

Senior Thesis


Biogeochemical Dynamics of Dissolved Si
in Taylor Valley, Antarctica

By
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ABSTRACT

This thesis is part of the McMurdo Dry Valleys (MCM) Long-Term Ecological Research (LTER) study in Southern Victoria Land, Antarctica. With the exception of the ice-covered lakes, there is little liquid water present in the valleys for most of the year. Chemical weathering is thought to occur more readily in warm and wet climates, however recent research has shown that it can occur in cold and dry environments. The chemical weathering of rocks and sediments in Taylor Valley occurs in the stream channels when liquid water is present, resulting from the melting of glacial ice during the austral summer. Not only is silicon an important element geologically, it is an important biogeochemical element, as aquatic microorganisms, such as diatoms, need it for growth. Silica (Si) is thought to be one of the chemicals that is dissolved by the glacier meltwater as it flows into the lakes. This thesis is an aqueous geochemical study of the Si found in the streams and lakes.

Water samples were collected at the beginning of the austral summer and then again in midsummer from Lakes Bonney, Fryxell and Hoare in the Taylor Valley for the past 3 field seasons. Stream samples from each of the lake basins were also collected during the summer months. To analyze the concentrations of reactive Si in the water samples, a colorimetric method was used.

Streams of the Lake Fryxell basin had the highest average Si concentrations, ~1.5 mg/L. Streams that flow into Lake Hoare had the lowest average concentrations, ~0.2 mg/L. This difference is most likely a result of the length of the streams. The streams in Lake Fryxell basin are longer than those of the Lake Hoare, and therefore the water is in contact with the underlying sediment for a longer period of time, resulting in more Si being dissolved. The annual flux of Si into the lakes was determined by calculating the average Si concentrations in the streams and multiplying by the volume of stream flow for each lake basin. The highest Si fluxes occurred in the Lake Bonney basin followed by Lake Fryxell and Lake Hoare. When these fluxes are normalized to lake area, the values range from 212 mgSi/m²yr in Lake Bonney, 29 mgSi/m²yr in Lake Fryxell and 12 mgSi/m²yr in Lake Hoare.

Si concentrations in the lakes vary over time due to physical, chemical and biological processes. The concentrations in the lakes could be influenced by dilution with stream water of lower Si concentrations, precipitation and dissolution of Si within the water column, or biological uptake of Si by diatoms. For example, a decrease in Si concentration occurred in the upper part of the water column of Lake Hoare between the early and midsummer sample collections in all three seasons. The change in Si is much greater than expected from uptake by diatoms. Approximately 0.03% of the Si decrease can be attributed to biological uptake, based on primary productivity measurements. Therefore, other physical processes must control the Si variations in Lake Hoare.

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INTRODUCTION

This research was undertaken as part of the McMurdo Dry Valleys Long-Term Ecological Research (MCM-LTER) project in Antarctica, which began in 1993. The dry valleys are among the coldest and driest ecosystems on Earth. Because of this, the region is considered to be a polar desert. The primary study location for the LTER project, Taylor Valley, contains alpine glaciers, ephemeral streams, perennially ice-covered lakes and rocky soils.

During the summer months, meltwater is generated on the glaciers and flows through streams to the lakes in the valley bottom. As water moves through the system, solute concentrations increase (Lyons et al., 1998b). The lakes are closed-basin lakes with no out-flowing streams. Because these lakes are perennially ice-covered, water is lost from the ice surface of the lakes by sublimation of ice while solutes accumulate in the lakes over time. All of the lakes are chemically and density stratified and are relatively stable (Lyons et al., 1998b). Dissolved components can be removed from the water column by chemical or biological processes. Solutes can also move through the water column by diffusion.

Although the dry valleys appear to be "lifeless", microbial communities can exist whenever liquid water is present (McKnight et al., 1999; Kennedy, 1993). Microorganisms including diatoms live in the lakes and streams of the dry valleys. Diatoms take up dissolved Si to build their shells.

GEOGRAPHY & CLIMATE

Taylor Valley (Figure 1), 77° 00'S, 162° 52'E, is part of the McMurdo Dry Valleys in Southern Victoria Land, Antarctica. Taylor Valley (TV) is 33 km long and 12 km wide and is bordered by the Asgard Range to the north and the Kukri Hills to its south (Figure 1). TV is a polar desert with a mean annual temperature of approximately -20 °C (Clow et al., 1988) and a total annual precipitation of less than 10 cm (Keys, 1980). Therefore, TV is among the coldest and driest terrestrial environments on earth. For approximately 2-3 months in the austral summer, the dry valley climate is characterized

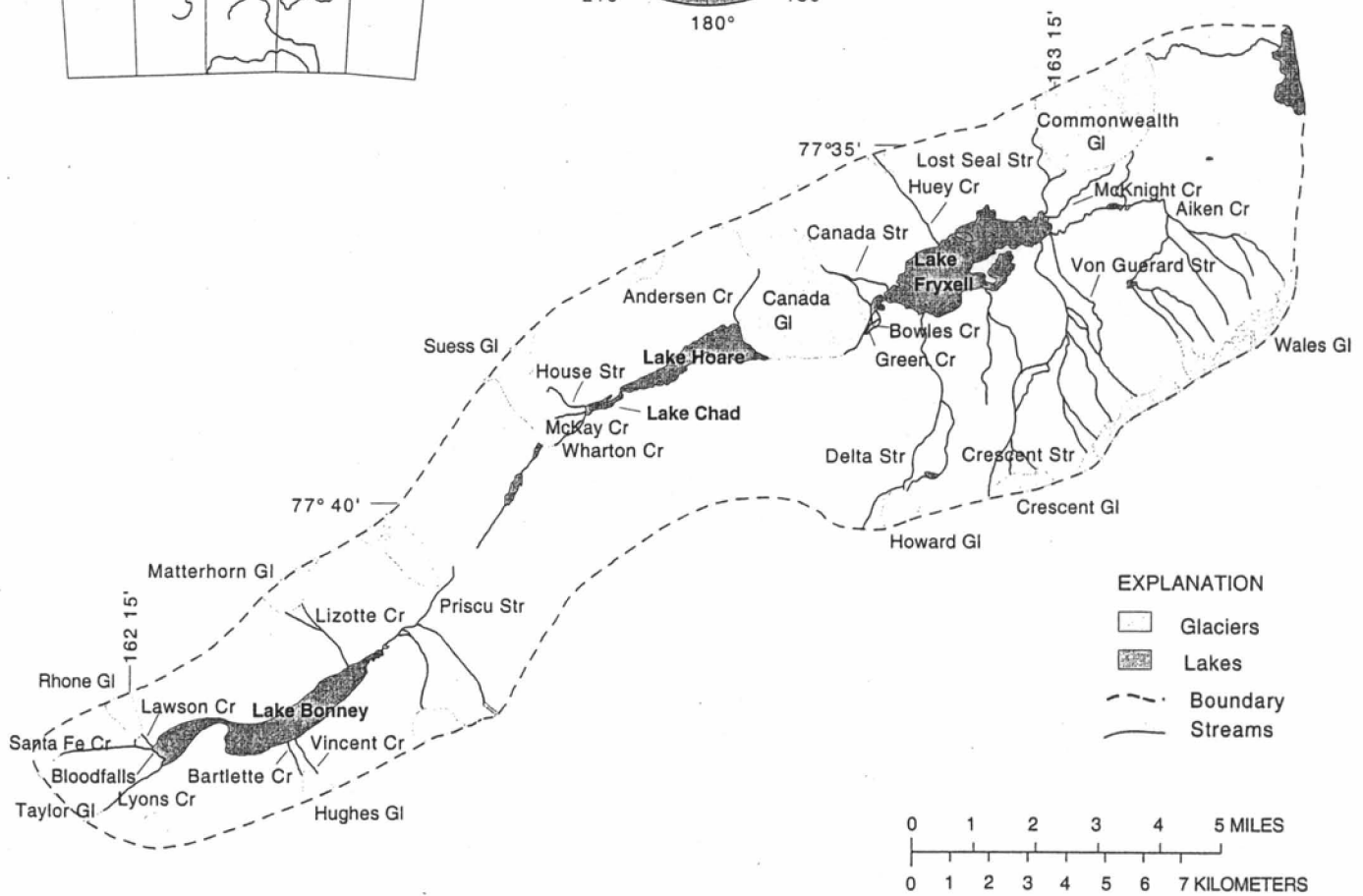
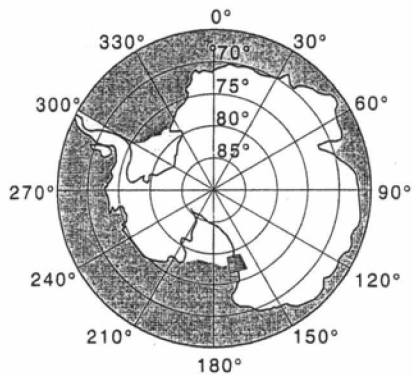
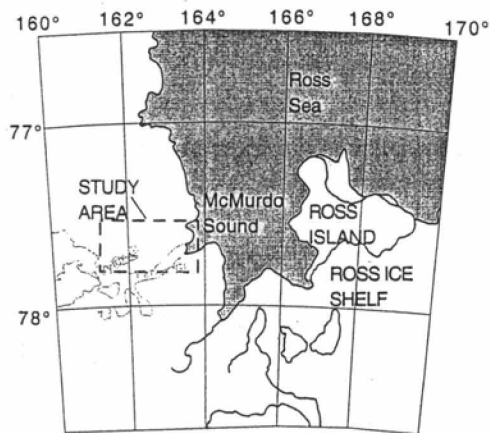


Figure 1. Map of Taylor Valley showing glaciers, streams and lakes.

by continuous daylight, near freezing air temperatures, and the presence of meltwater flow.

The differences in climate within TV are largely related to topographic setting within the valley (Lyons et al., 2000). One important cause of the climatic differences is the presence of Nussbaum Riegel, an 800m high hill in the center of TV. Nussbaum Riegel splits the valley into the Bonney basin and the Hoare and Fryxell basins. The long-term effect of the Nussbaum Riegel on the valley climate is reflected in the change in glaciers along the valley walls with less snowfall and warmer summer temperatures in the Bonney basin, compared to the Hoare and Fryxell basins (Fountain et al., 1998). Another important topographical feature in the valley is Canada Glacier, which blocks much of the narrow valley floor at the east end of Lake Hoare. Lake Bonney experiences a more continental climate (warmer, drier conditions) strongly influenced by katabatic winds, while Lake Fryxell experiences a more marine climate (wetter, colder, cloudy conditions) (Lyons et al., 2000). The climate of Lake Hoare tends to be closer to Lake Fryxell, but, depending on the season, shifts towards a Lake Bonney climate (Lyons et al., 2000).

GEOLOGY

Taylor Valley's geomorphology has been modified by the movement of glaciers, the inflow of ocean waters, and the waxing and waning of lacustrine environments over the past few million years (Porter and Beget, 1981). Because of glacier movements, the valley floor contains a mosaic of tills of differing age and composition (Péwé, 1960; Stuvier et al., 1981; Burkins et al., 1999). The ages of the morainal materials in the region date to 2.5 million years (Brown et al., 1991).

TV soils are composed of unconsolidated material ranging from sand to boulder size. Relatively flat areas are often covered by a desert pavement, a thin layer of coarse stones or gravel that overlie sandy material (Claridge and Campbell, 1977). Permafrost begins about 0.5 m below the ground surface (Conovitz et al., 1998).

The basement rocks of the McMurdo Dry Valley region are composed of Precambrian schists, gneisses, and marbles, which are overlain by the Ross Supergroup (schist, gneiss, marble, quartzite, hornfel, metasediments, limestone) (Warren, 1969).

Both the basement rocks and the Ross Supergroup are intruded by early Paleozoic Granite Harbor Intrusives (granite and granodiorites) (Campbell and Claridge, 1987; McKelvey, 1981). These rocks make up the Asgard Range to the north of TV and the Kukri Hills to its south (McKelvey, 1981). Farther inland, this rock sequence was eroded to form a peneplain, and is overlain by the Beacon Supergroup (Campbell and Claridge, 1987; McKelvey, 1981). This group of flat-lying, continental sediments can be broken down into the Taylor Group (Devonian to Carboniferous), consisting of conglomerates, sandstones, siltstones and thick quartz sandstones; and the Victoria Group (Permian to Jurassic) which is composed of glacial sediments (tillite, sandstone, shale, minor limestones), coal, sandstone, mudstone, and basaltic volcanoclastic beds (Campbell and Claridge, 1987). The Ferrar Group (Jurassic) consists of Ferrar Dolerite sills and Kirkpatrick Basalts (lava flows) (Campbell and Claridge, 1987; McKelvey, 1981). The more recent McMurdo Volcanics are composed of hornblende and olivine basalts (Campbell and Claridge, 1987). These rocks can be found near Mt. Erebus, which is still active today, and as basaltic cones in Taylor Valley (Campbell and Claridge, 1987; McKelvey, 1981). In addition, due to several glacial advances and retreats in Taylor Valley, the valley floor has Cenozoic till composed of granite, marble, gneiss, dolerite, and Beacon sandstone (Péwé, 1960). Also present in the valley are deltaic deposits and layers of silt and clay from Glacial Lake Washburn, as well as lake carbonate deposits (Hendy et al., 1979).

LAKES

TV contains three major closed basin lakes: Lake Bonney, Lake Hoare and Lake Fryxell (Figure 1). Lake Fryxell is closest to the ocean, ~8km from the coast. It is also the shallowest lake. Lake Hoare is ~15km west of the ocean and it is 'held' in place by the Canada Glacier (Lyons et al., 2000). Without the Canada Glacier in its current location, Lake Hoare would flow east and drain into Lake Fryxell. Lake Bonney begins ~30km inland (Lyons et al., 2000). The characteristics of these lakes are shown in Table 1.

Table 1 Characteristics of the Taylor Valley Lakes (Lyons et al., 2000)

Characteristic	Lake Fryxell	Lake Hoare	Lake Bonney
Surface area (m ²)	7.1 x 10 ⁶	1.91 x 10 ⁶	4.81 x 10 ⁶
Volume (1 x 10 ⁶ m ³)	25.2	17.5	64.8
Maximum depth (m)	21	34	40
Water temperature (°C)	0 ± 1.0	0 ± 4.0	-2 ± 7.0

Taylor Valley lakes are subject to extreme climate conditions. Lakes are covered with perennial ice that is currently 3-6 m thick. During most summers, a moat of water forms at the edge of the lakes, as the ice near the shore melts completely (Fountain et al., 1999). Glacial meltwater is transported to the lakes by ephemeral streams. From the 1970s until about 1990, there was a net gain in water to the lakes as lake levels had been generally rising (Chinn, 1993). Since 1990, lake levels have decreased (Doran et al., 2002). Over the winter the ice cover refreezes at the edges and accumulates more ice at the cover bottom. All year long, high winds ablate the surface of the ice cover and sublimation of the ice cover also results, due to the severely dry conditions.

The lakes have abundant planktonic and benthic microbial populations (Vincent, 1988). No higher forms of life, such as pelagic crustacea, mollusc, insects or fish, have been observed (Doran et al., 1994). Microbial mats are primarily composed of cyanobacteria, pennate diatoms and eubacteria (Wharton et al., 1983).

Lake variations

Over the past 10 years of MCM-LTER investigations in TV, it has become clear that landscape characteristics, both past and present, greatly influence the variability observed in the lakes (Lyons et al., 2000). These variations are great and the three major lakes in TV are different in many aspects. Lake Hoare is the freshest of the lakes throughout the water column, the bottom water of Lake Fryxell is brackish and both lobes of Lake Bonney have hypersaline bottom waters.

The major ionic ratios of the TV lakes, even in their fresh surface waters, are quite different (Lyons et al., 1998b). The lakes are different in their nutrient characteristics (Priscu, 1995), as well as their chlorophyll and algal distributions (Lizotte and Priscu, 1998). Primary production rates are also different in the lakes. Their

proximity and similar climate and basin geology make it even more difficult to explain their extraordinary chemical differences. The degree to which the individual lakes interact with their surrounding environment, especially the small variations in climate within the TV, are a major key to understanding their present and past development. Subtle climate differences within the landscape may account for the biological variations in the lakes and have a profound effect on the geochemistry and biogeochemistry of these lakes (Lyons et al., 2000).

STREAMS

Ephemeral streams transport glacial meltwater to terminal lakes that lose water only through sublimation and evaporation (Fountain et al., 1999). The only source of water to the streams is glacial melt during the austral summer (Conovitz et al., 1998). Snowfall in the dry valleys does not contribute significantly to the streams or to the general hydrology of the valleys because it usually sublimates before melting (Chinn 1981). For six to ten weeks per year (late November-early February), streams flow from their source to one of the three lakes. There is little to no stream recharge via base flow or overland flow. TV streams are first or second-order, typically shallow (< 30 cm), and vary in width (1-10 m, Green et al., 1988), length, and gradient (shallow Fryxell, steep Bonney and Hoare).

Stream flow is intermittent with highly variable discharge both daily and seasonally due to temperature fluctuations (Conovitz et al., 1998; McKnight et al., 1999). Associated with the stream channels in the hyporheic zone, the zone laterally and vertically adjacent to the stream where there is subsurface flow. Exchange of water between the stream and the hyporheic zone occurs during streamflow (McKnight and Andrews, 1993), and is an important process in the addition of solutes through weathering (Maurice et al., 2002).

The mean summer air temperature for the 5 year period 1994-1999 in Taylor Valley has been below the freezing point for fresh water, which has minimized glacier melt (Fountain et al, 1999). In non-typical years, such as 2001-2002, warmer temperature resulted in increased stream flow.

SILICA

Compounds of silicon occur in all natural waters. They may be present either as suspended solids or in solution. Silicon occurs in minerals such as quartz, feldspars, and clays. Biomineralisation of silicon in the form of opal or amorphous hydrated silicon oxide (biogenic silica, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$) is performed by a number of aquatic organisms, of which the diatoms are the most widely distributed. In the dissolved form, silicon is present as silicic acid, H_4SiO_4 . The undissociated monomeric form dominates in natural waters at pH below 9 (Aston, 1983; Stumm and Morgan, 1996). Silicic acid is derived either from weathering reactions of silicate and aluminosilicate minerals or from dissolution of the biogenic opal following death of the organisms.

It is well known that silicon cycling in temperate lakes is an annual event controlled by diatom production (Hoffmann et al., 2002). Dissolved silica is taken up by diatoms in the epilimnion. As the frustules settle and the lake stratifies, the planktonic diatom production often becomes limited by silica bioavailability. Diatom production during the following temperature-driven stratification period is then limited to allochthonous silicic acid input; because upward diffusion of silica which redissolved from the sediments and the benthic nepheloid layer is a slow but continuous process (Hoffmann et al., 2002).

The amorphous silica contained in diatoms dissolves five orders of magnitude faster than mineral silicates, at about $2 \times 10^{-9} \text{ mol cm}^{-2} \text{ s}^{-1}$ (Hurd, 1983). Most of the information available about diatom wall dissolution has been derived in the marine environment. Oceans are strongly undersaturated with respect to amorphous silica and the silica incorporated into diatom cells is quickly recycled after their death (Smetacek, 1999). Most freshwater systems are also strongly undersaturated. The rate of dissolution of the diatom skeletons is known to be affected by many factors including, the presence of protective organic skins (Bidle and Azam, 1999), temperature (dissolution slows in low temperature waters (Lewin, 1961; Werner, 1977; Lawson et al., 1978)), and the presence of salt (enhances the dissolution rates of diatoms (Kato and Kitano, 1968; Kamatani, 1971; Hurd and Birdwhistell, 1983; Barker et al., 1994)).

Silica dissolution has not been very extensively studied in lake water. In particular, there is no agreement as to whether biogenic silica dissolution begins in the

water column. Some authors show that the major fraction of SiO_2 produced annually in the form of frustules dissolves before being integrated in the permanent sediment (Parker et al., 1977). Variations in SiO_2 saturation will have great impact on Si dynamics and thus varies from lake to lake.

METHOD

Reactive silicate was measured colorimetrically using a method based on Mullin and Riley (1955). This method detects only monomeric and dimeric silicic acid; polymeric species do not participate in the reaction. Often the terms “reactive” and “non-reactive” are used to classify different fractions of dissolved silica in fresh and marine waters. They refer to the monomeric and polymeric silicon species, respectively, in solution. The reactive form will participate in the biological cycling of silicon in the hydrosphere. In contrast, it is assumed that polymeric forms are not available for biological uptake and utilisation. The reactive fraction is the dominant dissolved species in natural waters. (Hoffmann et al., 2002)

Collection

All samples for geochemical analysis were obtained with great care in order to minimize contamination. Members of the MCM-LTER team collected water samples from several Taylor Valley streams throughout the Austral summer over a period of three field seasons, 1999-2002. Lake samples were also collected early and mid summer during those seasons. Within 12 hours of collection, samples were filtered through $0.4 \mu\text{m}$ Nuclepore membrane filters into water washed high-density polyethylene (HDPE) Nalgene bottles.

Bottle Cleaning Procedures

HDPE Nalgene bottles were rinsed three times with distilled, deionized 18-M Ω (DI) water and then filled with DI water to soak overnight. Prior to analysis, the bottles were emptied and left in a class 100 laminar flow hood to dry.

Reagents

All reagents and solutions were made with fresh DI water and stored in HDPE Nalgene bottles.

Acid Ammonium Molybdate

1. 10 g Ammonium Molybdate dissolved by shaking in about 300 ml DI water.
2. 30 ml of concentrated hydrochloric acid was added to complete the solution of the salt.
3. Bottle filled with DI water to volume of 500 ml.

Reducing Agent

1. Sulfuric acid. 25% v/v. 400 ml.
2. Oxalic acid. 10%. 20.0 g of oxalic acid dihydrate dissolved by shaking in about 125 ml DI water. Bottle filled with DI water to volume of 200 ml.
3. Metol-sulphite solution. 4.0 g sodium sulfite and 6.6 g methylaminophenol sulfate dissolved by shaking in about 250 ml DI water. Bottle filled with DI water to volume of 330 ml. The solution was then filtered.
4. DI water. 70 ml.
5. The 4 components were then combined.

Procedure

A series of working standards were made from a 10 mg/L Si stock standard and a blank was included. Concentrations used were 0.0, 0.05, 0.1, 0.2, 0.5, 1.0, and 2.0 mg/L Si. Samples were stored and analyzed at room temperature. Most stream samples were diluted by a factor of 2. In order to reduce interference from salts, the high salinity stream and lake samples required increased dilution (Toxey et al. 1997). Lake Hoare samples were diluted at a factor of 4. Lake Fryxell and Lake Bonney samples were diluted at a factor of 10.

1. 20 ml of standard or sample was pipetted into a 60 ml HDPE bottle.
2. 3 ml of acid ammonium molybdate was added. Acid ammonium molybdate is used to convert reactive silica to yellow silicomolybdic acid.
3. Waited 10 minutes.
4. 15 ml of reducing agent was added. The reducing agent converts silicomolybdic acid to molybdenum blue.
5. 12 ml of DI water was added.
6. Standards and samples were left to stand overnight.

7. The optical density (absorbance) of the standards and samples was measured on a Milton Roy 501 Spectronic Spectrophotometer. Prior to analysis of the samples, the instrument was zeroed at a wavelength of 812 nm using a 1-cm width optical density cuvette containing a blank to subtract the absorbance of the cuvette from the sample absorbances. 2.5 mL of each standard or sample was measured. Cuvetes were thoroughly rinsed with DI water between standards and samples.
8. The absorbance of the standards and samples was recorded. (Table 2)
9. A calibration curve was computed using Excel software. The equation of the best-fit line (Figure 2) between the absorbance of the standards and their known concentrations was used to calculate lake and stream water Si concentrations from the absorbance values.

Table 2 Si Standards

Sample	Dilution Factor	Concentration	Absorbance	Calculation	Si mg/L
Blank	1	0.00	0.000	-0.001	-0.001
standard 0.05mg/L	1	0.05	0.015	0.045	0.045
standard 0.1mg/L	1	0.10	0.031	0.094	0.094
standard 0.2mg/L	1	0.20	0.065	0.199	0.199
standard 0.5mg/L	1	0.50	0.166	0.509	0.509
standard 1.0mg/L	1	1.00	0.330	1.013	1.013
standard 2.0mg/L	1	2.00	0.649	1.992	1.992

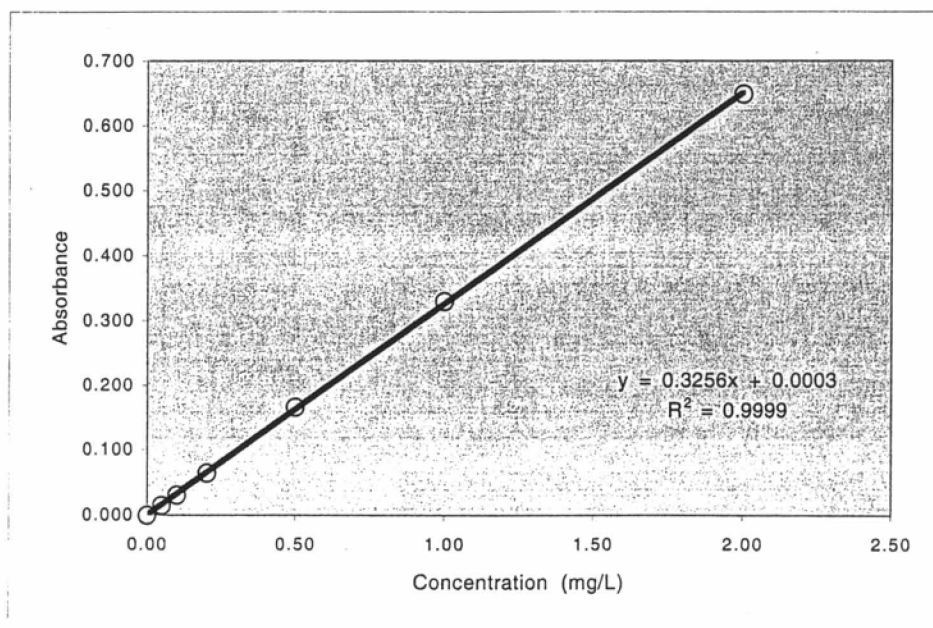


Figure 2. Example Calibration Curve

DISCUSSION

STREAMS

Dissolved Si present in stream water depends both on the original Si concentration of the glacier meltwater as well as the production of Si via chemical weathering. The latter is dependent upon the size and morphological characteristics of the drainage basin and on its geological setting (McKnight et al., 1999). Differences in stream chemistry reflect the differences in the source water flowing from the glaciers, the chemistry of the rocks and soils, and also the length of time the water is in contact with the regolith (Lyons et al., 1998). More recent work describing chemical weathering in these streams suggest that the rates of weathering aluminosilicates can be surprisingly high (Nezat et al., 2001; Maurice et al., 2002). Though there are low levels of reactive Si in the meltwaters from the glaciers, it is certain that concentrations of the H_4SiO_4 above 0.281 mg/L (10 μ m) must originate from silicate mineral weathering within the stream reaches (Lyons et al., 1998). Although paleodiatoms are present in perched deltas and lacustrine sediments in TV (Kellogg et al., 1980), dissolution of diatom debris is minimal in VonGuerard Stream and has not been found to contribute reactive Si to other TV streams (Blum et al., 1997). In addition it is hypothesized that present-day diatoms, due to low concentrations (<1% of biomass in most TV streams), have little impact on reactive Si concentrations (McKnight et al., 1998).

Average Si concentrations for the sampled streams (1999-2000 and 2000-2001) and stream lengths are shown in Table 3. In both seasons, Hoare basin streams have the lowest average concentration. In 99-00 the Bonney basin streams have the highest average concentration. However in 00-01, the highest stream average is in the Fryxell basin. In 99-00, the Si concentration of Red River (Blood Falls) is much larger than any of the other TV streams. This stream flows off of the snout of the Taylor Glacier over ice with incredibly high concentrations of Cl and other major ions and cations. Samples from this stream are the cause of the increased average Si concentration in the Bonney Basin for the 99-00 season.

Table 3 TV Stream Lengths and Si Average Concentrations

	Length (km)	1999 - 2000		2000 - 2001	
		Average Stream Si Concentration	(mg/L)	Average Stream Si Concentration	(mg/L)
Fryxell Basin			1.460		1.704
Aiken Creek	1.3	1.198		1.122	
Andrews Creek	1.5	0.378		-	
Bowles Creek	0.9	2.314		2.634	
Canada Stream	1.5	0.759		0.721	
Crescent Stream	5.6	-		-	
Delta Stream	11.2	2.279		3.756	
Green Creek	1.2	0.892		0.698	
Harnish Creek	5.1	-		-	
Huey Creek	2.1	2.296		-	
Lost Seal Stream	2.2	1.017		1.081	
Mariah Creek	0.9	0.232		1.989	
McKnight Creek	2.0	1.393		1.687	
VonGuerard Stream	4.9	3.301		1.644	
Hoare Basin			0.187		0.216
Andersen Creek	1.4	0.276		0.427	
House Stream	2.0	0.118		0.122	
McKay Creek	0.5	0.119		0.127	
Wharton Creek	1.0	0.237		0.186	
Bonney Basin			1.877		1.141
<i>East</i>			1.649		1.605
Bartlette Creek	1.0	1.544		1.415	
Bohner Stream	1.2	1.943		2.002	
Priscu Stream	3.8	1.104		0.870	
Vincent Creek	1.0	2.006		2.134	
<i>West</i>			2.060		0.770
Lawson Creek	0.3	0.536		0.442	
Lyons Creek	0.5	0.644		0.728	
Red River (Blood Falls)	0.1	6.807		0.452	
Santa Fe Creek	0.5	0.530		0.468	
Sharp Creek	-	1.781		1.763	

Figure 3 is a plot of length versus average Si concentration for both seasons. Lake Hoare has relatively short streams and low Si concentrations. Lake Fryxell has the longest streams and relatively high concentrations. There is a slight positive correlation between the length of the stream and the amount of Si in the stream water based on Fryxell streams. Overall in Taylor Valley, the streams with similar lengths have large ranges of Si concentration. From year to year, Si concentrations will vary within a stream. The longest of all TV streams, Delta Stream (11.2 km) had a higher average Si concentration in 00-01 than the previous year, while in the same basin, VonGuerard Stream (4.9 km) showed the opposite trend.

Figure 3 Taylor Valley Streams 1999-2001

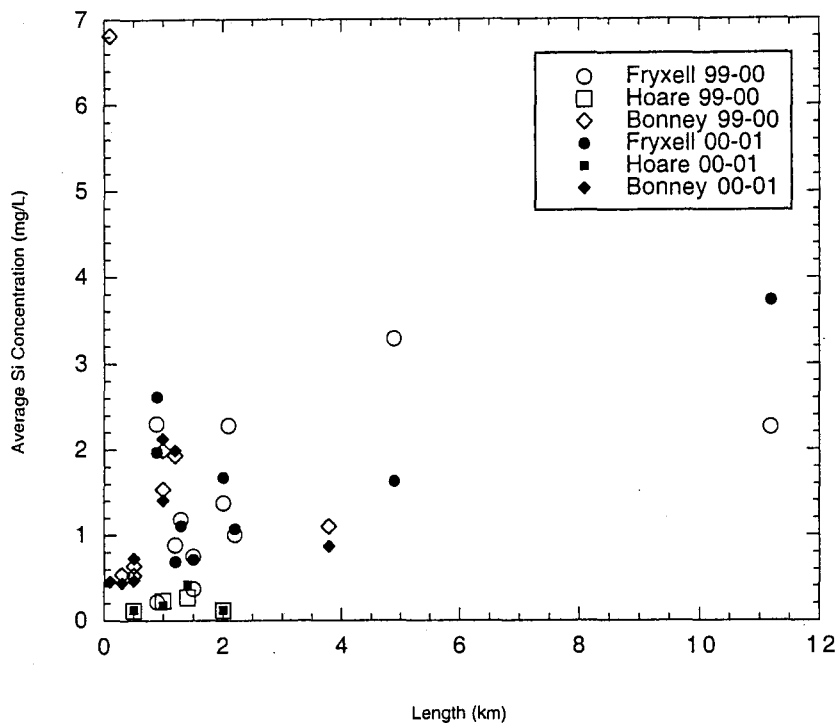


Table 4 Si Flux in Taylor Valley Lake Basins

	Average Si (mg/L)	Annual Flow 10 ³ (m ³ /yr)	Si Flux (kg/yr)	Sum of Basin Si Flux (kg/yr)	Lake Area (m ²)	Flux normalized to lake area (mgSi/m ² yr)	Si Volume for Lake (kg)	Residence time (yr)
Fryxell Basin				211.20	7291710	28.96	223798	1060
Aiken Creek	1.198	19.6	23.47					
Andrews Creek	0.378	-						
Bowles Creek	2.314	-						
Canada Stream	0.759	85.3	64.73					
Crescent Stream	-	0.2						
Delta Stream	2.279	0.8	1.82					
Green Creek	0.892	48.3	43.06					
Harnish Creek	-	0.0						
Huey Creek	2.296	1.7	3.90					
Lost Seal Stream	1.017	73.0	74.21					
Mariah Creek	0.232	-						
McKnight Creek	1.393	-						
VonGuerard Stream	3.301	0.0						
Hoare Basin				23.85	1941743	12.28	78327	3284
Andersen Creek	0.276	73.0	20.12					
House Stream	0.118	31.7	3.73					
McKay Creek	0.119	-						
Wharton Creek	0.237	-						
Bonney Basin				935.68	4415103	211.93	244437	261
<i>East</i>					3399579			
Bartlette Creek	1.544	-						
Bohner Stream	1.943	-						
Priscu Stream	1.104	46.3	51.13					
Vincent Creek	2.006	-						
<i>West</i>					1015524			
Lawson Creek	0.536	119.1	63.79					
Lyons Creek	0.644	73.3	47.24					
Red River (Blood Falls)	6.807	-						
Santa Fe Creek	0.530	1458.9	773.51					
Sharp Creek	1.781	-						

There are negligible contributions of H₄SiO₄ from atmospheric precipitation to the lakes (White and Blum, 1995). The Si found in the atmosphere is primarily present in particulate form, essentially of natural inorganic (quartz) or biological origin (diatoms). Wind stress on the land surface results in advection of soil grains into the atmosphere, the dust later falls on the water surface (moat) or ice cover as particulate matter in dry fallout. Atmospheric dissolved Si concentrations are expected to be very low, therefore, atmospheric input is assumed to be zero in this work.

Figure 4 shows plots of the Si profiles for the Taylor Valley lakes. Both the early and late summer samples in 1999-2000 are shown for Lake Fryxell and East and West Bonney. Seasons 99-00, 00-01, and 01-02 are displayed for Lake Hoare. The early sampling date represents the time before significant stream flow occurred.

The Si concentration in both Lake Hoare and Lake Fryxell increase with depth. There is a decrease in Si in the upper part of the water column of Lake Hoare and Lake Fryxell over the summer. The dilution of surface waters over the summer is caused by the introduction of less concentrated stream water and ice cover melt. The same effect occurs in Lake Hoare's surface waters for all three seasons. Over the three summers, bottom water Si concentrations have remained relatively constant in Lake Hoare.

The Bonney Basin lakes show little change in Si concentration from early to late summer. Both East and West Bonney have mid-depth Si maximums. The chemocline in East Bonney is about 2m higher than West Bonney. These Si maximums may be caused by density differences within the water column. The bottom waters of the Bonney basin are hypersaline. The Si may be unable to settle any lower in the water column due to the density increase in both lobes. In addition, Si may be chemically precipitated at depth in the east lobe of Lake Bonney (Lyons et al, 1998b).

In order to help with interpretation of the Si profiles, the Si/Cl ratios were determined. Cl is thought to be conservative and is not removed from the water column except by precipitation of NaCl in the deep waters of East Lake Bonney. Si/Cl profile for each lake in the Taylor Valley early and late summer are shown in Figure 5. In all cases, the ratio of Si/Cl is lower in the lakes than in the streams that flow into them. This suggests that Si is being removed relative to Cl in all of the lakes. The relatively straight Si/Cl profiles in Lake Hoare and Lake Fryxell suggest that the concentrations of both Si and Cl are dominated by physical processes such as evaporative concentration. The Si/Cl ratios are highest in Lake Hoare even though Si concentrations are lowest in the Lake Hoare streams. This may indicate that biogenic uptake of Si in Lake Hoare is the lowest of all the lakes. This is supported by primary production rate differences among the lakes as well, e.g. <http://huey.colorado.edu>. The very low Si/Cl ratios in the bottom of Lake Bonney reflect the very high concentrations of Cl at depth. Lake Bonney is thought to be the oldest of the Taylor Valley lakes and the Si/Cl profile reflects the long accumulation

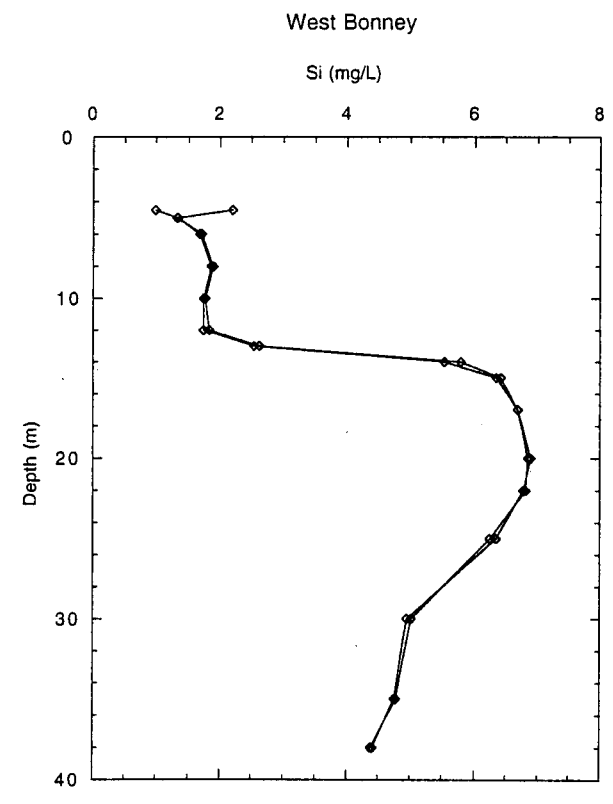
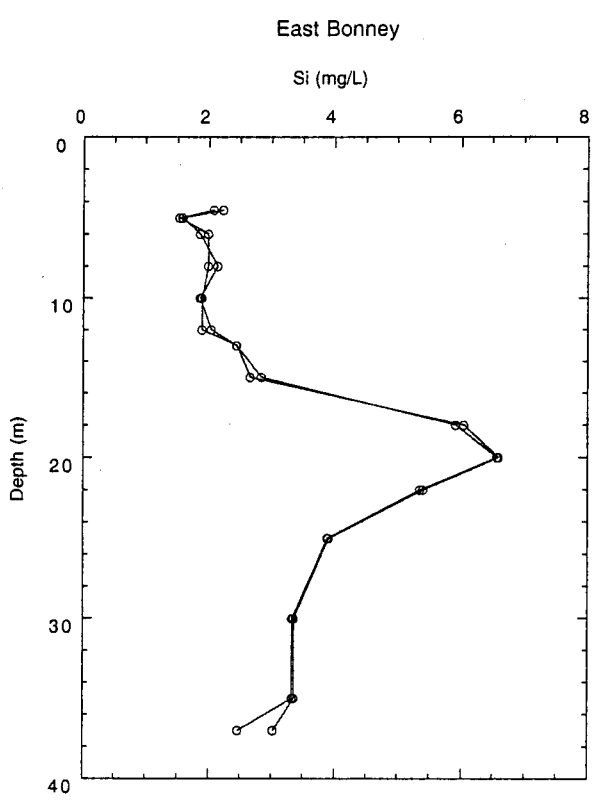
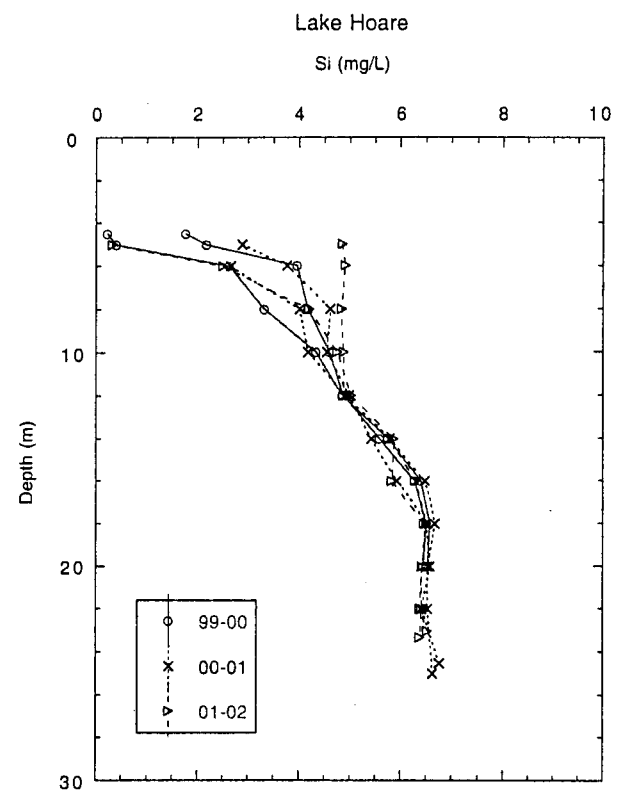
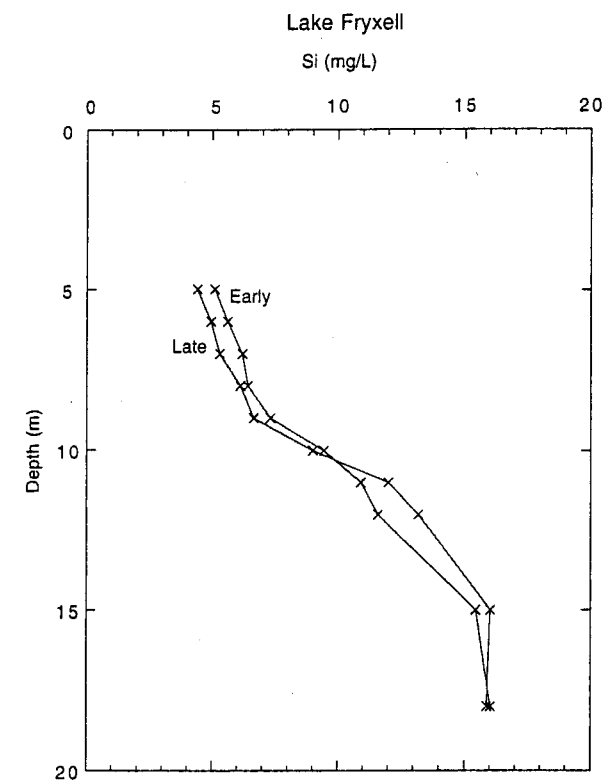


Figure 4 Si Profiles for Taylor Valley Lakes (1999-2000).

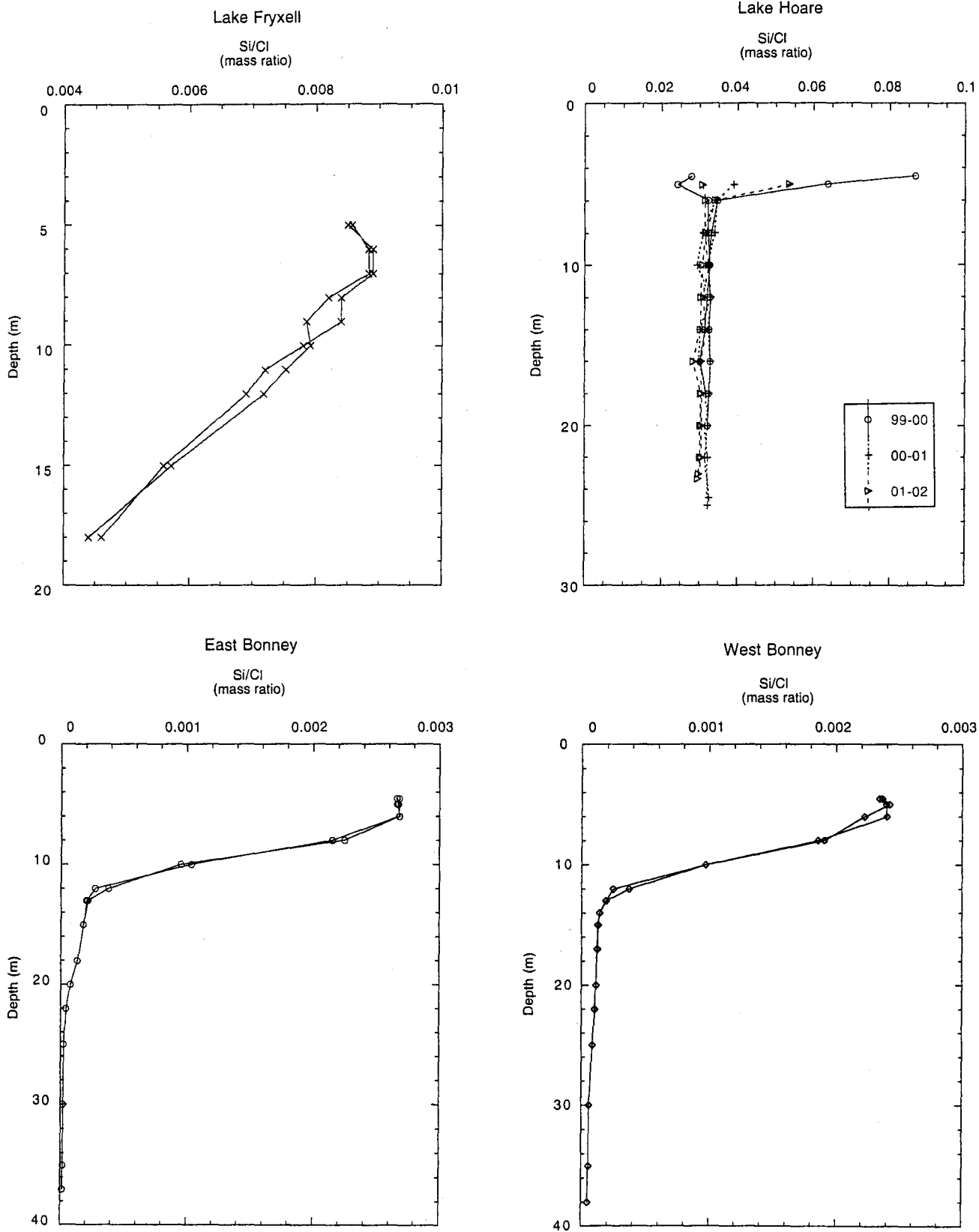


Figure 5 Si/Cl Profiles for Taylor Valley Lakes (1999-2000).

of salts within the lake (Lyons et al, 1998b). The low Si/Cl ratios in Lake Bonney overall may be due to removal of Si relative to Cl by both chemical and biological processes and modern diffusion of solutes throughout the water column.

The total pool of Si in each lake was calculated for the 1999-2000 season (Appendix C). Each lake was divided into layers based on midpoints between sample depths. The volume of each layer was multiplied by the Si concentration at the corresponding depth. There is no Si measurement for the ice cover or for water less than ~5 meters deep. This surface layer was assumed to have no Si for these calculations. The layers were then summed to calculate the total amount of Si in each lake. This was done for the early and late season samples. Lake Fryxell has the largest pool of Si followed by East Bonney, Hoare and West Bonney.

East Bonney, West Bonney and Fryxell lakes show an increase in the total Si pool from early in the austral summer to mid-summer. Lake Hoare does not show the same increase. In the 99-00, 00-01 and 01-02 seasons, there is a significant decrease in the calculated amount of Si from early to mid-summer. This is probably due to dilution of surface water by input of less concentrated ice cover melt and stream water, and uptake of Si by diatoms.

During the winters of 2000 and 2001, an increase in Si concentration occurred in the surface waters of Lake Hoare. This is probably caused by freeze concentration. Every winter approximately half of a meter of ice is frozen to the bottom of the ice cover. The water that freezes is relatively pure, resulting in the solutes being left behind. Therefore, Si and other solutes are forced into a smaller volume of water, increasing the concentration of the lake. In the early season sample of the three years discussed here, the pool of Si in Lake Hoare has 'recovered' to almost the same value. The calculations show that the lake was increasing in concentration each season. Two factors may control this phenomenon. Either a larger amount of Si from stream water entered the lake during the previous season, or more water was frozen to the ice cover, resulting in further freeze concentration.

The residence time for Si was calculated for the three lake basins (Table 4). The total amount of Si in each basin was divided by the Si flux. Lake Fryxell's residence time for Si was calculated to be just over 1000 years. This value corresponds to the time

that Lake Fryxell was thought to begin to refill (Lyons et al., 1998a). The Bonney basin has the shortest calculated residence time, 260 years. Lake Hoare was found to have the longest residence time, over 3200 years. These calculations are based on flow data from only 1999-2000 and there is variation from year to year. The flux is calculated from a little more than half of the streams that flow to these lakes. Higher amounts of discharge would increase the Si flux, therefore resulting in shorter residence times.

DIATOMS & PPR

The amount of primary productivity (PPR) in the lakes of TV varies between each lake and within the water column (Figure 6). West Bonney is the most productive lake with its max at 13m ($7.22 \mu\text{g C / L day}$). East Bonney's highest production is at 12m ($1.11 \mu\text{g C / L day}$), but it is not nearly as productive as West Bonney. Lake Fryxell's highest PPR is at 9 m ($2.08 \mu\text{g C / L day}$) and the max is at 5 m ($0.67 \mu\text{g C / L day}$) in Lake Hoare.

The percentage of Si taken up by diatoms was calculated in each lake on a layer basis of the sampled depths (Appendix D). The PPR averages for each layer are from measurements taken from 1993-1997. 180 day productivity cycle was used for these calculations. The Si/C ratio for diatoms is 0.3039 (Nelson et al., 1995). No more than 10% of PPR can be attributed to diatoms in the water column (Sarah Spaulding and John Priscu, personal communication).

The calculated percentage of Si taken up by diatoms is closely linked with the amount of primary production (Figure 6). In West Bonney the largest percentage of Si uptake occurs at 12 and 13m, over 1.5% for both layers. 13m is just above the chemocline. A significant increase in Si and other chemicals occurs at 14 m in West Bonney. East Bonney has the next highest percentage of Si uptake, at a depth of 12m ($>0.3\%$). In Lake Fryxell, about 0.15% of Si is taken up by diatoms in the layers 9m and above. The 3 lakes mentioned above all have surface waters less productive than their maximum layer and the % decreases with depth following the most productive layer. Lake Hoare's highest percentage (0.14) is at the first sampled depth (5m) and uptake decreases with depth.

The main sink for dissolved Si is its uptake by diatoms in the water column and in benthic mats and subsequent sedimentation of the diatom frustules to the lake bottom. In Lake Hoare, 10% of PPR can be attributed to diatoms in benthic mats, however production sites within mats are not constant. Diatoms are very mobile and move by their raphe structures (Sarah Spaulding, personal communication). Adsorption of Si onto particles (Swedlund and Webster, 1999) and authigenic formation of new silicate minerals was not considered as a major removal mechanism.

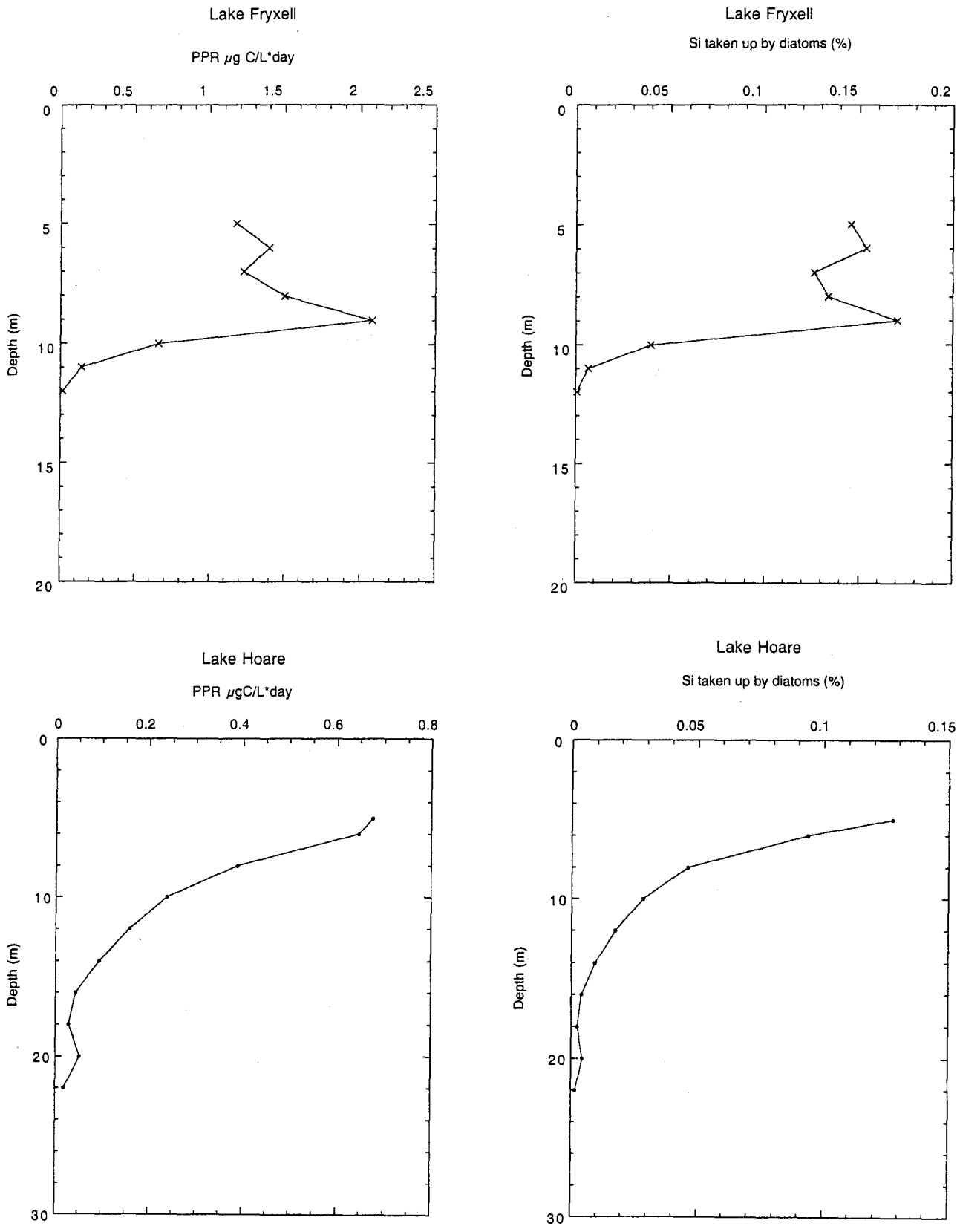


Figure 6 Primary Productivity Profiles and Percentage of Si Uptake by Diatoms Lake Fryxell (1999-2000) and Lake Hoare (2000-2001).

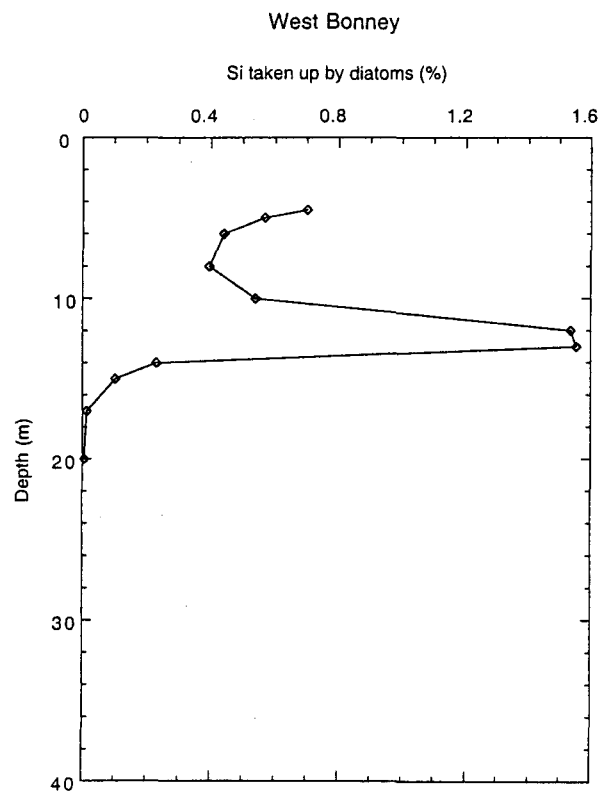
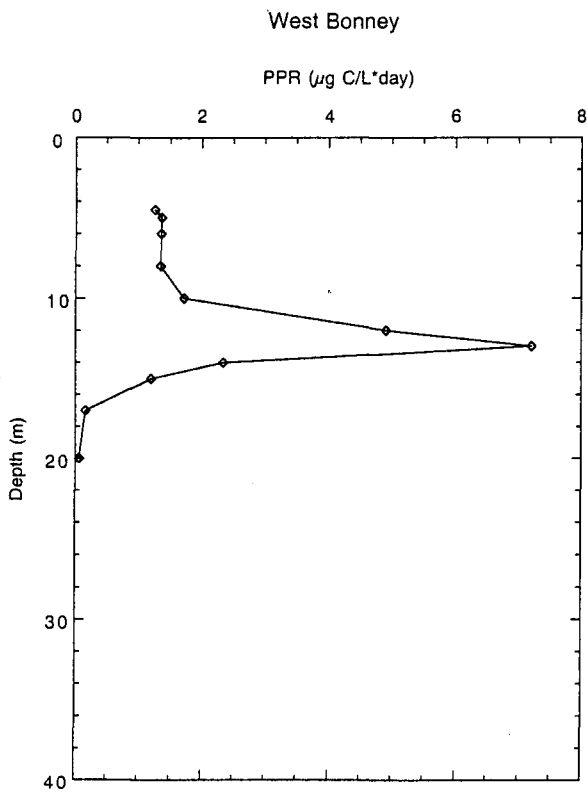
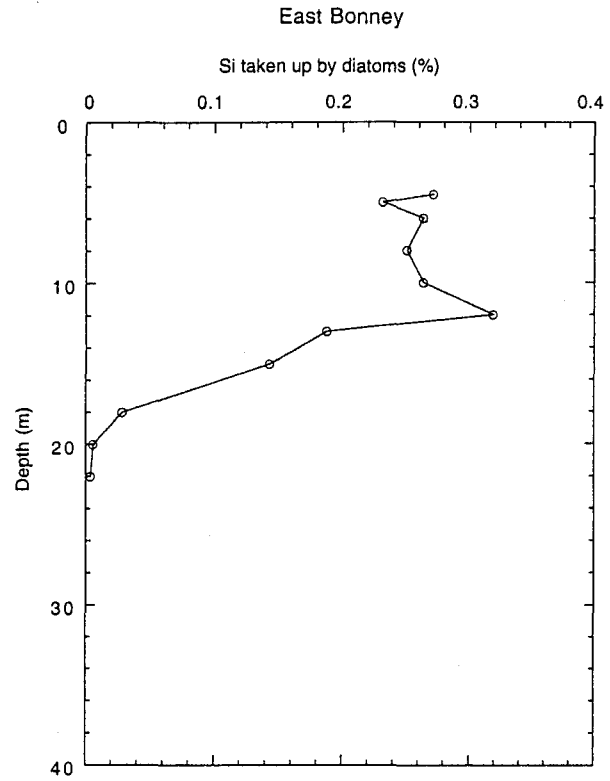
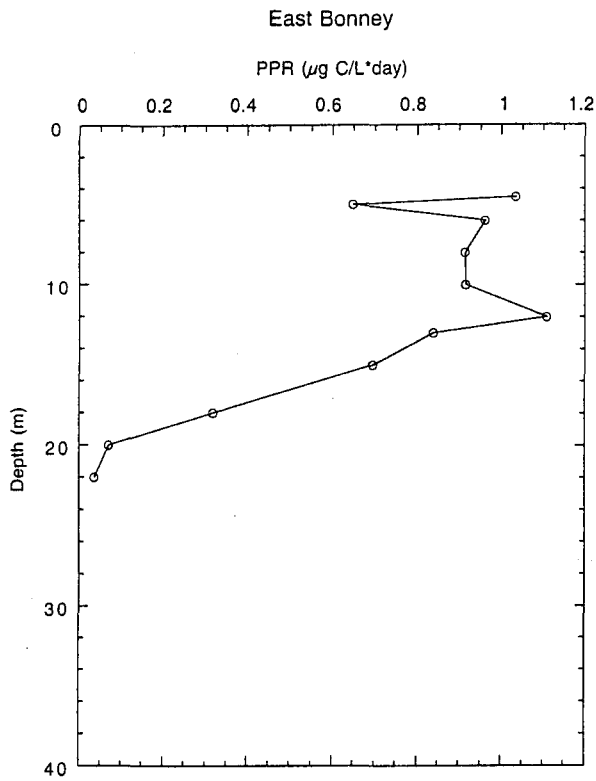


Figure 6 continued. Primary Productivity Profiles and Percentage of Si Uptake by Diatoms East and West Lake Bonney (1999-2000)

CONCLUSION

Si dynamics in Taylor Valley lakes are influenced by certain biological and physical processes that are not factors in temperate lakes. The productivity is limited by the short season when sunlight is available. A 3-6 m ice cover on the lake surface also limits transmission of light during the summer. The near freezing lake temperatures slow the rate of Si dissolution. The average amount of Si uptake by diatoms in the water column is low (<1%) for the lakes as a whole, however in certain areas of each lake productivity is greater.

On average, the glacial meltwater transported to the lakes has Si concentrations much lower than the lake Si concentrations. The amount of Si entering the lakes, based on flux calculations from the 1999-2000 season, is small compared to the total pool of silica in each lake. Residence time calculations were based on flows from one season, and flow varies from year to year, so they should be considered estimates only. However, the residence time calculated for Lake Fryxell is consistent with the historic refilling of the lake.

Climate differences exist between the lakes, even though they are relatively close in proximity. The Bonney Basin tends to be warmer than the Fryxell or Hoare basins. The amount of stream flow, and therefore amount of Si entering the lakes, is influenced by the amount of direct sunlight each basin receives and the temperature.

Freeze concentration followed by dilution with glacier meltwater input explains why Si concentrations in the surface waters of Lake Hoare are much higher early in the summer than the concentrations from the previous year's last sampling. This process probably occurs in Lake Fryxell and the Bonney Basin lakes as well.

The surface waters of all of the TV lakes are fresh, however their bottom waters are quite different. The chemical differences result in unique conditions for each lake. The hypersaline bottoms in the Bonney Basin lakes may explain why Si concentrations in these lakes have a mid-depth maximum. Lakes Fryxell and Hoare have maximum Si concentration at the deepest sample. The histories of these lakes may explain the differences in each of these lakes.

Examination of multiple years of stream flow data and lake Si profiles would give an increased understanding in the biogeochemical dynamics in these lakes. More accurate residence times could be calculated. Further annual analysis of Si in the Taylor Valley may provide a more complete picture of the biological, physical and chemical processes in the lakes and streams.

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APPENDIX A

Stream Si Concentration 1999-2000

Sample	Si mg/L	Average mg/L
Aiken Creek #1 991210@1255	1.322	1.198
Aiken Creek #2 991210@1330	1.551	
Aiken Creek #3 991210@1410	1.545	
Aiken Creek @ F5 000106@1440	0.633	
Aiken Creek @ F5 000112@1835	1.122	
Aiken Creek @ F5 991220@1410	0.974	
Aiken Creek @ F5 991227@1215	0.586	
Aiken Tributary 991210@1354	1.849	
Andersen Creek 991211@1618	0.279	0.276
Andersen Creek @ H1 000104@2010	0.257	
Andersen Creek @ H1 000111@1250	0.465	
Andersen Creek @ H1 000123@1810	0.707	
Andersen Creek @ H1 991204@1745	0.273	
Andersen Creek @ H1 991208@1200	0.301	
Andersen Creek @ H1 991208@1600	0.202	
Andersen Creek @ H1 991208@2000	0.159	
Andersen Creek @ H1 991208@2359	0.122	
Andersen Creek @ H1 991209@0400	0.152	
Andersen Creek @ H1 991209@0800	0.177	
Andersen Creek @ H1 991209@1200	0.214	
Andrews Creek 991228@1320	0.486	0.378
Andrews Creek @ mouth 000112@1320	0.270	
Bartlette Creek 000108@1850	1.573	1.544
Bartlette Creek 000118@1230	1.516	
Bohner Stream 000108@2000	1.955	1.943
Bohner Stream @ Priscu 000117@1440	1.988	
Bohner Stream @ Priscu 991209@1400	1.887	
Bowles Creek 000114@1810	2.345	2.314
Bowles Creek 991127@1550	2.387	
Bowles Creek 991228@1320	2.209	
Canada Stream @ F1 000106@1035	0.750	0.759
Canada Stream @ F1 000125@1655	0.701	
Canada Stream @ F1 991127@1425	0.652	
Canada Stream @ F1 991207@1500	0.881	
Canada Stream @ F1 991220@1915	0.620	
Canada Stream @ F1 991228@1240	0.949	
Delta Stream @ F10 000107@1720	2.418	2.279
Delta Stream @ F10 000123@1005	2.141	
Green Creek @ F9 000107@1455	0.633	0.892
Green Creek @ F9 000115@1405	0.751	
Green Creek @ F9 000122@1350	0.944	
Green Creek @ F9 991207@1625	1.325	
Green Creek @ F9 991227@0935	0.449	
Green Creek @ F9 991228@1125	0.583	
Green Creek @ mouth 000107@1455	0.732	
Green Creek @ mouth 000122@1310	1.257	
Green Creek @ mouth 991207@1555	1.714	
Green Creek @ mouth 991221@1200	0.527	
House Stream @ H2 000103@1300	0.078	0.118
House Stream @ H2 000110@1220	0.078	
House Stream @ H2 000123@1440	0.156	
House Stream @ H2 991208@1720	0.086	
House Stream @ H2 991211@1405	0.192	
House Stream @ H2 991225@1215	0.115	

Sample	Si mg/L	Average mg/L
Huey Creek @ F2 000106@1120	2.172	2.296
Huey Creek @ F2 000112@1625	2.388	
Huey Creek @ F2 000125@1425	2.411	
Huey Creek @ F2 991230@1330	2.215	
Lawson Creek @ B3 000109@1610	0.572	0.536
Lawson Creek @ B3 000118@1745	0.487	
Lawson Creek @ B3 991201@1615	0.436	
Lawson Creek @ B3 991209@1145	0.475	
Lawson Creek @ B3 991231@1255	0.708	
Lost Seal Stream 000121@1635	1.510	1.017
Lost Seal Stream @ F3 000106@1120	0.713	
Lost Seal Stream @ F3 991214@1955	1.353	
Lost Seal Stream @ F3 991220@1450	0.862	
Lost Seal Stream @ F3 991227@1710	0.645	
Lyons Creek 000109@1510	0.347	0.644
Lyons Creek @ B4 000118@1620	0.251	
Lyons Creek @ B4 991223@1305	0.331	
Lyons Creek @ B4 991231@1145	0.294	
Lyons Creek Trib. 000118@1640	1.999	
Mariah Creek 000114@1825	0.232	0.232
McKay Creek 000103@1230	0.085	0.119
McKay Creek 000110@1245	0.115	
McKay Creek 000123@1420	0.150	
McKay Creek 991225@1235	0.122	
McKay Creek (25ft-Lk Chad) 991211@1345	0.148	
McKay Creek @ Boulder 991208@1818	0.092	
McKnight Creek 000112@1815	1.554	1.393
McKnight Creek 991214@1925	2.067	
McKnight Creek 991220@1430	1.371	
McKnight Creek @ F3 000106@1415	1.079	
McKnight Creek @ F4 991227@1530	0.893	
Priscu Stream 991209@1256	0.719	1.104
Priscu Stream (before Bohner) 991224@1000	0.981	
Priscu Stream @ B1 000102@1210	1.265	
Priscu Stream @ B1 000108@1950	1.850	
Priscu Stream @ B1 000117@1355	0.707	
Red River (Blood Falls) 000118@2120	6.807	6.807
Santa Fe Stream @ B2 000109@1630	0.547	0.530
Santa Fe Stream @ B2 000118@1905	0.634	
Santa Fe Stream @ B2 991209@1112	0.322	
Santa Fe Stream @ B2 991231@1225	0.727	
Santa Fe Stream @ Flume (B2) 991201@1535	0.421	
Sharp Creek 000118@2055	1.822	1.781
Sharp Creek (50ft from inflow) 991223@1625	1.739	
Vincent Creek 000108@1900	2.030	2.006
Vincent Creek 000118@1245	1.982	
Von Guerard Stream @ front 000115@1255	3.301	3.301
Wharton Creek 000103@1220	0.134	0.237
Wharton Creek 000123@1425	0.309	
Wharton Creek 991211@1400	0.273	
Wharton Creek 991225@1245	0.233	

APPENDIX B

Stream Si Concentration 2000-2001

Sample	Si mg/L	Average mg/L
Aiken Creek (Upper) 001219@1860	0.837	1.122
Aiken Creek (Upper) 001226@1900	0.580	
Aiken Creek (Upper) 010104@2000	0.870	
Aiken Creek 001219@1930	2.146	
Aiken Creek 001226@1930	1.179	
Andersen Creek 001209@1400	0.311	0.427
Andersen Creek 010101@2146	0.207	
Andersen Creek 010107@1900	0.568	
Andersen Creek 010114@1500	1.084	
Andersen Creek @H1 001202@1950	0.152	
Andersen Creek @H1 001216@1530	0.243	
Bartlette Creek 001130@1940	1.167	1.415
Bartlette Creek 001222@1326	1.662	
Bohner Stream 001222@1210	2.237	2.002
Bohner Stream 010129	1.767	
Bowles Creek 010116@1615	2.634	2.634
Canada Stream 001204@1620	0.837	0.721
Canada Stream 001205@1445	0.928	
Canada Stream 001210@1440	0.574	
Canada Stream 001219@1824	0.519	
Canada Stream 001227@1505	0.665	
Canada Stream 010114@1410	0.870	
Canada Stream 010104@1435	0.931	
Canada Stream 010118@1450	0.559	
Canada Stream 010124@1450	0.607	
Delta Stream 001223@1310	3.399	3.756
Delta Stream 001227@1150	4.112	
Green Creek 001205@1553	0.776	0.698
Green Creek 001210@1135	0.525	
Green Creek 001219@1720	0.464	
Green Creek 001227@1315	0.549	
Green Creek 010110@1420	0.727	
Green Creek 001204@1720	0.837	
Green Creek 010104@1340	0.809	
Green Creek 010114@1300	0.760	
Green Creek 010116	0.797	
Green Creek 010124@1330	0.925	
Green Creek @ F9 001202@1130	0.513	
House Stream 001203@1330	0.140	0.122
House Stream 001217@1135	0.085	
House Stream 010101@1655	0.079	
House Stream 010107@1640	0.177	
House Stream 010120@1640	0.131	
Lawson Creek 001129@1730	0.320	0.442
Lawson Creek 001130@1615	0.269	
Lawson Creek 001207@1250	0.411	
Lawson Creek 001221@1450	0.379	
Lawson Creek 001229@1735	0.471	
Lawson Creek 010106@1250	0.250	
Lawson Creek 010112@1700	0.760	
Lawson Creek 010119@2110	0.913	
Lawson Creek 010129@1315	0.205	

Sample	Si mg/L	Average mg/L
Lost Seal Stream 001210@1715	0.895	1.081
Lost Seal Stream 001219@1944	1.024	
Lost Seal Stream 001227@1320	1.061	
Lost Seal Stream 010115@1850	1.352	
Lost Seal Stream 010123@1400	1.071	
Lyons Creek 001130@1850	0.152	0.728
Lyons Creek 001221@1711	0.238	
Lyons Creek 001229@1450	0.275	
Lyons Creek 010106@1215	0.490	
Lyons Creek 010112@1500	1.111	
Lyons Creek @ B4 001207@1549	0.300	
Lyons Creek Above Trib. 010126@1045	0.369	
Lyons Creek Tributary 010112@1520	1.700	
Lyons Creek Tributary 010126@1045	1.914	
Mariah Creek 001210@1230	1.515	1.989
Mariah Creek 001219@1750	2.283	
Mariah Creek 001227@1400	1.951	
Mariah Creek 010104@1355	2.207	
McKay Creek 001203@1415	0.139	0.127
McKay Creek 001209@1245	0.115	
McKay Creek 001217@1230	0.127	
McKay Creek 010101@1655	0.096	
McKay Creek 010107@1700	0.158	
McKay Creek 010120@1700	0.125	
McKnight Creek 001219@1944	1.687	1.687
Priscu Stream 001209@1517	1.061	0.870
Priscu Stream 001220@1840	0.668	
Priscu Stream 001222@1230	0.858	
Priscu Stream 001229@1420	0.619	
Priscu Stream 010106@1105	1.276	
Priscu Stream 010129@1540	0.742	
Red River 001222@1245	0.576	0.452
Red River 010106@1340	0.490	
Red River 010112@1700	0.687	
Blood Falls 001129@1730	0.228	
Blood Falls 001130@1630	0.219	
Blood Falls 001207@1525	0.435	
Blood Falls 001229@1715	0.433	
Blood Falls 010129@1245	0.546	
Santa Fe Creek 001122@1630	0.472	0.468
Santa Fe Creek 001129@1730	0.176	
Santa Fe Creek 001130@1730	0.368	
Santa Fe Creek 001207@1415	0.466	
Santa Fe Creek 001221@1315	0.764	
Santa Fe Creek 001222@1235	0.703	
Santa Fe Creek 001229@1630	0.441	
Santa Fe Creek 010106@1403	0.466	
Santa Fe Creek 010112@1655	0.502	
Santa Fe Creek 010119@1945	0.399	
Santa Fe Creek 010129@1225	0.393	
Sharp Creek 001207@1505	1.854	1.763
Sharp Creek 001221@1350	1.671	

<u>Sample</u>	<u>Si mg/L</u>	<u>Average mg/L</u>
Upper VonGuerard Stream 001219@1405	1.549	1.644
Upper VonGuerard Stream 001223@1555	1.495	
Upper VonGuerard Stream 001226@1730	1.750	
Upper VonGuerard Stream 010118@1945	1.580	
Upper VonGuerard Stream 010125@2203	1.848	
Vincent Creek 001222@1335	2.134	2.134
Wharton Creek 001203@1415	0.174	0.186
Wharton Creek 001209@1300	0.155	
Wharton Creek 001217@1245	0.155	
Wharton Creek 010101@1730	0.174	
Wharton Creek 010120@1710	0.271	

APPENDIX C

Lake Si Profiles and Layer Calculations

Sample	Sample Depth (m)	Si Conc. (mg/L)	Volume of layer (L)	Si within layer (kg)	Si below layer (kg)
Fryxell Early 99-00	surface	0.000	27206424773	0	223798
5 FRX 991030	5	4.413	3757085904	16578	207220
6 FRX 991030	6	4.968	3336304361	16574	190646
7 FRX 991030	7	5.307	3079504478	16342	174304
8 FRX 991030	8	6.139	2807622823	17237	157067
9 FRX 991030	9	6.664	2527909407	16845	140222
10 FRX 991030	10	9.007	2229542993	20082	120140
11 FRX 991030	11	12.029	1841155469	22147	97993
12 FRX 991030	12	13.201	2823230815	37269	60724
15 FRX 991030	15	16.038	2567481612	41176	19548
18 FRX 991030	18	15.883	1230705251	19548	0
Fryxell Late 99-00	surface	0.000	27206424773	0	227124
5 FRX 991223	5	5.125	3757085904	19254	207870
6 FRX 991223	6	5.632	3336304361	18789	189081
7 FRX 991223	7	6.200	3079504478	19094	169987
8 FRX 991223	8	6.435	2807622823	18067	151920
9 FRX 991223	9	7.325	2527909407	18517	133403
10 FRX 991223	10	9.461	2229542993	21093	112310
11 FRX 991223	11	10.918	1841155469	20101	92209
12 FRX 991223	12	11.600	2823230815	32748	59461
15 FRX 991223	15	15.474	2567481612	39730	19731
18 FRX 991223	18	16.032	1230705251	19731	0
Hoare Early 99-00	surface	0.000	7086221817	0	78327
4.5 HOR 991117	4.5	1.772	786502036	1393	76934
5 HOR 991117	5	2.174	1487603970	3233	73701
6 HOR 991117	6	3.965	2033922399	8064	65637
8 HOR 991117	8	4.172	2422437515	10106	55531
10 HOR 991117	10	4.598	2115938353	9730	45801
12 HOR 991117	12	4.866	1836403966	8936	36865
14 HOR 991117	14	5.585	1588044580	8869	27995
16 HOR 991117	16	6.267	1327018474	8317	19678
18 HOR 991117	18	6.499	1060779580	6894	12784
20 HOR 991117	20	6.450	1982021358	12784	0
Hoare Late 99-00	surface	0.000	7086221817	0	69774
4.5 HOR 000104	4.5	0.218	786502036	171	69603
5 HOR 000104	5	0.403	1487603970	599	69003
6 HOR 000104	6	2.628	2033922399	5345	63658
8 HOR 000104	8	3.333	2422437515	8073	55586
10 HOR 000104	10	4.334	2115938353	9170	46416
12 HOR 000104	12	4.841	1836403966	8889	37526
14 HOR 000104	14	5.755	1588044580	9140	28387
16 HOR 000104	16	6.398	1327018474	8490	19896
18 HOR 000104	18	6.571	1060779580	6970	12926
20 HOR 000104	20	6.522	1982021358	12926	0

Sample	Sample Depth (m)	Si Conc. (mg/L)	Volume of layer (L)	Si within layer (kg)	Si below layer (kg)
E. Bonney Early 99-00	surface	0.000	13034020972	0	194377
4.5 EBON 991106	4.5	2.082	1562658166	3253	191124
5 EBON 991106	5	1.533	3082392528	4726	186399
6 EBON 991106	6	1.990	4471537387	8899	177499
8 EBON 991106	8	1.990	5622384026	11190	166310
10 EBON 991106	10	1.899	5150777325	9780	156529
12 EBON 991106	12	1.899	3622459428	6878	149651
13 EBON 991106	13	2.447	3442566188	8425	141225
15 EBON 991106	15	2.661	5371811716	14293	126932
18 EBON 991106	18	6.044	4920312793	29738	97194
20 EBON 991106	20	6.593	3606808120	23778	73416
22 EBON 991106	22	5.404	4119759676	22263	51154
25 EBON 991106	25	3.910	5671748508	22179	28975
30 EBON 991106	30	3.362	5415354478	18205	10770
35 EBON 991106	35	3.362	2385972265	8021	2749
37 EBON 991106	37	3.027	908258029	2749	0
E. Bonney Late 99-00	surface	0.000	13034020972	0	194516
4.5 EBON 991228	4.5	2.228	1562658166	3482	191035
5 EBON 991228	5	1.583	3082392528	4878	186156
6 EBON 991228	6	1.859	4471537387	8314	177842
8 EBON 991228	8	2.136	5622384026	12008	165834
10 EBON 991228	10	1.859	5150777325	9577	156257
12 EBON 991228	12	2.044	3622459428	7403	148854
13 EBON 991228	13	2.443	3442566188	8411	140444
15 EBON 991228	15	2.843	5371811716	15270	125174
18 EBON 991228	18	5.916	4920312793	29108	96066
20 EBON 991228	20	6.561	3606808120	23665	72401
22 EBON 991228	22	5.363	4119759676	22093	50308
25 EBON 991228	25	3.888	5671748508	22049	28259
30 EBON 991228	30	3.334	5415354478	18057	10203
35 EBON 991228	35	3.334	2385972265	7956	2247
37 EBON 991228	37	2.474	908258029	2247	0
W. Bonney Early 99-00	surface	0.000	3942501879	0	50059
4.5 WBON 991111	4.5	0.984	477981468	471	49589
5 WBON 991111	5	1.320	943830971	1246	48343
6 WBON 991111	6	1.685	1351282120	2278	46066
8 WBON 991111	8	1.868	1664349882	3110	42956
10 WBON 991111	10	1.746	1489130179	2601	40356
12 WBON 991111	12	1.746	1004923220	1755	38601
13 WBON 991111	13	2.539	617255912	1567	37033
14 WBON 991111	14	5.526	575417418	3180	33854
15 WBON 991111	15	6.349	785478134	4987	28867
17 WBON 991111	17	6.684	1113437253	7442	21425
20 WBON 991111	20	6.897	924686714	6378	15047
22 WBON 991111	22	6.774	775148356	5251	9796
25 WBON 991111	25	6.348	923928102	5865	3931
30 WBON 991111	30	4.947	558376103	2762	1169
35 WBON 991111	35	4.752	185065465	879	290
38 WBON 991111	38	4.413	65627191	290	0
W. Bonney Late 99-00	surface	0.000	3942501879	0	51016
4.5 WBON 991230	4.5	2.197	477981468	1050	49966
5 WBON 991230	5	1.337	943830971	1262	48704
6 WBON 991230	6	1.706	1351282120	2305	46400
8 WBON 991230	8	1.890	1664349882	3146	43254
10 WBON 991230	10	1.767	1489130179	2631	40623
12 WBON 991230	12	1.829	1004923220	1838	38785
13 WBON 991230	13	2.628	617255912	1622	37163
14 WBON 991230	14	5.793	575417418	3333	33830
15 WBON 991230	15	6.407	785478134	5033	28797
17 WBON 991230	17	6.684	1113437253	7442	21355
20 WBON 991230	20	6.838	924686714	6323	15032
22 WBON 991230	22	6.807	775148356	5276	9755
25 WBON 991230	25	6.254	923928102	5778	3977
30 WBON 991230	30	5.025	558376103	2806	1172
35 WBON 991230	35	4.779	185065465	884	287
38 WBON 991230	38	4.379	65627191	287	0

Sample	Sample Depth (m)	Si Conc. (mg/L)	Volume of layer (L)	Si within layer (kg)	Si below layer (kg)
Hoare Early 00-01	surface	0.000	7872723853	0	79205
HOR 5m 001111	5	2.896	1487603970	4309	74896
HOR 6m 001111	6	3.764	2033922399	7657	67240
HOR 8m 001111	8	4.608	2422437515	11162	56078
HOR 10m 001111	10	4.546	2115938353	9618	46460
HOR 12m 001111	12	4.980	1836403966	9144	37315
HOR 14m 001111	14	5.426	1588044580	8617	28699
HOR 16m 001111	16	5.922	1327018474	7858	20840
HOR 18m 001111	18	6.492	1060779580	6887	13954
HOR 20m 001111	20	6.567	855764247	5620	8334
HOR 22m 001111	22	6.405	677257825	4338	3996
HOR 24.5m 001111	24.5	6.753	591748443	3996	0
Hoare Late 00-01	surface	0.000	7872723853	0	72544
HOR 5m 010103	5	0.280	1487603970	417	72127
HOR 6m 010103	6	2.661	2033922399	5412	66715
HOR 8m 010103	8	4.012	2422437515	9720	56995
HOR 10m 010103	10	4.174	2115938353	8831	48164
HOR 12m 010103	12	4.918	1836403966	9031	39134
HOR 14m 010103	14	5.785	1588044580	9188	29946
HOR 16m 010103	16	6.467	1327018474	8582	21364
HOR 18m 010103	18	6.678	1060779580	7084	14280
HOR 20m 010103	20	6.529	855764247	5588	8692
HOR 22m 010103	22	6.529	811251083	5297	3395
HOR 25m 010103	25	6.616	513114180	3395	0
Hoare Early 01-02	surface	0.000	7872723853	0	84702
HOR 5m 011102	5	4.855	1487603970	7223	77479
HOR 6m 011102	6	4.917	2033922399	10001	67478
HOR 8m 011102	8	4.843	2422437515	11732	55746
HOR 10m 011102	10	4.880	2115938353	10326	45420
HOR 12m 011102	12	4.868	1836403966	8939	36481
HOR 14m 011102	14	5.755	1588044580	9140	27341
HOR 16m 011102	16	6.285	1327018474	8341	19000
HOR 18m 011102	18	6.507	1060779580	6903	12098
HOR 20m 011102	20	6.409	855764247	5484	6613
HOR 22m 011102	22	6.409	528180283	3385	3228
HOR 23.3m 011102	23.3	6.372	506694064	3228	0
Hoare Late 01-02	surface	0.000	7872723853	0	71060
HOR 5m 011222	5	0.319	1487603970	475	70585
HOR 6m 011222	6	2.501	2033922399	5087	65498
HOR 8m 011222	8	4.202	2422437515	10179	55319
HOR 10m 011222	10	4.745	2115938353	10039	45279
HOR 12m 011222	12	5.028	1836403966	9234	36046
HOR 14m 011222	14	5.854	1588044580	9296	26750
HOR 16m 011222	16	5.829	1327018474	7736	19014
HOR 18m 011222	18	6.458	1060779580	6850	12164
HOR 20m 011222	20	6.421	855764247	5495	6669
HOR 22m 011222	22	6.372	528180283	3365	3303
HOR 23m 011222	23	6.520	506694064	3303	0

APPENDIX D

Percentage of Si Uptake by Diatoms

Sample	Sample Depth (m)	average PPR ($\mu\text{g C/l}^*\text{d}$)	Volume of layer (L)	Si within layer (kg)	Carbon (kg)	Si (kg)	10% due to Diatoms	% Si used in layer
Fryxell Early 99-00								
5 FRX 991030	5	1.1779	3757085904	16578	796.6	242.1	24.21	0.146
6 FRX 991030	6	1.3976	3336304361	16574	839.3	255.1	25.51	0.154
7 FRX 991030	7	1.2241	3079504478	16342	678.5	206.2	20.62	0.126
8 FRX 991030	8	1.5024	2807622823	17237	759.2	230.7	23.07	0.134
9 FRX 991030	9	2.0794	2527909407	16845	946.2	287.5	28.75	0.171
10 FRX 991030	10	0.6600	2229542993	20082	264.9	80.5	8.05	0.040
11 FRX 991030	11	0.1412	1841155469	22147	46.8	14.2	1.42	0.006
12 FRX 991030	12	0.0190	2823230815	37269	9.7	2.9	0.29	0.001
Hoare Early 00-01								
HOR 5m 001111	5	0.6759	1487603970	4309	181.0	55.0	5.50	0.128
HOR 6m 001111	6	0.6468	2033922399	7657	236.8	72.0	7.20	0.094
HOR 8m 001111	8	0.3884	2422437515	11162	169.3	51.5	5.15	0.046
HOR 10m 001111	10	0.2381	2115938353	9618	90.7	27.6	2.76	0.029
HOR 12m 001111	12	0.1596	1836403966	9144	52.8	16.0	1.60	0.018
HOR 14m 001111	14	0.0946	1588044580	8617	27.1	8.2	0.82	0.010
HOR 16m 001111	16	0.0434	1327018474	7858	10.4	3.1	0.31	0.004
HOR 18m 001111	18	0.0289	1060779580	6887	5.5	1.7	0.17	0.002
HOR 20m 001111	20	0.0526	855764247	5620	8.1	2.5	0.25	0.004
HOR 22m 001111	22	0.0189	677257825	4338	2.3	0.7	0.07	0.002
E. Bonney Early 99-00								
4.5 EBON 991106	4.5	1.0360	1562658166	3253	291.4	88.6	8.86	0.272
5 EBON 991106	5	0.6500	3082392528	4726	360.6	109.6	10.96	0.232
6 EBON 991106	6	0.9616	4471537387	8899	774.0	235.2	23.52	0.264
8 EBON 991106	8	0.9137	5622384026	11190	924.7	281.0	28.10	0.251
10 EBON 991106	10	0.9153	5150777325	9780	848.6	257.9	25.79	0.264
12 EBON 991106	12	1.1089	3622459428	6878	723.1	219.7	21.97	0.319
13 EBON 991106	13	0.8400	3442566188	8425	520.5	158.2	15.82	0.188
15 EBON 991106	15	0.6963	5371811716	14293	673.3	204.6	20.46	0.143
18 EBON 991106	18	0.3206	4920312793	29738	283.9	86.3	8.63	0.029
20 EBON 991106	20	0.0711	3606808120	23778	46.1	14.0	1.40	0.006
22 EBON 991106	22	0.0366	4119759676	22263	27.1	8.2	0.82	0.004
W. Bonney Early 99-00								
4.5 WBON 991111	4.5	1.2573	477981468	471	108.2	32.9	3.29	0.699
5 WBON 991111	5	1.3700	943830971	1246	232.7	70.7	7.07	0.568
6 WBON 991111	6	1.3574	1351282120	2278	330.2	100.3	10.03	0.441
8 WBON 991111	8	1.3574	1664349882	3110	406.6	123.6	12.36	0.397
10 WBON 991111	10	1.7226	1489130179	2601	461.7	140.3	14.03	0.540
12 WBON 991111	12	4.9079	1004923220	1755	887.8	269.8	26.98	1.537
13 WBON 991111	13	7.2163	617255912	1567	801.8	243.7	24.37	1.555
14 WBON 991111	14	2.3432	575417418	3180	242.7	73.8	7.38	0.232
15 WBON 991111	15	1.2005	785478134	4987	169.7	51.6	5.16	0.103
17 WBON 991111	17	0.1595	1113437253	7442	32.0	9.7	0.97	0.013
20 WBON 991111	20	0.0600	924686714	6378	10.0	3.0	0.30	0.005