Applied Geochemistry 58 (2015) 46–61

Contents lists available at ScienceDirect

Applied Geochemistry

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

# Reconstructing the evolution of Lake Bonney, Antarctica using dissolved noble gases

Rohit B. Warrier [a,*], M. Clara Castro [a], Chris M. Hall [a], Fabien Kenig [b], Peter T. Doran [b]

[a] University of Michigan, Department of Earth and Environmental Sciences, 1100 N. University Ave., Ann Arbor, MI 48109-1063, USA
[b] University of Illinois at Chicago, 845 W. Taylor St., Chicago, IL 60607, USA

ARTICLE INFO

*Article history:*
Available online 9 March 2015
Editorial handling by D. Gooddy

ABSTRACT

Lake Bonney (LB), located in Taylor valley, Antarctica, is a perennially ice-covered lake with two lobes, West Lake Bonney (WLB) and East Lake Bonney (ELB), which are separated by a narrow ridge. Numerous studies have attempted to reconstruct the evolution of LB because of its sensitivity to climatic variations and the lack of reliable millennial-scale continental records of climate in this region of Antarctica. However, these studies are limited by the availability of accurate lacustrine chronologies. Here, we attempt to better constrain the chronology of LB and thus, the evolution of past regional climate by estimating water residence times based on He, Ne and Ar concentrations and isotopic ratios in both WLB and ELB.

$^{3}$He and $^{4}$He excesses up to two and three orders of magnitude and 35–150 times the atmospheric values are observed for WLB and ELB samples, respectively. In comparison, while measured $^{40}$Ar/$^{36}$Ar ratios are atmospheric (∼295.5) in ELB, WLB samples display $^{40}$Ar/$^{36}$Ar ratios of up to ∼315 reflecting addition of radiogenic $^{40}$Ar. Both $^{4}$He and $^{40}$Ar excesses clearly identify the addition of subglacial discharge (SGD) from underneath Taylor Glacier into WLB at depths of 25 m and 35 m. He isotopic ratios suggest that He excesses are predominantly crustal (>93%) in origin with small mantle contributions (<7%). These crustal $^{4}$He and $^{40}$Ar excesses are used together with basement rock production rates of these isotopes to derive first-order approximations of water residence times for both lobes. Numerous factors capable of affecting water residence times are evaluated and corrected $^{4}$He and $^{40}$Ar water ages are used to place further constrains into the reconstruction of both WLB and ELB history. Combined $^{4}$He and $^{40}$Ar ages in WLB suggest maximum water residence times of ∼250 kyrs BP. These results support the presence of remnant water from proglacial lakes that existed during Marine Isotope Stage 7 (160–240 kyrs) in WLB, in agreement with previous studies. In comparison, $^{4}$He ages in ELB are much younger (<27 kyrs BP) and display a complex evolutionary history that is very different from WLB. $^{4}$He ages also suggest that the ELB ice cover formed significantly earlier (∼1.5 kyrs BP) than previously reported. The timing of these hydrologic changes in ELB appears to correspond to regional and global climatic events that are recorded in both the Taylor Dome ice-core record as well as in other Dry Valley Lakes.



## 1. Introduction

Understanding the response of global climate forcing in high latitude regions such as Antarctica is essential to predicting future climate change because of the enormous freshwater masses they store in the form of ice. In particular, investigating past climate shifts in the Antarctic margins is critical because they are extremely sensitive to changes in ocean-atmospheric circulation. The McMurdo Dry Valleys (MDVs), located on the western coast of the Ross Sea (Fig. 1A and B), is an area of active wind-driven convection and ocean–atmosphere heat exchange (Steig et al., 1998a,b). However, reliable millennial-scale continental records of climate other than the Taylor Dome ice core (Steig et al., 1998a, 2000) in this region of Antarctica are scarce (Hall et al., 2010; Middleton et al., 2012). Additional independent paleoclimate proxies and further chronology controls are needed in this region to constrain global climate models and to clarify the evolution of regional and global climate change.

Taylor Valley, one of the main east–west dry valleys, has a number of perennially ice-covered, closed-basin lakes that respond to climatic variations through hydrologic changes (Green et al., 1988; Lyons et al., 1998; Doran et al., 2002; Dowling et al., 2014). Lake Bonney (LB), located in western Taylor valley

* Corresponding author.
*E-mail addresses:* warrierr@umich.edu (R.B. Warrier), mccastro@umich.edu (M. Clara Castro), cmhall@umich.edu (C.M. Hall), fkenig@uic.edu (F. Kenig), pdoran@lsu.edu (P.T. Doran).

http://dx.doi.org/10.1016/j.apgeochem.2015.02.013
0883-2927/

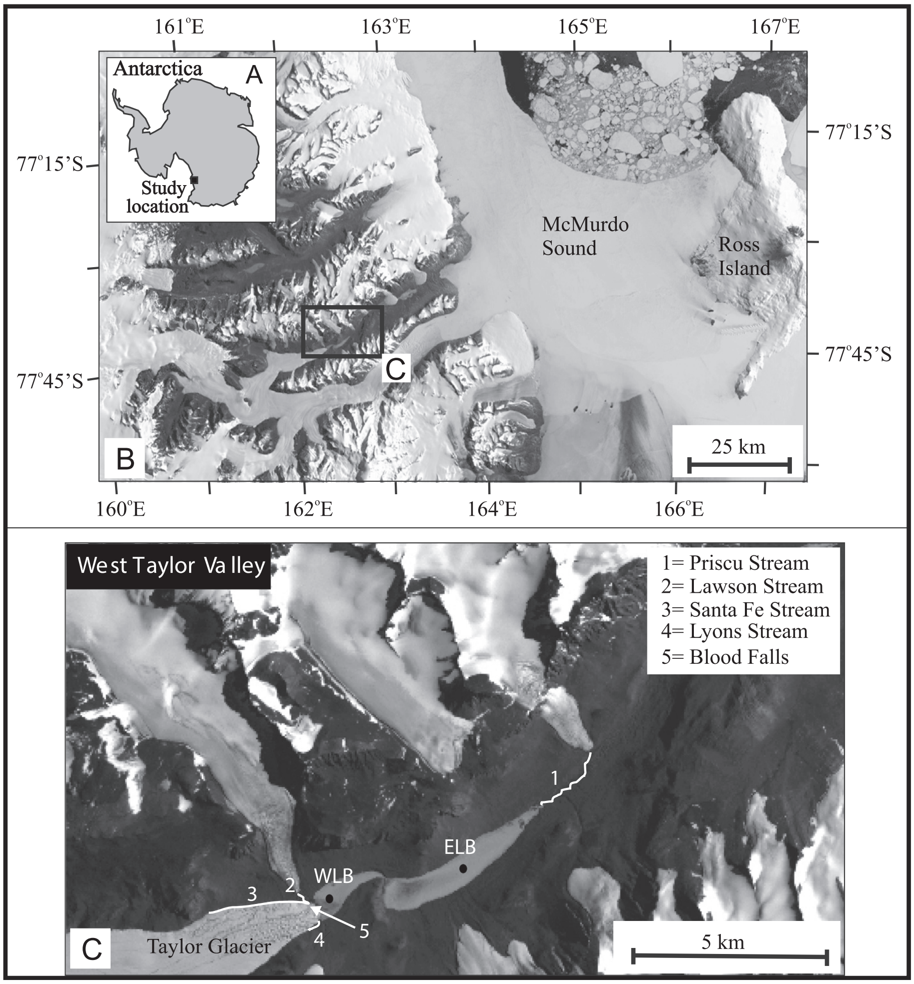


**Fig. 1.** (A) Map of Antarctica along with (B) map of McMurdo Sound region with location of Taylor Valley indicated; (C) Map of western Taylor Valley indicating location of Lake Bonney, Taylor Glacier, major inflowing streams and sampling location (black circles). North is to the top. All figures are based on Landsat imagery.

(Fig. 1C), is one such lake that displays significant changes in both modern and historic lake levels (Hendy, 2000; Bomblies et al., 2001; Doran et al., 2002). LB consists of two lobes, East Lake Bonney (ELB) and West Lake Bonney (WLB), which are separated by a narrow ridge with a ~13 m deep sill. WLB receives most of its water input from Taylor Glacier, an outlet glacier of the East Antarctic Ice Sheet (Matsubaya et al., 1978; Doran et al., 2014), while ELB receives most of its input from WLB over the sill. Because the evolution of LB is intimately connected to the dynamics of Taylor Glacier, a number of studies have attempted to reconstruct the history of LB and thus, the climate evolution in this area. These studies have used diverse tools including $\delta^{18}O$ and $\delta D$ of water, chloride profiles (Hendy et al., 1977; Lyons et al., 1998), geochronology of land forms (Hall et al., 2000; Higgins et al., 2000), $\delta^{37}Cl$ (Lyons et al., 1999), helium isotopes (Poreda et al., 2004), $^{14}C$ dating of inorganic and organic carbon reservoirs (Doran et al., 1999, 2014) as well as lake sediment sequence analysis (Doran et al., 1999; Bishop et al., 2001; Wagner et al., 2006, 2010, 2011). While these studies agree on some portions of the history of LB, multiple questions remain concerning its evolution because of a limited availability of accurate lacustrine chronologies. For example, dissolved inorganic $^{14}C$ (Doran et al., 2014) and Na as well as Cl diffusion cell calculations (Hendy et al., 1977) indicate WLB bottom water ages between ~15–26 kyrs, coincident with the presence of proglacial Lake Washburn. In contrast, measured He concentrations suggest that WLB has existed as an ice-covered lake for hundreds of thousands of years (Poreda et al., 2004). Additional independent chronology controls are needed to clarify the history of LB and thus, the regional and global climate evolution of the region.

Because of their conservative nature and their source specific isotopic signatures (atmosphere, crust, mantle), noble gases (He, Ne, Ar, Kr and Xe) have been widely used to enhance our knowledge of groundwater flow circulation (e.g., Torgersen and Ivey, 1985; Castro et al., 1998a,b; Castro and Goblet, 2003; Ruzié et al., 2012; Warrier et al., 2012) and to determine groundwater residence times (e.g., Castro et al., 1998a,b; Patriarche et al., 2004; Castro and Goblet, 2005). In particular, concentrations of He, Ne and Ar in groundwater frequently exceed those expected for water in solubility equilibrium with the atmosphere (Air Saturated Water: ASW). In these systems, excesses result mainly from the crust due to radioactive decay of U/Th, and K for $^{4}He$ and $^{40}Ar$, respectively, as well as nucleogenically by secondary $\alpha$ or n-reactions on target elements such as Li and O for $^{3}He$ and $^{21}Ne$ (Ballentine et al., 1991; Ozima and Podosek, 2002; Gilfillan et al., 2009; Darrah et al., 2014). By measuring the concentration of these isotopes and by estimating their fluxes into groundwater, it is possible to determine the residence times of water in these systems (e.g., Castro and Goblet, 2005; Jean-Baptiste et al., 2001).

Here, we attempt to better constrain the chronology of LB and thus, the evolution of past regional climate by estimating water residence times based on He, Ne and Ar concentrations and isotopic ratios in both WLB and ELB.