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**THE McMURDO DRY VALLEYS LONG-TERM ECOLOGICAL
RESEARCH PROGRAM: NEW UNDERSTANDING OF THE
BIOGEOCHEMISTRY OF THE DRY VALLEY LAKES:
A REVIEW¹**

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Abstract: The McMurdo Dry Valleys Long-Term Ecological Research (MCM-LTER) site represents the highest-latitude location of the 24 LTER sites supported by the U.S. National Science Foundation. Although the perennial ice-covered lakes in the dry valleys have been investigated since IGY, detailed, ecosystem-based studies have been conducted on these lakes since 1993 by LTER investigators. A review of recent findings on the biogeochemistry and food-chain dynamics of these lakes is summarized within. The lakes are much more complicated and more dynamic than previously thought. The importance of collecting long-term data is imperative if an understanding of how these sensitive systems respond to climate change is to be gained.

INTRODUCTION

The U.S. National Science Foundation (NSF) established the Long-Term Ecological Research Program in 1980 in order to better facilitate the collection of long-term data sets within a number of ecological settings (Callahan, 1984). The need for long-term environmental records was recognized to better evaluate ecological trends, as well as to understand the role of both natural and human disturbance on ecosystems. The LTER program addresses the study of ecological processes over long periods and across broad scales (Colwell, 2001). The LTER program is based on five core research areas: (1) pattern and control of primary production; (2) spatial and temporal distribution of populations; (3) pattern and control of organic matter accumulation in soils/sediments; (4) patterns of inorganic input and movement; and (5) patterns and frequency of disturbance to the research site. These core areas are intended to help focus research activities and formulate hypotheses in order to better compare and contrast data collected throughout the LTER site network (Callahan, 1984). In addition to the aspect of the collection of long-term physical, chemical, and biological data, long-term manipulations and/or experiments are conducted at each site. All data collected are "managed" so present and future generations can utilize them, with data being placed on the website of each LTER program within two years of collection. LTER sites are encouraged to conduct inter-site comparisons allowing for the integration and synthesis of information. Currently there are 24 LTER sites funded by the NSF (<http://www.lternet.edu>) that are coordinated through the Network office at the University of New Mexico.

There are four polar LTER sites: Bonanza Creek, a forested site in Central Alaska; Toolik Lake, an Arctic tundra site north of the Brooks Range, Alaska; Palmer, a marine-oriented site on the Antarctic Peninsula; and the McMurdo Dry Valleys (MCM-LTER), a polar desert site in southern Victoria Land, Antarctica (~78°S). The MCM-LTER was established in 1993, and is currently in the middle of its second six-year funding cycle. The MCM-LTER is by far the coldest and driest of all the LTER sites, and represents an "end-member" environment that contains a microbial-dominated ecosystem. For example, the most similar sites to MCM-LTER with respect to temperature or precipitation within the LTER Network are the Toolik Lake and Sevilleta (warm desert) sites. However, MCM-LTER has no megafauna, no vertebrates, and no vascular vegetation.

The research in the initial funding cycle of MCM-LTER was focused on how the constraints of the overall physical environment and its modification by material transport affected the function and structure of this unusual ecosystem (Wharton, 1995). Over the past three years, MCM-LTER scientists have evaluated the role of "legacy,"

or past climatic conditions (or the ecological overprinting), on today's ecosystem in the dry valleys. Clearly, the role of climate has been important in influencing overall ecosystem development and function. This concept of legacy, or ecological "carry-over," serves to link past and present (Vogt et al., 1997). Ecosystem legacies within the MCM range from the response of glaciers (10^4 – 10^6 yrs) to the existence of ancient lake waters (10^2 – 10^5 yrs). Because the MCM landscape is remarkably stable compared to temperate landscapes, small (subtle by temperate standards) variations in climate have great ecological consequences. Climate change is essentially the ecological driver within the MCM. Small changes in climate parameters are amplified through the change of state of H_2O . The role of liquid water is critical to the existence of life within these valleys. Therefore, the production, transport, and accumulation of liquid water is the key to the overall understanding of how this ecosystem works. Like other desert ecosystems, the relationship of the abundance of water to life is paramount; but unlike warm deserts, variations in hours above freezing rather than rainstorms, etc. become the critical factor in the well being of the ecosystem as a whole. The coupling between meteorology, hydrology, and biology may be more tightly related in this ecosystem than for other ecosystems on our planet.

Summarized below are many of the scientific findings of the MCM-LTER program as they are related to the study of the ice-covered lakes in Taylor Valley, the major study area for MCM-LTER, over the past nine years (Fig. 1). The lakes in Taylor Valley (TV) have been investigated since the IGY period (1957–1958), yet their unusual ecology and biogeochemistry still pose intriguing questions to the limnological community as a whole. This is due in part to analogies that have been made between these lake systems, and those that might have existed on early Mars (Doran et al., 1998) or even our Precambrian "Snowball Earth" (Fairchild, 1993; Lyons et al., 1999b). Even though these systems have been studied since the early 1960s, the MCM-LTER investigations were the first to integrate ecological, biogeochemical, and paleolimnological techniques, as well as geochemical/water mass balances of all the major lakes in Taylor Valley, southern Victoria Land. Much of the first six years of the MCM-LTER work is summarized in two synthesis volumes (Prisco, 1998; Bioscience, 1999). Below we have attempted to synthesize our most recent findings regarding the biogeochemistry of these unusual limnological systems.

THE McMURDO DRY VALLEYS

The McMurdo Dry Valleys are the most extensive ice-free regions in Antarctica (4800 km²) and are located along the Transantarctic Mountains in southern Victoria Land (Fig. 1). The MCM comprise three major ice-free valleys—the Taylor, Wright, and Victoria Valleys—along with many smaller, adjoining areas (Campbell and Claridge, 1987). Although the MCM-LTER works in other regions within the MCM system, the major geographic focus of the MCM-LTER is Taylor Valley (Fig. 1). The valleys are ice-free primarily because the Transantarctic Mountains block the flow of ice from the polar plateau. Taylor Valley is a glacially carved valley, trending NE-SW. The valleys are mosaics of glaciers, soils, exposed bedrock, ephemeral streams, and perennially ice-covered lakes. They are among the coldest and driest environments on Earth, with an average annual temperature of $\sim -20^\circ\text{C}$ and total precipitation of 6 cm or less (Fountain et al., 1999).

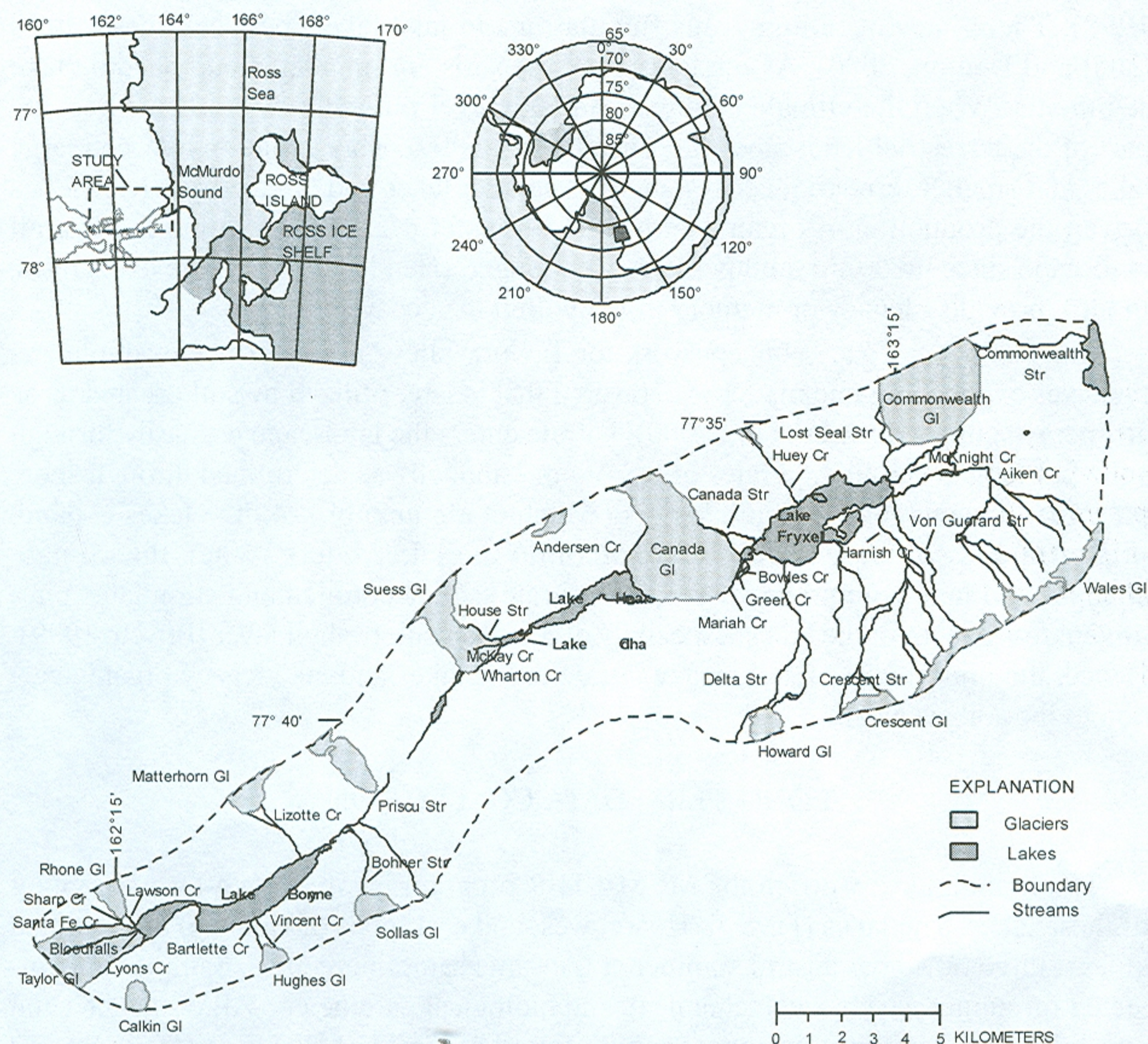


Fig 1. Taylor Valley, Southern Victoria Land, Antarctica, primary location of the McMurdo Dry Valleys LTER.

Despite these extreme climatic conditions, biological communities exist in the lakes, stream, soils, and, in some cases within the bedrock (Friedman, 1982; Prisco, 1995). A recent geomorphological model divides the MCM area into coastal, intermediate, and interior regions (Marchant and Denton, 1996), which corresponds to varying elevations. The lowest elevation, or coastal region, shows modern geomorphic development, while the inland areas show little to no modern activity with little change over the past four million years (Marchant and Denton, 1996). The primary focus area of the MCM-LTER has been in the coastal areas where aeolian and fluvial processes presently occur. Because of their climatic sensitivity, much has been written and debated concerning the past climatic histories of the dry valleys since the beginning of Tertiary time, and it will not be repeated here. A number of recent reviews examine the climate history over longer time scales and the debate concerning this history continues (e.g. Miller and Mabin, 1998). The time of earth history that has directly impacted the ecosystems of the MCM is the period since the Last Glacial Maximum (LGM). Since this time (past ~20 k yrs), lake levels within Taylor Valley have waxed and waned as the climate has varied. From the LGM into the early Holocene, Glacial Lake Washburn filled Taylor Valley (Doran et al., 1994). The most recent low stands of the lakes occurred ~1000 yr. ago (Wilson, 1964; Lyons et al.,

1998). There have been numerous fluctuations in lake levels between these times (Hall and Denton, 2000). As the lakes rise, the soils are inundated and become lake sediments. When the climate changes and lake level falls, these sediments become part of the terrestrial landscape (Moorhead et al., 1999). This variation between large lakes and smaller terrestrial ecosystems and smaller lakes and large areas of soils, has driven the production of organic carbon and transfer of nutrients within the overall landscape since the LGM, and perhaps even longer, (Hendy, 2000). These exchanges, in turn, provide a legacy or memory effect within the ecosystem.

How does this legacy concept work for Taylor Valley? Consider one example: As the lakes expand, organic matter is deposited that is later utilized by soil organisms as an energy source (Burkins et al., 2000). Nitrate enters the landscape primarily through snowfall with accumulation rates of 0.8 mg m^{-2} annually as determined through snow pit measurements on the local glaciers (Welch et al., unpubl.). As the lakes expand, this nitrate is solubilized from the soils into the lake waters. When the climate changes and lake volume decreases, this nitrate is concentrated and stimulates phytoplankton growth in the lakes, especially at the deep chlorophyll layer (Priscu, 1999). Hence, the importance of soil legacy nitrate to the lakes and lake legacy organic carbon to the soils is clear.

LONG-TERM DATA COLLECTION

The limnological work in the MCM-LTER program involves long-term sampling of these lakes. The lakes (Fryxell, Hoare, west and east lobes of Bonney) are sampled at least three times per austral summer at the same sampling depths. Samples are collected for numerous physical, chemical, and biological parameters. All of the data and our collecting/sampling protocols can be found at the MCM-LTER website, <http://huey.colorado.edu>. These data can be compared temporally to discern any chemical or biological trends related to changing climatic variables. Recent work has shown, for example, that even though lake levels had been rising through the 1980s (Chinn, 1993), in the 1990s lake levels have decreased. With this decrease has come a change in ice-cover thickness, lake chemistry, as well as biomass and primary production (Doran et al., 2002). The importance of having long-term data, collected and analyzed in the same manner, is clearly seen in this example. A brief summary of some of our most recent findings is found below.

THE MICROBIAL LOOP AND MIXOTROPHY IN THE PELAGIC FOOD CHAIN OF THE MCM LAKES

Much data now exist that support the premise that dissolved organic carbon (DOC) can be an important source of carbon to bacteria in lakes in general (Tranvik, 1992), and especially the MCM lakes (Takacs et al., 2001). The DOC concentrations in the MCM lakes euphotic zones can be quite high, varying from 0.4 to $>10 \text{ mg L}^{-1}$ (Matsumoto et al., 1984; McKnight et al., 1991; Lyons et al., 2000). Unlike DOC found in other lacustrine systems, the MCM lake DOC is solely derived from aquatic microbial production, with none produced from terrestrial sources (McKnight et al., 2001). The DOC in the lakes is thought to be a byproduct of phytoplankton growth (McKnight et al., 1991). Initial carbon budgets for the Taylor Valley lakes indicate

that DOC consumption may be a very important process in the pelagic ecosystem and carbon turnover within these lakes (Priscu et al., 1999). The higher N (relative to C) content and the lack of aromatic character of the fulvic acid in these lakes probably makes them more susceptible to microbial degradation (McKnight et al., 1991).

Another key issue regarding food chain dynamics and ecosystem function in these lakes is how primary producers overwinter when there is no sunlight for ~4 months of the year. A proposed explanation is that mixotrophy, or the alternation between autotrophy (i.e., photosynthesis), when there is light present, and heterotrophy, during darkness, sustains the primary producers in these extreme environments. The production of vegetative resting stages may also provide another overwinter strategy. A series of recent papers tend to support the notion that mixotrophy is a major ecological behavior of microorganisms in these lakes, as was initially hypothesized by Laybourn-Parry (1997). It is clear that cryptophytes within both Lake Fryxell and Lake Hoare can resort to heterotrophy (Roberts and Laybourn-Parry, 1999), and that as much as 31% of their carbon requirements can come from heterotrophy, even in the austral spring when light is present (Marshall and Laybourn-Parry, in review). Mixotrophic ciliates and heterotrophic nanoflagellates are also abundant in these lakes (Roberts and Laybourn-Parry, 1999). Using overwinter automated samplers in Lake Fryxell, McKnight et al. (2000) also have observed evidence of heterotrophic growth of chlorophyte and cryptophyte species. This heterotrophy ranges from particle capture (phagotrophy) to DOC uptake. Because of the stability of the water column and lack of physical mixing due to the ice cover, vegetative cells of algae can maintain their position in the water column in Lake Fryxell throughout the austral winter (McKnight et al., 2000).

There also appears to be little herbivory in these lakes. Priscu et al.'s (1999) carbon mass balance for Lake Bonney suggests that only 4% of the autotrophy is consumed on a yearly basis. This is, however, a lower limit, as loss to rotifer grazing has yet to be determined. The data available indicate that herbivory may be of minor importance in these lakes, as compared to other aquatic systems (Cyr and Pace, 1993).

The protozoan communities of these lakes have also been recently described and their distribution, in part, is related to the chemical and physical structure of the water column (Roberts et al., 2002). It is felt that the protozoan communities in these lakes are likely to suffer from prolonged physiological stress (Laybourn-Parry et al., 2000). These authors found no relationship between mean cell volume and growth rate, suggesting the very low temperatures in the lake environments greatly impact their growth.

Recent work has also demonstrated that virus-like particles (VLP) are abundant in high densities in many Antarctic lakes (Kepner et al., 1998; Priscu et al., 1999; Laybourn-Parry et al., 2001). In a subset of these lakes in the Vestfold Hills in East Antarctica, the VLPs vary with DOC, with higher concentrations in the more saline lakes (Laybourn-Parry et al., 2001). The Taylor Valley lakes also have high VLP concentrations, with virus to bacteria cell ratios ranging from 2 to 141 (Kepner et al., 1998), but this translates to ~1:1 ratio in terms of carbon (Priscu et al., 1999). Priscu (unpubl. data) has further shown that the burst size (i.e., number of lysogenic prophage per bacterial cell) is about 30, indicating a relatively high rate of viral infection. It has been speculated that these VLPs may regulate microbial populations within the

Taylor Valley lakes (Kepner et al., 1998), but it is clear that more research is needed in order to better understand their overall role in ecosystem dynamics and carbon turnover (Priscu et al., 1999). From all these recent studies, it is now certain that the pelagic realm of the MCM lakes, like lakes from other portions of Antarctica, are dominated by microbial loop organisms (Laybourn-Parry, 1997).

From a biogeochemical cycling point of view, one of the most intriguing observations by us in the Taylor Valley lakes is that their respiration to photosynthesis ratio (R:P) is >1 . Both Priscu et al. (1999) and Lyons et al. (2000) have recently pointed out this feature. This is certainly not unusual, in that most lakes, rivers, and many estuaries have this similar feature (del Giorgio et al., 1997; Kemp et al. 1997; Wang and Veizer, 2000). However in the above cases, large amounts of organic carbon are transported from the landscape into these aquatic environments, leading to excess respiration. This is simply not the case in the MCM systems (Priscu et al., 1999), where there is little, if any, organic matter transferred from the landscape into these lakes (Lyons et al., 2000). For example, the total particulate organic carbon (POC) pool in Lake Fryxell ranges between 826 and 1318 kmol, depending on the time of year. Our best estimate of the DOC flux via streams into Lake Fryxell for the 1998–1999 field season is 9 kmol, or from 0.7 to 1.1% of the total available in the lake. Although the POC entering the lake has a relatively low C:N ratio (Fig. 2), demonstrating a source from algal mats, within the streams themselves, the total allochthonous input is not large enough to drive these high relative rates of respiration in the lakes, as previously pointed out by Priscu et al. (1999).

Priscu et al. (1999) have speculated that this “inbalance” in the lakes’ net ecosystem metabolism (NEM; Kemp et al. 1997), with respiration carbon losses exceeding new carbon gains, may be due to some, yet unknown, dynamic process that oscillates temporally between net autotrophy and net heterotrophy. This oscillation may be related to past legacy effects, in that at times of lower lake levels, when ice-covers were lost, and cryconcentration of solutes within the lakes occurred, these systems were net autotrophic systems (i.e., concentration of nutrients to higher levels via cryconcentration and more light input due to the lack of ice cover). In this case, the lakes accumulated organic matter. Now, with increased water input diluting the nutrients within the concentrated hypolimnia, and fresh surface waters so that ice covers can be maintained at 3–5 m thickness, these systems are net carbon respiring ones. This is a very compelling hypothesis, as we now are beginning to comprehend the influence of past conditions on the ecosystem function today. Knowing the temporal frequency of these changes, coupled with our knowledge of the rates of various important biological processes within the lakes today, would allow us to quantify the overall importance of these legacy effects.

CONTROLS ON PRESENT-DAY MAJOR-ELEMENT GEOCHEMISTRY

The chemistry of the surface waters of the three major Taylor lakes (including both basins of Lake Bonney) and that of Lake Vanda, in Wright Valley to the north of TV (from Green and Canfield, 1984), are shown in Table 1. The work of Green et al. (1988) demonstrated that the solute geochemistry of the MCM lakes is a mixture of marine aerosol and weathering products. When the molar ratios of the surface waters of the lakes are compared to that of seawater, subtle variations in the geochemistry of

TABLE 1

Major-Element Geochemistry of MCM Lakes with Seawater for Comparison^a

	Na	Cl	K	Mg	Ca	DIC
Hoare	2.47	2.2	0.27	0.22	0.75	1.72
Fryxell	7.9	7.59	0.54	0.99	1.35	4.68
W Bonney	10.27	11.87	0.36	1.47	1.79	0.91
E Bonney	11.7	14.35	0.38	1.78	2.05	1.41
Vanda	2.68	8.26	0.44	0.96	2.18	0.93
Seawater	481	559	10.5	54.1	10.5	2.11

^aLake Vanda data are from Green and Canfield (1984). All values are in mmol L⁻¹.

these lakes can be observed. For example, Lake Hoare and Fryxell are enriched in Na relative to Cl, compared to marine aerosol (i.e., equivalent of seawater), while Lake Vanda is depleted. The east lobe of Lake Bonney is slightly depleted, while the west lobe is much like that expected for marine aerosol. In fact, with the exception of Ca, SO₄, and HCO₃, this lake resembles seawater in its major solute ratios. This is not too surprising as Blood Falls is a major source of solutes to Lake Bonney, and it resembles cryoconcentrated seawater in its bulk chemistry (Lyons et al., 1999a). Lake Hoare is enriched in Ca, K, Na, HCO₃, and SO₄ with respect to Cl, compared to marine aerosol, while Lake Fryxell is enriched in Ca, K, Mg, and HCO₃. Lake Vanda is enriched in Ca, K, HCO₃, and Cl. These differences in lake surface water geochemistry reflect variations in at least three geochemical processes occurring in the MCM today: the geographic variation in aerosol composition within the valleys; the rate and type of material being chemically weathered in the stream channels; and the variation of dust dissolution occurring on glacier surfaces, as melt water generation occurs.

Although the primary source of major solutes to the landscape of the MCM is from marine aerosol, the geochemistry of the aerosol changes with distance from the ocean, and with elevation (Keys and Williams, 1981; Lyons et al., 2002b) as the marine character of the aerosol decreases. Thus, more inland aerosol has a more stratospheric character with greater amounts of NO₃, and less Cl. This can be observed from our snow pit analysis of the glacier surfaces and within the soluble salts in the soils (Keys and Williams, 1981). Recent investigations of chemical weathering within the stream channels and hyporheic zones of the streams indicate high rates of silicate mineral dissolution (Nezat et al., 2001; Maurice et al., 2002). This work is supported by past, and our more recent, Sr isotopic studies, indicating that much of the Sr entering the lakes is from silicate mineral weathering (Jones and Faure, 1978; Lyons et al., 2002a). Finally, it is now apparent that aeolian-transported dust in the surface of the glaciers can also undergo "weathering" *in-situ*, adding solutes to the initial melt water (Lyons et al., 2002b). These waters can be further modified by biological processes occurring at the glacier surface (Tranter, unpubl. data) and in the streams (Lyons et al., 2002a). Because in TV the primary wind direction is via katabatic winds blowing from west to east (Fig. 1), the greatest abundance of dust accumulates on the western portions of the glacier snouts. Great differences in stream geochemistry have been observed between streams emerging from the eastern and

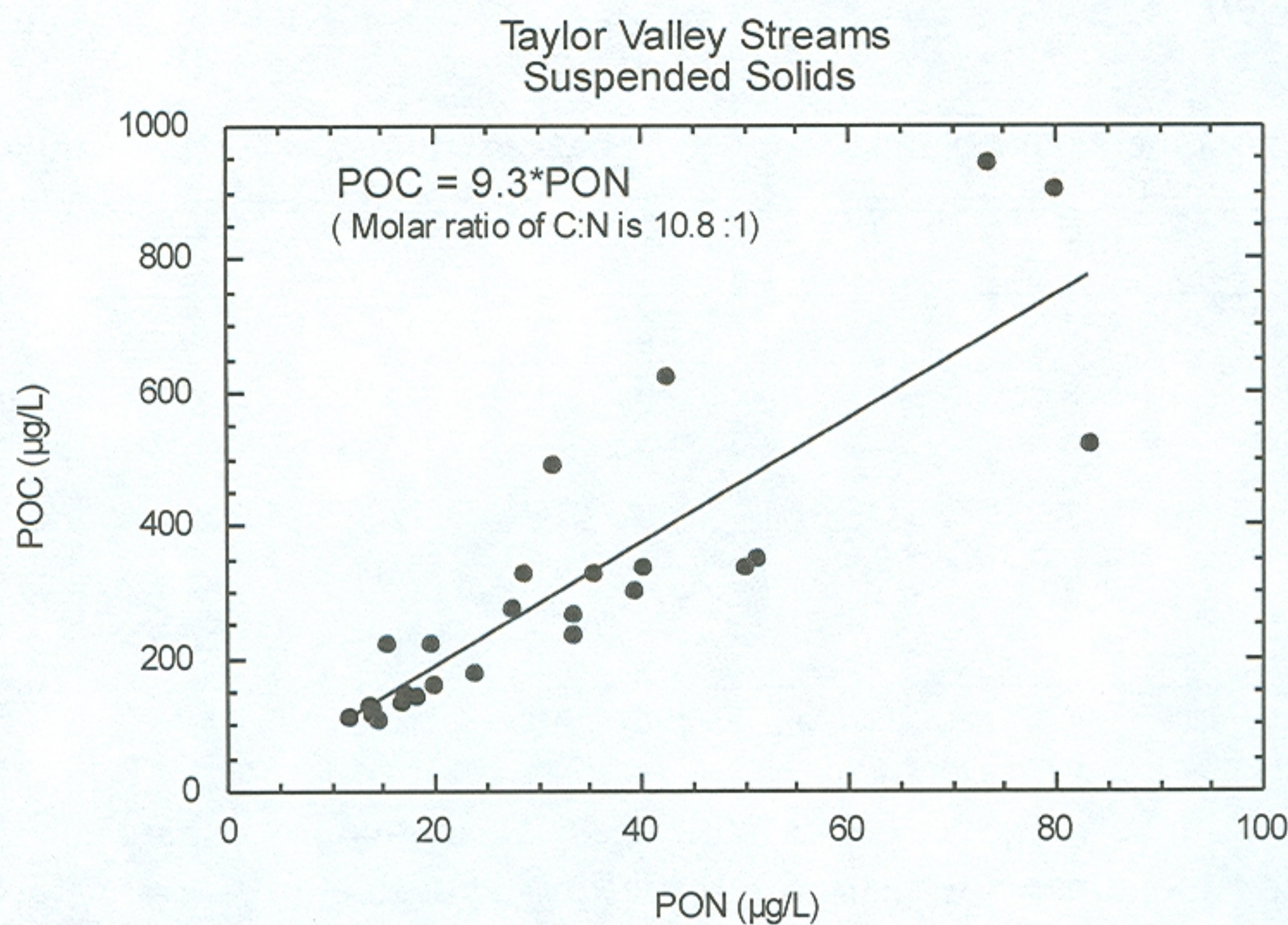


Fig. 2. Plot of particulate organic carbon (POC) versus particulate organic nitrogen (PON) from Taylor Valley streams.

western snouts of the same glacier, with higher solute concentrations in the western ones (Lyons et al., 2002b). Our original thoughts regarding the chemical evolution of these aquatic systems, from glaciers to the lakes, have been modified substantially since the beginning of the MCM-LTER work. Chemical weathering and *in-situ* glacier processes exert important, but heretofore uninvestigated geochemical overprinting on the primary precipitation deposited on the glaciers. We are currently attempting to better quantify the role of these glacier hydrogeochemical processes in a more systematic manner.

BIOGEOCHEMICAL EVOLUTION OF LAKES: COMPARISON TO ARCTIC LAKES

There has been little attempt to compare and contrast lakes of the Arctic to the MCM lakes. Doran et al. (1999) noted that the variation in ice-cover leads to a continuum of lakes in polar regions, from ones having perennial ice cover, such as the TV lakes, to those in the Arctic and Antarctic that lose their ice-covers through portions of the year. They argued that the principle control on this continuum of ice-cover is summer air temperature. Although there are Arctic lakes that do not lose their ice-covers in the summer, the TV lakes are different in that their ice covers are very thick (3–5 m) (Doran et al., 1999). The influence of ice cover and its role in establishing the structure and function of the lake ecosystem has been well documented (Lizotte and Prisco, 1992; Wharton et al., 1993). The ecological impact of the loss of ice covers from the TV is not well known, however. There is little doubt that the biogeochemical and ecological evolution of these systems are greatly affected by the nature of the ice covers.

Recently Engstrom et al. (2000) have evaluated the Holocene evolution of lake systems in the Arctic, as deglaciation has occurred, and lakes have developed on once glaciated landscape. Their results have provided important insights on the coupling of

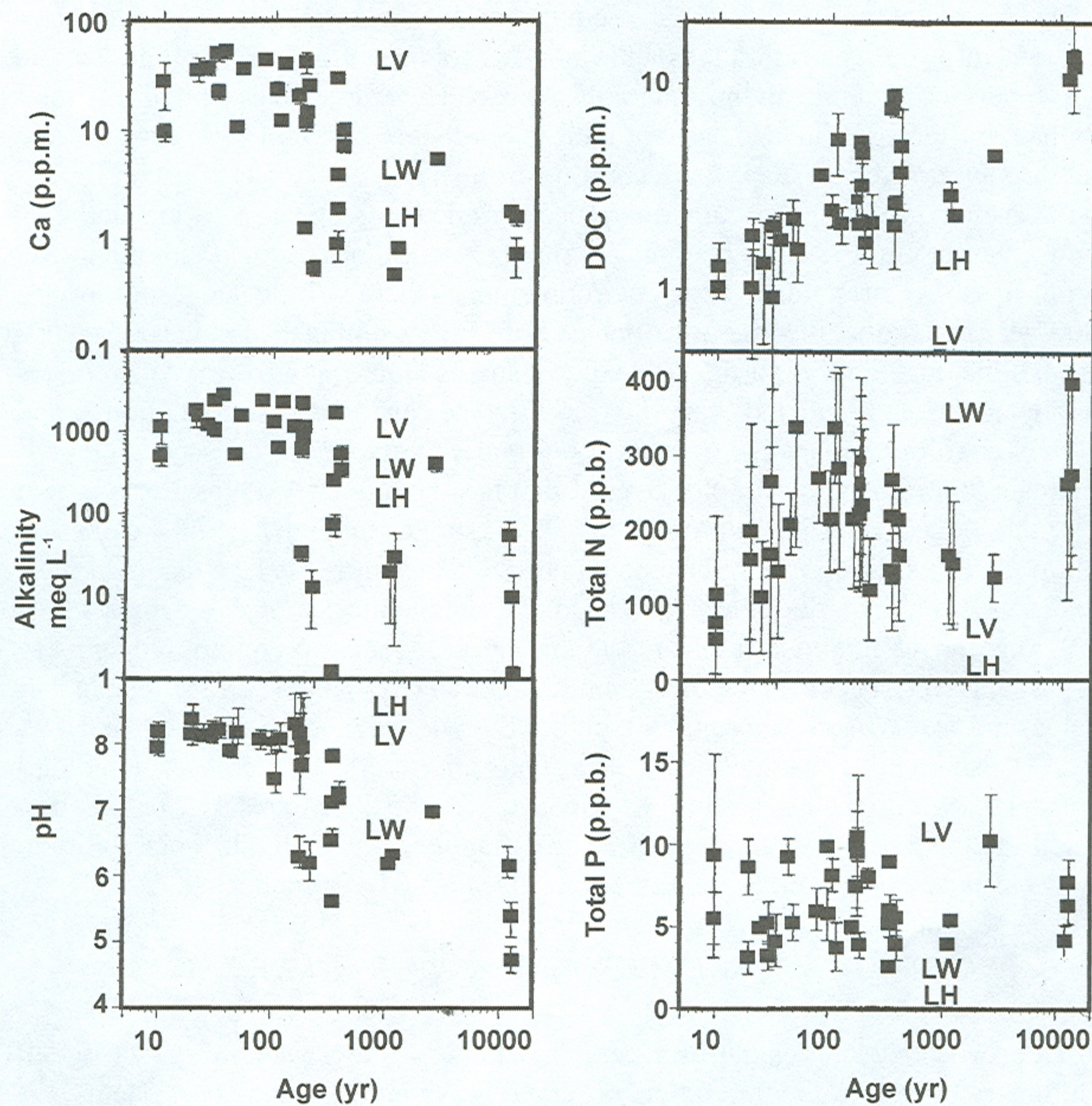


Fig. 3. Concentrations of various dissolved constituents versus age for Arctic Lakes from Engstrom et al. (2000) and the surface waters of Lake Wilson (LW), Lake Vanda (LV), and Lake Hoare, the Victoria Land Coast, Antarctica.

terrestrial and aquatic environments as the newly deglaciated landscapes are populated by boreal lake ecosystems. Because glacier retreat, as in the Glacier Bay, Alaska region, can be well dated, the age of the lakes is well known. Engstrom et al. (2000) have provided a series of plots from these lakes relating the concentrations of various elements/compounds through time (Fig. 3). These plots establish chemical and biological trends during the existence of these lakes. We have plotted chemical data from three lakes from the Victoria Land coast, Antarctica, where we can presently constrain the age of the lakes' surface waters: Lake Hoare, Lake Vanda, and Lake Wilson (~80°S, from Webster et al., 1996). The Antarctic data do not follow all the same trends as the Arctic lakes (Fig. 3). For example, although the alkalinity of the Antarctic lakes are close to what is expected based on the Arctic trends, the DOC data are much lower than expected in the Antarctic lakes. Values for pH and Ca are generally higher in the Antarctic lakes. There is also more variability in the N and P data for the Antarctic lakes.

The lower DOC and higher Ca, alkalinity, and pH reflect the lack of terrestrial carbon input into the Antarctic lakes and more carbonate buffering (through Ca and HCO_3^- input) through time in the Antarctic systems. The Arctic lakes tend to lose their carbonate buffering influence early in their evolutionary history (~500 yrs), as acid input through time eliminates its effects (Engstrom et al., 2000). The constant formation of Ca-rich dust through weathering processes and landscape desiccation, and then its introduction into the lakes may play a much more important role than previously thought in the Antarctic dry valley environments, as there is little suggestion over a ~1000-year period that the role of carbonate buffering is diminished in these systems. This alkaline dust input is particularly significant, as Holocene snow in Antarctica is naturally acidic (Legrand and Mayewski, 1997). The cause for the variation in N and P in the Antarctic systems is not known, but may relate to both landscape and geographical variations. For example, Lake Vanda has the higher P values, but it is also fed by the longest river in Antarctica, the Onyx, suggesting enhanced P weathering input to the lakes. Lake Wilson has the highest N values. It is the lake that is farthest inland, away from a marine source of aerosol. Glaciochemical work has demonstrated that as one moves inland, away from the marine influence, precipitation chemistry changes, and NO_3^- becomes the most dominant anion (Allen et al., 1985). The higher N values in Lake Wilson may suggest a higher flux via the melting of snow/ice. However, it is also possible that these differences in N and P reflect differences in biological processes within the lakes. More work will need to be done to resolve these issues. In addition, the lack of Antarctic lakes of differing ages greatly inhibits our ability to perform analyses as elegant as those that Engstrom et al. have conducted.

EVOLUTION OF LAKE MICROBIOTA: WHAT DO WE KNOW?

In a provocative and insightful paper, Vincent (2000) reviewed our knowledge of evolutionary origins of the microbiota observed in Antarctic aquatic ecosystems. We know that Antarctica continues to receive microorganisms from outside Antarctica and that these consist of a high frequency of cosmopolitan species. The best example of this is the work done on Vostok ice and Lake Vostok ice recently by Abyzov et al. (1998) and Priscu et al. (1999). Vincent (2000) does point out, however, that there is also some evidence of endemism in the limnological environments of Antarctica, especially associated with the more saline lake environments. As more research is done using 16S rDNA, on the various ecological communities, a better assessment of the origin of the organisms within these unusual systems should emerge. However, a number of potentially endemic species of bacteria, fungi, algae, and protozoa have already been identified in Antarctic lakes and soils (Vincent, 2000). What role these endemic species play in the structure and function of these lake ecosystems is a significant unanswered question.

CONCLUSIONS

Over the past nine years, ongoing monitoring and experiments funded through NSF's Long-Term Ecological Research Program have led to a much more detailed understanding of the hydrologic, geochemical, and ecological dynamics of the lakes in Taylor Valley, southern Victoria Land, Antarctica. These lakes are extremely

dynamic systems that respond rapidly to what would be called "subtle" climate variations in more temperate environments. Work has shown that the microbial loop is a major process within these lakes, and the memory of past carbon and nutrient concentrations are important drivers of present-day ecological structure and function within these lakes. Clearly, we have just begun to establish the linkages between the physiochemical changes in the glacier-stream-lake system, and the variation in biological parameters within the lakes. How the ecological system responds to longer-scale climate changes is still not resolved. Although "simple" in organism type, the system itself is far from simple. Our continued quest is to better define the function and structure of these unusual environments and compare and contrast them to more temperate lake systems.

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