentially influencing the Patagonian shelf waters and coastal fronts.

1. Introduction

Patagonia is the only large landmass in the southern hemisphere south of ca. 40°S, which contains numerous broad-scale Quaternary palaeoenvironmental/palaeoclimate records (e.g., Garreaud et al., 2013). In particular, the Patagonian coastal area (Argentina) in the southwestern Atlantic (**SWA**), located at a passive margin near the Drake Passage and western Antarctica (Fig. 1A), exhibits spectacular and unique Quaternary molluscan-rich marine deposits (Fig. 1B–I, 2), nowhere else so extensively abundant and well preserved in South America, formed by high sea-level episodes during interglacials of the Middle to-Late Pleistocene (Marine Isotope Stage (**MIS)** 11, 9, 7 and 5) and during the mid-Holocene (throughout the manuscript we use mid-Holocene in a broad sense and not as reference to the stratigraphic epoch) (MIS 1) (Lisiecki and Raymo, 2005; Aguirre et al., 2011; Gibbard and Lewin, 2016; Düsterhus et al., 2016; Head et al., 2017) (Appendixes A.1, A.2). Earlier highstands (pre-MIS 11) are preserved further inland, but their molluscan content is either scarce and/or highly abraded or completely unpreserved. Unique oceanographic and environmental conditions characterize the southern SWA, the only area of the southern hemisphere where a permanent injection of cold, nutrient-rich subpolar waters extend beyond 40°S (Gersonde and Zielinski, 2000; Piola et al., 2018; Franco et al., 2018; Combes and Matano, 2018). Influenced by three of the largest thermal fronts of the world oceans (Subtropical/ Subantarctic/ Polar) and high chlorophyll-a concentrations along a variety of local oceanic fronts (Acha et al., 2004; Acha, 2015; Piola et al., 2018), this sector of the South Atlantic-Southern Ocean represents a key area to investigate modern and past atmospheric-oceanic changes (Bianchi et al., 2005; Anderson et al., 2009; Buizert and Schmittner, 2015; Yao, 2017; Panassa et al., 2018). Overall, this setting offers an unmatched opportunity to study potential linkages between littoral Late Quaternary molluscan assemblages and physical/biotic features of the southern SWA at a macrogeographical scale during the most recent climatic cycles.

Furthermore, in marine settings of the southern hemisphere, palaeoclimate/paleoceanographical records linked to Late Quaternary climate oscillations are less well known than those of the Northern Hemisphere (e.g., Lisiecki et al., 2008; Yin and Berger, 2015). This difference applies especially to the context of the Southern Ocean (i.e., south of 50°S, encircling Antarctica, including subantarctic regions and the southern parts of the South Atlantic, South Pacific and Indian oceans; Koubbi et al., 2014). Current knowledge from this region includes qualitative or quantitative data sets derived from a variety of disciplines and approaches, ranging from characterizations of modern abiotic and biotic features, geological and oceanographical aspects, climate and palaeoclimate models (e.g., Hodell et al., 2002; Wefer et al., 2003; Cortese et al., 2007; Clark, 2014; Roberts et al., 2017; Anderson et al., 2018; Saunders et al., 2018; Brook and Buizert, 2018; Combes and Matano, 2018). However, while most contributions are focused on the open or deep ocean, there are notably fewer nearshore records, particularly from the southern SWA, whose thermal evolution and that of the adjacent continents are still not fully understood (Bianchi and Gersonde, 2002; Hodell et al., 2003; Gersonde et al., 2005; Chiessi et al., 2015; Voigt et al., 2015, 2016; Howe et al., 2016).

Coastal marine palaeoclimate records are essential to increase our understanding of ocean-atmospheric climate dynamics (Harley et al., 2006). Even when continental shelves represent only a minor percentage of the total ocean, they hold an important fraction of the global carbon reservoir, and contribute significantly to global marine primary production and dissolved organic carbon (Dai et al., 2012; Bauer et al., 2013; Bianchi et al., 2005, 2009; Carreto et al., 2016), factors that can strongly respond to climate changes. Regional trends of biotic responses to climate change from nearshore settings can help to delineate potential future impacts of sea-surface temperature (**SST**) and circulation changes (Maslin and Swann, 2006; Gruber, 2015), considering that coastal marine systems are expected to be strongly affected by future increases in atmospheric CO_2 (increasing temperature by ca. 2 °C in the next 100 yrs.) (Walther et al., 2002; Bernhardt and Leslie, 2013). Coastal data on past sea-levels can also provide complementary information linked to ice sheet dynamics during deglaciations (Dutton et al., 2015), still poorly understood in the area of southernmost Patagonia-Western Antarctica, particularly in relation to the impact that icebergs, subglacial meltwater and iceberg/meltwater macro and micronutrient inputs have on total Southern Ocean productivity (e.g., Death et al., 2014; Hansen et al., 2016; Henley et al., 2017; Paparazzo and Esteves, 2018).

Specifically, regarding records from late Quaternary coastal deposits of Argentina, we also note that palaeoclimatic interpretations are scarce and have so far been contradictory. One example can be seen in SST conditions during the mid-Holocene (MIS 1) in a broad sense and the Last Interglacial (MIS 5e). Based on molluscan evidence, some authors argued for a warmer-than-present mid-Holocene Climatic Optimum (Hypsithermal), while others have contradicted this conclusion or reported warming in isolated localities only – mostly in the northern (Bonaerensian) sector (Fig. 1). In addition, during the Last Interglacial, similar, warmer-or-colder-than-present surface waters have been postulated (Feruglio, 1950; Aguirre, 1993; Aguirre et al., 2011, 2017).

In the present study, we reexamine Late Quaternary molluscan remains from the Patagonian coastal area, between San Antonio Oeste (Golfo San Matías, 40° 47′S-40° 49′S) and the southern Santa Cruz province (49°20′S) (Figs. 1A, 2), to interpret eventual palaeoclimate changes relative to the present based on various sources of evidence. Based on shell $\delta^{18}O$ and $\delta^{13}C$ variations of *Protothaca antiqua* (King) (Bivalvia), collected from Late to Middle Pleistocene, mid-Holocene and modern Patagonian nearshore strata (Fig. 1B–F), and of the coeval Pleistocene *Tegula atra* (Lesson) (Gastropoda) (Fig. 1G–I), in combination with palaeobiodiversity, palaeobiogeographical and bioerosion trends (Aguirre et al., 2011, 2013, 2017; Richiano et al., 2013, 2015, 2017), we aim to investigate how SST and productivity levels in the Pleistocene (especially MIS 5e) and mid-Holocene (MIS 1) compare to today along the Patagonia coast and whether general patterns can be linked to climate changes and coastal fronts. Particular questions to be addressed are: 1) Were Late to Middle Pleistocene interglacial surface oceanic waters in Patagonia colder or warmer than during the mid-Holocene and today?; 2) Was Last Interglacial productivity higher or lower relative to the mid-Holocene and present day?; 3) How do SST and productivity compare in the Mid-Holocene relative to today along the Patagonia coast?; 4) Could the overall molluscan patterns be linked to biological responses to ocean fronts? Finally, we hypothesize that overall trends, geographically and through time, could be responses to different ocean-atmospheric conditions; alternatively, no objective distinction is possible.