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Magnitude, geomorphologic response and climate links of lake level oscillations at Laguna Potrok Aike, Patagonian steppe (Argentina)

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A B S T R A C T

Laguna Potrok Aike is a large maar lake located in the semiarid steppe of southern Patagonia known for its Lateglacial and Holocene lake level fluctuations. Based on sedimentary, seismic and geomorphological evidences, the lake level curve is updated and extended into the Last Glacial period and the geomorphological development of the lake basin and its catchment area is interpreted.

Abrasion and lake level oscillations since at least ~50 ka caused concentric erosion of the surrounding soft rocks of the Miocene Santa Cruz Formation and expanded the basin diameter by approximately 1 km. A high lake level and overflow conditions of the lake were dated by luminescence methods and tephra correlation to the early Lateglacial as well as to ~45 ka. The lowest lake level of record occurred during the mid-Holocene. A further lake level drop was probably prevented by groundwater supply. This low lake level eroded a distinct terrace into lacustrine sediments. Collapse of these terraces probably caused mass movement deposits in the profundal zone of the lake. After the mid-Holocene lake level low stand a general and successive transgression occurred until the Little Ice Age maximum; i.e. ca 40 m above the local groundwater table. Frequent lake level oscillations caused deflation of emerged terraces only along the eastern shoreline due to prevailing westerly winds. Preservation of eolian deposits might be linked to relatively moist climate conditions during the past 2.5 ka.

Precisely dated lake level reconstructions in the rain-shadow of the Andes document high Last Glacial and low Holocene lake levels that could suggest increased precipitation during the Last Glacial period. As permafrost in semiarid Patagonia is documented and dated to the Last Glacial period we argue that the frozen ground might have increased surficial runoff from the catchment and thus influenced the water balance of the lake. This is important for investigating the glacial to Holocene latitudinal shift and/or strengthening of the Southern Hemispheric Westerlies by using lake level reconstructions as a means to assess the regional water balance. Our interpretation explains the contradiction with investigations based on pollen data indicating drier climatic conditions for the Last Glacial period.

1. Introduction

Lake level reconstructions are mostly aiming at hydrological, i.e. paleoclimatic reconstruction. However, prior to any paleoclimatic interpretation, non-climatic aspects of lake level oscillations need to be identified and excluded from any paleoclimatic scenario (Duck et al., 1998). Furthermore, multiple lines of evidence (sedimentary, geomorphological, and more recently anthropogenic causes) are an advantage. A robust indicator to infer the lake level history is the occurrence of wave-cuts, beach terraces and beach ridges as they are directly formed at the shoreline. These structures allow exact reconstructions of former water levels and can be identified in seismic, bathymetric and hypsometric profiles as well

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as in sediment cores. Furthermore, in combination with profundal sediment core data, reconstruction of former water depths becomes possible. Inherent disadvantages of using terraces as paleoenvironmental archives are their sensitivity to subaerial and subaquatic erosion and accumulation as well as to difficulties in dating. Additionally, terraces require a relatively stable water level for an extended period of time to be formed.

Reconstructions from Patagonian lakes east of the Andes reveal distinct lake level changes during the Holocene (Stine and Stine, 1990; Gilli, 2003; Haberzettl et al., 2007; Anselmetti et al., 2009; Fey et al., 2009). As most lakes at the foot of the Andes are of glacial origin, evidence for pre-Holocene lake levels can only be found in extra-Andean Patagonia. So far, geomorphology-based lake level reconstructions are only known from Lago Cardiel (Stine and Stine, 1990) and Laguna Cari-Laufquén (Cartwright et al., 2011). A third promising site for lake level reconstructions is the currently endorheic Laguna Potrok Aike (Zolitschka et al., 2006; Haberzettl et al., 2007, 2009). Multiproxy sediment and seismic analyses suggest that it is an ephemeral water body for at least the last 51 ka (Kliem et al., 2013; Recasens et al., in press) and desiccated before, probably during Marine Isotope Stage (MIS) 4 (Gebhardt et al., 2012). A previous study of the total inorganic carbon (TIC) contents suggested that this sediment parameter could be an important lake level proxy for the Holocene and the Lateglacial as carbonates precipitate from the calcium-supersaturated water body caused by lower lake levels (Haberzettl et al., 2007). Low concentrations of TIC during the Last Glacial cycle suggest high lake levels (Hahn et al., 2013). Therefore, a survey and dating of lacustrine terraces around Laguna Potrok Aike provides the opportunity to identify high lake levels in Patagonia during the Last Glacial period.

A pole to equator shift of the Southern Hemispheric Westerlies (SHW) versus a combination of temperature decrease and increased rainfall have been intensively discussed to explain high lake levels during the Last Glacial Maximum (LGM) for Laguna Cari-Laufquén at 41°S in Patagonia (Cartwright et al., 2011). These authors concluded that well-dated shoreline reconstructions of higher latitudes are required to distinguish between both explanations. A further complication for large parts of Patagonia is the fact that the hydrology during glacial conditions additionally might have been affected by permafrost increasing surficial runoff. However, permafrost features in this region have not been dated precisely so far (Trombotto, 2000; Bockheim et al., 2009).

In this study we combine available seismic and sediment core data as well as geomorphological evidence obtained in the framework of the ICDP related “Potrok Aike Maar Lake Sediment Archive Drilling Project” (PASADO) to document range, shape and timing of lake level features at Laguna Potrok Aike. Lake levels were dated using luminescence dating and tephra layers as marker horizons. We also consider lake internal sedimentological processes and a range of external consequences and causes related to lake level changes, including evidences of basin expansion, terrace preservation and relict catchment permafrost. Dating of relict permafrost features contributes to the overall question whether such conditions have affected the amount of runoff from the catchment into the lake. This is of importance as it potentially could solve the contradiction of high Patagonian lake levels being in response to less precipitation during the Last Glacial period. Such dry climates were suggested by paleobiological evidences (Markgraf et al., 2007; Recasens et al., in press). Moreover, this approach helps to evaluate links between shifts in SHW and the regional water balance.

2. Site description

Laguna Potrok Aike is located in the older western part of the Pali Aike Volcanic Field (PAVF), a region in the Province of Santa Cruz (Argentina) characterized by extensive backarc volcanism (Mazzarini and D’Orazio, 2003; Ross et al., 2011). Scoria cones, plateau lavas and maar volcanoes are common in the catchment area. A basaltic clast from the phreatomagmatic tephra outcropping east of the maar was dated by Ar/Ar technique to 0.77 ± 0.24 Ma (Zolitschka et al., 2006) and provides an age for its eruption. Outcrops of weakly compacted sandstone exist along the perimeter of the lake on subaerial terraces (Fig. 1). The sandstones belong to the fine-grained molasse-type fluvial deposits of the Lower Miocene Santa Cruz Formation, the youngest geological unit in the Magallanes Basin (Uliana and Biddle, 1988). The spatially extensive Pliocene and Pleistocene glaciations left behind glaciofluvial deposits and basal till in the catchment area. However, according to geomorphological and stratigraphic evidences glaciers stopped beyond the catchment, and thus did not contribute to the lake water balance during at least the last five glacial periods (Caldenius, 1932; Mercer, 1976; Rabassa and Clapperton, 1990; Meglioli, 1992; Coronato et al., 2013).

Due to the proximity of the Antarctic continent and its small land mass, southern Patagonia does not warm up during austral summers like comparable latitudes in the northern hemisphere (Weischet, 1996). The mean annual air temperature at Rio Gallegos (6 m a.s.l., 85 km north-east of the study site) is 7.4 ± 0.7 °C, with a July (winter) minimum of 1.0 ± 1.5 °C and a January (summer) maximum of 13.0 ± 1.2 °C (Zolitschka et al., 2006). Mean annual wind speeds of 7.4 m/s occur at Rio Gallegos from a primarily western direction (Weischet, 1996; Baruth et al., 1998). Indeed, the regional climate is strongly affected by the SHW, but the rain shadow effect east of the Andean mountain chain decreases precipitation to less than 300 mm/a in the PAVF (Mayr et al., 2007b). An annual precipitation sum of 150 mm has been observed at the meteorological station near Laguna Potrok Aike (Zolitschka et al., 2006). A more recent series of precipitation measurements (1999–2005) at Laguna Potrok Aike shows that easterly wind directions are often combined with precipitation whereas west winds generally carry no considerable amounts of moisture per rainfall event (Mayr et al., 2007b).

Steppe vegetation covers the entire catchment area of Laguna Potrok Aike between the Andean forest ecotones located about 80 km to the west and the coast of the Atlantic Ocean about 100 km to the east (Wille et al., 2007; Schäbitz et al., 2013). Sheep farming activities of early European settlers altered the natural vegetation and are likely the main factor causing higher erosion rates since the 19th century (Liss, 1979; Aagesen, 2000).

In a limnological context, Laguna Potrok Aike today is a polymictic and subsaline maar lake at an elevation of 113 m a.s.l. (Fig. 1). It has a maximum diameter of 3.5 km, and a present-day water depth of 100 m with a water volume of 0.41 km^3 (Zolitschka et al., 2006). There is extensive geomorphological evidence for rapid and sizable past hydrological variations, including numerous subaerial and subaqueous lake level terraces, sediment mass movements and a possible Lateglacial paleo-outflow channel related to an exceptional high lake level (Haberzettl et al., 2005, 2007; Anselmetti et al., 2009). Today the lake has neither a permanent tributary nor a surficial outflow. Thus, the episodic or ephemeral surface runoff which occurs mainly after spring snowmelt rapidly enters the lake through gullies (arroyos) deeply cut into the surrounding subaerial terraces (Haberzettl et al., 2005; Mayr et al., 2007a).

3. Methods

To construct a precise topographic map, a differential GPS survey with a dense grid was carried out using the Trimble R3 GPS System. Data were post-processed with the Trimble Business Center software (Version 1.0.2076.14363). The bathymetric dataset