Quaternary Science Reviews 71 (2013) 205–218

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

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

The last Glacial–Interglacial transition in Patagonia, Argentina: the stable isotope record of bulk sedimentary organic matter from Laguna Potrok Aike

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ARTICLE INFO

Article history:
Received 28 October 2011
Received in revised form
11 May 2012
Accepted 28 May 2012
Available online 7 July 2012

Keywords:
Stable carbon and nitrogen isotopes
Primary productivity
Lake sediments
South America
Last deglaciation
ICDP
PASADO

ABSTRACT

An investigation of stable isotope ($\delta^{13}C_{TOC}$ and $\delta^{15}N_{TN}$) and elemental parameters (TOC, TN contents and TOC/TN ratios) of bulk organic matter (<200 μm) from sediment cores recovered from the Patagonian lake Laguna Potrok Aike (Argentina) in the framework of the ICDP deep drilling project PASADO provided insights into past changes in lake primary productivity and environmental conditions in South Patagonia throughout the last Glacial–Interglacial transition. Stratigraphically constrained cluster analyses of all proxy parameters suggest four main phases. From ca 26,100 to 17,300 cal. years BP, lacustrine phytoplankton was presumably the predominant organic matter source in an aquatic environment with low primary productivity rates. At around 17,300 cal. years BP, abrupt and distinct shifts of isotopic and elemental values indicate that the lacustrine system underwent a rapid reorganization. Lake primary productivity (phytoplankton and aquatic macrophytes) shows higher levels albeit with large variations during most of the deglaciation until 13,000 cal. years BP. The main causes for this development can be seen in improved growing conditions for primary producers because of deglacial warming in combination with expedient availability of nutrients and likely calm wind conditions. After 13,000 cal. years BP, decreased $\delta^{13}C_{TOC}$ values, TOC, TN contents and TOC/TN ratios indicate that the lake approached a new state with reduced primary productivity probably induced by unfavourable growing conditions for primary producers like strengthened winds and reduced nutrient availability. The steady increase in $\delta^{15}N_{TN}$ values presumably suggests limitation of nitrate supply for growth of primary producers resulting from a nutrient shortage after the preceding phase with high productivity. Nitrate limitation and consequent decreased lacustrine primary productivity continued into the early Holocene (10,970–8400 cal. years BP) as reflected by isotopic and elemental values.

1. Introduction

Stable isotope analysis of bulk organic matter has been widely used in ecological research (e.g. Fry, 2006; Michener and Lajtha, 2007). However, these variables not only provide present day environmental information, but the isotopic composition of e.g. sedimentary organic matter preserves also evidence of past environmental changes (Meyers, 1994). Stratigraphic changes in carbon and nitrogen isotope composition of organic matter contained in lake sediments thus help trace histories of environmental and climate change (e.g. Meyers and Lallier-Vergès, 1999; Meyers, 2003; Lücke and Brauer, 2004).

Although several lacustrine isotope records have provided evidence for climate changes during the last deglaciation in the northern hemisphere (e.g. Yu and Eicher, 1998;; von Grafenstein et al., 1999;; Lücke et al., 2003;; Parplies et al., 2008) and in the mid-latitudes of the southern hemisphere (e.g. Valero-Garcés et al., 2005; Bertrand et al., 2010), understanding of late Quaternary climate changes in the southern hemisphere higher latitudes is still incomplete because of the lack of long, continuous and high-resolution terrestrial records. Hence, due to its unique geographic

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http://dx.doi.org/10.1016/j.quascirev.2012.05.025

location, records from southernmost Patagonia can offer new palaeoclimatic insights and an important linkage with marine records from southern oceans and ice core records from Antarctica. The sediment archive of Laguna Potrok Aike, further developed by the Potrok Aike maar lake sediment archive drilling project (PASADO) within the framework of the International Continental Scientific Drilling Program (ICDP), has initiated interdisciplinary multiproxy investigations to advance the understanding of past environmental and climatic changes in South Patagonia throughout the last Glacial–Interglacial cycle (e.g. Recasens et al, in press; Hahn et al., 2013). Here we report on the results of high-resolution carbon and nitrogen isotope analyses of bulk sedimentary organic matter from Laguna Potrok Aike for a time window from 26,075 to 8400 cal. years BP, including the last Glacial Maximum (LGM) and the glacial–Interglacial transition period, and discuss their paleoenvironmental significance. Our investigation builds on the earlier studies of surface and older sediments as well as core catcher samples (Mayr et al., 2009; Kastner et al., 2010; Lücke et al., 2010) and expands their scope with respect to temporal resolution and depositional history.

2. Site description

Laguna Potrok Aike is located at 113 m above sea level in the Pali Aike Volcanic Field in southern Patagonia, Argentina (51° 58′ S, 70° 23′ W, Fig. 1A) and originated from a phreatomagmatic explosion (Zolitschka et al., 2006). A detailed description about geomorphological characters and landscape evolution of the Laguna Potrok Aike area can be found in Coronato et al. (2013). During the last Glacial the catchment of the lake was not covered by the Patagonian glaciers (Zolitschka et al., 2006). Under modern conditions, Laguna Potrok Aike is a polymictic, phosphorous-rich and subsaline lake with a surface area of 7.58 km^2 and a maximum depth of 100 m (further lake characteristics in Zolitschka et al., 2006). The lake has presently only several episodic inflows through gullies and canyons and a catchment area of about 200 km^2. Subaerial and submerged paleoshorelines around and in the lake indicate pronounced lake-level fluctuations resulting from past hydrological changes (Zolitschka et al., 2006; Anselmetti et al., 2008; Gebhardt et al., 2011; Kliem et al., 2013a). The littoral zone of Laguna Potrok Aike is covered by aquatic macrophytes (e.g. *Potamogeton pectinatus* and *Myriophyllum* cf. *quitense*) from a water depth of ca 1.5–15 m (Wille et al., 2007). Phosphate, as an important nutrient, appears to be unlimited in Laguna Potrok Aike (total phosphorus measurements: 1297–3609 μg/L), since the total phosphorus concentration is rather high presumably related to the regional geology (Zolitschka et al., 2006). The observed nitrate concentrations in lake water were considerably variable (nitrate measurements: <0.05–3.07 mg/L) and indicate a potential nitrate limitation for primary production (Zolitschka et al., 2006). The climate at Laguna Potrok Aike is influenced by the rain shadow of the Andes and nowadays characterized by semiarid steppe with a high annual evaporation/precipitation ratio of up to 24 (Wille et al., 2007; Ohlendorf et al. 2013). The modern vegetation in the area around Laguna Potrok Aike is a dry Magellanic steppe with grasses, shrubs, bushes and cushions as a result of overgrazing because of sheep farming during the last 100 years (Aagesen, 2000; Wille et al., 2007).

Laguna Potrok Aike is located at the center of the present-day Southern Hemisphere Westerlies that are characterized by their strong intensity associated with a strong meridional pressure gradient between the semi-permanent high pressure cells located over the subtropical South Pacific and South Atlantic oceans and the subpolar low pressure belt at approximately 60° S (Cerveny, 1998; Paruelo et al., 1998). As topographic barrier for the Westerlies, the Andes play a crucial role in determining the Patagonian precipitation pattern in the lee of the cordillera. Precipitation in the eastern part of South Patagonia is additionally affected by air masses coming from the Atlantic Ocean resulting in a more evenly distributed seasonal precipitation (Paruelo et al., 1998). Meteorological data of Laguna Potrok Aike have also shown the influence of rain-bringing easterly winds on the precipitation in the area (Mayr et al., 2007). A mean annual precipitation of 251 ± 62 mm and a mean annual temperature of 7.4 ± 0.7 °C are recorded at the weather station in Río Gallegos at the Atlantic coast, ca 90 km east of Laguna Potrok Aike where both mean annual precipitation and temperature are 30–40% lower compared to the coastline (Zolitschka et al., 2006). Mean annual values of wind speed vary between 4 and 6 m/s in the central part of Patagonia (Paruelo et al., 1998) and around 7.4 m/s at Río Gallegos (Baruth et al., 1998). The seasonal distribution of the wind speed, particularly in southern South Patagonia, shows a maximum during austral summers and a minimum during austral winters (Baruth et al., 1998; Garreaud et al., 2009).

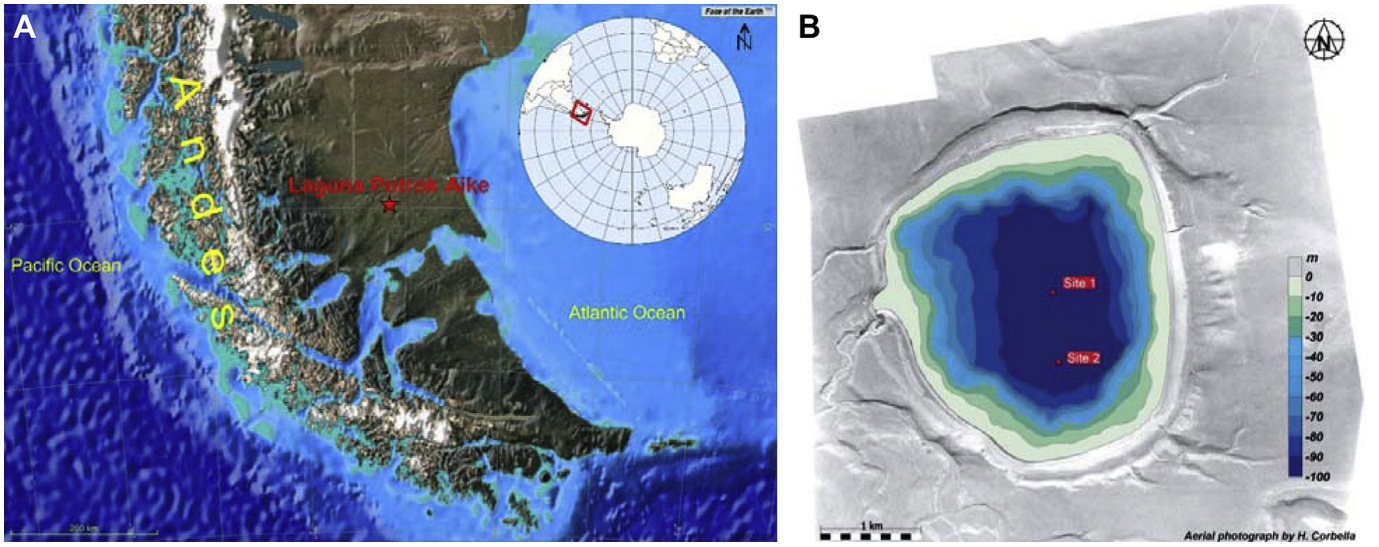

Fig. 1. A) Location of Laguna Potrok Aike (red star) in South Patagonia in the relief map modified from http://jules.unavco.org/voyager/EarthScope. Red frame marked in the inserted map (source: Sean Baker/Wikipedia) shows the location of South Patagonia on the Southern Hemisphere. B) Drilling sites in 2008 in the aerial photography of Laguna Potrok Aike with bathymetry. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)