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Halogen geochemistry of the McMurdo dry valleys lakes, Antarctica: Clues to the origin of solutes and lake evolution

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Abstract—We have determined the halogen and boron concentrations in the ice-covered lakes of Taylor Valley, Antarctica, to better establish the sources of salts and evolutionary histories of these unusual water bodies. In addition, we report on a series of ^{129}I measurements that were compared with previous ^{36}Cl data that also help constrain the source of solutes and histories of the lakes. The new data, when put into context of previous work on these systems over the past forty years, allow us to make the following conclusions. The primary source of solutes to Lake Hoare, the youngest of the lakes, is the dissolution of marine aerosols and aeolian salts and the chemical weathering of dust on the glaciers. The geochemistry of Lake Fryxell, the brackish water lake, is primarily dominated by the diffusion from a halite-saturated brine at the sediment-water interface and the recent infilling of the lake by glacier meltwater. These waters have chemical weathering and marine aerosols components. Lake Bonney has two distinct lobes whose hypersaline hypolimnia have different chemistries. Both of the lobes are remnants of ancient marine waters that have been modified by the input of weathering products. This lake has also been modified by periods of cryogenic concentration when solutes have been lost via mineral precipitation. Thus the geochemistry of Lake Bonney owes its unusual geochemistry, in part, to variations in the climate in the Taylor Valley over at least the past 300kyr. The ^{129}I data from the Taylor Valley are similar to those from fracture fluids in crystalline rocks from the Northern Hemisphere. *Copyright © 2005 Elsevier Ltd*

1. INTRODUCTION

The geochemistry of the ice-covered lakes of the McMurdo Dry Valleys region of Antarctica (henceforth referred to as "the dry valleys") has been investigated for over forty years. These lakes are unusual in that over a relatively small geographic area, the geochemistry of the lakes varies dramatically from entirely freshwater (i.e., Lake Hoare) to the hypersaline hypolimnia of Lake Bonney. In addition to the differences in salinity, the lakes have very different major ionic ratios as well (Lyons et al., 1998a). The earliest investigations of these systems noted the diversity in their chemistries, and speculated on the origins of these differences (Angino et al., 1962; Angino and Armitage, 1963). Recent work has utilized more sophisticated analytical techniques and approaches than the pioneering work of Angino and his co-workers, yet the ultimate explanation of the sources of solutes to the lakes and geochemical evolution of the saline waters is still enigmatic (Wilson, 1979; Green et al., 1988; Lyons and Mayewski, 1993; Lyons et al. 1998a, 1998c). What is agreed upon is that climatic variations affecting the hydrologic cycle within the valleys have greatly influenced the amount of freshwater flow entering into these closed-basin systems. These variations in freshwater input through time have greatly affected the dynamics of these lakes, thereby changing their size and salinity through time (Wilson, 1964; Hendy et al., 1977; Matsubaya et al., 1979; Lyons et al., 1998b, Poreda et al., 2004). Stream flow from the glaciers currently occurs for 4–10 weeks during the austral summer. During periods of cooler summers, stream flow diminishes. If cool conditions last for long periods, eventually the ice covers on the lakes are lost through sublimation, the lake volumes are substantially decreased, and the salinity increases. When the climate ameliorates and austral summers are milder, the stream flow increases and the ice-covers are re-established as the lake volumes increase. These drawdown-refill cycles have apparently occurred many times over at least the past ~300,000 yrs (Hall and Denton, 2000; Hendy, 2000) and may have taken place over even a longer time period (Barrett and Hambrey, 1992). Lake Bonney and Lake Fryxell in Taylor Valley (Fig. 1) and Lake Vanda in Wright Valley represent the consequences of at least one such drawdown event, in that the salinities in their hypolimnia are greatly elevated with respect to the surface waters. Therefore, it is now clear that the strongly stratified density and chemical profiles observed in some of the lakes are produced by climatic variations. The amelioration of the climate over the past ~1 kyr has led to a substantial refilling of the majority of these lakes with freshwater (Wilson, 1964; Lyons et al., 1998a, 1998b).

Although our overall understanding of the role of climate on hydrologic processes in the dry valleys is at a much better stage of development than in the 1960s, the questions of solute sources and a more detailed understanding of the chemical evolution of these unusual lakes remain unanswered. In syn-

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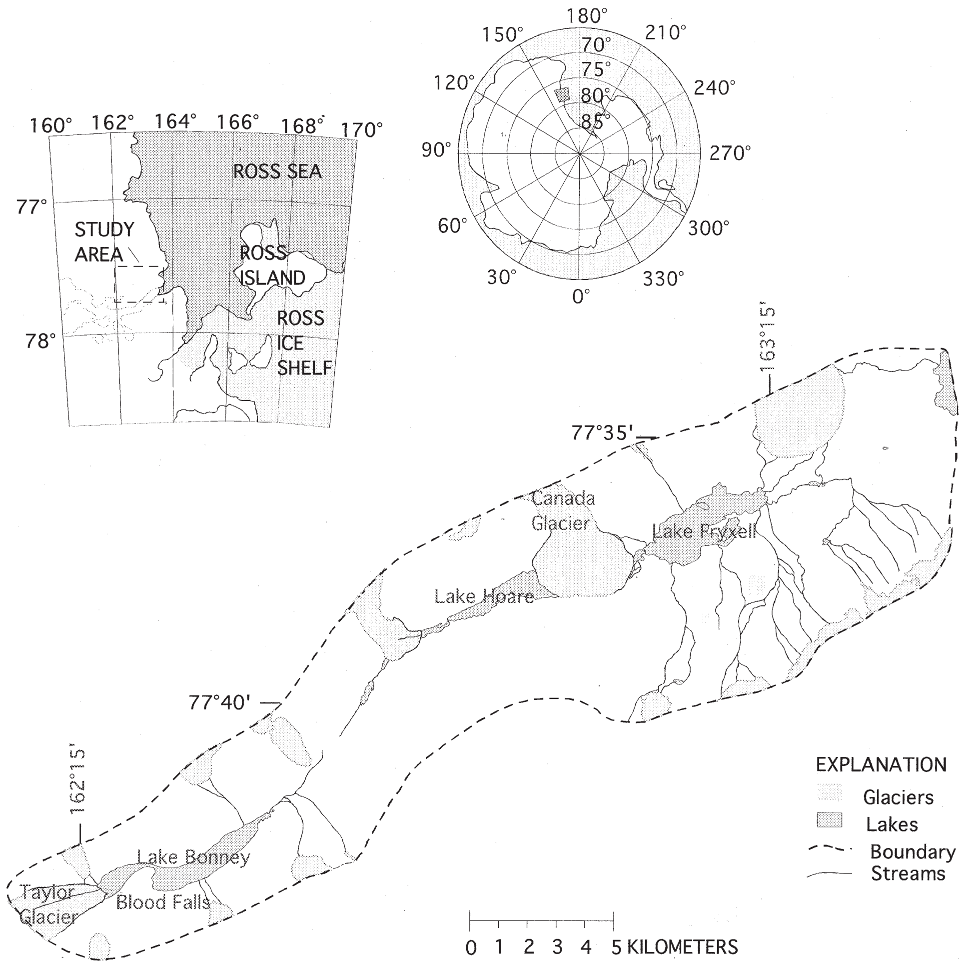

Fig. 1. Location map.

thesizing all the previous work cited above, four major sources of solutes to these lakes have been proposed: 1) hydrothermal; 2) remnant seawater; 3) glacier melt and precipitation; 4) a combined glacier melt-precipitation and chemical weathering source. Of these four possibilities, even after 40 yr. of investigation, none of these can be eliminated conclusively (Lyons and Mayewski, 1993), but our most recent work suggests the first one is highly unlikely (Poreda et al., 2004). In this paper, we present both chemical and isotopic measurements from the lakes of Taylor Valley, including halogens and boron, and combine these measurements with previous data to provide the most conclusive evidence to date on the geochemical origins of these lakes. In addition, this is the first investigation to utilize iodine-129 to determine the sources of halides into the lakes of the dry valleys. Until now, ^{129}I investigations of brines in the polar regions have been limited to fracture fluids emplaced in the Canadian Shield and northern Europe during previous ice ages (Fabryka-Martin et al., 1989; Bottomley et al., 2002; Starinsky and Katz, 2003). This study complements work of the past decade, where the environmental isotope ^{36}Cl was employed to determine salinity sources to the lakes in the dry valleys (Carlson et al., 1990; Lyons et al., 1998c) and also provides direct evidence of the active processes leading to the observed ^{129}I/I and ^{36}Cl/Cl ratios in polar regions. This multi-faceted approach provides compelling evidence that the age of the lakes, their location within the landscape, and their overall "sensitivity" to climate change have all influenced their isotopic composition and geochemical evolution.

2. STUDY AREA AND LAKE DESCIPTION

The McMurdo Dry Valleys (77°40'S, 163°E) are the largest ice-free region in Antarctica. Even though the environment in the dry valleys is considered to be a polar desert, with a mean annual temperature of -18°C and a precipitation rate of <10 cm yr^{-1} water equivalent, currently there is sufficient glacier melt to produce stream flow into the lakes. In Taylor Valley there are three major lakes, Lake Bonney, Lake Fryxell and Lake Hoare (Fig. 1). Lake Bonney has two lobes separated by a 13 m deep sill. Since 1993, Taylor Valley has been the location of the McMurdo Dry Valleys (MCM) Long-Term Ecological Research (LTER) site supported by the National Science Foundation, where meteorological, glaciological, hydrological, biogeochemical and ecological data are collected on a regular basis. This collection of long-term data has allowed researchers to better establish the ecological response to climatic forcing, especially in the lake systems (Doran et al.,

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