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Deciphering lake and maar geometries from seismic refraction and reflection surveys in Laguna Potrok Aike (southern Patagonia, Argentina)

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ABSTRACT

Laguna Potrok Aike is a bowl-shaped maar lake in southern Patagonia, Argentina, with a present mean diameter of ~3.5 km and a maximum water depth of ~100 m. Seismic surveys were carried out between 2003 and 2005 in order to get a deeper knowledge on the lake sediments and the deeper basin geometries. A raytracing model of the Laguna Potrok Aike basin was calculated based on refraction data while sparker data were additionally used to identify the crater-wall discordance and thus the upper outer shape of the maar structure. The combined data sets show a rather steep funnel-shaped structure embedded in the surrounding Santa Cruz Formation that resembles other well-known maar structures. The infill consists of up to 370 m lacustrine sediments underlain by probably volcanoclastic sediments of unknown thickness. The lacustrine sediments show a subdivision into two sub-units: (a) the upper with seismic velocities between 1500 and 1800 m s^{-1}, interpreted as unconsolidated muds, and (b) the lower with higher seismic velocities of up to 2350 m s^{-1}, interpreted as lacustrine sediments intercalated with mass transport deposits of different lithology and/or coarser-grained sediments. The postulated volcanoclastic layer has acoustic velocities of >2400 m s^{-1}. The lake sediments were recently drilled within the PASADO project in the framework of the International Continental Scientific Drilling Program (ICDP). Cores penetrated through lacustrine unconsolidated sediments down to a depth of ~100 m below lake floor. This minimal thickness for the unconsolidated and low-velocity lithologies is in good agreement with our raytracing model.

1. Introduction

Southern South America is the only present-day landmass between 38°S and Antarctica. Investigation of its terrestrial environmental archives thus offers the unique opportunity to link climate archives of northern South America via Patagonia and the Antarctic Peninsula with those of Antarctica.

Laguna Potrok Aike, a hydrologically closed maar lake in southernmost Patagonia, is presently located at the boundary between the Southern Hemisphere Westerlies (SHW) and the Antarctic Polar Front, just north of the Strait of Magellan. The lake is extremely sensitive to hydrological and closely related climatological variations as reflected by subaerial and subaquatic terraces formed by lake level fluctuations (Haberzettl et al., 2005, 2008; Anselmetti et al., 2009). The lake has therefore been identified as a target of deep drilling within the International Continental Scientific Drilling Program (ICDP), and was finally drilled in austral spring 2008 within the "Potrok Aike Maar Lake Sediment Archive Drilling Project" (PASADO; Zolitschka et al., 2009a). Seven drill cores of two sites encountered lacustrine sediments to ~100 m below lake floor and retrieved an important record of the regional climate history for the past glacial stage. Core opening of the PASADO cores took place during summer/autumn 2009 and has shown that roughly 50% of the material is redeposited (Zolitschka et al., 2009b). Knowledge on the basin structure and geometries is in any case a prerequisite to understand the sedimentary record and subsequently to interpret the paleoclimate record that will derive from the PASADO cores. This knowledge should help to distinguish between specific sedimentation patterns related to this lake and background sedimentation related to regional environmental change.

On the basis of the lake's morphology, the presence of a phreatomagmatic tephra found on the leeward side of the lake and

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due to its location within the Pali Aike Volcanic Field, the origin of Laguna Potrok Aike is thought to be related to maar eruptions (Zolitschka et al., 2006). Maar craters originate from the contact of rising magma with groundwater resulting in explosive, phreatomagmatic explosions. During these explosions, fragmented magma and bedrock is ejected from an explosion chamber to the surface. Multiphase explosions, back-fall breccia of ejected material, subsidence above the collapsed explosion chamber and dyke intrusions create the funnel-shaped part of a maar-diatreme volcano. These explosions cause a depression in the local groundwater level, and thus subsequent explosions take place at successively greater depths. Recent maars were shown to be formed by several successively deeper explosions in a time span of only a few days (small maars) to months (with up to several hundred explosions; large maars) (Lorenz, 1986; Lorenz, 2003, and references therein). Collapse of the surrounding bedrock fills the root zone with breccias after each single explosion. The collapse structure propagates to the surface and results in the initial maar crater. Lower layers of the collapse breccia are chaotic, unbedded, and characterized by a higher content of reworked material coming from surrounding bedrock, while upper layers are well-stratified and dominated by phreatomagmatic tephra beds (Lorenz, 2003). A tephra ring forms outside the crater during the phreatomagmatic activity of the maar-diatreme volcano and contains tephras related to the subsequent explosions in stratigraphic order. Once eruptions end, a lake is formed inside the crater up to the local groundwater level, and lacustrine sedimentation starts. Many of the older maars can be completely filled by post-eruptive sediments of any kind and have changed into dry maars, e.g., in the German Eifel region (e.g., Schaber and Sirocko, 2005).

Four extensive seismic surveys carried out from 2003 to 2005 unravel the deeper structure and geometries of the lake basin and confirm its presumed origin. This study summarizes the deeper structural information resulting from two seismic surveys in 2004 and 2005.

2. General settings of the investigated area

Laguna Potrok Aike is situated at 110 m a.s.l. in the Pliocene to late Quaternary Pali Aike Volcanic Field (Santa Cruz, southern Patagonia, Argentina) at about 52°S and 70°W, some 80 km north of the Strait of Magellan and about 90 km west of the city of Río Gallegos (Fig. 1a). The lake has a diameter of about 3.5 km. It is almost circular and bowl-shaped with a 100 m deep, flat plain in its central part (Fig. 1b). To date, lake level fluctuates interannually by at least 1 m. All measurements relative to the present lake level are therefore given with respect to the 2003 AD lake level. This closed lake basin contains a sub-saline water body and has only episodic inflows with discharge restricted to major snowmelt events with the most important inlet situated on the western shore.

Only two volcanic structures in the Pali Aike Volcanic Field contain permanent lakes, Laguna Potrok Aike and Laguna Azul (Haberzettl et al., 2005; Mayr et al., 2005; Zolitschka et al., 2006). Laguna Potrok Aike is the larger and deeper of these two lakes and located in the oldest, western part of the Pali Aike Volcanic Field which is a northwest–southeast-striking tectonovolcanic belt with a length of more than 150 km and a width of ~50 km. This backarc volcanic area is located in the Magellan Basin about 300 km east of the active Andean volcanic arc (Mazzarini and D'Orazio, 2003). The volcanism is characterized by plateau-like lava flows, scoria cones, and approximately 100 maars (500 to 4000 m in diameter, Zolitschka et al., 2006) of which all except of 2 are at least occasionally dry, dating from 0.01 Ma closer to the Atlantic Ocean to 3.8 Ma in its western part (Corbella et al., 2000; Corbella, 2002). Based on an Ar/Ar age determination, a phreatomagmatic tephra quite likely associated with the Laguna Potrok Aike eruption was formed around 770 ka (Zolitschka et al., 2006). The bedrock of the Pali Aike Volcanic Field consists of Oligocene marine sandstones and shales (Patagonia Formation) overlain by up to 1 km thick Miocene molasse-type fluvial sediments (Santa Cruz Formation) and Plio- to Pleistocene fluvioglacial sediments of the so-called Patagonian Plains related to the extended glacier advances that occurred between 3.5 and 1.0 Ma ago (Zolitschka et al., 2006).

3. Data acquisition and processing

Four seismic campaigns were carried out on the lake as site surveys in Laguna Potrok Aike prior to deep drilling in order to (a) gain a deeper insight into the sedimentary architecture of the lacustrine infill and (b) reveal the geometries and, subsequently, confirm the maar origin of the lake basin.

The first seismic survey was carried out in 2003 by the ETH Zurich (Switzerland) using a 3.5 kHz pinger system. This was followed by a second survey by the University of Geneva (Switzerland) in 2004 with two one cubic-inch airguns to get deeper sediment penetration (Anselmetti et al., 2009). Although both surveys imaged only the

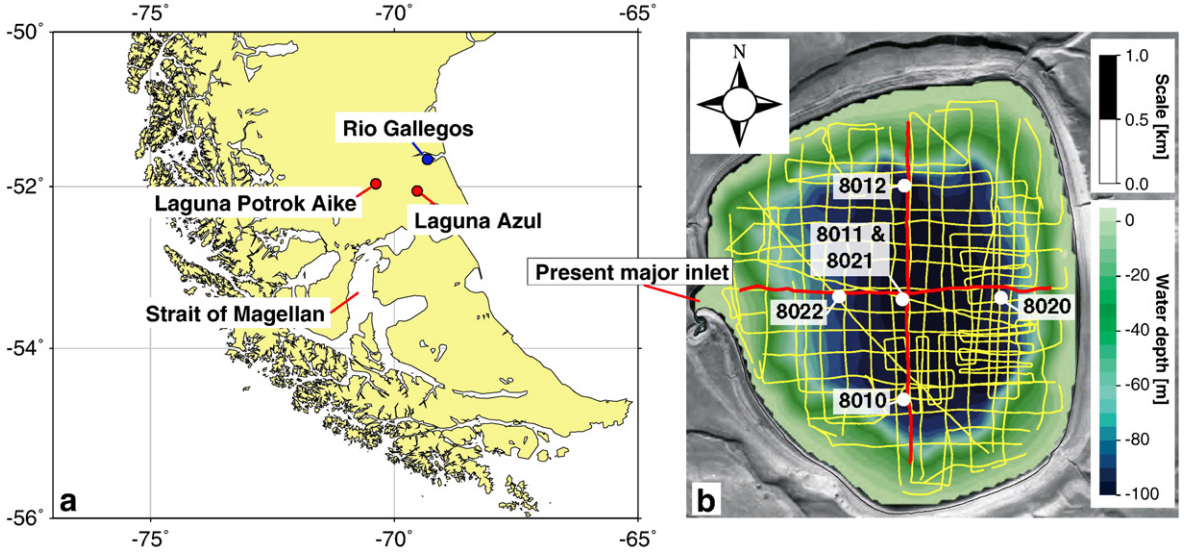

Fig. 1. General setting of Laguna Potrok Aike. a) Location of the lake in southern South America, b) Aerial photograph overlain by bathymetry. Yellow lines mark the sparker surveys, red lines the refraction profiles (S–N: AWI-20058010, W–E: AWI-20058020), and white circles the position of the sonobuoys. Note that the slope is inclined much more gently in the western part than in the remainder of the lake.