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Holocene variations in productivity associated with changes in glacier activity and freshwater flux in the central basin of the Strait of Magellan

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ABSTRACT

One of the most important factors controlling fjord primary production in southernmost Patagonia is the variability in the thermohaline structure of the water column. In the present-day environment, thermal stratification is mostly related to freshwater input and in particular, the seasonal melting of glaciers. Here we assess whether this relation between fjord productivity and freshwater input holds true for the Holocene, using a sediment record from the central basin of the Strait of Magellan (core MD07-3132, 53°44.17′S; 70°19.03′W, 301 m). Our approach relies on a proxy-based reconstruction of fjord sea surface temperature (alkenone SST), paleosalinity, freshwater input, and paleoproductivity. The results indicate that, during the early Holocene, the accumulation rate (AR) of marine organic carbon was low (<20 kg m^{-2} kyr^{-1}), most likely due to high freshwater contribution resulting in low salinity and low SSTs. After 8.5 kyr BP and during the mid and late Holocene all the productivity proxies increase. The AR's of marine organic carbon (~30 kg m^{-2} kyr^{-1}), biogenic $CaCO_3$ (~60 kg m^{-2} kyr^{-1}) and biogenic opal (425 kg m^{-2} kyr^{-1}) reached the highest values during the last millennium. This increase was probably driven by the marine transgression where marine macronutrient-rich waters entered into the central basin, while lowered precipitation and decreased meltwater input contributed to increase the basin's SSTs and salinity. The late Holocene rise in productivity was interrupted by a low salinity phase between 3.2 and 2.2 kyr BP, during which productivity returned to early Holocene conditions in response to increased input of glacial clays, as suggested by high values of K/Si ratio (~1.2). Our results indicate that meltwater contribution from glaciers plays a crucial role in controlling fjord productivity on seasonal to millennial timescales.

1. Introduction

The productivity patterns in the fjord system of the Strait of Magellan between 52° and 56°S are mainly influenced by changes in light regime and freshwater input from precipitation and glacier melting, all of which play a role at different timescales from seasonal to millennial. In the Patagonian fjords limnetic and oceanic features overlap generating strong vertical and horizontal physicochemical gradients (e.g., Sievers and Silva, 2008; González et al., 2013). At present, the interaction between the resulting surface freshwater layer and nutrient-rich saline bottom water (mixing and/or stability of the water column) strongly controls primary production fluctuations and species composition (e.g., Saggiomo et al., 1994; Pizarro et al., 2000; Iriarte et al., 2007; Torres et al., 2014). At millennial timescales, the interaction between climate and glacier dynamics could also have affected sea-surface temperature (SST), the thermohaline characteristics of the water column, and consequently paleoproductivity of the Magellan fjord system.

The Strait of Magellan crosses the southern tip of the South American continent from the Pacific Ocean and the hyperhumid southernmost Andes in the west to the semiarid grasslands area and the Atlantic Ocean in the east (Fig. 1). Here, Late Glacial coastline evolution was mainly controlled by glacier dynamics, global sea level rise and the regionally distinct degree of isostatic uplift (Kilian et al., 2013a).

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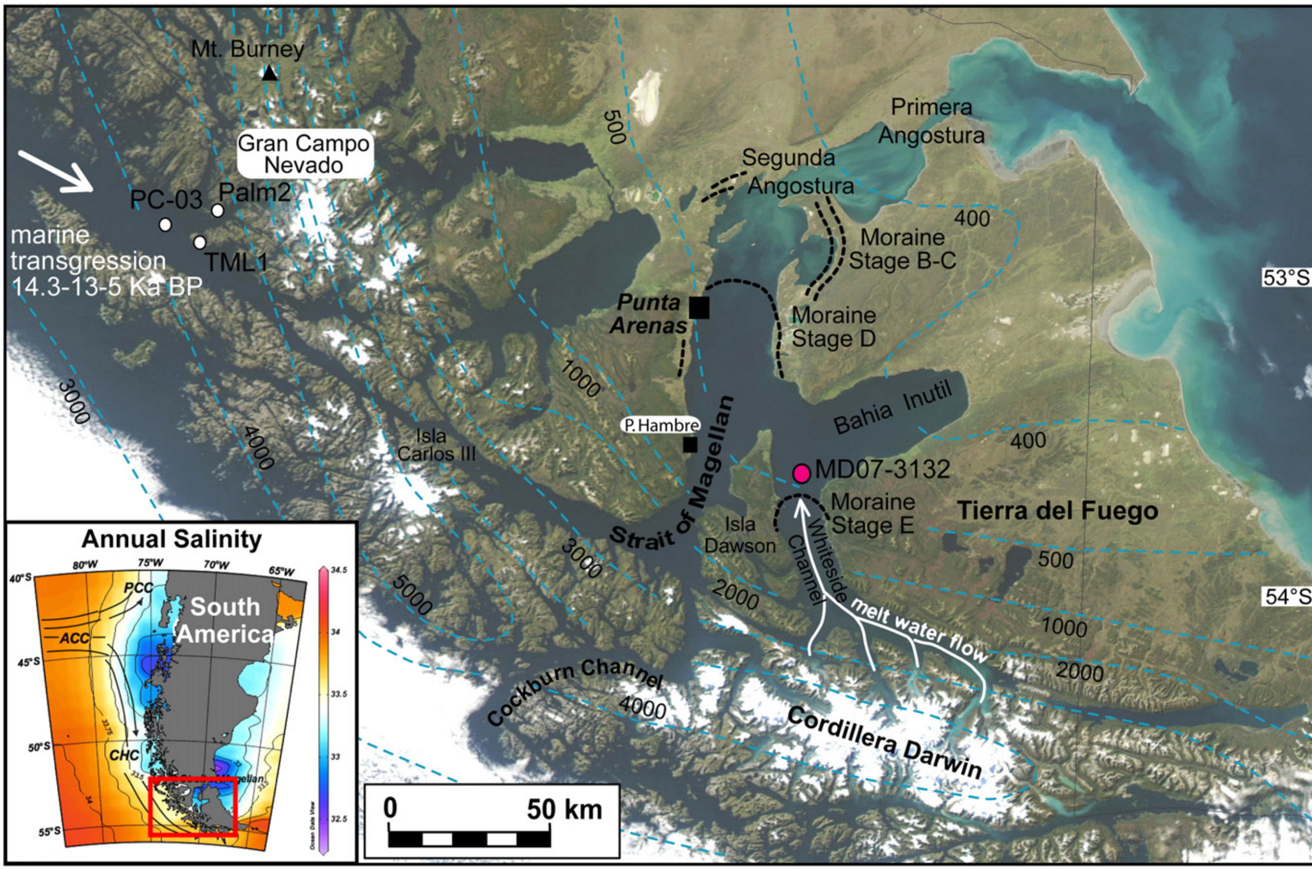

Fig. 1. Map of the Strait of Magellan basin and location of sediment cores MD07-3132 (red dot), PC-03, JPC-67 and TML1 (white dots). The blue dashed lines represent the annual precipitation, which ranges from ~3200 to 9800 mm at the Pacific coast to ~750 mm at the Automatic Weather Stations in the Skyring fjord east of the Andean climatic divide, and to ~500 mm at Punta Arenas (Schneider et al., 2003). The marine transgression for the western entrance is based on Kilian et al. (2007b). The black stippled lines represent moraine stages B–E after McCulloch et al. (2005b) and Bentley et al. (2005a, b). Stage D culminated before 17.7 kyr and reached the latitude of Punta Arenas, and Stage E occurred at 11.7–15.5 kyr BP during which the ice limit reached the northern tip of Isla Dawson (e.g. Bentley et al., 2005a, b; McCulloch et al., 2005a, b; Sugden et al., 2009). The inset figure shows the distribution of surface annual salinity off the coast of Chile (World Ocean Atlas 2009), with less saline waters in the Patagonian fjord region and an increase in salinity towards the open ocean. In addition, the modern surface circulation in the Southeast Pacific off southernmost Chile is shown. CHC: Cape Horn Current; ACC: Antarctic Circumpolar Current; PCC: Peru–Chile Current; SAF: South Antarctic Front.

The influence of environmental conditions and climate on marine productivity during the deglaciation and the Holocene have been mostly investigated for sites located close to the Pacific entrance of the Strait of Magellan (Kilian et al., 2007a; Kilian and Lamy, 2012; Harada et al., 2013), but no detailed studies have been published for the central basin of this fjord system.

This study focuses on sediment core MD07-3132 from the Whiteside Channel (Fig. 1), which belongs to the central basin of the Strait of Magellan. This site is mainly influenced by calving glaciers form Cordillera Darwin that produce a nutrient-poor freshwater supply that is modified by regional precipitation, most likely linked to the Southern Westerly winds (SWWs) (Lamy et al., 2010). During the Holocene, the strength and direction of these winds together with deglaciation and the marine transgression may have further influenced the thermohaline conditions that in particular controlled paleoproductivity. Sediment cores from the western Strait of Magellan suggest a marine transgression at ~14.3 kyr BP (Kilian et al., 2007a, b). In the central Strait of Magellan, Sugden et al. (2005) and McCulloch et al. (2005a, b) proposed the existence of a proglacial lake during the Late Glacial formed by an ice dam lake near Segunda Angostura (Fig. 1). The thermohaline structure and circulation in these environments and associated sediment transport are widely unexplored and may have changed fundamentally after the marine transgression (Kilian et al., 2007a, b; Kilian and Lamy, 2012).

The current knowledge of Late Glacial and Holocene-temperature conditions in southern Patagonia is based on a limited number of SST reconstructions from the Chilean continental margin at 41°S (Kaiser et al., 2005; Lamy et al., 2007) and at 53°S (Caniupán et al., 2011; Siani et al., 2013). Further temperature records are available from the South Atlantic at 53°S (Bianchi and Gersonde, 2004), as well as DOME C Antarctic ice core temperatures (EPICA Community Members, 2004). These records reveal an early Holocene climate optimum between 12 and 8 cal kyr BP that follows the Antarctic Cold Reversal. This warm phase had ~2 °C SST higher compared to the late Holocene and was accompanied by a southward shift in the SWWs with an intensified core between 50 and 55°S (Lamy et al., 2010). On the other hand, the westerly-related increased precipitation and melting of glaciers during summer and especially during the early Holocene may have caused lower salinities and comparatively lower SSTs (Caniupán et al., 2014). The effect of these Holocene changes in temperature and precipitation on aquatic bioproductivity remains however relatively unknown. Here we use a multi-proxy analysis of sediment core MD07-3132 to estimate the influence of changes in temperature, precipitation and marine transgression on paleoproductivity throughout the Holocene. More specifically, our approach is based on a proxy-reconstruction of fjord sea surface temperature (alkenone SST), paleosalinity (chlorine to water content ratio and accumulation rate [AR] of biogenic carbonate), freshwater input (chemical signature of allochtonous glacial clay, AR of terrestrial organic carbon and siliciclastics), and paleoproductivity (AR of marine organic carbon, biogenic opal and carbonate).