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Using paleolimnology to establish baseline conditions for metal contaminants in advance of proposed mining to inform a northern community-led aquatic monitoring program, Tłı̨chǫ Lands, Northwest Territories, Canada.

by

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Abstract

The Marian Watershed Stewardship Program (MWSP), a community-driven aquatic ecosystem monitoring program, was developed by the Tłı̨chǫ Government to address concerns regarding the cumulative impacts of multiple potential stressors. In particular, the MWSP aims to develop methods that will be effective for detecting potential pollution from the proposed cobalt-gold-copper-bismuth NICO mine within Tłı̨chǫ Lands. In collaboration with the MWSP, paleolimnological methods and geochemical normalization are used to establish pre-mine baselines of lake sediment metals concentrations in the Marian River watershed prior to mine development. This baseline framework can be used to assess for pollution from surficial sediment once the mine becomes operational. Stratigraphic sediment metal concentration results from four lakes are normalized to lithogenic and biogenic elements (Al, Ti, OM, C_{org}). The application of normalizing techniques to metals within the stratigraphic record aims to account for natural variation as a result of biogeochemical and physical processes that may affect sediment metals concentrations. Application of this method results in a set of lake- and metal-specific baselines established for four lakes. Results show metal concentrations are substantially higher in lakes on or adjacent to the ore body compared to lakes located in the surrounding granitic bedrock terrane. Temporal variations in the concentrations of many metals of concern are small, which provide values that can effectively serve as baselines for ongoing monitoring. An exception is arsenic, a metalloid of major concern, which increases variably in the latter half of the 20th century. There are multiple possible explanations for this trend, including far-field atmospheric emissions, increase in erosion of arsenic-bearing sources in the lake catchments, and/or post-depositional diagenetic mobilization in the lake sediment profile. Notably, increases in arsenic concentrations also occur in the early part of the past millennium likely indicating the potential for variation in the catchment-derived supply of arsenic to these lakes. Additional studies are required to further characterize processes that cause arsenic variations in these lake sediment records. Variation in sediment metals concentrations on both temporal and spatial scales in this region demonstrate the need for lake-specific baselines for accurate interpretation of contemporary sediment monitoring data. This paleolimnological approach may be may be expanded to other lakes in the region for additional monitoring. This unique opportunity allowed for the development of a well-informed and robust monitoring program, which applies a scientific approach to meet the needs of a northern community initiative.

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Dedication

I dedicate this research to Mona, Jarvis, Richard, Lisa-Marie, and Narcisse, the Tłįchǫ Environmental Monitors I have had the pleasure of working with over the past many years. Thank you for sharing with me, laughing with and at me, feeding me, and pulling me out of the water on many occasions. Masi.

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Chapter 1: Introduction and Research Context

The historic development of extractive industries in the Northwest Territories (NT), Canada, has led to substantial pollution of the terrestrial and aquatic environment (Hocking et al. 1978; Jamieson, 2014, 2017; Thienpont et al. 2016). The term *legacy* is now commonly used to describe the history of pollution from dozens of historic mining operations located throughout the NT, which began in the mid-20th century, and have resulted in environmental problems. These include major land disturbance, on-site contamination from fuels and processing chemicals, and most significantly, extensive metals contamination of the terrestrial and aquatic environment, all of which remain a major concern today. Environmental damage in the NT is best exemplified by the deep and wide-reaching footprint of arsenic (As) contamination from the former Giant and Con gold mines. Located just outside of the City of Yellowknife, these operations generated ~237,000 tonnes of toxic As_2O_3 (INAC, 2010), releasing ~21,000 tonnes through aerial emissions to the surrounding landscape. The vast majority of this As_2O_3 is now stored in derelict mine shafts beneath the former mine site, subsequently requiring hundreds of millions of dollars (CAD) in remediation costs from the federal government (INAC, 2010). Because mining and resource extraction remain the economic lifeblood of the NT today and into the future, and in response to the environmental, social and economic impacts of mining pollution, present Federal, Territorial, and regional governments have implemented strict policy in regards to mitigating the environmental impacts from mining operations and resource development.

Traditional land users are highly aware of the cumulative impacts of both industrial pollution from mining activities and the broad scale impacts of climate change on their traditional Lands. First Nations groups, such as the Tłı̨chǫ Community located to the northwest of Yellowknife, are acutely sensitive to these stressors that have impacted their traditional livelihoods and culture identity, which are tied to the land and water. In the past twenty years, environmental policy and legislation inclusive of Traditional Knowledge has been prioritized, and consultation and social and cultural impact assessments are required prior to resource development. Importantly, as the NT moves towards finalizing Devolution (*Northwest Territories Land and Resources Devolution Agreement*, 2013), the process of gaining governmental independence from the federal government, major land claims and self-governance treaties, such as the Tłı̨chǫ Agreement (2003), are being signed and negotiated between the federal and provincial governments and First Nations groups. The Tłı̨chǫ Agreement, signed in 2003 and ratified in 2005, is a precedent-setting land claim and self-governance treaty between the Federal / Territorial and Tłı̨chǫ leadership which gives legal ownership of 39,000 km^2 of surface and subsurface lands, self-governance, and expansive rights within Tłı̨chǫ Traditional Lands. Exempt from the lands claim are small areas of pre-existing mineral rights leases, such as the NICO deposit, and several highly contaminated sites from former mining operations including the infamous Ray Rock uranium mine and Colomac mine, which fall under federal jurisdiction with a legal obligation of environmental restoration by the federal government (INAC, 2010)

Commencing with the signing of the Tłı̨chǫ Agreement and self-governance, under an ethos of environmental protectionism, the Tłı̨chǫ Government formed the Department of Lands and Cultural Protection. Of primary concern were the impacts of resource development and climate change on the wildlife, land and water the Tłı̨chǫ culture and livelihoods depend on. During the past decade, several monitoring programs have been initiated by the Tłı̨chǫ aimed at assessing and protecting caribou, fish, and aquatic ecosystems. In 2013, the Marian Watershed Stewardship Program (MWSP) was established. The MWSP was formed in response to community concerns regarding the observed impacts of climate change on the watershed and, to a larger degree, the potential impacts of the development of the Fortune Minerals NICO mine, a sizable sulfide ore deposit with economically significant cobalt, bismuth, gold and copper reserves. Located in the south-central Marian River watershed, a large and culturally important area of Tłı̨chǫ Lands, the development of the NICO deposit poses major concern over issues of metals contamination, particularly As, to the aquatic and terrestrial environment as well as the impacts of lands disturbance. The MWSP aims to establish natural baseline conditions of the aquatic environment through the sampling of fish, water and sediment prior to mine development. These baseline data can then be used to assess for pollution and pollution-related impacts once the mine becomes operational. Here, a northern community initiative has incorporated a scientific approach to meet their monitoring needs, understanding the value of data from a western scientific and legal framework. The inclusion of science into a northern community led program demonstrates the strengths of combining two knowledge types, traditional Tłı̨chǫ knowledge and science, and demonstrates a progressive working paradigm for science in a northern community.

In addition to those initiated independently by communities such as the Tłı̨chǫ, the application of aquatic monitoring programs has become standard legal operating procedure required as part of the initial environmental assessment prior to resource development as well as for continuing operations (Roach & Walker, 2016). In the wake of major historic contamination, all three levels of government have legislation and policy aimed to prevent the large-scale contamination of previous industrial development such as the Federal *Fisheries Act* (1985) and *Canadian Environmental Assessment Act* (2012) and the NT *Waters Act* (2012). In addition, the Mackenzie Valley Land and Water Board, which oversees resource development applications and operations to mining and industry, employs regulations aimed at ensuring both environmental science and Traditional Knowledge are applied to assess cumulative impacts and environmental monitoring efforts in the NT. From Part 6 of the *Mackenzie Valley Resource Management Act (1998)*:

> *146. The responsible authority shall, subject to the regulations, analyze data collected by it, scientific data, traditional knowledge and other pertinent information for the purpose of monitoring the cumulative impact on the environment of concurrent and sequential uses of land and water and deposits of waste in the Mackenzie Valley.*

With the intention of creating an inclusionary process, respectful of the environmental and cultural integrity of aquatic and terrestrial ecosystems, environmental monitoring programs are continuing to be developed and improved to assess for the cumulative impacts of multiple stressors such as mining and climate change from traditional knowledge and scientific perspectives.

Within this multidisciplinary and multiple knowledge-based approach to monitoring, scientific research, which informs an understanding of natural processes and conditions, has a unique opportunity to undertake valuable initiatives that meet the goals of researchers and the needs of northerners.

Aquatic monitoring programs, such as the MWSP, require an informed knowledge of the aquatic environment, including biological, geochemical, and physical conditions in order to adequately design and implement a sampling program which is sufficiently capable of identifying potential changes due to industrial and climate change impacts (Reuthers, 2009; Dowdeswell et al. 2010). Monitoring practitioners need a thorough understanding of the current research and theory of (bio)geophysical processes to inform the design and implementation of effective monitoring programs. Monitoring, as a systematic process-based practice, is not directly research but requires research initiatives to establish best practices. In the setting of the MWSP, and elsewhere in the NT, collaboration between northern communities and scientific researchers provides a leading-edge approach that is mutually beneficial as both parties seek to understand the function and processes of the natural environment and provide informed solutions through knowledge generation and continued monitoring.

The development of aquatic monitoring programs that utilize a variety of techniques and methodologies is critical to understanding the effects of industrial development and climate change (Smol, 1992, 2008; Reuther, 2009; Dowdeswell et al. 2010; Wiklund et al. 2014). In addition to water sampling for various parameters, sediment quality assessment is an integral component required to understand complex aquatic systems (Reuther, 2009). As sediment is a complex matrix of inorganic and organic, and biotic and abiotic material transported and accumulated from the atmosphere, terrestrial, and aquatic environments, it plays a key role in understanding a breadth of processes and conditions on a landscape scale (Smol, 1992, 2008; Reuther, 2009; Schindler, 2009). In order to accurately assess for environmental change due to human impacts, there must be an adequate knowledge of baseline conditions representative of the range of natural variation (Ford, 1989; Smol, 1992; Kersten & Smedes, 2002; Dowdeswell et al. 2010). However, most monitoring programs which incorporate sediment sampling, particularly those in the NT, typically operate on very short time frames and are thus unable to ascertain natural variation in sediment conditions from short-term and often sporadic sediment sampling programs. This paucity of long-term data can be resolved by incorporating paleolimnological approaches to establish baselines of sediment conditions. Sediment cores taken from lakes are natural archives of materials, which reflect landscape processes and changes, allochthonous matter, as well as internal processes, accumulating over time. As such, sediment cores can be used to assess natural variation and identify historic contaminant pollution, including metals (Cooke et al. 2007; Wiklund et al. 2014; Boyle et al. 2015). Below, the application of paleolimnology to assess contamination is briefly reviewed and the behaviour of select metals within the sediment record is highlighted.

Literature Review: Relevant Previous Research

Metals within the Lake Sediment Record

Metals and metalloids are ubiquitous within the environment. Lake sediment metals concentrations will be reflective of weathering of the parent material, potential biogeochemical interactions in soils and lakes (Reuther, 2009; Borch et al. 2010; Boyle et al. 2015). The addition of anthropogenic-derived metals to a landscape and subsequent lake sediment, defined as contamination, adds an additional complexity as these contaminants become constituents within the sediment strata either remaining stable since deposition or being enacted upon and incorporated into sediment biogeochemical processes (Couture et al. 2010; Jamieson, 2014; Outridge & Wang, 2015; Galloway et al. 2015, 2018). Sediment may act as both a sink and source of metals to the aquatic environment dependent on the solubility, redox conditions, affiliation with organic matter (OM), and speciation of the metal (Canavan et al. 2007; Boyle et al. 2015). Metals will preferentially bind to the fine sediment fraction, organic matter, and Fe-Mn oxides/oxyhydroxides and organic complexes bound to clay particles (Loring, 1991; Loring & Rantala, 1992; Sanei & Goodarzi, 2006; Canavan et al. 2007; Borch et al. 2010; Couture et al. 2010; Boës et al. 2011; Outridge & Wang, 2015). Although it has been established that Fe-Mn (hydrox)oxide coating on sediment will bind many metals under various redox conditions, which often remain stable through the sediment record, recent studies are now elucidating the complex interactions between metal(oid)s and OM as both a contributor to diagenetic redox processes and accumulators of metal(oids). Recent findings suggest that it is not necessarily the quantity of OM available to the sediment, but rather the type and origin of OM that may contribute to mobility within the sediment record (Sanei & Goodarzi, 2006; Eiche et al. 2017; Galloway et al. 2018).

Paleolimnological Approaches

Paleolimnological studies have been widely used to identify periods of resource extraction through human history, from the multi-millennial reconstruction of Andean metallurgical activity by Cooke et al. (2007, 2008), which develops a regional perspective on atmospheric metals pollution from lake sediment cores of mountain lakes, to the now immense body of work surrounding global atmospheric Pb emissions which has led researchers to understand atmospheric pathways and sources of global contaminant transport (Shirahata et al. 1980; Perez-Rodriguez et al. 2018). Although these studies are crucial to understanding anthropogenic impacts on large scales and magnitudes, researchers and monitoring practitioners require additional site-specific knowledge and baseline frameworks to assess for pollution and environmental change. In order to effectively assess contemporary sediment for pollution, an understanding of baseline conditions, defined here as the pre-industrial natural range of variation, must be developed. Paleolimnological approaches offer an effective solution for the assessment of historic environmental contamination when long-term records are unavailable (Smol, 1992, 2008).

Distinguishing anthropogenic and natural variation of metals concentrations is essential for contemporary monitoring of sediment (Loring, 1991; Kersten & Smedes, 2002; Dowdeswell et al. 2010). Geochemical normalizing agents are commonly applied to account for differences in sediment characteristics such as grain size and the related effects of transport, erosional variation, and heterogeneous sedimentary environments. Because metals will preferentially bind to the fine sediment fraction, typically defined as <63 um, lithogenic normalizing agents, also referred to as *passive* normalizers, are used to account for changes in grain size and the subsequent processes of transport and erosional variation. This technique is described by Loring (1991), who recommends the use of either aluminum (Al) or lithium (Li) as lithogenic normalizing agents. The rationale is that Al or Li is incorporated into the sediment particle matrix in silicates and fine particles at the same ratio as the metal of interest bound either to (hydrox)oxide coatings on fine grains or within the mineral itself. The use of geochemical normalization is further developed by Kersten & Smedes (2002), who describe the use of linear regression models, or two-component linear mixing models, between metals and normalizing agents, or co-factors. Kersten and Smedes (2002) also identify the correlation between organic matter and metals, highlighting that although OM may be a reactive constituent, it is advocated that OM be used as a normalizer where applicable in monitoring initiatives. Importantly, Kersten & Smedes (2002) advocate for the development of site-specific baselines as opposed to comparison to crustal compositions, using multiple normalizing agents, in the interpretation of temporal data in sediment cores in order to accurately assess monitoring data. Boës et al. (2011) further explore the selection criteria of lithogenic normalizing agents. They assessed Ti, Zr, Al, and Rb, and concluded that a combination of all four be used when possible to account for changes in normalizer-metal relationships within the local environment. Dated sediment cores and geochemical normalization techniques allow for the formation of baseline data in which background sediment metal concentrations prior to industrial development can be assessed, establishing a range of pre-industrial conditions by which to compare modern sediment concentration values (Loring, 1991; Kersten & Smedes, 2002; Wiklund et al. 2014). From linear regression relationships described by both Loring (1991) and Kersten & Smedes (2002), 95% prediction intervals (PI) can be applied to assess for pollution. Values above this PI may be considered evidence for potential pollution. In addition, the use of enrichment factors (EF), which calculate an enrichment value above the baseline relationship, can be used to quantify the magnitude of potential pollution.

Geochemical normalization techniques, as described above, have been used in several studies to assess for metals pollution. Wiklund et al. (2014) evaluated pollution trends from river sediment data collected by a regional monitoring program using sediment cores taken from flood-prone lakes in the Peace-Athabasca Delta. Pre-industrial baselines from these lakes showed no influence of contamination from contemporary river sediment when compared to the pre-industrial baselines. MacDonald et al. (2016) applied geochemical normalization to the sediment record of a lake with known flood history in the Slave River Delta to assess for metal contaminants arising from oil sands development in northern Alberta. Although no evidence of oil sands related pollution was found, an acute atmospheric As pollution signal from was detected and linked to corresponding Giant Mine operations. Lintern et al. (2016a, b) effectively identify historic sources and pathways of metal(oid) contamination from storm and floodwater to an Australian wetland using geochemical normalizing approaches. In addition to identifying the mechanisms and history of contamination, Lintern et al. (2016b) also use paleolimnological records to establish site-specific remediation targets based on established pre-industrial baselines. These studies demonstrate the ability of paleolimnological approaches to inform resource management and monitoring.

In the NT, the majority of paleolimnological research has focussed on quantifying the impacts of intensive As pollution from Giant and Con mines with studies aimed to understand the range and fate of As_2O_3 and the toxicological impacts on aquatic ecosystems. Because of the extent and magnitude of As pollution in the area surrounding Yellowknife, the body of research surrounding the impacts of As on the aquatic environment is enormous. Thienpont et al. (2016) report a multi-trophic level response to As contamination within Pocket Lake upon the onset of Giant mine operations. The collapse of algal, zooplankton, and macroinvertebrates is due to high levels of As within the sediment and water. Although sediment concentrations of As have returned to background conditions, As concentrations within the water remain highly elevated due to the solubility of As_2O_3 and dissolution from the sediment. As such, no indication of ecological recovery has occurred. The persistence of As pollution to surface sediment and waters 65 years after Giant mine emissions began have major implications to contemporary aquatic ecosystem health (Galloway et al. 2015; Thienpont et al. 2016; Galloway et al. 2017). The recent study by Schuh et al. (2019) exemplifies the range of complex interactions which influence sediment As concentrations in Long Lake, a site that received substantial As from aerial emissions. Sediment cores taken from multiple locations of various depths demonstrated a range of As profiles determined by redox conditions and sediment quality. Sediment As concentrations were highest within the deepest point of the lake due to focussing of fine grained As_2O_3 particulate. Substantial spatial heterogeneity in As concentrations within a lake illustrate important considerations in the selection of appropriate monitoring locations.

Because As contamination from the development of the NICO mine is a major concern, the MWSP requires detailed knowledge of pre-industrial As concentrations and the environmental conditions that influence its natural temporal and spatial variation. Seen from the brief foray into the literature surrounding the complexity of As contamination to the aquatic environment from Giant mine emissions, an understanding of the basic concepts regarding As in the aquatic environment is needed to inform monitoring and assessment of sediment in an area abundant in natural As.

Controls on Arsenic Behaviour: Redox and Organic Matter

Arsenic is a complex anionic metalloid. The most common natural source of As to the environment is from the erosion of arsenopyrite and other As-bearing minerals (Smedley & Kinniburgh, 2002). Anthropogenic sources of As to the environment are often a result of mining and processing of refractory ores, combustion of coal, and the use of arsenic-based compounds in wood preservation (Smedley & Kinniburgh, 2002). In soils and sediments containing both geogenic and anthropogenic sources, its toxicity within the environment is dependent on concentration, speciation, and state (Smedley & Kinniburgh, 2002; Borch et al. 2010). Arsenic can be highly mobile within sediment, as well as groundwater environments, via diagenetic processes. Under oxic conditions, As will readily bind to Fe-Mn oxide/(oxy)hydroxides on sediment particles, concentrating in the uppermost strata of sediment or groundwater environments (Smedley & Kinniburgh, 2002; Borch et al. 2010). When or if conditions become anoxic, As will mobilize through dissolution to the surrounding pore water and upper water column (Martin, 2002; Smedley & Kinniburgh, 2002; Bauer & Blodau, 2005; Couture et al. 2008, 2010; Borch et al. 2010). Like other metal(oids)s, organic matter plays a critical secondary role in the mobility, cycling, and toxicity of As (Smedley & Kinniburgh, 2002; Borch et al. 2010; Eiche et al. 2017). Under reducing conditions, OM may be an electron donor, further enhanced by microbial reduction of OM and the formation of complexes with humic complexes, leading to enrichment in portions of the organic fraction but also leading to As dissolution from oxide/(oxy)hydroxides (Smedley & Kinniburgh, 2002; Bauer & Blodau, 2005; Couture et al. 2008, 2010; Borch et al. 2010; Jamieson, 2014; Lawson et al. 2016; Eiche et al. 2017). Thus, As may translocate through many different states within the aquatic environment through dissolution and precipitation, in both solid and aqueous phases, based on redox conditions and OM availability.

Despite extensive As contamination from industrial processes around the world, geogenic As poses a greater hazard to human health internationally due to high concentrations within groundwater aquifers in densely populated regions (Mukherjee et al. 2008; Alam et al. 2010; Lawson et al. 2016). The most notable regions of high geogenic As concentrations are within aquifers of Bangladesh and the Bengal Basin, Cambodia, and Vietnam, where hundreds of millions of people are affected by toxic levels of As in shallow groundwater aquifers. Again, the determining factors affecting the mobility and toxicity of As are changes in redox conditions, in this case the availability of oxygen with changing hydrological conditions, and the quantities and sources of OM within and to the aquifers (Mukherjee et al. 2008; Alam et al. 2010). Within these regions, accelerated demand for water resources from rapid population growth and industrial development have led to a reduction in the water table of primarily shallow aquifers and have impacted rates of groundwater recharge and percolation (Mukherjee et al. 2008; Alam et al. 2010; Lawson et al. 2016). With a reduction in water table leading to changes in aerobic conditions, stimulation of microbial reduction of OM at various depths can cause an increase in As to these sediments which may mobilize through dissolution to the water table (Alam et al. 2010; Pi et al. 2015; Lawson et al. 2016; Eiche et al. 2017). Recent work by Eiche et al. (2017) has identified significant interactions between the type and source of organic matter and mobility of As within aquifers, citing definitive linkages between aquatically produced organic content within clays and an increase in microbial reduction, leading to major enrichment in this strata which may contaminate the affected region of the aquifer through dissolution.

Although a vast amount of research has been done on As contamination of shallow aquifers, many of the key relationships occurring among OM, redox activity, and microbial degradation in groundwater can be applied to the sediment column in lakes, especially those which cycle through oxic/anoxic states. It can be theorized that these findings may be in line with Sanei & Goodarzi (2006) or Eiche et al. (2017) in which aquatic-derived OM complexes, which are more labile than terrestrially-derived OM, can bind to clay and fine particles. This can result in increased metals concentrations, in this case As, in sediment and water through both the binding to organic complexes and also reduction and dissolution by microbial reduction of this labile organic matter and desorption.

Experiment-based research by Bauer & Blodau (2006) demonstrated that under abiotic conditions, the addition of dissolved organic matter (DOM) to As contaminated sediments resulted in the desorption and mobilization of As bound to Fe-oxides of sediment leading to dissolution and an increase in dissolved As concentrations. This demonstrates the simple kinetic effect of DOM on As mobility. In studies by Martin & Pedersen (2002, 2004), an increase in aquatic productivity, inferred from an increase in planktonic diatom species due to increased nutrient supply and improvements in post-mining water quality, led to an increase in As concentrations to the surface sediment and aqueous solution. This trend continued over time as aquatic productivity increased, so too have sediment As concentrations. This increase in As is attributed to enhanced mobility within the sediment accelerated by the increase in microbial reduction of autochthonous organic material in the upper strata. Recent work by Galloway et al. (2018) further ties the previous research together in the NT, identifying the role of autochthonous labile organic matter in mediating the persistence of elevated As through the influence of microbial reduction and the binding and formation of complexes to OM substrate. With climate warming predicted to increase carbon flux to the aquatic environment and increase aquatic productivity in the NT (Thienpont et al. 2013; Vonk et al. 2013; Abbot et al. 2018), the increase of labile organic matter associated with this autochthonous production may further enhance and mediate As mobility, from both anthropogenic and geogenic sources.

Moving Forward: Applying Research Theory to Monitoring

From this brief literature review, the complexities of metals geochemistry in the aquatic environment are evident, particularly concerning As geochemistry within lake sediment. An applied monitoring approach must be well informed of the theoretical research required to understand these complexities and challenges. The application of geochemical normalization requires site-specific knowledge (Kersten & Smedes, 2002) and a thorough understanding of the pre-existing biogeochemical and physical conditions and processes. This knowledge base will help inform both the monitoring approach and the interpretation of data from sampling initiatives. Monitoring programs such as the MWSP require a strong knowledge foundation in order to effectively assess for mining-related pollution. Due to the posed risk of As contamination, as well as other metals, to the surrounding watershed, a thorough understanding of the pre-industrial biogeochemical and physical conditions that influence metals concentrations in monitoring locations is essential for baseline formation and continued monitoring.

Objectives

The MWSP is a unique community-led initiative that incorporates scientific monitoring approaches with Tłı̨chǫ knowledge of the Marian River watershed. The collection of surface sediment is currently an integral part of the sampling design. However, as the development of the NICO mine draws closer, the few years of sampling data at various locations are not sufficient to constitute an effective baseline. As invited researchers into this collaborative initiative, the objective of this research is to strengthen this monitoring program by establishing baseline sediment metals concentrations using sediment cores collected from lakes throughout the Marian River watershed to develop a robust dataset to inform future assessment of sediment quality. The use of paleolimnological methods, including geochemical normalization, is employed to develop lake-specific metals baselines prior to mine development that represent the range of natural variation in sediment metal(oid) concentrations. Baselines are developed using multiple normalizing agents to establish lake- and metal-specific relationships representing specific geological and biogeochemical conditions. This framework can then be used by the MWSP to assess for pollution through continued surface sediment sampling at these locations.

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Chapter 2: Research Manuscript for Submission.

Title.

Using paleolimnology to establish baseline conditions for metal contaminants in advance of proposed mining to inform a northern community-led aquatic monitoring program, Tłı̨chǫ Lands, Northwest Territories, Canada.

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Introduction

Industrial resource extraction in the Canadian North has typically been developed prior to or in absence of adequate environmental monitoring programs, which are needed to assess pollution. Consequently, a decades-old legacy of mining operations in the Northwest Territories (NT) exists, which has driven economic and social development, but which has also had significant and often catastrophic impacts on the aquatic environment due to land disturbance and intensive metals pollution from aerial emissions, tailings, and effluent discharge (Hocking et al. 1978; Jamieson, 2014; Thienpont et al. 2016; Gavel et al. 2018). The extraction of metal ores at former mining operations has led to extensive on-site and point source metal(oid)s contamination at many locations throughout the NT including Rayrock (uranium), Tundra (arsenic), Colomac (arsenic/cyanide), Discovery (arsenic/cyanide/mercury) and most notoriously, Giant and Con gold mines (arsenic/cyanide/sulphur/mercury) (INAC, 2010). Giant mine, located a few kilometers north of Yellowknife, was in operation from 1936-1999 and generated 237,000 tonnes of arsenic trioxide (As_2O_3), the most soluble and toxic form of arsenic, through extraction and processing of gold ore from arsenopyrite (INAC 2007; Plumee & Morman, 2011; Galloway et al. 2015). A total of ~21,000 tonnes of As_2O_3 were emitted to the surrounding landscape and the remainder was stored in derelict mine shafts beneath the former site and tailing ponds (INAC, 2007; Galloway et al. 2015). These operations have left not only substantial environmental pollution, but also burdened the Canadian Federal government with billions of dollars in clean-up and remediation costs (AANDSI 2018; Jamieson, 2014), and created an atmosphere of distrust with local and First Nations residents. Continuing issues and concerns surrounding the extent and severity of Giant Mine pollution (INAC, 2018; Palmer et al. 2016; Galloway et al. 2016) as well as contemporary Alberta Oilsands operations for example (Dowdeswell et al. 2010; Schindler, 2010; Kurek et al. 2013; Wiklund et al. 2014), exemplify the major difficulties in attempting to assess pollution post-development.

In response to previous mining pollution, and to address ongoing mining activities and required restoration standards, the implementation of aquatic monitoring programs has become a legally required process to assess aquatic environments for industrial-related impacts (Mackenzie Valley Resource Management Act, 1998; Roach & Walker, 2016). Additionally, pressure from local First Nations and Inuit groups have resulted in a growing number of inclusionary environmental policies and legislation that mandate the application of monitoring programs aimed to address the cultural, economic and ecological issues stemming from past environmental degradation in the NT (Mackenzie

Valley Resource Management Act, 1998; GNWT Waters Act, 2014; Canadian Environmental Assessment Act, 2012; Fisheries Act [MMER, Part 2, section 7] 2018).

The assessment of lake and river sediment quality is an integral part of aquatic contaminant monitoring programs (Reuther, 2009). The composition of deposited sediment material is a reflection of both autochthonous processes and allochthonous sources. Allochthonous constituents, both natural and contaminants, are transported from catchment erosion, and fluvial and atmospheric pathways, with deposition of these materials into the sediment reflecting the energy within the system (Kersten & Smedes, 2002; Outridge & Wang 2015; Blais et al. 2017). Contaminants within sediment may be transported from both regional and global sources, especially through atmospheric deposition. Sediments, particularly the fine grained and organic fractions may have a high binding capacity to metal(oid)s and compounds making them effective sinks for both natural constituents and anthropogenic contaminants (Kersten & Smedes, 2002; Kurek et al. 2013; Cooke & Bindler 2015; Galloway et al. 2015; Outridge & Wang, 2015). In addition, the sampling of sediment is simple and multiple samples may be taken within a location to quickly develop an understanding of spatial variation and transport mechanism of metal(oid)s and contaminants. Because of these reasons, the analysis of sediment is very useful to monitoring programs aiming to assess pollution.

Unfortunately, because monitoring programs are often initiated after the development of industrial projects or as part of a mandated short-term prior assessment, natural pre-development baseline conditions representing the range of natural variability often remain unknown, inhibiting the ability to accurately identify industrial pollution (Kersten & Smedes, 2002; Bowman & Somers 2005; Hawkins et al. 2010; Wiklund et al. 2014). In addition to this paucity of data identifying temporal variability, data that are available may also be inadequate for baselines as the natural processes which deliver and mediate metals to the aquatic environment are being rapidly altered by climate change. Particularly in the NT, this includes increasing trends in slumping, permafrost thaw and nutrient release, forest fires, increases chemical weathering, and increases and changes to aquatic productivity (van Griethuysen et al. 2005; Kokelj et al. 2013; Abraham et al. 2017; Abbot et al. 2018; Galloway et al. 2018; Gibson et al. 2018; Lehnherr et al. 2018; St. Pierre et al. 2018; Wauthy et al. 2018; Zolkos et al. 2018). These changes may accelerate the delivery and cycling of metals to the sediment as well as re-mobilize historically deposited contaminants from the catchment landscape, further complicating our ability to comprehend and interpret short-term monitoring data (Johansen et al 2003; Blais et al. 2004; van Griethuysen et al. 2005; Abraham et al. 2017; Lehnherr et al. 2018).

The application of paleolimnological approaches allows for the establishment of baseline pre-industrial sediment metal concentrations, which enables anthropogenic pollution to be distinguished from natural variation. Sediment cores are stratigraphic archives of deposition history incorporating natural and anthropogenic material including metals and contaminants (Smol, 1992, 2008; Kersten & Smedes, 2002). The use of geochemical normalization techniques applied to the stratigraphic record of lake sediment cores can be used to establish baseline metals concentrations representative of the range of natural variation (Kersten & Smedes, 2002; Loring, 1991). Metal concentrations that exceed the baseline range of natural variation, either within the sediment record or from future surface sediment sampling, may be assessed for potential anthropogenic pollution. Normalizing sediment metals concentrations to lithogenic elements such as Al, Ti, or Li can account for the effect of grain size on these trace metal concentrations as well as geologic heterogeneity within a landscape (Loring, 1991; Loring & Rantala, 1992; Kersten & Smedes, 2002; Boës et al. 2011; Wang et al. 2015). Additionally, organic matter (OM) and organic carbon (C_{org}) may be alternately used as a normalizers to account for those metal(oid) concentrations strongly associated to the organic fraction through the formation of complexes and biological processes within the sediment column (Loring & Rantala, 1992; Kersten & Smedes, 2002; Wang et al. 2015). Without the use of normalization and detailed paleolimnological assessment of the stratigraphic record, increases in future sediment metal concentrations may be falsely interpreted. The use of geochemical normalization to assess for anthropogenic pollution in northern aquatic environments has been successfully applied by Wiklund et al. (2014, 2017) to assess for contaminants in river sediment transported over a floodplain landscape and to assess and quantify aerial deposition of pollutants from industrial point sources. The application of geochemical normalization by MacDonald et al. (2016) allowed for the identification of potential Giant mine arsenic pollution from a lake sediment record in the Slave River Delta. Lintern et al. (2016) successfully used geochemical normalization in conjunction with hydrological records to identify historic sources and pathways of pollution to inform storm water management strategies. These previous studies have focussed primarily on identifying pollution from single study sites after mining operations have initiated. With the continuing development of natural resources in the NT, particularly mining, there is much opportunity to develop and incorporate paleolimnological baselines into aquatic monitoring programs prior to future extraction operations.

Tłı̨chǫ Lands occupy 39,000 km^2 in the central NT (Figure 1). With the signing of the Tłı̨chǫ Agreement, a precedent-setting land settlement and self-governance treaty in 2005, the Tłı̨chǫ government has full legal surface and subsurface ownership of Tłı̨chǫ Lands. Directed by an ethos of environmental protection and in response to community concerns about mining development and climate warming impacts, the Tłı̨chǫ Government established the Marian Watershed Stewardship Program (MWSP), which aims to monitor the aquatic ecosystem through fish, water, and sediment sampling. Having experienced the long-lasting implications of uranium contamination from the historic Ray Rock mine within the Marian River watershed (INAC, 2010), the Tłı̨chǫ community are particularly concerned with the future development of the NICO project, a proposed Co-Au-Cu-Bi mining operation located in the south-central region of Tłı̨chǫ Lands within the Marian River watershed (Figure 2). Conducted in full collaboration with the Tłı̨chǫ Government, this research applies paleolimnological methods to establish and provide sediment metal baselines for multiple lakes for use by the MWSP prior to the NICO mine development. Continued monitoring of surface sediment at these locations can then be used to assess and identify potential pollution using these baselines once the mine becomes operational. This unique opportunity allows for the development of a well-informed and robust monitoring program, which applies a scientific approach to meet the needs of a northern community initiative. To this author's knowledge, this research may be the first to provide and incorporate critical paleolimnological baselines into an aquatic monitoring program prior to industrial development.

Study Area

The Marian River watershed is located entirely within Tłı̨chǫ Lands between Great Bear and Great Slave lakes (Figure 1). The Marian River, fed by the Emile and Le Martre rivers, flows south draining a watershed of 23,608 km^2 into Marian Lake (GNWT ENR, 2015), a sub-basin of the North Arm of Great Slave Lake. The climate of the region is typical of the continental sub-arctic with long, cold winters and short, warm summers.

The Marian River watershed contains two distinct physiographic regions including the Taiga Shield to the east and northeast and the Taiga Plains to the west and southwest with the Marian River delineating the two. The Taiga Shield in this region is characterized by granitic bedrock with sparse vegetation in the form of mostly black spruce alder and shallow soils in low-lying depression areas underlain by discontinuous permafrost (GNWT ENR, 2008). The Taiga Plains are of low relief and characterized as boreal wetland of sedge and black spruce consisting primarily of peatlands underlain by discontinuous to continuous permafrost (GNWT ENR, 2008; Wolfe et al. 2017). The surficial geology is characterized by fine clay-rich glaciolacustrine sediment, a remnant of Glacial Lake McConnell (Wolfe et al. 2017).

The four study lakes (Grid, Nico, Peanut, and MW01) are located in the south-central region of the Marian River watershed, ~175 km northwest of Yellowknife and ~85 km north of the Tłı̨chǫ community of Behchokǫ̀ (Figure 1). The study area is located in the Great Bear Magmatic Zone (GBMZ) geologic region. Grid, Nico, and Peanut lakes are located on and adjacent to the NICO deposit, while MW01 is located ~2 km northeast of the deposit (Figure 2, 3). The NICO deposit, hosted within the Treasure Lake Group (TLG), is a unique mineralized formation with major economic metals including Co, Au, Bi and Cu. It is enriched in these metals compared to the surrounding TLG due to latter stage re-mineralization processes (Acosta-Gangora et al. 2015). Economically viable minerals in ore exist in graded strata in multiple lenses, bound to pyrite and arsenopyrite as well as cobaltite and chalcopyrite (Golder Fortune Report, 2011; Acosta-Gangora et al. 2015). As a result, this sulfide mineral ore body is naturally enriched in many metal(oid)s.

Catchment areas of the four study lakes were calculated using ArcGIS 10.3 software with vector data retrieved from the Polar Geospatial Centre ArcticDEM Project (Porter et al. 2018) in 2 m resolution. Grid Lake (63.553191°N, 116.740344°W, 240 m.a.s.l.) is a small lake, with an area of ~3.2 ha, located at the northern edge of the NICO deposit within a small catchment (~0.65 km^2). Grid Lake is ~2.5 m deep and drains to the south to Nico Lake through wetlands. Nico Lake (63.546420°N, 116.704036°W, 201 m.a.s.l.), located adjacent to the NICO deposit, is larger with an area of ~53 ha, and a catchment area of ~5.6 km^2. Nico Lake is 8 m deep and flows into Peanut Lake through a small stream. Peanut Lake (63.537653°N, 116.710884°W, 193 m.a.s.l.), located at the southern portion of the NICO deposit, has an area of 22 ha and a catchment of 18 km^2. Peanut Lake is 6 m deep and flows into Burke Lake, which then flows out through Burke Creek into the Marian River. Lake MW01 (63.569409°N, 116.690188°W, 213 m.a.s.l.), located ~2 km northeast of the NICO deposit, has an area of ~38 ha and a catchment of 19.15 km^2, which includes low relief wetlands. MW01 is 7 m deep.

Methods

Sediment Core Collection

Sediment cores were collected from MW01 (38.0-cm long) from an inflatable canoe in September 2015 and from Grid (43.0-cm long), Nico (58.5-cm long) and Peanut (58.0-cm long) lakes from the ice surface in April 2016 with the use of a Glew hammer corer. Cores were obtained from the maximum depth of each lake ascertained from bathymetric maps provided by a previous environmental assessment (Golder Fortune Report, 2010). Cores were sectioned at 0.5-cm intervals using a vertical extruder (Glew, 1988) and placed into Whirlpak bags. Samples were kept at 4°C and shipped back to the University of Waterloo for storage prior to further analysis.

Laboratory Analysis

Loss-on-Ignition

Subsamples (~0.5 g) of wet sediment were analysed by Loss-on-Ignition to determine water content, organic matter (OM) content, and mineral matter content (MM). Subsamples were heated at 90°C for 24 hours, 550°C for 2 hours, and 950°C for 2 hours, respectively, following the methods outlined by Heiri et al. (2001). Values are reported as percent sample mass.

Radiometric Dating

Radiometric dating was performed at the University of Waterloo using an Ortec Coaxial HPGe Digital Gamma Ray Spectrometer. Pre-weighed sediment subsamples at selected 0.5 cm intervals were freeze dried and packed into STARRSTEDT tubes to a known volume, sealed with a silicon cap and epoxy, and allowed to equilibrate for 21 days allowing for ^{222}Rn to decay to equilibrium with ^{226}Ra prior to ^{210}Pb activity measurement. ^{226}Ra was calculated based on a weighted mean value of ^{214}Bi and ^{214}Pb activity. Lake MW01 subsamples were measured at 0.5-cm intervals for the following depths: 0.0-0.5, 0.5-1.0, 1.0-1.5, and every second 0.5-cm interval to 20.5 cm. For Peanut Lake, 0.5-cm subsample intervals were measured for the following sample depths: 0.0-0.5, 0.5-1.0, 1.0-1.5, and every second 0.5-cm interval to 11.5 cm. For Nico Lake, 0.5-cm subsamples were measured from the following depth intervals: 0.0-0.5, every second 0.5-cm interval to 21.5 cm, and 21.5-22.0, 22.0-22.5, 22.5-23.0, 24.0-24.5, 25.0-25.5, 25.5-26.0, and 30.0-30.5 cm. For Grid Lake, 0.5-cm subsamples were measured from the following depth intervals: 0.0-0.5, 0.5-1.0, 1.0-1.5, 2.0-2.5, 2.5-3.0, 3.0-3.5, and every second 0.5-cm interval to 12.5 cm.

The Constant Rate of Supply (CRS; Appleby 2001) model was used to determine ages for the interval in which unsupported ^{210}Pb was present. A linear extrapolation was applied to depths below the presence of unsupported ^{210}Pb. Measurements of ^{137}Cs are included to support ^{210}Pb CRS dates where applicable. The CRS model is also used to calculate dry mass sedimentation rates for the interval in which unsupported ^{210}Pb is present. The CRS model is well suited for this environment because of its ability to incorporate varying sedimentation rates within the lake sediment records (Appleby, 2001).

Organic Carbon and Nitrogen Elemental and Isotope Analysis

Subsamples of wet sediment were prepared for organic carbon and nitrogen elemental and isotope analysis using standard methods (Wolfe et al. 2001). Subsamples from every 0.5-cm interval were treated with 10% HCl at 60°C for 2 hours to remove carbonate content and then rinsed repeatedly with deionized water until a neutral pH was achieved. Samples were then freeze dried to remove all moisture content and passed through a 500-um sieve to remove coarse material. The fine fraction was then further sub-sampled and sent to University of Waterloo Environmental Isotope Laboratory for analysis using a 4010 Elemental Analyzer (Costech Instruments) coupled to a Delta Plus XL (Thermo-Finnigan) continuous flow isotope ratio mass spectrometer. Results utilized here are reported as %C_{org} by dry weight. Percent nitrogen and carbon and nitrogen isotope values are reported in the Appendix.

Sediment Metals Analysis

Sediment metals analysis was conducted on subsamples at 1 cm intervals for the upper 50 cm of cores and subsequently at 2 cm intervals below 50 cm core depth. Subsamples (~1 g) were freeze dried, ground and homogenized, and then analysed using the EPA 200.2/6020A method at ALS Environmental in Waterloo, ON. Though a partial digestion, this method aims to liberate labile metals bound to sediment that may be environmentally available.

A suite of metals and elements of interest (MEI) were selected for this study based on those identified in the Canadian Council of Ministers of the Environment (CCME 2014) guidelines. CCME sediment quality guidelines prescribe two threshold values for quality assessment including *Interim Sediment Quality Guidelines* (ISQG) and the higher *Probable Effects Level* (PEL). In cases where sediment quality guidelines were unavailable, the CCME Soil Quality Guideline (SQG_E) is used. Selected MEI include arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), uranium (U), and zinc (Zn). In addition to CCME identified elements, cobalt (Co), iron (Fe), sulphur (S), antimony (Sb), and selenium (Se) were included because they may exist in concentrations exceeding toxicity limits (Co, Se), they may be utilized as proxies for geochemical change (Fe, S), and they may serve as potential indicators of transport of deposit-derived sediment once the mine becomes operational (Co, S, Se).

Numerical and Statistical Analysis

Because many metals bind preferentially to fine grained (<63 um) particles (Loring, 1991; Foster & Charlesworth, 1996; Kersten & Smedes, 2002; Boës et al. 2011) to which Al and Ti will have a strong association in the sediment particle matrix, this makes them effective lithogenic normalizing agents (NA) to assess for metals pollution in the sediment stratigraphic record (Kersten & Smedes, 2002; García-Alix et al. 2013; Wiklund et al. 2014; Lintern et al. 2016; Pérez-Rodríguez et al. 2018). Many metals, including As, C, Cu, S, Fe, S, Se, Sb, and Zn, may preferentially bind to or have strong affinity to organic material which may vary in abundance in lacustrine records due to biological processes such as aquatic productivity and microbial reduction (Krumgalz et al. 1992; Meyers & Ishiwatari, 1993; Bauer & Blodau 2006; Chen et al. 2007; Marchand et al. 2011; Campbell & Nordstrum, 2014; Galloway et al. 2015, 2018). In addition, many MEI including As, Cu, Sb, and Zn may have a high affinity for the organic fraction of sediment containing humic material and form organic complexes within the sediment matrix (Tessier et al. 1992; El Bilai et al. 2001; Smedley & Kinniburgh, 2002; Galloway et al. 2015, 2018). The use of organic matter (OM) and elemental organic carbon (C_{org}) as a potential NA is additionally recommended by Kersten & Smedes (2002) and Loring & Rantala (1992) to complement lithogenic NA. For these reasons, percent organic matter (OM) and percent organic carbon (C_{org}) were also identified as potential biogenic NA to MEI.

Regression analysis was completed between the four NAs (Al, Ti, OM, C_{org}) and the above identified MEI for each sediment core to determine the most appropriate lake- and MEI-specific NA for further statistical analysis. Relationships that resulted in values with a positive slope coefficient (m-coefficient) and were deemed statistically significant (p-value < 0.05) were selected as appropriate normalizing agents. In cases of multiple potential NA, the NA with the highest R^2 values was used. MEIs with no significant correlation to NAs are reported but not further evaluated. Linear relations were calculated using the entire stratigraphic record to establish baseline MEI-NA relationships. 95% prediction intervals (PI) were calculated to define the natural range of expected variability for the entire sediment record of each core, as recommended and applied elsewhere (Loring, 1991; Soto-Jiménez & Páez-Osuna, 2001; Wiklund et al. 2014).

The use of standard linear regression analysis offers several strengths when evaluating MEI values as potential contaminants. The baselines calculated here, based on the linear relationships, function well for identifying statistical outliers within the MEI data and for future evaluation of contemporary surface sediment. However, because of the nature of the sediment data from sediment cores, the data fail to meet some assumptions associated with conventional linear regression. Given that sediment cores are contiguous records, the data are temporally autocorrelated and include dependence among observations, resulting in increased variance of the coefficient estimates and an underestimation of standard errors. Additionally, while C_{org} and OM are likely colinear, they were tested separately. While these violations are acknowledged, the application of these linear models does not depend on their predictive power, and as such, allows for variance in error estimation while maintaining utility for monitoring purpose.

Because the purpose of this study is to establish pre-NICO mine baselines, which will be used to assess for potential pollution once the mine is operational, and not a pre-industrial baseline, the complete stratigraphic record was used in baseline calculations. Operationally, this assumes the lake records represent pristine conditions up to and including the present. However, sample points within the linear regressions plots are categorized into three chronological intervals to assess and interpret for temporal trends relating to past hydroclimatic conditions and in recognition of the possibility of the lakes recording far-field anthropogenic pollution. These intervals include: 1) pre-1700, 2) ~1700-1936, representing the period that includes the Little Ice Age (LIA: 1600-1900 as identified in northern Alberta; Wolfe et al. 2008) and early post-LIA 20th century and prior to mining in NWT, and 3) post-1936, representing the onset of industrial-scale mining in NWT and other modern industrial development.

Residual metal concentrations were calculated for the ~1700-2016 period using the entire stratigraphic record following methods outlined in Wiklund et al. (2014). This identified time period is selected as a climatically-relevant and includes the Little Ice Age (Wolfe et al. 2008) to recent warming. As in Wiklund et al. (2014), an upper 95% PI was calculated for each normalizer-MEI relation to the residual 1700-2016 record using the x-max value of the selected NA. This provides a conservative estimate of the upper limit of natural variation.

Results

Radiometric Dating

Radiometric profiles for all lakes display a classic pattern of exponential decline in ^{210}Pb values with depth (Figure 4). Background ^{226}Ra values are reached at different depths for the four lakes, reflecting the varying sedimentation rates among the four lakes.

At Lake MW01 (Figure 4a), ^{210}Pb activity declines from 0.544 Bq g^{-1} at the top of the sediment record and reaches background concentrations (i.e., ^{226}Ra) of 0.069 Bq g^{-1} at 18.75 cm. Extrapolation using the CRS model indicates that the bottom of the core is ~1647 CE. Lake MW01 displays a relatively constant total sedimentation rate since ~1880 (0.014–0.019 g cm^{-2} yr^{-1}) with the exception of an abrupt and high-magnitude sedimentation event at ~1920 (0.155 g cm^{-2} yr^{-1}).

^{210}Pb activity in the Peanut Lake core (Figure 4b) declines from 0.426 Bq g^{-1} at the top of the core to 0.091 Bq g^{-1} at 9 cm where it reaches background ^{226}Ra concentrations. Using the CRS dating model, dates were extrapolated to ~632 CE at the bottom of the core. Peanut Lake calculated total sedimentation rates from ~1918-1960 fluctuate between ~0.024 g cm^{-2} yr^{-1} and ~0.012 g cm^{-2} yr^{-1} and are mainly between 0.010 and 0.015 g cm^{-2} yr^{-1} from ~1960 to the present.

The ^{210}Pb activity in the Nico Lake (Figure 4c) core declines from 0.682 Bq g^{1} at the top of the core to 0.082 Bq g^{1} at 12-cm core depth where it reaches background ^{226}Ra concentrations. Using the CRS dating method and extrapolation, the base of the Nico Lake sediment core is ~1139 CE. Calculated total sedimentation rates peak at ~1895 and ~1935 (0.014 g cm^{-2} yr^{-1}) and otherwise narrowly range between 0.008 and 0.012 g cm^{-2} yr^{-1}.

Grid Lake (Figure 4d) ^{210}Pb activity declines from 0.881 Bq g^{-1} at the top of the core reaching ^{226}Ra background concentration of 0.115 Bq g^{-1} at 5 cm depth. Using the CRS dating method and extrapolation, the base of the sediment core is ~679 BC. ^{137}Cs measurements from Grid Lake (Figure 4d**)** show a peak of 0.065 Bq g^{-1} at 2.25-cm depth. This ^{137}Cs peak corresponds to ~1971 of the ^{210}Pb generated CRS dates, suggesting reasonable agreement between the two radiometric methods. Although the alignment between the two radiometric timelines may be somewhat coarse, this is likely attributed to the very slow sedimentation rate between sample section intervals and post-depositional mobility of ^{137}Cs in organic matter. Sedimentation rates at Grid Lake are very slow, ranging between 0.0027-0.0042 g cm^{-2} yr^{-1}.

Regression and Correlation Analysis of Metal Concentrations

The identified *effective* relationships between MEI and NA, bolded within Table 1, are those that have a positive m-coefficient and significant p-value (<0.05). R^2 values were also considered in the selection of the NA. This results in selection of a NA specific to each MEI, which also varies among the lakes. These identified MEI:NA relationships are used in baseline calculations.

For Lake MW01, effective NA:MEI relations are established for the following eleven MEI: 1) Al was selected as a NA for Cr, Co, Cu, Ni, and U; 2) Ti was selected as a NA for Fe and Pb; 3) OM was selected as a NA for As and Sb; and 4) C_{org} is selected as a NA for S. For Peanut Lake, twelve effective NA:MEI relationships are established: 1) Al is selected as a NA for Cd, Co, Cr, Fe, Ni, Pb, U and Zn; 2) Ti is selected as a NA for As and Cu; and 3) OM is selected as a NA for Sb and Se. For Nico Lake, nine effective NA:MEI relations are established: 1) Al is selected as a NA for Cr, Fe, and Pb; 2) Ti is selected for As and U; 3) OM is selected for Co and Zn; and 4) C_{org} is selected as a NA for Cu and Se. For Grid Lake, nine effective NA:MEI relations are established: 1) Al is selected as a NA for Cd, Ni, Se, U and Zn; 2) Ti is selected as a NA for As, Cr and Pb; 3) and OM is used as a NA for Co.

Establishing Baselines for MEI Concentrations

Lake MW01

Lake MW01 MEI:NA relations demonstrate that with the exception of a few values above and below the 95% PI, MEI cluster fairly tightly around linearly regressed baselines (Figure 5). To further contextualize the MEI concentrations, CCME guidelines have been added to the plots. Single data points for Co, S, and U that plot above the 95% PI are from sediments deposited prior to 1936 indicating natural variance. As, Fe, and Sb, each display single values above the 95% PI values that occur during the post-1936 period. MEI normalized to Al and OM (As, Co, Cr, Cu, Ni, U) cluster into two distinct groups that align with the stratigraphic time interval designations. As and Sb values are higher during the post-1936 interval, whereas Co, Cu, Ni, and U are lower during the post-1936 interval. The entire stratigraphic record of Cr is above the CCME value of 35.9 $\mu g\ g^{-1}$ (ISQG) and several of the post-1936 values of As are just above the CCME value of 5.9 $\mu g\ g^{-1}$ (ISQG).

Temporal trends in MW01 residual sediment metal concentrations allow for assessment of the variation of MEI in a chronological context (Figure 6). As with the crossplots in Figure 5, MEI mainly plot within the range of natural variation from the period of 1700-2015. As, Fe, and Sb experience increase in concentrations during the post-1936 interval beginning at ~1950. Residual Pb concentrations show a narrow range of values during the 1700-1936 interval. However, starting at ~1936, there is a steady increase in residual Pb concentration values peaking in ~1978, approaching the 95% PI. Residual Pb decreases after ~1978.

Peanut Lake

Peanut Lake regression results demonstrate that the majority of MEI concentrations plot within natural variation around their respective baselines with a few exceptions (Figure 7). A small number of pre-1700 As, Ni, and Se values plot clearly above the 95% PI. Sb is the only MEI that displays post-1936 values above the 95% PI. The MEI concentrations of Peanut Lake are considerably higher than those of MW01, most of which are highest in the pre-1700 period. The entire As record plots well above the CCME PEL of 17 $\mu g\ g^{-1}$ and many of the Cr values exceed the PEL of 90 $\mu g\ g^{-1}$. Residual MEI concentrations show that Cd, Cu, Pb, and Sb display increasing trends post-1936 followed by more recent declines (Figure 8).

Nico Lake

Nico Lake regression results establish MEI baselines which indicate a minor degree of natural variation (Figure 9). All MEI possess sample points above the 95% PI although the majority of these are in the pre-1936 periods. As observed in Peanut Lake, As has several points well above the 95% PI from the pre-1700 period. Fe and Pb possess sample points elevated above the 95% PI during the post-1936 period although these concentrations do not exceed CCME guidelines. Several MEI concentrations records are elevated compared to the previous Lake MW01 and Peanut Lake values although they remain in the range of natural variation. The complete stratigraphic record of As, Cr, Cu, and the majority of Zn sample points are elevated above CCME guidelines. Residual concentrations plotted for 1700 to 2016 further demonstrate the natural range of MEI (Figure 10). Residual Pb concentrations closely resemble those of Peanut Lake with an increasing trend initiating at ~1945, peaking at ~2000, and then declining slightly in recent years.

Grid Lake

Grid Lake regression results establish baselines that demonstrate a narrow range of variability for most MEI (Figure 11). MEI concentrations are substantially higher than those of the previous lakes due to the position of Grid Lake on the NICO deposit. CCME guidelines are exceeded for the majority of samples from the As, Cd, CO, Se, U, and Zn records. Few data points from Cd, Co, Ni, and Se are above the 95% PI from the pre-1936 periods. Arsenic concentrations in Grid Lake are extremely high reaching upwards of 2950 μg g^{-1} in the pre-1700 time period. With the exception of Pb, recent post-1936 MEI concentrations are lowest within the stratigraphic record. Three of the four post-1936 Pb sample points exceed the 95% PI. Of those MEI normalized to Al and Ti, sample points cluster into two distinct groups delineated by a gap in NA concentrations. Most residual MEI concentrations decline during the latter part of the 20th century, with the exception of residual Pb concentrations which rises (Figure 12).

Discussion

Paleolimnological-defined baselines and normalization

As human activities continue to drive environmental change, the ongoing expansion of aquatic monitoring programs and research require effective and accurate assessment of sediment quality. In particular, effective programs require an understanding of pre-industrial conditions. Here it is demonstrated that paleolimnological methods are uniquely equipped to establish baseline sediment metal concentrations that are site-specific and represent critical temporal and spatial variation which are capable of differentiating between the influence of geology, natural processes, and anthropogenic pollution. Results clearly demonstrate that MEI concentrations within the study lakes are a reflection of the specific surficial geology determined by proximity to the NICO ore body and catchment characteristics. For instance, many MEI concentrations such as As, Co, Cu, Sb, and U increase dramatically with decreasing distance from the deposit. The multiple agent lake- and MEI- specific normalizing approach results in the establishment of site-specific baselines that are reflective of the specific geochemical and biogeochemical conditions within individual lakes influenced by both catchment and internal conditions. These paleolimnological baselines provide an essential foundation to ongoing monitoring efforts.

The influence of OM and C_{org} on various sediment metal(oid)s has been well documented in many studies (Smedley & Kinniburgh, 2002; Martin & Pedersen, 2002, 2004; Bauer & Blodau, 2006; Sanei & Goodarzi, 2006, Galloway et al. 2018) and were evaluated as a potential NA in early exploration of geochemical normalization (Loring & Rantala, 1992; Kersten & Smedes, 2002). Here, OM or C_{org} were identified as the appropriate NA for several MEI including As, Co, Cu, Fe, Sb, and Zn. Several biogeochemical processes may account for these strong relations. Many of these MEI will preferentially bind to the organic fraction, especially the autochthonous fraction, thus changes in lake productivity may influence MEI concentrations (Sanei & Goodarzi, 2006; Galloway et al. 2018). Organic matter may also be derived from the catchment and variability in this process could play a role in variability of these MEI concentrations. However, low C/N ratios (see Appendix) in the sediments of these lakes indicate that the OM is mainly autochthonous. Use of OM and C_{org} may also account for the effects of potential post-depositional mobility, which may be enhanced by reductive conditions caused by aquatic productivity and microbial activity in the sediment (Martin & Pedersen, 2002, 2004; Galloway et al. 2018). Unlike the application of Al and Ti as normalizers, which reflect the catchment geology, OM and C_{org} may contribute to concentrations of these MEI in the upper sediment strata through reductive conditions which enhances diagenetic mobility and the formation of organic-MEI complexes (Loring & Rantala, 1992; Smedley & Kinniburgh, 2002; Martin & Pedersen, 2002, 2004; Sanei & Goodarzi, 2006; Taipa & Audry, 2012; Galloway et al. 2018). Given that climate change will continue to influence OM and C_{org} in lake sediments in this region, their continued assessment of potential use as NAs is recommended for future monitoring.

Baseline conditions in this study are defined as the full length of the stratigraphic record. This defining period of pre-NICO mine conditions, which was specifically designed to identify post-NICO mine change in sediment MEI concentrations, was initially considered pristine. However, MEI values elevated above the 95% PI suggests that pollution from historic (and ongoing) regional and global long-range atmospheric sources is present in the sediment records. Increasing trends of residual Pb concentrations in all lakes in the mid-late 20th century can likely be attributed to atmospheric Pb pollution caused by the rapid onset of post-war industrialization and increased consumption of leaded fuel (Renberg et al. 2002; Perez-Rodriguez et al. 2018) (Figure 13). This historic trend is recognized and well documented in many high latitude natural archives (Shotyk et al. 2005; Michelutti et al. 2009; Wiklund et al. 2014, 2017; Perez-Rodriguez et al. 2018). The decline in Pb concentrations at ~1980, best illustrated in the Lake MW01 profile, corresponds to multiple North American and global regulations phasing out Pb from gasoline and diesel (Renberg et al. 2002; Garcia et al. 2013; Wiklund et al. 2014). The persistence of elevated Pb in the Peanut, Nico, and Grid profiles may be due to continued supply from the catchment or ongoing global Pb emissions to high latitudes (Shotyk et al. 2005; Michelutti et al. 2009). Although Pb concentrations are well below the CCME ISQG (35 $\mu g\ g^{-1}$) in all of the lake sediment records, normalization demonstrates a level of sensitivity sufficient to identify this discrete period of historic pollution. Furthermore, the consistent timing of this Pb trend among the four lakes supports the accuracy of the ^{210}Pb-based chronologies. These results demonstrate that even at these remote locations, anthropogenic pollution can still be detected and is subsequently incorporated into our pre-NICO baseline calculations for the assessment of future pollution.

Arsenic: Natural Variability vs Pollution

Arsenic contamination to the watershed from the development of the NICO mine is a primary concern and thus the As data generated here warrant close scrutiny. Although As is naturally enriched in the NICO ore body and sediment of the adjacent lakes (Grid, Nico, Peanut), a redistribution of this metalloid from the deposit area via fluvial and aeolian transport of mined ore material, which would constitute contamination, could have significant impacts in adjacent lakes that are naturally low in As concentrations such as MW01. Arsenic is a complex anionic metalloid; both its toxicity and mobility within the aquatic environment are dependent on its state and speciation (Smedley & Kinniburgh, 2002; Borch et al. 2010; Jamieson, 2014; Galloway et al. 2015). Influenced by pH, redox potential, and reductive conditions driven by microbial activity, aquatic productivity, and organic compounds, As may be mobile within the sediment profile (Martin & Pedersen, 2002; Smedley & Kinniburgh, 2002; Couture et al. 2008, 2010; Borch et al. 2010; Campbell & Nordstrom, 2014; Galloway et al. 2015. 2018). Arsenic may bind to Fe – Mn oxides/oxyhydroxides, the surface of clay fractions, and to organic compounds within the sediment, and it may then enter aqueous solution through desorption under anoxic conditions at the sediment-water interface (Smedley & Kinniburgh, 2002; Couture et al. 2008, 2010; Borch et al. 2010; Campbell & Nordstrom, 2014; Galloway et al. 2015). Given this complexity of As in the aquatic environment, stratigraphic interpretation of As in lake sediment core records is challenging.

In the three lakes adjacent to the NICO deposit, elevated and broadly ranging sediment As concentrations (Grid Lake: 726 -2950 µg g^{-1}, Nico Lake: 93-318 µg g^{-1}, Peanut Lake: 28-101 µg g^{-1}; Figure 14) are a reflection of the weathering of arsenopyrite and other As-rich minerals (Acosta-Gangora et al. 2015). Hence, local geology exerts a first-order control on As concentrations in the lake sediment records. Superimposed on this are additional processes that generate stratigraphic variation in As concentrations. For example, Grid, Nico, and Peanut all experience substantial enrichment in sediment As concentrations between 760 and 1220 CE (Figure 14). While these concentrations do not exceed the 95% PI at Grid Lake (Figure 12), concentrations exceed the 95% PIs at Peanut (Figure 8) and Nico lakes (Figure 10). This interval of high As concentrations corresponds to increases in organic matter content, which is particularly evident at Peanut Lake (Figure 14). An increase in aquatic productivity during this interval may explain the increased As concentrations due to arsenic's affinity to bind to the aquatic carbon fraction and influence of increased microbial reduction (Martin & Pedersen, 2002, 2004; Couture et al. 2010; Eiche et al. 2017; Galloway et al. 2018). This increase at depth could be additionally explained by sulphate reduction during this period, which could immobilize As to the sediment under anoxic sulfur-reducing conditions (Borch et al. 2010; Couture et al. 2010).

Small variations in As concentration at the top of Grid, Nico and Peanut profiles (Figure 14) may represent some minor mobility under redox conditions. Elevated As concentrations at the sediment-water interface at Peanut Lake is consistent with upward mobility under oxic conditions at the time of core collection (Tessier, 1992; Couture et al. 2008, 2010; Borch et al. 2010). Peak As concentration just below the sediment-water interface at Grid and Nico lakes can be attributed to downward mobility and sequestration to Fe-Mn (oxy)hydroxides and potential release of As into aqueous solution of the overlying waters resulting from anoxic conditions at the time of core collection (Couture et al. 2008, 2010; Borch et al. 2010). Similar As variations in the upper strata of lake sediment cores have been observed by Couture et al. (2008, 2010) and were explained by seasonal changes in redox conditions. Hence, seasonality may play a major role in sediment As concentrations within these lakes.

The As concentrations of MW01 are substantially lower than those of the other three consistent with its more distal location from the NICO deposit. In the upper sediment of Lake MW01, As concentration increases after 1950. There are at least three explanations for this trend. Similar to the other lakes, this increase in concentration in the upper strata may be due to redox mobility and binding to (oxy)hydroxides under aerobic conditions. OM increases during this interval, which may indicate the influence of aquatic productivity on As concentrations. Notably, Sb concentrations also increase after 1950 (Figure 6). Sb is an additional element associated from Giant mine emissions. The additional increase in Sb concentrations at 1950 also suggest the potential influence of long-range aerial emissions from Giant mine. This potential pollution signal may only be noted at MW01 as the naturally elevated As concentrations of the other lakes would overwhelm this signal.

The influence of increasing aquatic productivity on the mobility and sequestration of As to the organic portion of the upper sediment column may continue to increase in the sub-arctic as climate warming enhances aquatic productivity and carbon sources in areas impacted by industrial As contamination (Galloway et al. 2018). Pi et al. (2015) and Eiche et al. (2017) identify the relationship of the sedimentary organic fraction to As, but additionally its role in As toxicity and mobility in groundwater as dependent on the source as either terrigenous or the more labile autochthonous component. As climate warming is expected to increase aquatic productivity in the North, it can be predicted that As mobility will be influenced in this study region. The early period of As enrichment in the three lakes proximal to the NICO deposit may be a result of increased aquatic productivity related to the Medieval Climate Anomaly identified by Patterson et al. (2017) and Dalton et al. (2018) in which conditions would have been warmer and potentially drier, potentially increasing aquatic productivity, and the depth and rate of microbial reduction of OM. This trend may be analogous to the relationship observed in MW01 in which recent climate-driven acceleration of aquatic productivity may be influencing As concentration in the upper sedimentary organic fraction. Under a scenario of increased As deposition to the surrounding watershed lakes from mining activity and simultaneous climate warming increases on autochthonous productivity, As may become substantially mobilized within the aquatic environment to the upper sediment strata (Martin & Pedersen, 2002; Marchand et al. 2011; Galloway et al. 2018). A modern example of this phenomenon is outlined by Martin & Pedersen (2002, 2004). In this study, the remediation of a lake which had received historic As pollution, led to an increase in As concentrations of surface sediment and water. The increase in aquatic productivity from improved water quality and nutrient cycling led to an increase in OM and microbial reduction driving enhanced As mobility. Cumulative impacts of both contamination and climate warming confound ability to predict As mobility and deposition within lakes of the Marian River watershed.

Considerations for Continued Sediment Monitoring

For continued monitoring at these lakes by the MWSP, it is recommended that surface sediment be collected twice a year from these four lakes at the location of previous coring every two years prior to mine development. The first collection period should occur during the late winter months (late March – early April) from the ice surface. This will provide data for MEI concentrations under potentially anoxic conditions in some lakes, and is equivalent to the timing of the sediment core collection of Peanut, Nico, and Grid Lakes. The second collection should be in late summer (late-August / early September), representative of oxic conditions, equivalent to the time period in which the sediment core from MW01 was obtained. These two sample periods will be useful in determining seasonal variation of sediment MEI concentrations and, in particular, if they differ due to redox conditions in the upper sediment strata. In addition to the sediment metals analysis (EPA 200.2/6020A), sediment should also be analysed for the other parameters undertaken in the sediment core methodologies including loss-on-ignition and measurement of elemental organic carbon. The continuation of water quality measurements, not discussed within this manuscript, should also be included including on-site measurements of pH, O_2, temp and conductivity from the top and the bottom depths using a hand-held meter and the analysis of total and dissolved metals (EPA 200.2/6020A, filtered) and total and dissolved nutrients.

The continued success and strength of the MWSP involves the ongoing cooperation between the Tłı̨chǫ Government and the academic partner (i.e., Wilfrid Laurier University). With the successful training of the MWSP community monitors in the collection of surface sediment and sediment cores as described in the methods, collected samples may be sent to Wilfrid Laurier University for analysis and interpretation. Ongoing monitoring efforts can be further developed to meet the needs of the MWSP by consultation with the academic partner. With defined roles between the two partners regarding sample collection and analysis, and the opportunity for positive knowledge exchange, the MWSP can grow in capacity and effectiveness.

Conclusions

Establishing baselines using paleolimnological approaches can be an efficient and relatively low-cost method of generating valuable data for use in aquatic ecosystem monitoring efforts. Here, it is demonstrated that this approach, which utilizes four NA to establish lake- and MEI-specific baselines, can be applied to generate a robust dataset representing multiple centuries of sediment accumulation. These data can effectively compensate for the lack of long-term monitoring of sediment quality. Because monitoring initiatives are typically conducted on short time frames (1 to 4 years) through government programs, academic research endeavours, or as part of mandated operating procedures for resource development, employing paleolimnological approaches are an effective strategy for rapid assessment of pre-disturbance conditions and establishment of baseline data.

The pre-NICO baselines demonstrate that natural sediment MEI concentrations vary throughout the stratigraphic records due to changes in local catchment-erosional and in-lake processes. Importantly, the major variation and magnitude of MEI concentrations, especially As concentrations, among the lakes in this relatively small area, demonstrate the need for lake- and NA-specific baselines and the potential sensitivities of these relationships to mining impacts. The assessment of As concentrations in the sediment records are difficult yet essential.

Sediment quality analysis, aided by the paleolimnological baselines established through this research, is an integral element of the MWSP. Learning from the legacy of mining contamination in the

NT, particularly the RayRock and Con/Giant mine, the Tłı̨chǫ Governments MWSP initiative is now well equipped with a thorough set of baseline data needed to detect potential MEI pollution at these four lakes from the NICO mine development.

As aquatic monitoring programs continue to be employed in the North in response to industrial development and the rapid broad scale environmental changes due to climate warming, the need for an understanding of natural conditions is crucial to our understanding of the direction and magnitude of these cumulative impacts. Under these conditions, scientific research is needed to inform best practices of monitoring programs. In addition, the previous northern scientific operating paradigm of *community involvement* within scientific research is transitioning into *community-led* research. As social-political progress in the North is coincident with rapid environmental change, scientific research aimed at supporting community initiatives can help protect Lands and support community's legal autonomy. This research demonstrates this new paradigm. Here, use of paleolimnology to establish pre-development baselines for the MWSP in collaboration with the Tłı̨chǫ Government demonstrates a progressive narrative between science and Northern communities that should be further encouraged and cultivated.

Table 1. Results of regression analysis between normalizing agent and metals and elements of interest. Selected relationships for baseline calculations are highlighted in grey.

Lake	**Lake MW01 1647-2015, n=43**											
Metal/Agent	Aluminum			Titanium			%Organic Matter			%Corg		
	R^2	m coeff	p-value 0.05	R^2	m coeff	p-value 0.05	R^2	m coeff	p-value 0.05	R2	m coeff	p-value 0.05
Aluminum	1	1.00	1	0.687	0.016	6.61703E-12	0.796	-0.428	1.00E-15	0.760	-0.673	2.75547E-14
Antimony	0.409	-0.022	3.91E-06	0.314	0.000	9.42E-05	**0.515**	0.012	6.16E-08	0.457	0.018	6.44E-07
Arsenic	0.671	-0.428	1.95294E-11	0.440	-0.007	1.25414E-06	**0.760**	0.219	2.80E-14	0.644	0.324	9.87E-11
Cadmium	0.004	0.001	0.671201483	**0.106**	0.000	0.032995028	0.009	0.000	0.536778956	0.037	0.001	0.218851992
Chromium	**0.867**	2.084	1.38131E-19	0.858	0.040	5.73449E-19	0.807	-0.965	2.97E-16	0.820	-1.565	7.28348E-17
Cobalt	**0.496**	0.241	1.34377E-07	0.237	0.003	0.000919333	0.278	-0.086	0.000278055	0.241	-0.130	0.000824291
Copper	**0.399**	0.574	5.54179E-06	0.216	0.008	0.001705235	0.344	-0.256	3.54E-05	0.313	-0.393	9.48E-05
Iron	0.148	0.347	0.010810452	**0.161**	0.007	0.00765995	0.105	-0.140	0.034016664	0.034	-0.128	0.238432898
Lead	0.203	0.097	0.002437322	**0.207**	0.002	0.002203571	0.118	-0.035	0.024240291	0.178	-0.070	0.004834645
Nickel	**0.589**	0.792	1.90009E-09	0.587	0.015	2.13155E-09	0.484	-0.344	2.25E-07	0.616	-0.625	4.79E-10
Selenium	0.011	-0.003	0.507782273	0.072	0.000	0.080945126	0.059	0.003	0.116323907	0.079	0.006	0.067000689
Sulfur	0.422	-67.333	2.39524E-06	0.660	-1.625	3.76681E-11	0.618	39.072	4.11E-10	**0.680**	65.967	1.08E-11
Titanium	0.687	42.929	6.61703E-12	1.000	1.000	1	0.742	-21.394	1.23546E-13	0.816	-36.117	1.22E-16
Uranium	**0.4484254**	0.081	9.08E-07	0.098838	0.001	0.04005358	0.347	-0.034	3.29E-05	0.198	-0.042	2.76E-03
Zinc	0.082	-3.907	0.062815004	0.058	-0.064	0.119354126	0.074	1.784	0.077089363	0.224	4.987	0.001361933

Lake	**Peanut Lake 632-2016, n=56**											
Metal/Agent	Aluminum			Titanium			%Organic Matter			%Corg, n=45		
	R^2	m coeff	p-value 0.05	R^2	m coeff	p-value 0.05	R^2	m coeff	p-value 0.05	R2	m coeff	p-value 0.05
Aluminum	1.000	1.000	1	0.869	0.017	1.68E-25	0.268	-0.675	4.44E-05	0.333	-1.199	3.34E-05
Antimony	0.012	-0.002	0.428265085	0.028	0.000	0.221319714	**0.435**	0.018	3.31E-08	0.461	0.036	3.00E-07
Arsenic	0.253	2.895	7.92E-05	**0.283**	0.055	2.42E-05	0.012	-0.817	0.425137701	0.127	-1.945	0.016092427
Cadmium	**0.586**	0.006	6.31E-12	0.465	0.000	7.02E-09	0.009	-0.001	0.480304089	0.014	-0.002	0.445004267
Chromium	**0.932**	2.149	3.10E-33	0.827	0.037	3.40E-22	0.201	-1.301	5.38E-04	0.241	-2.326	6.26E-04
Cobalt	**0.358**	0.001	1.11E-06	0.234	0.011	0.000157109	0.014	-0.190	0.382906935	0.001	-0.066	0.852680112
Copper	0.358	0.734	1.11E-06	**0.402**	0.010	1.53E-07	0.005	-0.079	0.615630696	0.004	-0.114	0.683150326
Iron	**0.685**	0.824	3.78E-15	0.504	0.013	9.11E-10	0.022	-0.192	0.278515005	0.026	-0.345	0.289760768
Lead	**0.614**	0.209	9.09E-13	0.566	0.004	2.33E-11	0.062	-0.087	0.063588798	0.007	-0.041	0.590051099
Nickel	**0.859**	1.203	1.27E-24	0.722	0.020	1.20E-16	0.110	-0.563	0.012322885	0.146	-1.016	0.009592873
Selenium	0.020	0.002	0.30116834	0.000	0.000	0.898863128	**0.238**	0.008	0.000138526	0.192	0.011	2.60E-03
Sulfur	-	-	-	-	-	-	-	-	-	-	-	-
Titanium	0.869	51.618	1.68E-25	1.000	1.000	1	0.438	-47.854	2.76E-08	0.514	-83.869	2.96E-08
Uranium	**0.373**	0.201	5.80E-07	0.323	0.003	4.99E-06	0.0486	-0.095	1.02E-01	-	-	-
Zinc	**0.430**	1.972	4.10E-08	0.207	0.025	0.000427886	0.014	0.467	0.382391506	0.003	0.411	0.702711629

Lake	**Nico Lake 1139-2016, n=52**											
Metal/Agent	Aluminum (mg/g)			Titanium			%Organic Matter			%Corg		
	R^2	m coeff	p-value 0.05	R^2	m coeff	p-value 0.05	R^2	m coeff	p-value 0.05	R2	m coeff	p-value 0.05
Aluminum	1	1.0000	0	0.582	0.011	4.798E-11	0.253	-0.271	0.000167	0.285	-0.566	4.60E-05
Antimony	0.012	0.014	0.434671859	0.011	0.000	0.454986993	0.021	0.008	0.312338	0.065	0.025	0.06856
Arsenic	0.094	9.913	0.026989165	**0.168**	0.211	0.002569603	0.066	-5.024	0.069788227	0.002	-1.834	0.730974
Cadmium	0.001	0.002	0.869278279	0.006	0.000	0.587125	0.020	0.005	0.326665	0.000	0.000	0.956638311
Chromium	**0.880**	2.496	1.46599E-23	0.621	0.030	4E-12	0.286	-0.769	5.35E-05	0.374	-1.713	1.49E-06
Cobalt	0.002	0.126	0.730823179	0.062	-0.009	0.074813	**0.277**	0.721	7.19821E-05	0.214	1.204	0.000564
Copper	0.020	0.497	0.321907966	0.036	-0.009	0.179473797	0.179	0.800	0.001962	**0.196**	1.600	0.001008
Iron mg/g	**0.359**	0.621	3.42757E-06	0.030	0.003	0.218215	0.001	0.021	0.789248	0.037	-0.202	0.174195
Lead	**0.104**	0.114	0.021014511	0.011	0.001	0.465824	0.017	0.025	0.357081198	0.023	-0.055	0.280159338
Nickel	0.073	1.024	0.055703238	0.064	0.013	0.070978923	0.007	-0.167	0.567999142	0.053	-0.888	0.101474
Selenium	0.007	0.004	0.552547	0.000	0.000	0.954949	0.191	0.010	0.001186	**0.318**	0.025	1.32E-05
Sulfur	-	-	-	-	-	-	-	-	-	-	-	-
Titanium	0.582	52.478	4.80E-11	1.000	1.000	1	0.372	-23.258	2.05306E-06	0.280	-38.603	5.47E-05
Uranium	0.261	0.812	1.11E-04	**0.387**	0.014	8.43E-07	0.127	-0.309	0.009466792	0.021	-0.247	3.00E-01
Zinc	0.049	1.484	0.12042831	0.071	-0.025	0.055775712	**0.154**	1.423	0.004403	0.026	1.110	0.250183727

Lake	**Grid Lake -679-2016, n=44**											
Metal/Agent	Aluminum (mg/g)			Titanium			%Organic Matter			%Corg		
	R^2	m coeff	p-value 0.05	R^2	m coeff	p-value 0.05	R^2	m coeff	p-value 0.05	R2	m coeff	p-value 0.05
Aluminum	1.000	1.000	1	0.897	0.017	2.17E-22	0.647	-0.542	4.89E-11	0.497	-0.745	9.17E-08
Antimony	0.003	0.024	0.726770263	0.007	-0.001	0.58099358	0.023	-0.046	3.27E-01	0.031	-0.084	2.52E-01
Arsenic	0.397	170.541	4.58E-06	**0.453**	3.219	5.60E-07	0.267	-94.338	0.000329565	0.273	-149.498	0.000275542
Cadmium	**0.318**	0.016	6.65E-05	0.220	0.000	1.34E-03	0.130	-0.007	0.016157877	0.135	-0.011	0.014047935
Chromium	0.940	2.826	2.65E-27	**0.960**	0.051	4.94E-31	0.676	-1.617	7.55E-12	0.523	-2.228	2.97E-08
Cobalt	0.224	-13.252	1.16E-03	0.395	-0.311	4.91E-06	**0.149**	7.281	0.009703465	0.060	7.255	0.108597236
Copper	0.009	-4.492	5.31E-01	0.000	-0.012	9.27E-01	0.012	3.457	0.474232296	0.009	4.536	0.549620299
Iron mg/g	0.089	0.530	4.96E-02	0.076	0.009	6.97E-02	0.067	-0.310	0.090334089	0.079	-0.528	0.064804515
Lead	0.782	0.413	1.77E-15	**0.915**	0.008	3.89E-24	0.576	-0.239	2.33E-09	0.338	-0.287	3.52E-05
Nickel	**0.709**	1.047	8.13E-13	0.513	0.016	4.64E-08	0.378	-0.515	9.13E-06	0.358	-0.787	1.78E-05
Selenium	**0.320**	0.118	6.24E-05	0.200	0.002	0.002324561	0.143	-0.053	0.011319174	0.187	-0.095	3.33E-03
Sulfur	0.023	-0.399	0.323563679	0.048	-0.010	0.15524063	0.021	0.258	0.344550574	0.001	0.091	0.832116485
Titanium	0.897	53.612	2.17E-22	1.000	1.000	1	0.684	-31.563	4.66E-12	0.494	-42.066	1.03E-07
Uranium	**0.706**	2.750	9.98E-13	0.634	0.046	1.03E-10	0.621	-1.739	2.23E-10	0.460	-2.348	4.16E-07
Zinc	**0.175**	3.582	4.75E-03	0.036	0.029	0.216804645	0.028	-0.964	0.279354165	0.063	-2.273	0.100596567

Figure 1. Tłı̨chǫ Lands, Northwest Territories. The red outline identifies the 39,000 km^2 of Tłı̨chǫ owned Lands claim as defined by the Tłı̨chǫ Agreement (2005).

Figure 2. Geological map from the Geological Survey of Canada extracted from *the Tumi Lake and Bea Lake sheets (NTS 85-N/7 and 85-N/10), Northwest Territories*, depicting the area surrounding the NICO deposit and the four study lakes.

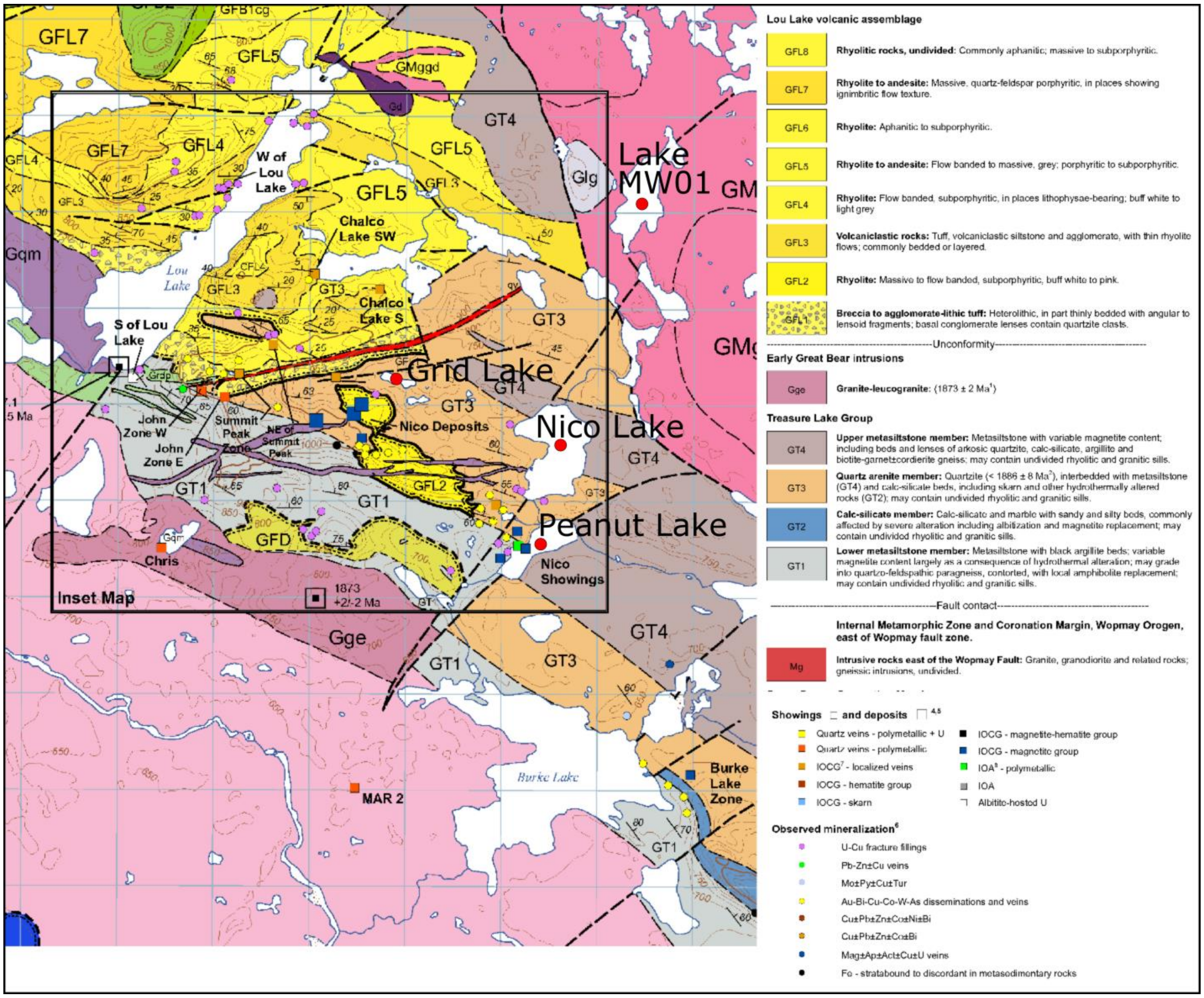


Figure 3. Study area with sediment core collection locations labelled as red circles.

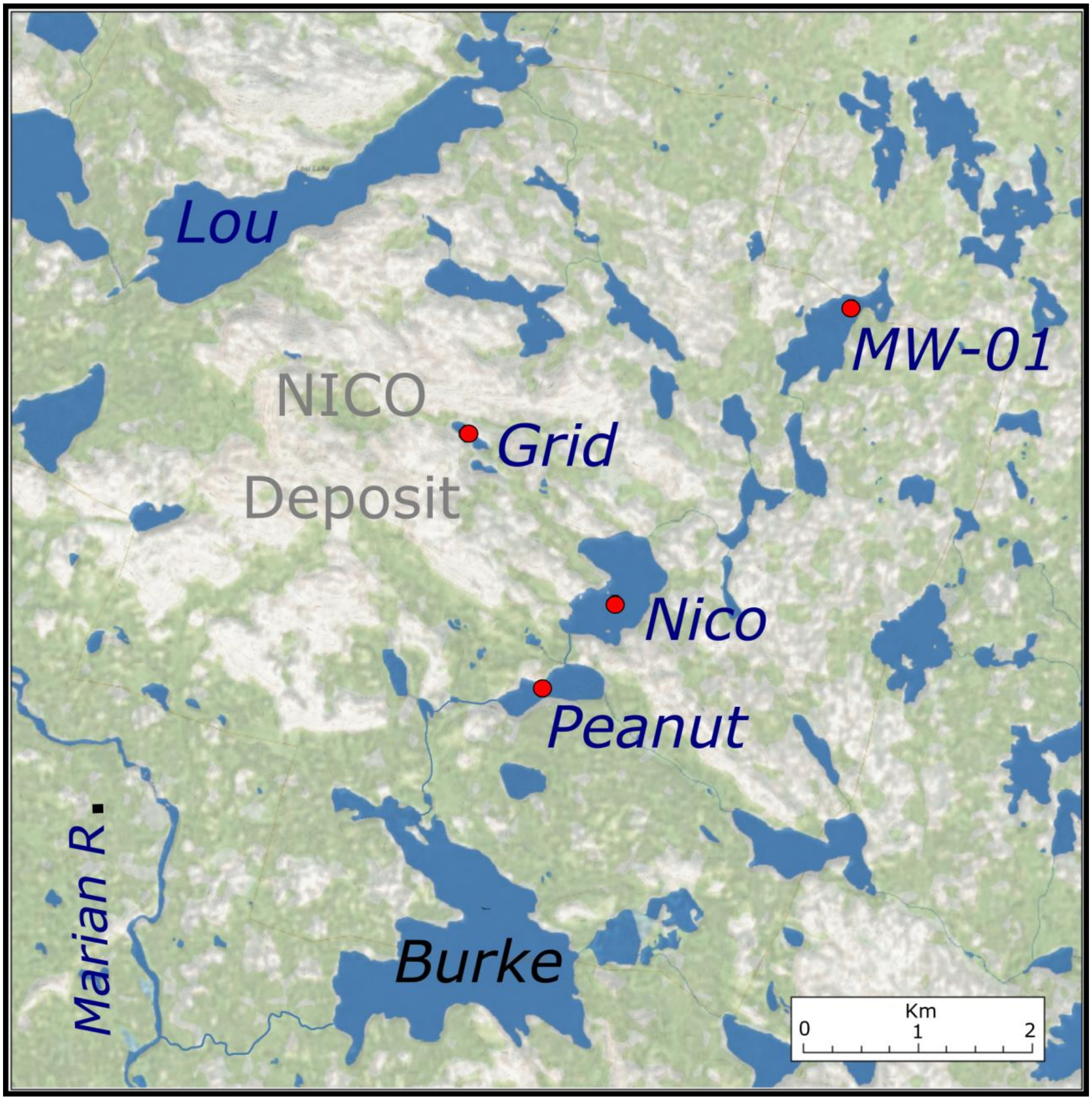


Figure 4. ^{210}Pb activity, depth-age profile and sedimentation rates are shown for a) Lake MW01, b) Peanut Lake, c) Nico Lake, and d) Grid Lake. Radiometric profiles of ^{210}Pb, ^{226}Ra and ^{137}Cs by depth are presented in the left panels with error bars indicating standard deviation. Corresponding age-depth profiles for ~1700 to present are presented in the middle panel with error bars indicating CRS ± years.

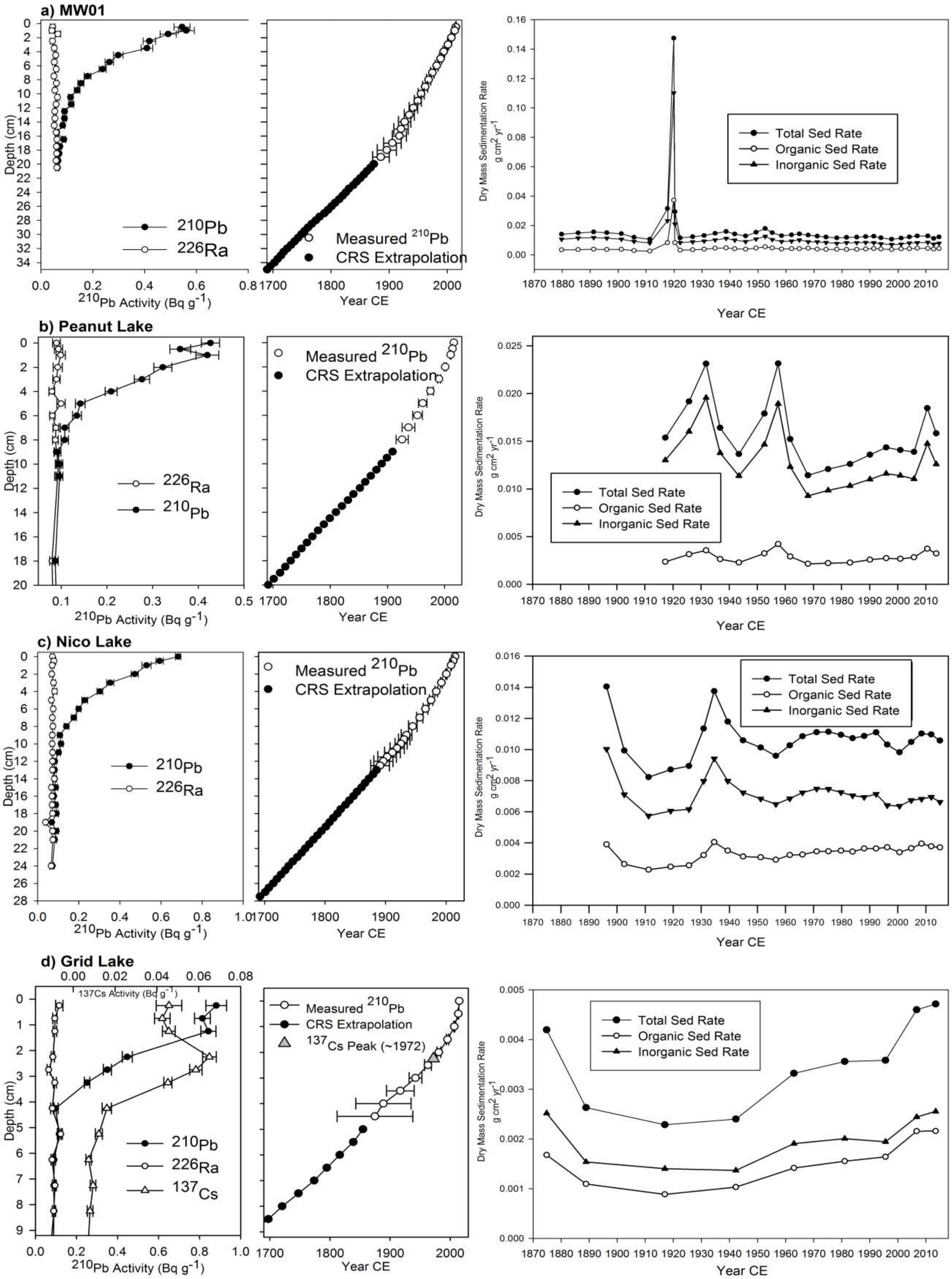


Figure 5. Lake MW01 linear regression relationships between Metals and Elements of Interest and Normalizing Agents. Solid black line is calculated from the entire stratigraphic record (~1647-2015 CE). Black dashed lines are calculated 95% prediction intervals. Red dashed lines are CCME sediment and soil quality guidelines. White circles identify samples from the pre-1700 period, grey circles identify samples from the 1700 to 1936 period, black circles identify samples in the post-1936 period.

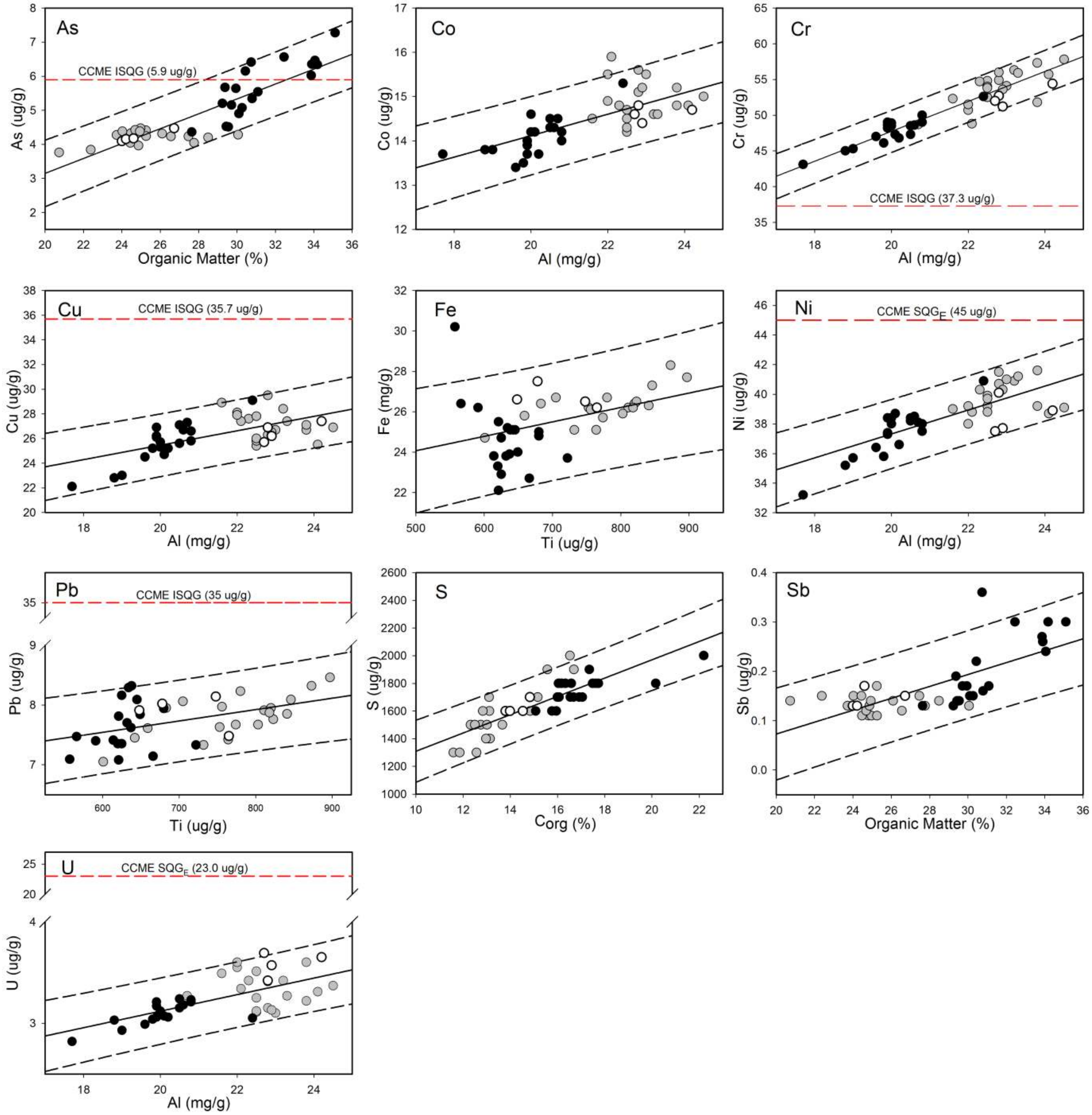


Figure 6. Lake MW01 residual metals concentrations plotted by year (~1700-2016 CE). Solid black line represents ~1647-2016 baseline. Dashed black line represents 95% prediction interval calculated from the widest normalizing agent value. Grey data points span ~1700 -~1936. Black data points span ~1936 to 2015.

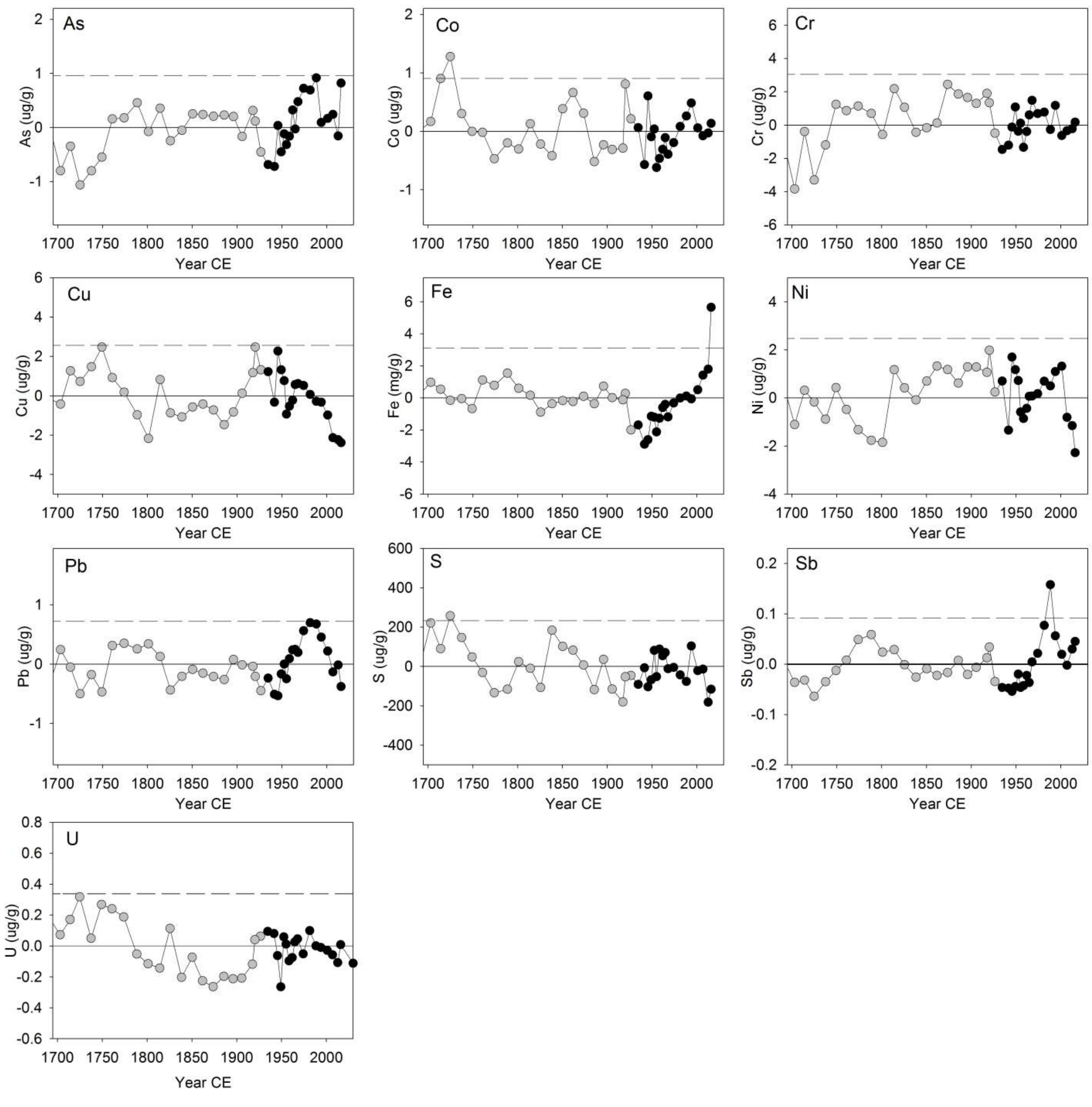


Figure 7. Peanut Lake linear regression relationships between Metals and Elements of Interest and Normalizing Agents. Solid black line is calculated from the entire stratigraphic record (~632-2015 CE). Black dashed lines are calculated 95% prediction intervals. Red dashed lines are CCME sediment and soil quality guidelines. White circles identify samples from the pre-1700 period, grey circles identify samples from the 1700 to 1936 period, black circles identify samples in the post-1936 period.

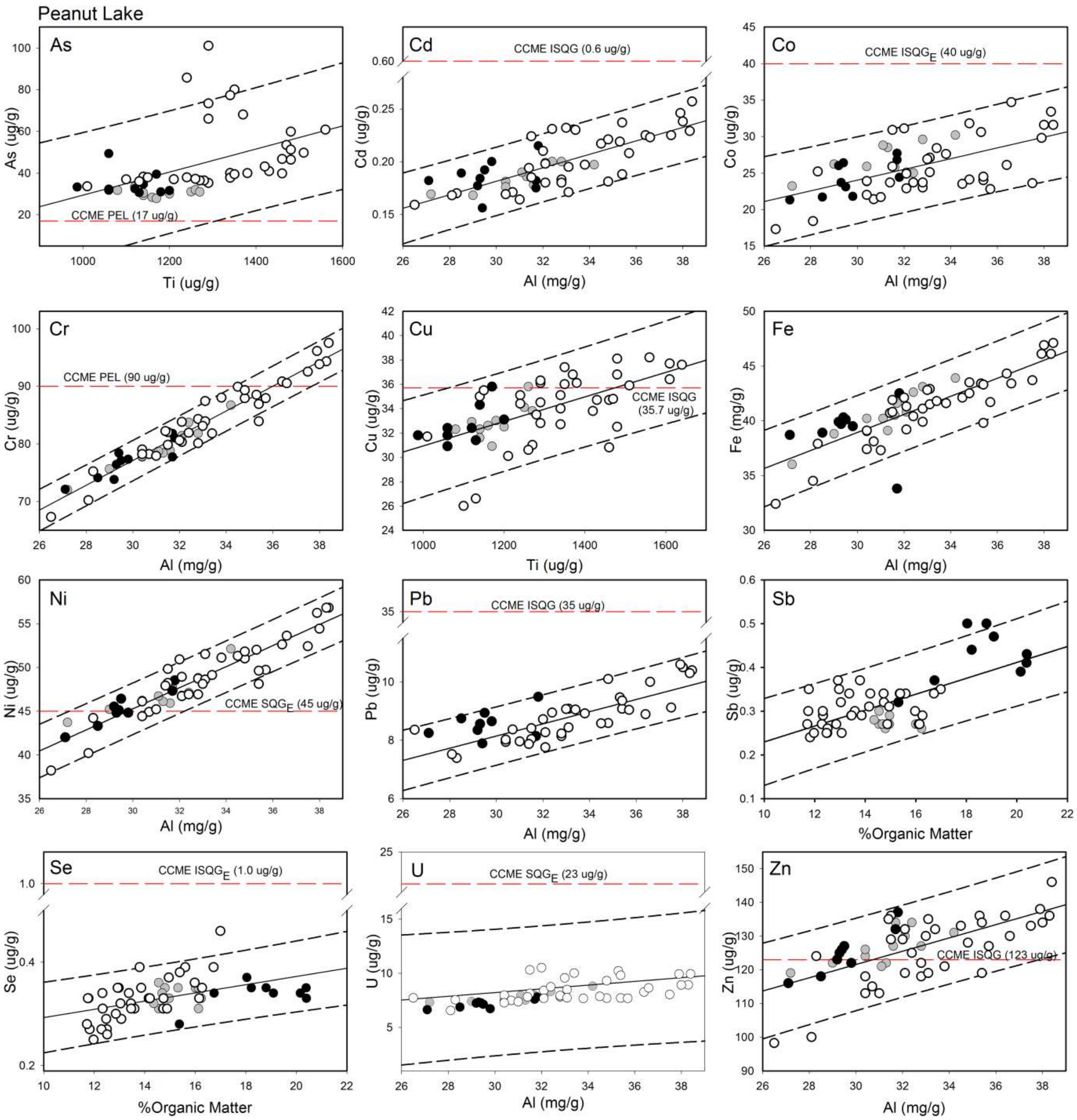


Figure 8. Peanut Lake residual metals concentrations plotted by year (~1700-2016 CE). Solid black line represents ~632-2016 baseline. Dashed black line represents 95% prediction interval calculated from the widest normalizing agent value. Grey data points span ~1700 -~1936. Black data points span ~1936 to 2016.

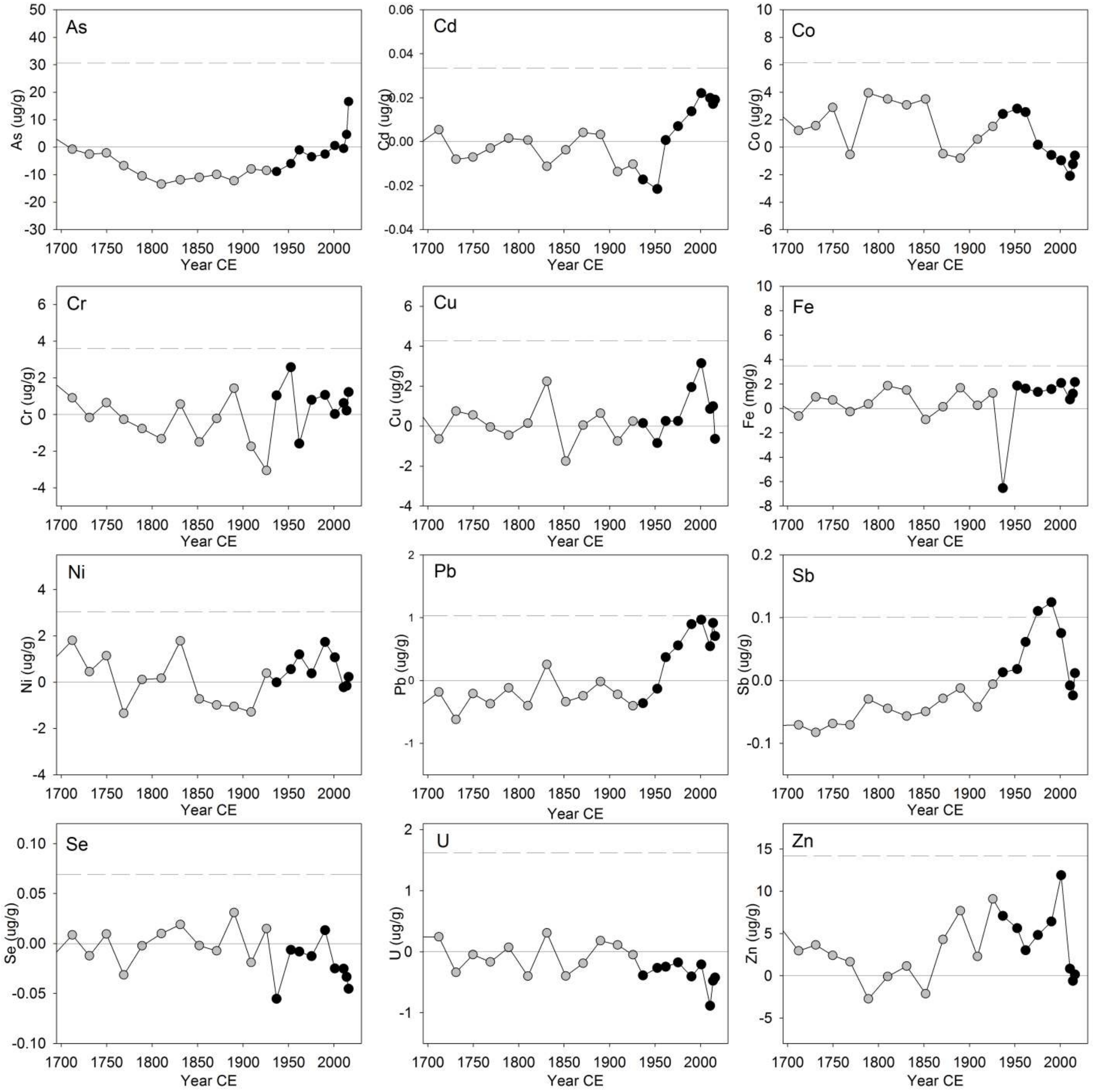


Figure 9. Nico Lake linear regression relationships between Metals and Elements of Interest and Normalizing Agents. Solid black line is calculated from the entire stratigraphic record (~1139-2015 CE). Black dashed lines are calculated 95% prediction intervals. Red dashed lines are CCME sediment and soil quality guidelines. White circles identify samples from the pre-1700 period, grey circles identify samples from the 1700 to 1936 period, and black circles identify samples in the post-1936 period.

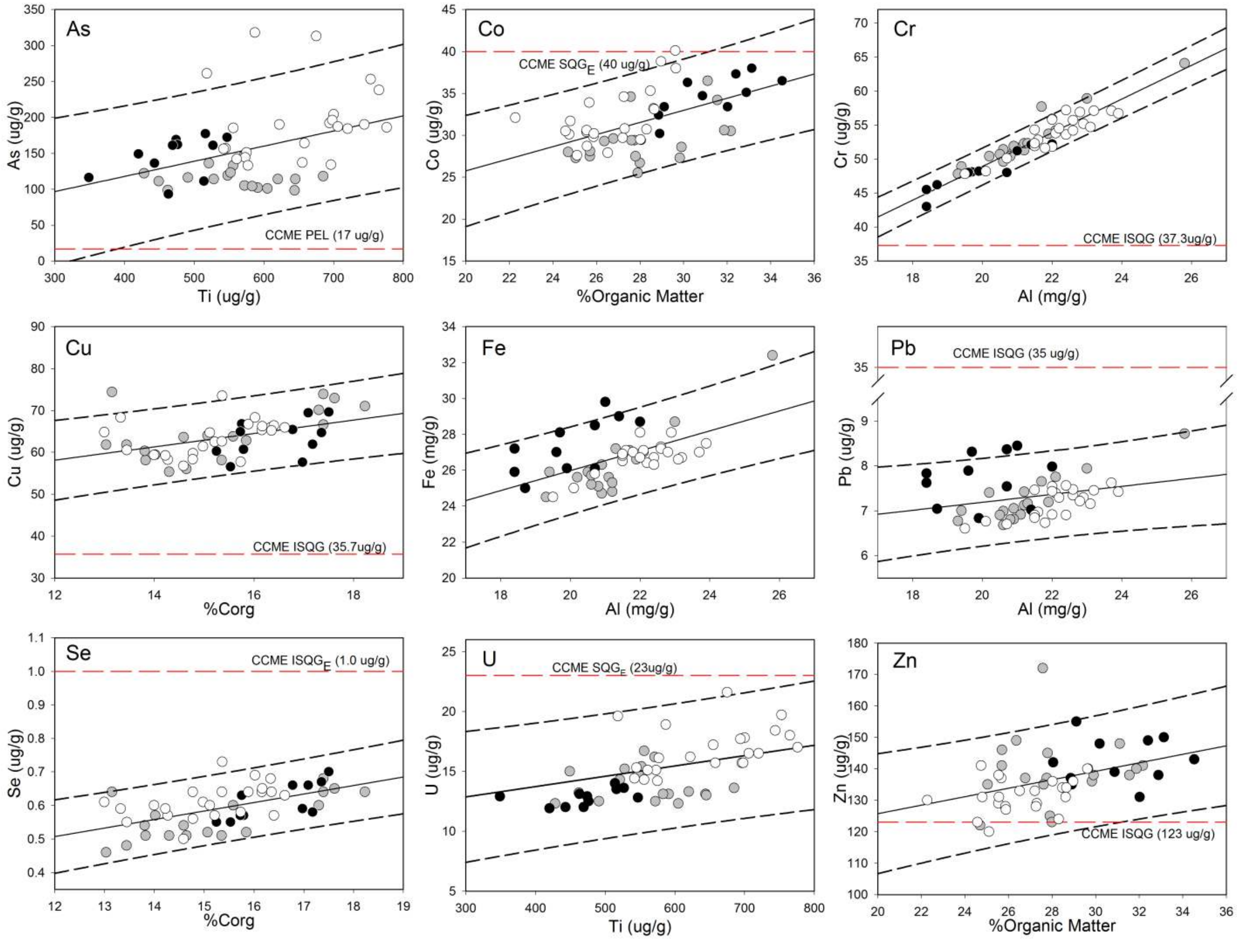


Figure 10. Nico Lake residual metals concentrations plotted by year (~1700-2016 CE). Solid black line represents ~1139-2016 baseline. Dashed black line represents 95% prediction interval calculated from the widest normalizing agent value. Grey data points span ~1700 -~1936. Black data points span ~1936 to 2016.

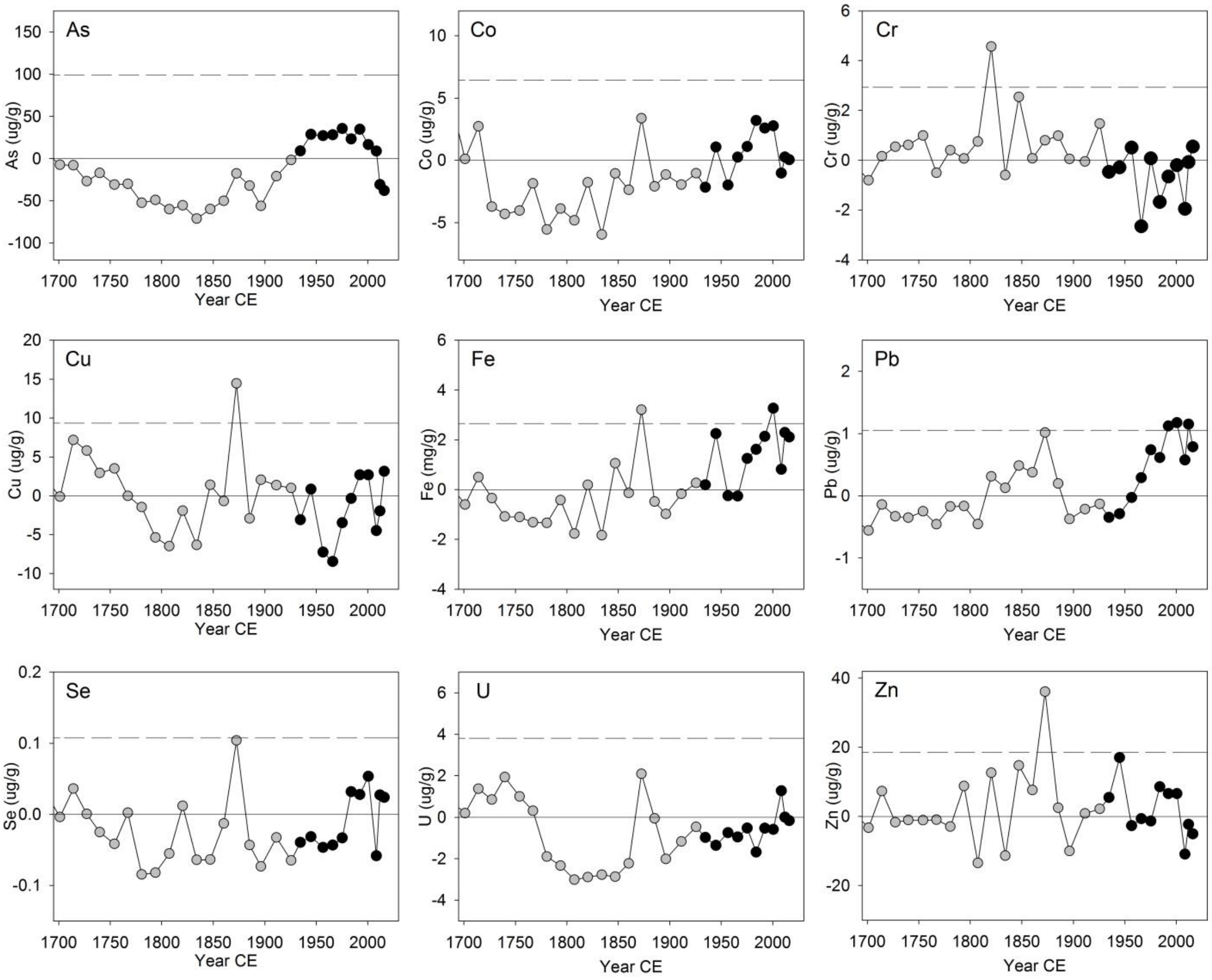


Figure 11. Grid Lake linear regression relationships between Metals and Elements of Interest and Normalizing Agents. Solid black line is calculated from the entire stratigraphic record (~679 BC-2015 CE). Black dashed lines are calculated 95% prediction intervals. Red dashed lines are CCME sediment and soil quality guidelines. White circles identify samples from the pre-1700 period, grey circles identify samples from the 1700 to 1936 period, and black circles identify samples in the post-1936 period.

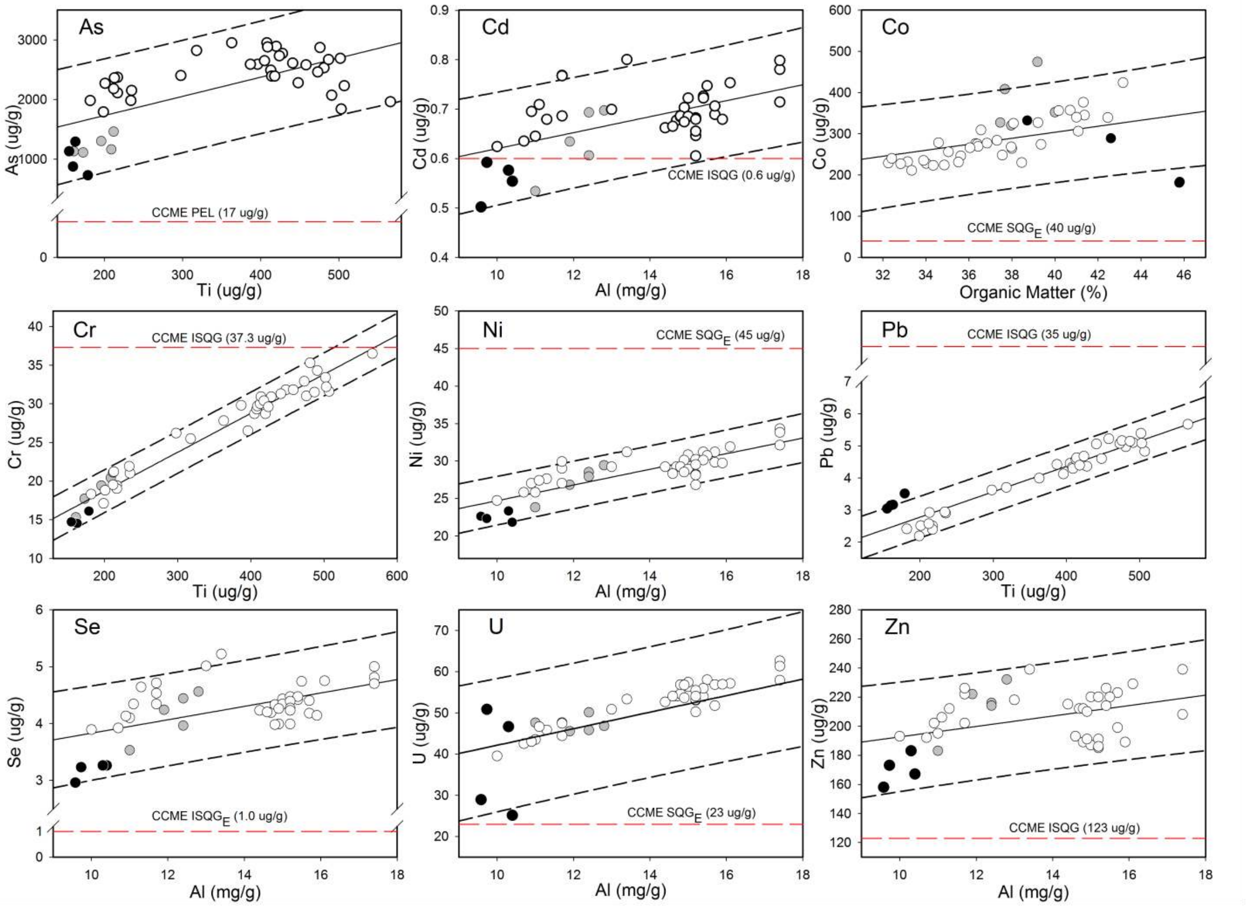


Figure 12. Grid Lake residual metals concentrations plotted by year (~1700-2016). Solid black line represents ~679 BC-2016 baseline. Dashed black line represents 95% prediction interval calculated from the widest normalizing agent value. Grey data points span ~1700 -~1936. Black data points span ~1936 to 2016.

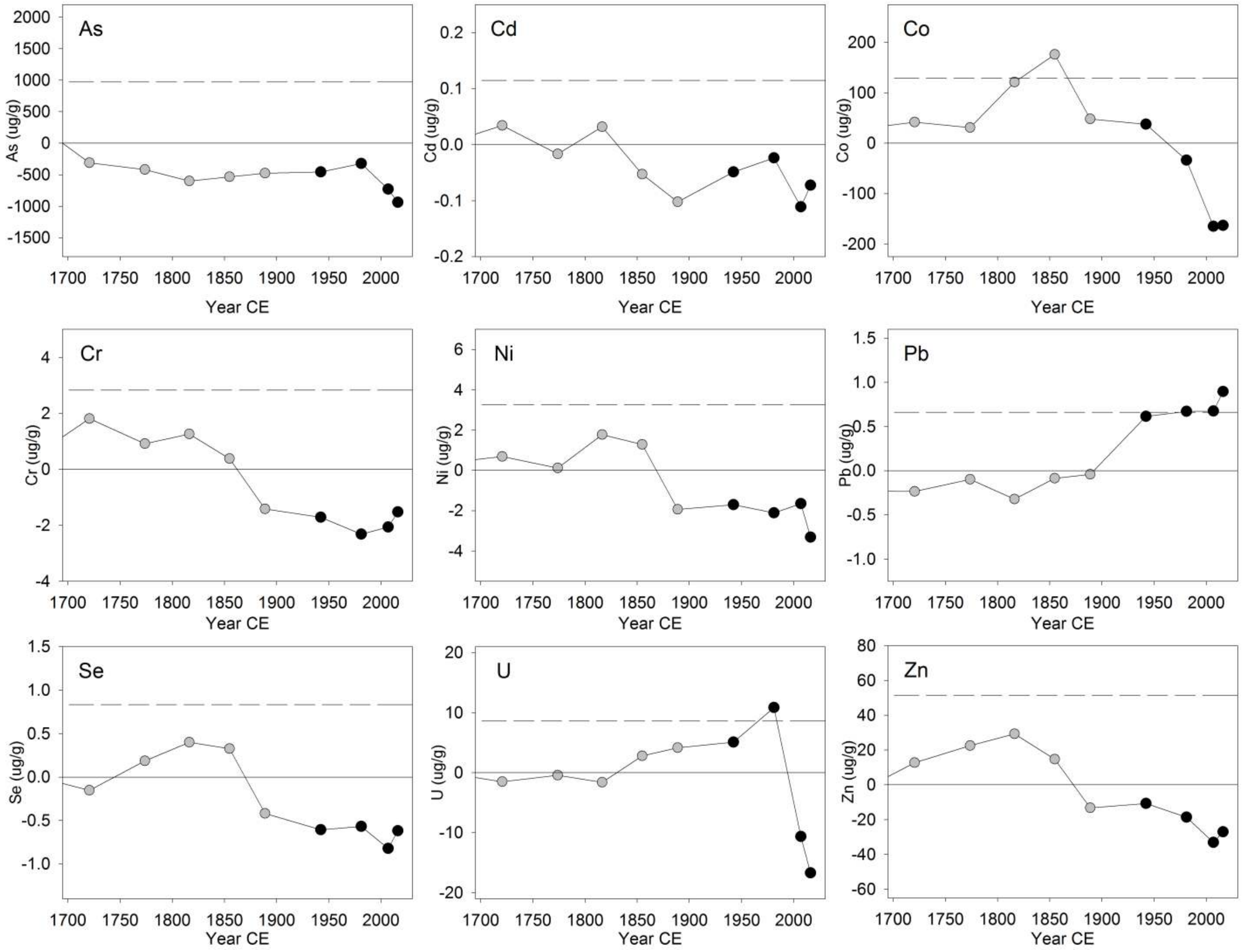


Figure 13. Residual Pb concentrations from the four study lakes from ~1900 to present.

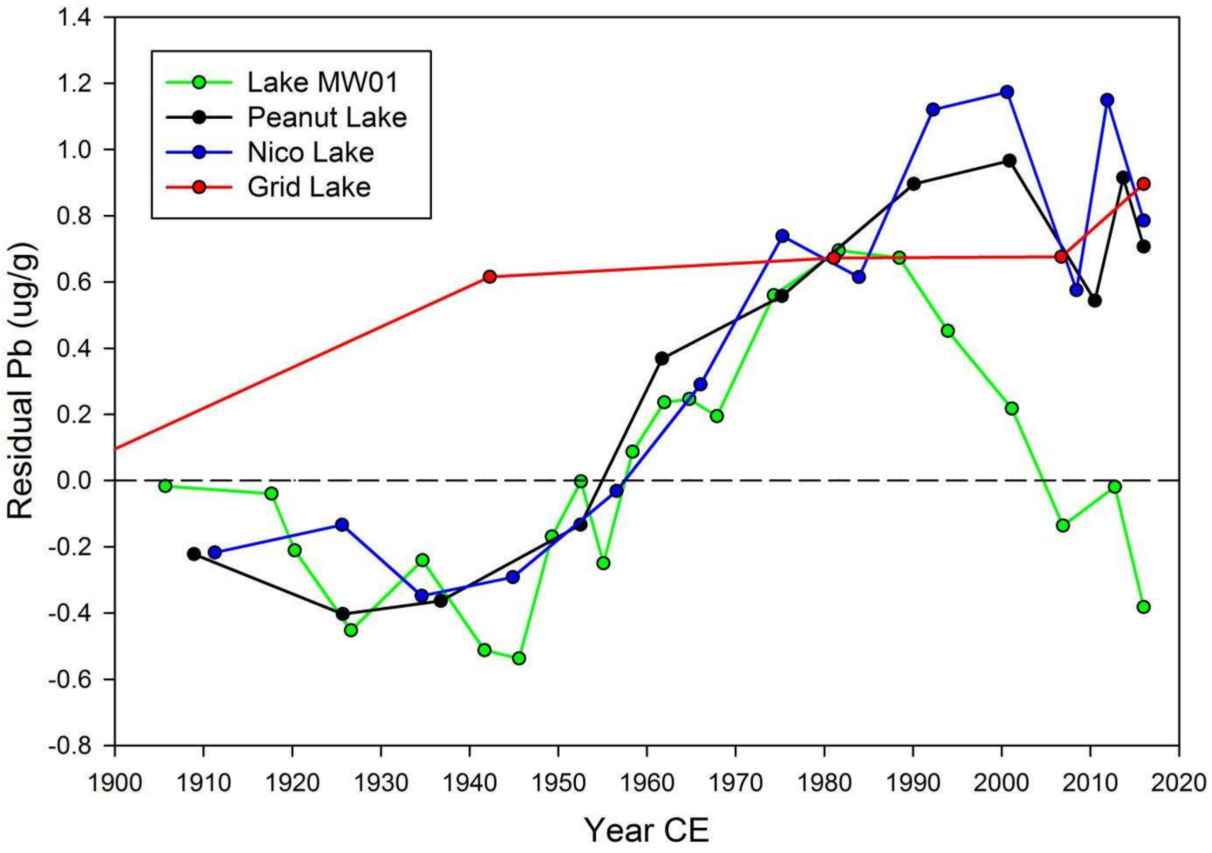
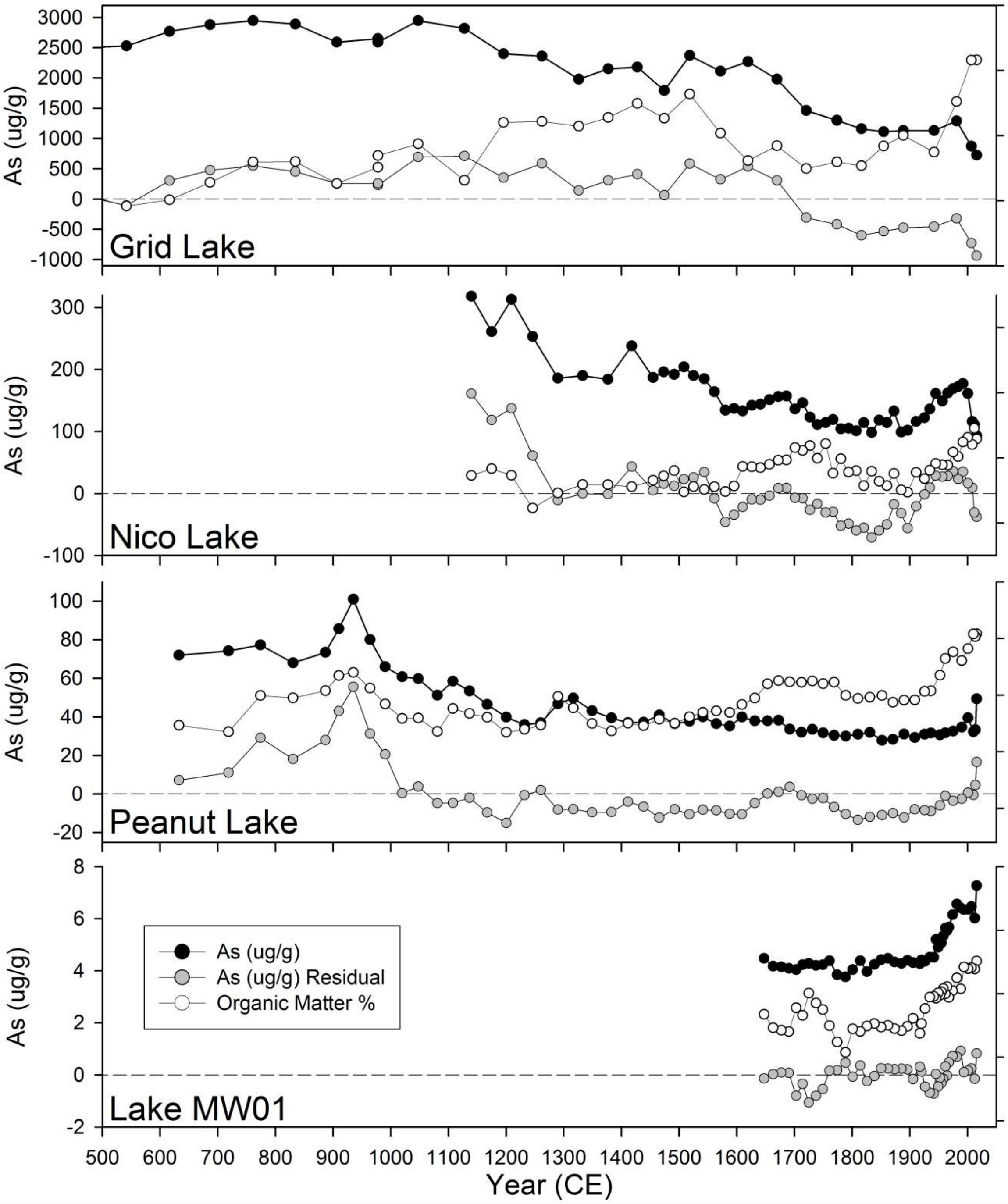


Figure 14. Raw and residual As concentrations (μg g^{-1}) and percent organic matter content (OM%) from the four study lakes.



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Chapter 3. Conclusions

Key Findings and Relevance

This study demonstrates the successful mergence between paleolimnological research and environmental monitoring. The establishment of site-specific baselines using multiple normalizing agents has produced an invaluable dataset to be used by the Marian Watershed Stewardship Program. The framework established here will provide pre-NICO mine reference conditions of sediment concentrations that can be used to assess for pollution of surface sediment once the NICO mine becomes operational. Here, the use of paleolimnological methods has filled a knowledge gap and identified the range of natural variation of MEI concentrations to effectively inform monitoring efforts.

The major differences in magnitude of metal(oid) concentrations among the four study lakes is substantial particularly for arsenic. This demonstrates the importance of determining site-specific baselines that are representative of lake-specific catchment characteristics such as geology and physical processes and lake biogeochemical processes. The inclusion of biogenic normalizing agents (OM, C_{org}) is an initial effort to account for the bio-mediated influence of potentially mobile elements within the individual lakes. As this environment continues to change due to the influence of climate change or from the development of the NICO mine, these baseline relationships inclusive of bio-mediated responses can offer major insight as hydrological and biogeochemical conditions are altered.

The complexity of arsenic biogeochemistry and the natural magnitude and range of variation of concentrations creates a challenge for interpreting arsenic within the sediment record. Substantial enrichment of arsenic in the early sediment record in Peanut, Nico, and Grid lake cores indicate a natural process, which exerted major influence on arsenic concentrations. Further studies are required to develop an understanding of metal mobility in the sub-arctic, particularly in regards to arsenic. Although the theme and objective of this research has focussed on developing a baseline dataset, a product to be applied to monitoring, the exploration and interpretation of the metals data has revealed the complexity of the biogeochemical processes responsible for variation and has stimulated this researcher to further study and evaluate these processes.

As equally important as the generation of a statistically strong dataset, is the collaborative relationship between researchers and the Tłı̨chǫ community during this study. This research study exemplifies the positive direction that northern research is evolving towards. The Tłı̨chǫ community are leaders in the North. By identifying the need for science in community-led initiatives such as the MWSP, this is setting an example for collaborations between other northern communities and scientists. The inclusionary approach of the MWSP, which combines traditional Tłı̨chǫ knowledge and western science knowledge, gives strength to the MWSP and generates mutual respect for both knowledge forms.

Recommendations for Future Research

To complement the knowledge developed from sediment core analysis, the collection of additional surface samples within study lakes, collected coincident to the resampling at coring location, should be implemented to develop an understanding of natural in-lake spatial variation of MEI. This can provide valuable understanding of intra-lake differences associated with differences in physical catchment and geochemical conditions at various depths, such as differences in grain size due to various transport conditions, sedimentation rates, and varying redox environments (Birch et al. 2001; Pientz & Vincent, 2012; Engstrom & Rose, 2013; Blais et al. 2014; Schuh et al. 2019). Concentrations of redox-sensitive MEI may experience substantial spatial variation within a lake due to differing physical and geochemical environments (Sharif et al. 2008; Schuh et al. 2018). Schuh et al. (2018) identified the temporal and spatial variation of arsenic associated with seasonality, redox conditions, and grain size at multiple depths in a single lake, demonstrating the need for additional site sampling locations to complement the maximum depth location for a complete understanding of spatial variability. The addition of multiple surface sediments may enhance the ability to accurately interpret MEI concentrations in monitoring as mine impacts may be spatially heterogeneous within a given lake and the transport and deposition of potential mining derived material to the maximum depth sample location may occur more slowly than near-shore locations.

Using the methods developed by Couture et al. (2008), additional study could be undertaken to reconstruct the original depositional history of arsenic within the sediment profiles of these lakes through pore water collection and diagenetic modelling. In conjunction with biological proxies such as diatoms and cellulose oxygen isotope composition, this may help to elucidate the paleohydrological and paleoproductivity conditions in which arsenic concentrations were elevated in the past. In addition, this method may also help to determine the possibility of very far-field arsenic delivery to Lake MW01 from historic Giant mine emissions.

Lastly, to enhance future monitoring initiatives, sediment MEI baselines should be established from additional surrounding lakes which have been previously cored as well as from lakes which could be collected prior to the NICO operations. Sediment cores from Lou and Burke lakes (Sept. 2015) and Hislop Lake (Sept. 2017) should be analysed and interpreted to establish additional MEI baselines for continued use in MWSP sediment monitoring. These lakes are both culturally important to the Tłı̨chǫ community and are relatively accessible compared to those four lakes from this study. Additional lakes could also be considered for future core collection with a focus on ascertaining a representative reference condition lake similar in surficial geological and hydrological characteristics such as the lake identified by Golder Associates (2010). This *Reference Lake*, located 1.5 km south of the deposit, could be cored for comparable data to initial industry-led contemporary baseline studies (Figure 15). From Figure 15, the initial inclusion of Tumi and Rabbit Lake as sediment locations would appear ideal. However, these lakes both have considerable surface area, are quite shallow (3 m) and experience significant mixing according to local Tłı̨chǫ land-users, making them less favourable for paleolimnological analysis. With continued consultation with Tłı̨chǫ traditional land-users, additional sediment cores should be collected from culturally relevant, scientifically important, and easily accessible locations.

Reflections on the North

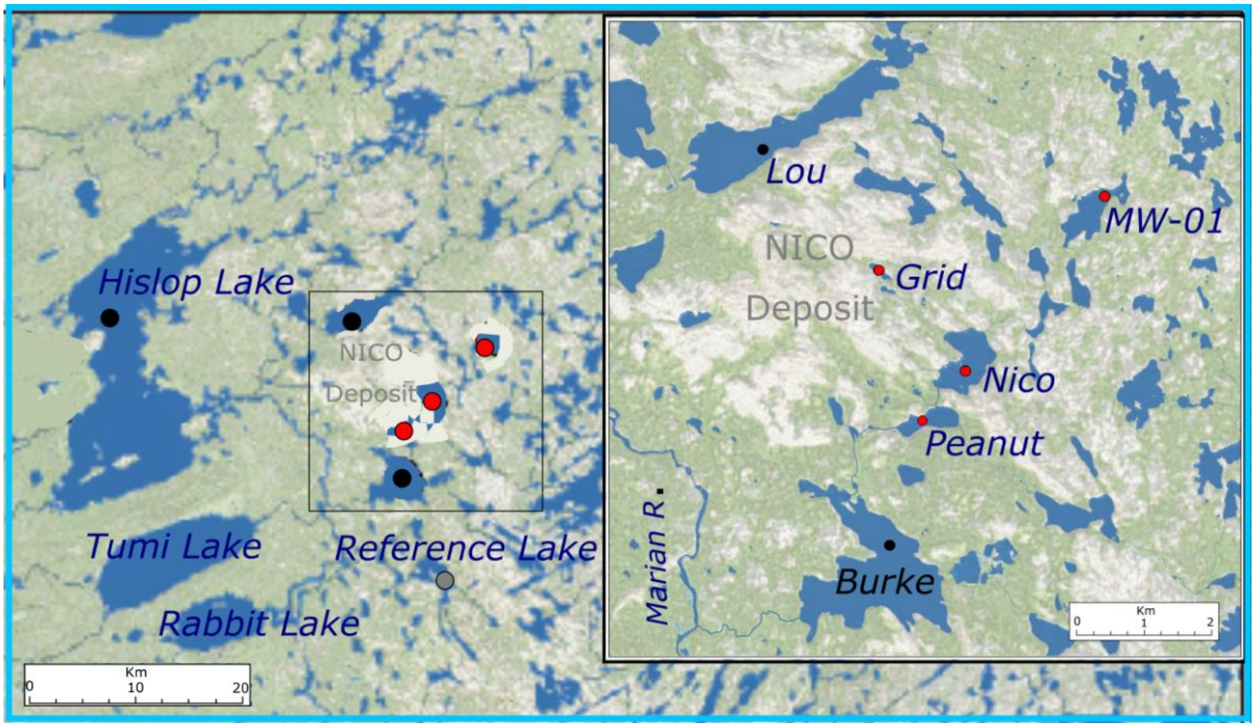
Since the arrival of European settlers, the Canadian economy has been driven by the extraction of natural resources. In modern times, rapid post-war industrialization and access to expanding domestic and foreign markets has led to the major expansion of large-scale mining operations in the oil and gas and metal-mineral sectors. Although the development of this natural wealth has led to significant economic and social prosperity, these activities have unfortunately resulted in extensive environmental damage from major land disturbance and pollution. The Canadian North has historically been wealthy in extractable natural resources. The Northwest Territories (NT) remains abundant in extractable metal-mineral resources and may best encapsulate Canada's mining history with major past, current, and future mining operations, shaping its identity today.

Operating under the perception of remoteness and neglect, historic mine operations were oblivious to the immense environmental damage caused by pollution primarily from metals contamination. This same ethos of ignorance also prevailed to marginalize and degrade the lives and identity of First Nations people who were culturally akin to their Lands that were now so readily exploited. Canada's historic attitude of cultural environmental denigration for the sake of resource extraction has created a *legacy* of major pollution and cultural oppression especially in the North, a blemish which Canada is finally attempting to reconcile as our society's political conscience is catching up to it on an international stage. Again the Northwest Territories may best exemplify this recent shift in environmental and cultural ethical framework. As Canada's governments are aggressively working towards reconciliation with First Nations, so too are Treaties, environmental policies, and programs being developed around resource extraction that are inclusive of the those culturally tied to the Land in the NT.

Mining and resource extraction will continue to play a key role in the Canadian and Northern economy and identity. Our modern lives depend on these commodities for employment and material goods. Through inclusionary policy and reconciliation and basic cognisance of the value of the environment, especially water resources, resource extraction can proceed to be developed in a manner that is equitable to all parties and environmental degradation is limited through strict guidelines supported by environmental monitoring, Traditional Knowledge, and western science research.

The North, as a term that could once be considered a broad and vague colloquialism invoking a scene of uninhabited barren wilderness, has now come to encompass a unique Canadian place where the natural environment and culture have developed a resilient and celebrated identity. For this researcher, the term now invokes the faces of those northerners now friends, and the place they call home that has given this research purpose and meaning.

Figure 15. Coring locations of four study lakes, Grid, Nico, Peanut, and Lake MW01 identified by red circle, Lou, Burke and Hislop Lakes as black circles, and the potential future coring location of *Reference Lake,* grey circle.



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Appendices

Appendix 1. Coring locations and YSI water measurements at time of collection.

Lake	Nico Lake	Peanut Lake	Grid	Lake MW01
Sample Date	Apr. 2, 2016	Apr. 2, 2016	Apr. 2, 2016	Sept. 2, 2015
Latitude	63.546420°N	63.537653°N	63.553191°N	63.569409°N
Longitude	116.704036°W	116.710884°W	116.740344°W	116.690188°W
Elevation (MASL)	201	193	240	213
Core Length (cm)	58.5	58	43	38
Depth (m)	8	6	3	7
Temperature C, at 3.5m	4.6	2.2	2.7	9
Cond Sp. at 3.5m	138	111	369	66
pH	8.2	7.9	7.47	7.24
DO % at 3.5m	8	36	5.5	-
DO mg/L at 3.5m	0.78	4.5	0.75	-

Appendix 2, Measured radioisotope values of ^{210}Pb, ^{137}Cs, ^{226}Ra (dpm/g) and CRS chronology of Study Lakes.

MW01

Core Mid-Depth (cm)	CRS Year	CRS error +/-2 Sigma	Total Measured ^{210}Pb (dpm/g)	210Pb error, 1 std. dev.	^{226} Ra dpm/g	226 Ra error, 1 std. dev.
0.5	2014.67	0.2231	32.6589	1.8687	2.7139	0.5503
1	2012.75	0.3530	33.6307	1.8417	2.5240	0.5763
1.5	2010.67	0.5042	29.4558	1.8717	3.9391	0.6099
2.5	2004.05	1.0148	25.1005	1.4438	2.6692	0.5012
3.5	1997.72	1.3510	24.5305	1.3383	3.0736	0.4179
4.5	1991.35	1.7276	17.8878	1.0952	3.4210	0.4249
5.5	1985.26	2.1360	15.8330	0.9769	3.0939	0.4154
6.5	1978.15	2.6954	14.2717	0.8406	3.5235	0.3826
7.5	1971.16	3.3361	10.8019	0.7833	3.0280	0.3788
8.5	1964.78	4.0092	9.2383	0.6902	3.5696	0.3681
9.5	1958.38	4.8164	8.3893	0.6413	3.2205	0.3780
10.5	1952.54	5.5983	6.8577	0.5070	3.8357	0.3792
11.5	1945.57	6.7433	7.0275	0.5534	3.5034	0.3587
12.5	1938.60	8.0368	5.4684	0.4712	3.2190	0.3370
13.5	1930.73	9.7299	5.4318	0.4945	3.2512	0.3409
14.5	1922.14	12.1279	5.0276	0.4459	3.0822	0.3209
15.5	1919.90	12.1809	3.6298	0.3564	3.5055	0.2906
16.5	1911.32	13.8592	5.2973	0.4588	3.7061	0.3336
17.5	1901.15	16.3472	4.3982	0.3813	3.5889	0.2977
18.5	1891.26	17.2491	4.1908	0.3631	3.6409	0.2852
20.5	1856.63		3.8242	0.3524	3.6864	0.3044

Peanut Lake

Core Top-Depth (cm)	CRS Year	CRS error +/-2 Sigma	Total Measured ^{210}Pb (dpm/g)	210Pb error, 1 std. dev.	^{226} Ra dpm/g	226 Ra error, 1 std. dev.
0.0	2013.70	0.38	25.5872	1.1921	5.3708	0.5002
0.5	2010.50	0.78	21.6269	1.3609	5.6315	0.5354
1.0	2005.75	1.28	25.1817	1.5010	5.9295	0.6083
2.0	1995.88	2.34	19.3437	1.1712	5.5388	0.5918
3.0	1983.02	3.90	16.5987	1.0000	5.3773	0.4838
4.0	1968.02	6.43	12.5550	0.7908	4.7672	0.3939
5.0	1957.41	7.78	8.4993	0.6332	5.9766	0.5439
6.0	1943.46	10.32	8.0490	0.5855	4.8383	0.3610
7.0	1931.76	11.50	6.4638	0.5543	5.3042	0.3909
8.0	1917.24	10.39	6.4623	0.4843	5.2265	0.3823
9.0	1908.91		5.5085	0.4330	5.3655	0.3409
10.0	1899.16		5.7867	0.4130	5.6132	0.3826
11.0	1890.02		5.7739	0.4473	5.526063	0.366288
18.0	*1721.40*		5.2220	0.3885	4.79255	0.322927

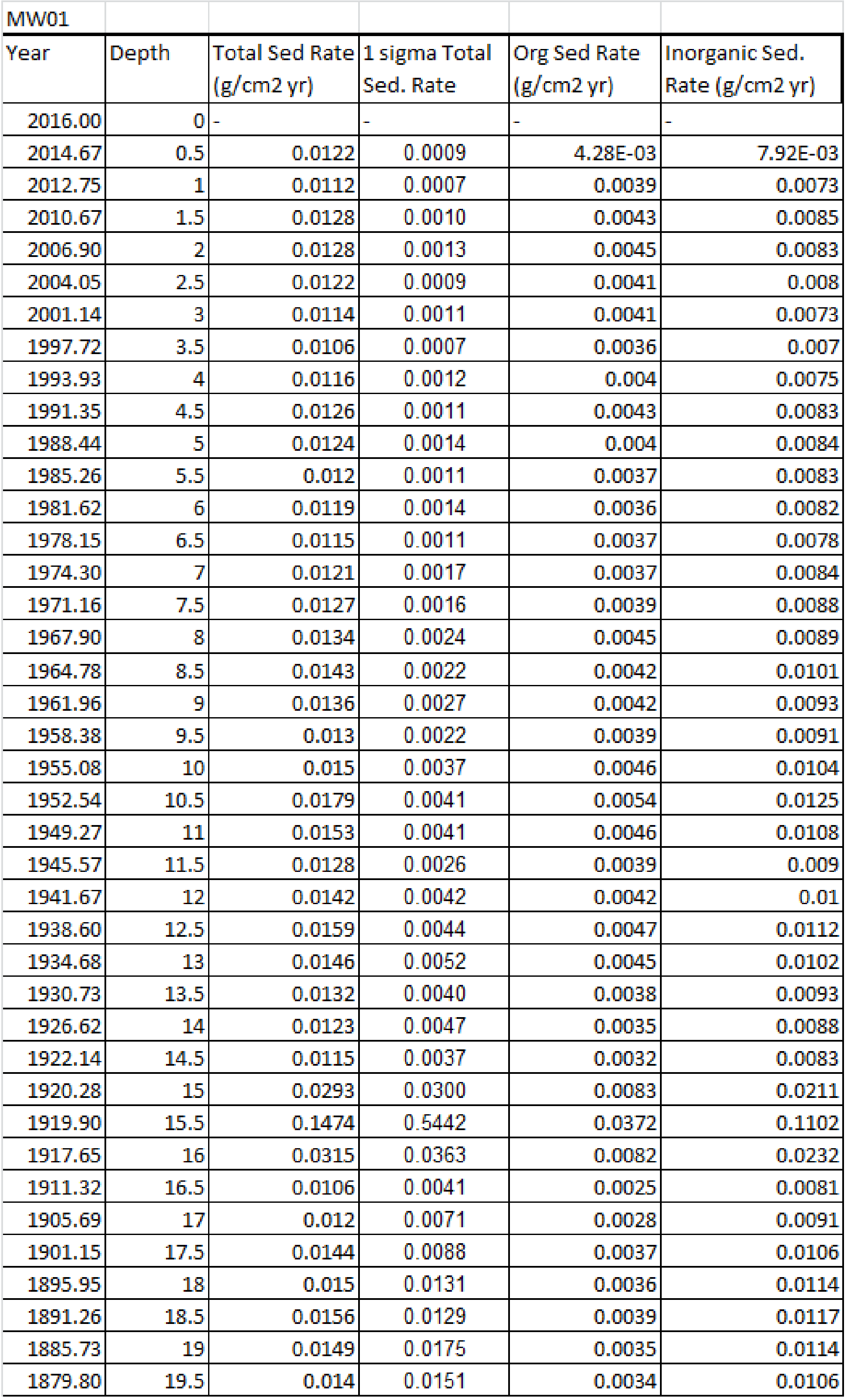
Nico Lake

Core Top-Depth (cm)	CRS Year	CRS error +/-2 Sigma	Total Measured ^{210}Pb (dpm/g)	210Pb error, 1 std. dev.	^{226} Ra dpm/g	226 Ra error, 1 std. dev.
0	2011.91	0.29	40.9662	0.8007	4.3289	0.4634
1	2004.78	0.72	31.7625	1.3378	4.2368	0.5568
2	1996.25	1.26	28.3304	1.0489	4.1045	0.5201
3	1988.02	1.85	21.1454	1.0520	4.6274	0.5281
4	1979.75	2.52	18.1419	0.8621	4.9701	0.6515
5	1971.09	3.36	13.7180	0.8385	4.0225	0.4721
6	1961.54	4.49	11.9568	0.6722	4.4985	0.4967
7	1951.17	6.06	10.5524	0.7739	4.2705	0.4635
8	1939.44	8.07	8.3825	0.7041	4.4315	0.4770
9	1930.87	9.39	6.4727	0.6734	4.2645	0.5078
10	1919.10	11.64	6.7999	0.6106	4.2349	0.4535
11	1902.57	15.36	6.1199	0.5440	4.3368	0.4304
12	1890.86	15.34	4.9772	0.5142	4.3224	0.3195
13	1879.39		4.9359	0.4812	4.3081	0.4512
14	1866.13		4.9194	0.5828	4.8588	0.5319
15	1852.78		5.2684	0.6052	4.0085	0.4299
16	1840.15		4.7013	0.4826	4.1721	0.4240
17	1825.81		5.2463	0.6153	4.2139	0.5129
18	1813.81		5.4489	0.5748	4.3400	0.5623
19	1801.21		4.1075	0.4786	2.2932	0.3242
20	1787.40		5.4696	0.5444	4.3421	0.4507
21	1773.83		4.9473	0.5372	4.4047	0.4938
21.5	1761.19		5.1722	0.4794		
22	1746.59		3.6770	0.5387		
22.5	1754.08		5.0830	0.5334		
24	1733.91		4.2854	0.5028	3.9421	0.4766
25	1720.32		5.4041	0.5239		
25.5	1714.21		5.7051	0.5874		
30	1648.71		4.3773	0.4211	4.5826	0.3698

Grid Lake

Core Top-Depth (cm)	CRS Year	CRS error +/-2 Sigma	Total Measured ^{210}Pb (dpm/g)	210Pb error, 1 std. dev.	^{226} Ra dpm/g	226 Ra error, 1 std. dev.	137Cs Activity (dpm/g)	137Cs error, 1 std. dev.
0.0	2013.48	0.42	52.8639	3.0012	6.9332	1.0680	2.7458	0.3669
0.5	2006.72	1.00	48.8168	2.3335	5.6492	0.6545	2.5533	0.2247
1.0	1995.60	1.89	50.5583	2.1990	5.6656	0.5422	2.7393	0.1822
2.0	1962.98	5.54	26.8315	1.4496	5.0569	0.4725	3.9035	0.1958
2.5	1942.28	10.67	20.9972	1.1767	3.8569	0.4642	3.5161	0.1800
3.0	1916.98	22.83	15.0753	0.8039	5.6436	0.4547	2.7168	0.1161
4.0	1874.84	63.00	5.8783	0.7006	4.9059	0.5025	0.9636	0.1320
5.0	1838.84		6.9181	0.5656	7.3739	0.4711	0.7354	0.0981
6.0	1794.84		5.4018	0.4454	4.8308	0.3536	0.4419	0.0770
7.0	1747.46		5.3587	0.4381	5.7117	0.3649	0.5696	0.0760
8.0	1697.59		5.4115	0.4795	5.3100	0.3635	0.4833	0.0801
9.0	1643.76		4.7025	0.3876	5.2755	0.3352	0.4419	0.0675
10.0	1595.18		4.9754	0.3769	5.5229	0.3528	0.3753	0.0629
11.0	1545.79		5.1932	0.3990	5.6183	0.3488	0.3468	0.0656
12.0	1498.08		4.7947	0.4190	5.7832	0.3851	0.2405	0.0694
20.0	*1011.70*		7.3620	0.5793	7.8183	0.4534	-0.0570	0.1189
24.0	*724.41*		6.9553	0.5230	7.6299	0.4155	-0.0025	0.0087

Appendix 3. Total dry mass sedimentation rates calculated from CRS.

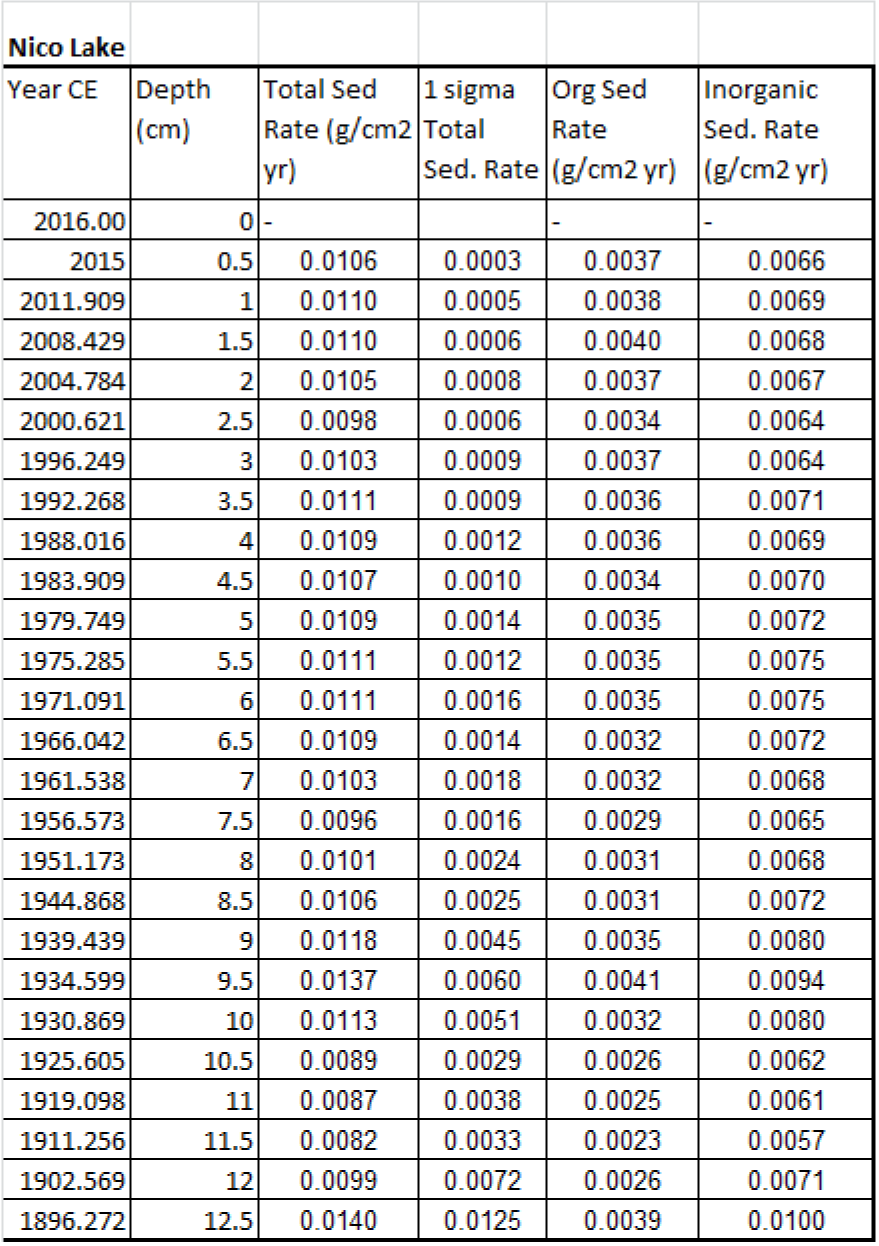


MW01

Year	Depth	Total Sed Rate (g/cm2 yr)	1 sigma Total Sed. Rate	Org Sed Rate (g/cm2 yr)	Inorganic Sed. Rate (g/cm2 yr)
2016.00	0	-	-	-	-
2014.67	0.5	0.0122	0.0009	4.28E-03	7.92E-03
2012.75	1	0.0112	0.0007	0.0039	0.0073
2010.67	1.5	0.0128	0.0010	0.0043	0.0085
2006.90	2	0.0128	0.0013	0.0045	0.0083
2004.05	2.5	0.0122	0.0009	0.0041	0.008
2001.14	3	0.0114	0.0011	0.0041	0.0073
1997.72	3.5	0.0106	0.0007	0.0036	0.007
1993.93	4	0.0116	0.0012	0.004	0.0075
1991.35	4.5	0.0126	0.0011	0.0043	0.0083
1988.44	5	0.0124	0.0014	0.004	0.0084
1985.26	5.5	0.012	0.0011	0.0037	0.0083
1981.62	6	0.0119	0.0014	0.0036	0.0082
1978.15	6.5	0.0115	0.0011	0.0037	0.0078
1974.30	7	0.0121	0.0017	0.0037	0.0084
1971.16	7.5	0.0127	0.0016	0.0039	0.0088
1967.90	8	0.0134	0.0024	0.0045	0.0089
1964.78	8.5	0.0143	0.0022	0.0042	0.0101
1961.96	9	0.0136	0.0027	0.0042	0.0093
1958.38	9.5	0.013	0.0022	0.0039	0.0091
1955.08	10	0.015	0.0037	0.0046	0.0104
1952.54	10.5	0.0179	0.0041	0.0054	0.0125
1949.27	11	0.0153	0.0041	0.0046	0.0108
1945.57	11.5	0.0128	0.0026	0.0039	0.009
1941.67	12	0.0142	0.0042	0.0042	0.01
1938.60	12.5	0.0159	0.0044	0.0047	0.0112
1934.68	13	0.0146	0.0052	0.0045	0.0102
1930.73	13.5	0.0132	0.0040	0.0038	0.0093
1926.62	14	0.0123	0.0047	0.0035	0.0088
1922.14	14.5	0.0115	0.0037	0.0032	0.0083
1920.28	15	0.0293	0.0300	0.0083	0.0211
1919.90	15.5	0.1474	0.5442	0.0372	0.1102
1917.65	16	0.0315	0.0363	0.0082	0.0232
1911.32	16.5	0.0106	0.0041	0.0025	0.0081
1905.69	17	0.012	0.0071	0.0028	0.0091
1901.15	17.5	0.0144	0.0088	0.0037	0.0106
1895.95	18	0.015	0.0131	0.0036	0.0114
1891.26	18.5	0.0156	0.0129	0.0039	0.0117
1885.73	19	0.0149	0.0175	0.0035	0.0114
1879.80	19.5	0.014	0.0151	0.0034	0.0106

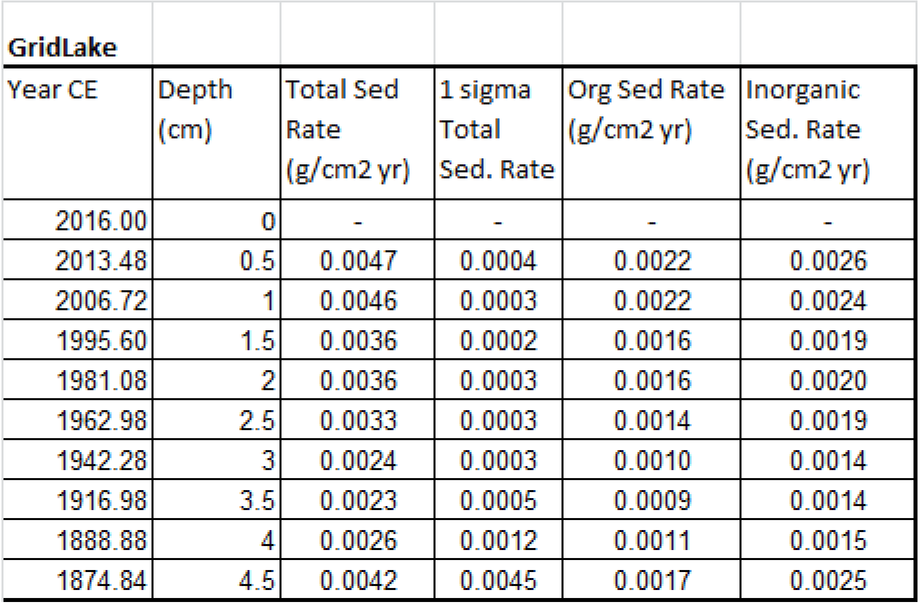
Peanut Lake

Year CE	Depth (cm)	Total Sed Rate (g/cm2 yr)	1 sigma Total Sed. Rate Error	Org Sed Rate (g/cm2 yr)	Inorganic Sed. Rate (g/cm2 yr)
2016.00	0	-		-	-
2013.70	0.5	0.0158	1.16E-03	3.23E-03	1.26E-02
2010.50	1	0.0185	1.79E-03	3.72E-03	0.0147
2005.75	1.5	0.0139	1.29E-03	2.83E-03	0.011
2000.90	2	0.0141	1.79E-03	2.67E-03	0.0114
1995.88	2.5	0.0143	1.57E-03	2.74E-03	0.0116
1990.09	3	0.0136	1.88E-03	2.57E-03	0.011
1983.02	3.5	0.0126	1.44E-03	2.27E-03	0.0103
1975.22	4	0.0121	1.88E-03	2.21E-03	9.85E-03
1968.02	4.5	0.0114	1.64E-03	2.15E-03	9.27E-03
1961.71	5	0.0152	4.56E-03	2.90E-03	0.0123
1957.41	5.5	0.0231	0.0107	4.21E-03	0.0189
1952.50	6	0.0179	7.93E-03	3.23E-03	0.0147
1943.46	6.5	0.0136	3.35E-03	2.28E-03	0.0114
1936.75	7	0.0164	7.58E-03	2.63E-03	0.0138
1931.76	7.5	0.0231	0.0141	3.55E-03	0.0196
1925.71	8	0.0192	0.013	3.15E-03	0.016
1917.24	8.5	0.0154	7.35E-03	2.35E-03	0.013



Nico Lake

Year CE	Depth (cm)	Total Sed Rate (g/cm2 yr)	1 sigma Total Sed. Rate	Org Sed Rate (g/cm2 yr)	Inorganic Sed. Rate (g/cm2 yr)
2016.00	0	-		-	-
2015	0.5	0.0106	0.0003	0.0037	0.0066
2011.909	1	0.0110	0.0005	0.0038	0.0069
2008.429	1.5	0.0110	0.0006	0.0040	0.0068
2004.784	2	0.0105	0.0008	0.0037	0.0067
2000.621	2.5	0.0098	0.0006	0.0034	0.0064
1996.249	3	0.0103	0.0009	0.0037	0.0064
1992.268	3.5	0.0111	0.0009	0.0036	0.0071
1988.016	4	0.0109	0.0012	0.0036	0.0069
1983.909	4.5	0.0107	0.0010	0.0034	0.0070
1979.749	5	0.0109	0.0014	0.0035	0.0072
1975.285	5.5	0.0111	0.0012	0.0035	0.0075
1971.091	6	0.0111	0.0016	0.0035	0.0075
1966.042	6.5	0.0109	0.0014	0.0032	0.0072
1961.538	7	0.0103	0.0018	0.0032	0.0068
1956.573	7.5	0.0096	0.0016	0.0029	0.0065
1951.173	8	0.0101	0.0024	0.0031	0.0068
1944.868	8.5	0.0106	0.0025	0.0031	0.0072
1939.439	9	0.0118	0.0045	0.0035	0.0080
1934.599	9.5	0.0137	0.0060	0.0041	0.0094
1930.869	10	0.0113	0.0051	0.0032	0.0080
1925.605	10.5	0.0089	0.0029	0.0026	0.0062
1919.098	11	0.0087	0.0038	0.0025	0.0061
1911.256	11.5	0.0082	0.0033	0.0023	0.0057
1902.569	12	0.0099	0.0072	0.0026	0.0071
1896.272	12.5	0.0140	0.0125	0.0039	0.0100



GridLake

Year CE	Depth (cm)	Total Sed Rate (g/cm2 yr)	1 sigma Total Sed. Rate	Org Sed Rate (g/cm2 yr)	Inorganic Sed. Rate (g/cm2 yr)
2016.00	0	-	-	-	-
2013.48	0.5	0.0047	0.0004	0.0022	0.0026
2006.72	1	0.0046	0.0003	0.0022	0.0024
1995.60	1.5	0.0036	0.0002	0.0016	0.0019
1981.08	2	0.0036	0.0003	0.0016	0.0020
1962.98	2.5	0.0033	0.0003	0.0014	0.0019
1942.28	3	0.0024	0.0003	0.0010	0.0014
1916.98	3.5	0.0023	0.0005	0.0009	0.0014
1888.88	4	0.0026	0.0012	0.0011	0.0015
1874.84	4.5	0.0042	0.0045	0.0017	0.0025

Appendix 4. Loss-on-Ignition, organic carbon and nitrogen elemental and isotope composition (including calculated C/N values).

Lake MW01											
Depth	Year CE	%H2O	%OM	%MM	LOI 1000	%CaCO3	%C	%N	δ13C	δ15N	C/N
0.0	2015	96.11	35.11	62.50	2.39	5.44	22.20	2.08	-31.14	2.17	10.66794
0.5	2014.67	93.86	34.83	61.56	3.60	8.19	17.15	1.63	-31.33	2.23	10.51778
1.0	2012.75	93.16	33.87	64.27	1.87	4.24	20.16	1.87	-30.69	1.67	10.80822
1.5	2010.67	91.67	35.38	61.08	3.54	8.04	18.47	1.81	-31.24	1.64	10.18433
2.0	2006.90	92.76	34.06	62.94	3.00	6.81	17.61	1.62	-30.82	1.91	10.86163
2.5	2004.05	92.85	35.65	61.00	3.34	7.60	17.45	1.60	-30.56	1.90	10.87504
3.0	2001.14	92.29	33.90	64.89	1.21	2.75	17.73	1.61	-30.49	1.59	10.996
3.5	1997.72	91.57	34.93	63.70	1.37	3.11	17.25	1.52	-30.33	1.16	11.3748
4.0	1993.93	92.60	34.18	64.54	1.28	2.90	17.35	1.56	-30.24	1.48	11.12072
4.5	1991.35	92.13	32.25	66.36	1.39	3.16	17.01	1.54	-30.05	1.12	11.07827
5.0	1988.44	91.82	30.73	67.89	1.38	3.13	17.05	1.54	-29.96	1.37	11.05562
5.5	1985.26	91.13	30.56	67.87	1.57	3.58	16.54	1.48	-29.87	1.62	11.16127
6.0	1981.62	91.56	32.45	66.23	1.32	3.01	16.54	1.49	-29.90	1.70	11.10887
6.5	1978.15	91.04	30.50	66.67	2.83	6.44	16.25	1.45	-29.74	1.39	11.18968
7.0	1974.30	92.38	30.43	67.26	2.30	5.23	17.48	1.53	-29.73	1.47	11.43092
7.5	1971.16	90.81	33.67	65.34	1.00	2.26	16.04	1.40	-29.60	1.51	11.44765
8.0	1967.90	91.22	29.37	68.03	2.59	5.89	16.07	1.39	-29.55	1.62	11.56369
8.5	1964.78	90.47	31.09	67.13	1.78	4.05	16.33	1.40	-29.58	1.65	11.64071
9.0	1961.96	90.63	29.94	68.02	2.04	4.63	16.58	1.43	-29.49	1.89	11.56961
9.5	1958.38	90.19	30.78	67.84	1.37	3.12	16.07	1.38	-29.38	1.45	11.61918
10.0	1955.08	90.40	30.26	67.33	2.40	5.47	16.68	1.42	-29.20	1.58	11.71858
10.5	1952.54	90.42	29.71	68.93	1.36	3.09	16.18	1.40	-29.16	1.52	11.58307
11.0	1949.27	89.90	30.10	68.35	1.55	3.53	16.91	1.47	-29.00	1.68	11.54218
11.5	1945.57	89.78	29.24	68.72	2.05	4.66	15.95	1.38	-29.16	1.72	11.5206
12.0	1941.67	90.13	29.54	68.26	2.20	5.00	16.00	1.39	-29.24	2.14	11.53664
12.5	1938.60	89.37	30.56	67.27	2.17	4.93	16.27	1.43	-29.00	1.94	11.41227
13.0	1934.68	90.04	29.43	68.49	2.08	4.72	15.76	1.39	-29.11	2.04	11.35026
13.5	1930.73	89.82	28.41	69.19	2.40	5.45	16.25	1.43	-28.91	1.92	11.35452
14.0	1926.62	89.55	27.64	69.19	3.17	7.20	15.07	1.33	-28.88	1.79	11.37048
14.5	1922.14	90.03	28.21	70.22	1.58	3.59	15.33	1.35	-28.80	1.97	11.35798
15.0	1920.28	88.69	25.25	72.74	2.01	4.56	13.66	1.18	-28.54	2.04	11.53699
15.5	1919.90	87.66	26.21	71.20	2.59	5.88	13.81	1.19	-28.30	1.91	11.58516
16.0	1917.65	87.47	23.72	74.26	2.02	4.58	12.56	1.10	-28.26	2.33	11.45381
16.5	1911.32	88.20	23.73	73.81	2.47	5.60	13.23	1.14	-28.09	2.24	11.56523
17.0	1905.69	87.18	26.09	72.89	1.02	2.32	13.09	1.12	-28.12	2.13	11.65982
17.5	1901.15	87.23	24.26	74.33	1.41	3.20	12.94	1.11	-28.04	2.32	11.65217
18.0	1895.95	87.21	24.82	73.86	1.33	3.02	12.32	1.06	-28.05	2.33	11.58477
18.5	1891.26	86.52	23.54	75.00	1.46	3.32	12.87	1.10	-27.84	2.24	11.67627
19.0	1885.73	85.59	24.15	73.88	1.97	4.47	13.13	1.09	-28.03	2.13	12.06332
19.5	1879.80	86.70	23.86	74.82	1.33	3.01	13.09	1.11	-27.93	2.39	11.75765
20.0	*1873.81*	85.62	24.48	74.08	1.44	3.27	12.75	1.09	-28.07	2.48	11.65413
20.5	*1868.16*	85.95	24.75	73.40	1.85	4.20	12.97	1.11	-27.94	2.21	11.72042
21.0	*1862.02*	86.30	24.97	73.24	1.79	9.03	13.11	1.10	-27.97	2.04	11.91283
21.5	*1856.63*	85.27	24.11	73.22	2.66	6.06	13.62	1.17	-28.00	2.51	11.67628
22.0	*1850.45*	87.06	24.69	72.99	2.31	5.26	12.83	1.09	-28.12	2.37	11.79722
22.5	*1844.22*	86.96	25.51	73.12	1.36	3.10	13.44	1.13	-27.95	2.47	11.89759
23.0	*1838.53*	84.71	25.26	72.67	2.07	4.71	13.10	1.11	-28.13	2.62	11.75995
23.5	*1830.86*	86.35	24.59	73.23	2.17	4.94	13.97	1.19	-28.05	2.40	11.75962
24.0	*1825.65*	86.69	24.86	73.18	1.96	4.44	12.97	1.11	-28.17	2.73	11.73181
24.5	*1820.25*	86.79	23.41	73.93	2.67	6.06	13.66	1.17	-27.75	2.51	11.69349
25.0	*1814.21*	85.92	24.03	74.42	1.56	3.54	13.01	1.11	-28.00	2.69	11.70712

Lake MW01 continued

25.5	*1807.20*	87.13	24.54	73.63	1.82	4.14	10.84	0.95	-27.99	2.66	11.40471
26.0	*1801.21*	85.80	24.44	74.58	0.98	2.22	12.49	1.09	-28.23	2.54	11.50294
26.5	*1795.14*	84.65	22.04	76.48	1.48	3.36	12.83	1.10	-28.38	2.58	11.71041
27.0	*1788.65*	83.11	20.73	78.05	1.22	2.77	11.59	0.98	-28.50	3.02	11.791
27.5	*1780.59*	82.12	20.70	77.44	1.86	4.23	11.59	0.97	-28.42	2.69	12.00306
28.0	*1774.09*	84.45	22.37	76.37	1.25	2.84	11.85	0.99	-28.55	2.83	12.00714
28.5	*1767.18*	84.17	24.28	73.97	1.75	3.98	13.53	1.13	-29.00	3.01	11.99697
29.0	*1760.88*	84.98	24.94	72.51	2.56	5.81	14.84	1.23	-29.48	2.54	12.07337
29.5	*1754.86*	86.10	26.59	71.61	1.80	4.09	15.41	1.28	-29.63	2.51	12.05342
30.0	*1749.26*	86.73	27.47	71.24	1.29	2.93	15.16	1.26	-29.27	2.48	12.04797
30.5	*1743.49*	86.51	25.83	70.68	3.48	7.92	15.67	1.30	-29.23	2.47	12.03186
31.0	*1737.57*	86.10	28.49	69.94	1.57	3.56	16.70	1.37	-29.38	2.20	12.21338
31.5	*1731.54*	85.77	30.35	67.62	2.03	4.62	16.46	1.37	-29.66	2.23	12.05151
32.0	*1724.86*	86.73	30.06	68.26	1.69	3.83	16.53	1.36	-29.36	2.30	12.17693
32.5	*1718.79*	87.18	29.05	69.20	1.75	3.98	16.88	1.41	-30.14	2.32	11.93651
33.0	*1714.14*	85.46	26.55	70.85	2.59	5.89	16.04	1.34	-29.82	1.76	11.97695
33.5	*1708.46*	85.19	27.81	70.21	1.98	4.49	15.46	1.28	-29.41	1.80	12.12461
34.0	*1703.13*	85.30	27.76	70.66	1.58	3.59	15.57	1.28	-29.53	2.04	12.17595
34.5	*1695.88*	85.01	26.83	70.81	2.36	5.36	14.94	1.24	-29.42	2.19	12.06651
35.0	*1690.43*	86.32	23.99	73.46	2.55	5.79	14.53	1.18	-29.21	2.15	12.26437
35.5	*1683.74*	83.78	23.78	74.36	1.86	4.22	13.60	1.13	-29.15	2.30	12.03447
36.0	*1677.28*	83.46	24.21	72.99	2.79	6.35	13.79	1.14	-29.22	2.30	12.14343
36.5	*1670.37*	84.45	24.75	73.76	1.49	3.38	14.35	1.19	-29.33	2.48	12.08191
37.0	*1663.08*	83.72	24.61	73.21	2.18	4.96	13.98	1.16	-29.20	2.23	12.08574
37.5	*1654.96*	83.41	25.38	72.15	2.47	5.61	14.62	1.20	-29.08	2.32	12.15811
38.0	*1647.37*	85.13	26.72	71.50	1.78	4.05	14.82	1.21	-29.38	2.21	12.20358

Peanut Lake

Peanut Lake											
Depth	Year CE	%H2O	%OM	%MM	LOI 1000	%CaCO3	%C	%N	δ13C	δ15N	C/N
0.0	2016	96.03	20.40	78.11	1.49	3.39	10.50	1.05	-31.33	4.41	10.01374
0.5	2013.70	89.73	20.15	78.12	1.73	3.93	10.30	1.02	-31.14	3.75	10.14535
1.0	2010.50	88.86	20.39	77.33	2.28	5.19	10.11	0.99	-30.93	3.90	10.21021
1.5	2005.75	88.39	18.97	78.97	2.05	4.66	10.05	1.00	-30.87	3.61	10.07458
2.0	2000.90	87.80	19.09	78.96	1.94	4.41	10.18	1.02	-30.75	3.64	10.02348
2.5	1995.88	86.99	18.95	78.95	2.11	4.78	10.05	1.00	-30.65	3.56	10.08043
3.0	1990.09	86.40	18.04	79.37	2.60	5.90	10.11	1.00	-30.69	3.72	10.12841
3.5	1983.02	85.52	18.33	79.21	2.46	5.60	9.81	0.97	-30.57	3.61	10.12327
4.0	1975.22	86.19	18.80	80.06	1.14	2.59	9.69	0.96	-30.48	3.32	10.14347
4.5	1968.02	85.24	19.05	79.59	1.35	3.07	9.65	0.95	-30.37	3.54	10.14637
5.0	1961.71	84.33	18.22	80.30	1.49	3.38	8.93	0.87	-30.07	3.43	10.27741
5.5	1957.41	84.77	18.08	80.77	1.15	2.62	8.55	0.83	-29.86	3.72	10.30996
6.0	1952.50	83.06	16.74	81.73	1.52	3.46	8.31	0.80	-29.87	3.36	10.32999
6.5	1943.46	82.18	16.06	81.51	2.44	5.54	8.17	0.79	-29.67	3.68	10.39523
7.0	1936.75	81.66	15.37	82.79	1.84	4.18	7.96	0.77	-29.64	3.66	10.39674
7.5	1931.76	82.18	16.43	82.13	1.44	3.28	7.80	0.74	-29.67	3.49	10.54479
8.0	1925.71	81.91	15.32	82.93	1.75	3.98	7.48	0.71	-29.60	3.68	10.50478
8.5	1917.24	80.60	15.61	82.48	1.91	4.35	7.55	0.72	-29.67	3.60	10.55009
9.0	1908.91	79.85	14.55	83.87	1.57	3.58	7.46	0.70	-29.72	3.38	10.58738
9.5	1899.16	79.93	14.15	84.09	1.77	4.02	7.38	0.69	-29.70	3.34	10.61784
10.0	1890.02	78.87	14.55	84.42	1.03	2.33	7.43	0.70	-29.74	3.32	10.66759
10.5	1880.68	78.83	14.30	84.22	1.49	3.38	7.43	0.70	-29.76	3.31	10.57953
11.0	1870.95	79.25	14.35	83.65	2.00	4.54	7.58	0.72	-29.81	3.45	10.56572
11.5	1861.14	78.65	14.71	83.36	1.93	4.39	7.35	0.69	-29.93	3.53	10.58343
12.0	1851.85	78.42	14.95	83.58	1.47	3.34	7.71	0.73	-29.97	3.47	10.62552
12.5	1840.65	77.69	14.34	83.98	1.68	3.82	7.66	0.73	-29.92	3.28	10.53411
13.0	1830.97	77.63	14.80	83.61	1.59	3.60	7.69	0.73	-29.95	3.47	10.57997
13.5	*1820.48*	77.50	15.00	83.67	1.32	3.01	7.46	0.70	-29.98	3.23	10.60447
14.0	*1810.08*	78.34	14.68	83.60	1.71	3.89	7.64	0.72	-29.93	3.29	10.56832
14.5	*1799.26*	79.15	14.65	83.74	1.61	3.65	7.76	0.73	-30.05	3.42	10.62775
15.0	*1788.93*	77.97	14.97	82.96	2.07	4.71	7.56	0.72	-30.01	3.29	10.56196
15.5	*1778.84*	78.74	14.63	83.41	1.96	4.45	7.80	0.74	-30.06	3.29	10.54317
16.0	*1768.90*	78.70	16.13	82.48	1.39	3.16	7.93	0.76	-30.09	3.33	10.49296
16.5	*1759.28*	78.97	15.39	82.53	2.08	4.72	8.12	0.77	-29.99	3.35	10.50501
17.0	*1749.77*	79.55	16.00	82.25	1.75	3.97	7.99	0.76	-30.14	3.40	10.5014
17.5	*1740.35*	79.08	16.12	82.29	1.59	3.62	8.09	0.77	-30.07	3.16	10.50851
18.0	*1731.09*	79.37	16.23	82.04	1.73	3.93	8.40	0.80	-29.98	3.37	10.49349
18.5	*1721.40*	78.41	15.97	82.27	1.75	3.99	8.30	0.79	-30.11	3.41	10.47051
19.0	*1712.31*	78.60	16.12	82.24	1.64	3.73	8.80	0.84	-30.13	3.42	10.46686
19.5	*1701.50*	79.37	16.11	82.17	1.73	3.92	8.92	0.85	-30.17	3.45	10.43049
20.0	*1691.81*	78.85	16.15	82.07	1.77	4.03	8.98	0.88	-30.22	3.36	10.15247
20.5	*1682.04*	79.18	16.43	82.15	1.42	3.24	8.20	0.80	-30.30	3.49	10.27106
21.0	*1672.68*	78.60	16.27	82.26	1.47	9.03	8.35	0.81	-30.34	3.56	10.31177
21.5	*1662.25*	79.63	15.63	82.36	2.00	4.55	7.72	0.74	-30.16	3.40	10.3844
22	*1653.30*	78.66	15.98	82.55	1.47	3.34	7.32	0.69	-29.86	3.67	10.55939
22.5	*1643.61*	76.83	16.33	82.06	1.62	3.67	7.22	0.68	-29.68	3.67	10.60051
23.0	*1631.36*	77.11	14.73	83.38	1.89	4.31	7.16	0.68	-29.66	3.63	10.52113
23.5	*1621.40*	76.34	14.63	83.52	1.85	4.21	7.18	0.68	-29.77	3.35	10.63994
24.0	*1609.01*	76.56	14.15	84.07	1.78	4.04	7.11	0.67	-29.76	3.67	10.59611
24.5	*1598.47*	77.08	13.96	84.42	1.63	3.70	6.87	0.65	-29.70	3.67	10.62434
25.0	*1587.82*	76.04	13.45	84.82	1.72	3.92	6.62	0.63	-29.71	3.68	10.52901

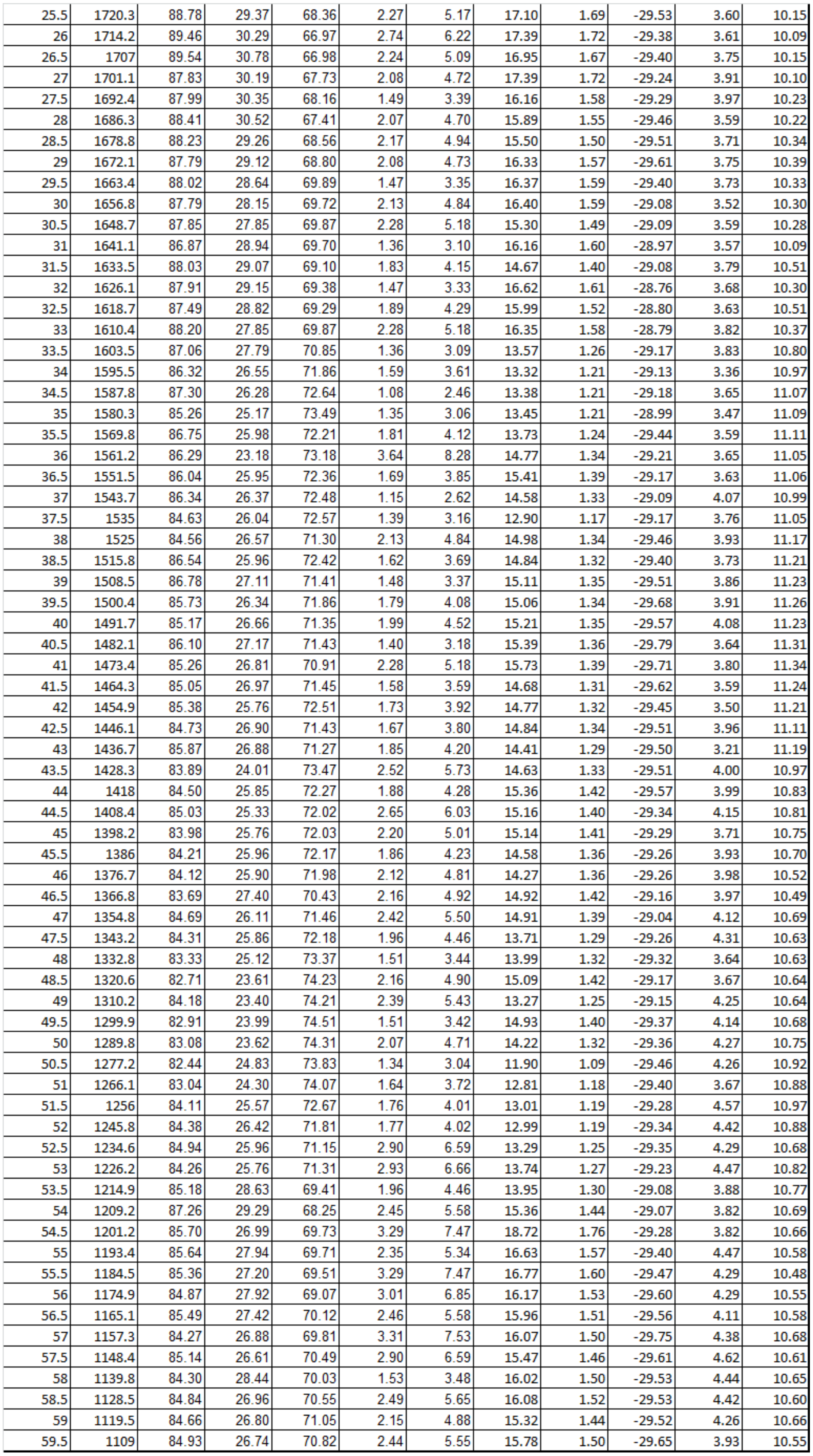
Peanut continued

25.5	*1574.67*	76.69	13.38	84.93	1.69	3.85	6.45	0.61	-29.72	3.53	10.61106
26.0	*1564.76*	75.63	13.59	84.70	1.71	3.88	6.33	0.60	-29.70	3.41	10.58044
26.5	*1553.51*	75.36	13.93	84.55	1.51	3.44	6.34	0.60	-29.74	3.63	10.62509
27.0	*1541.29*	75.44	13.46	84.62	1.92	4.37	6.10	0.58	-29.79	3.72	10.53736
27.5	*1528.88*	75.92	13.86	84.33	1.80	4.10	6.21	0.59	-29.76	3.59	10.59403
28.0	*1518.11*	74.47	13.07	85.15	1.78	4.04	6.30	0.60	-29.76	3.72	10.5321
28.5	*1506.54*	72.93	13.17	85.36	1.47	3.34	6.07	0.57	-29.76	3.61	10.61857
29.0	*1492.57*	71.24	12.50	85.71	1.79	4.06	6.26	0.60	-29.71	3.60	10.46637
29.5	*1478.42*	72.32	11.77	86.43	1.79	4.08	6.08	0.57	-29.76	3.70	10.65059
30.0	*1465.80*	73.40	12.86	85.43	1.72	3.91	6.14	0.58	-29.80	3.68	10.64335
30.5	*1450.98*	72.85	12.15	85.90	1.95	4.44	6.30	0.60	-29.87	3.68	10.5593
31.0	*1438.61*	73.29	12.29	85.93	1.79	4.06	7.01	0.66	-29.93	3.84	10.62521
31.5	*1424.63*	72.95	11.87	85.69	2.43	5.53	6.56	0.62	-29.88	3.57	10.6425
32.0	*1411.62*	71.99	12.51	85.51	1.98	4.50	7.10	0.66	-29.96	3.58	10.70338
32.5	*1397.69*	70.01	12.46	86.22	1.33	3.01	6.92	0.65	-29.94	3.71	10.71303
33.0	*1382.74*	68.25	11.82	86.50	1.68	3.82	6.75	0.63	-29.86	3.88	10.67997
33.5	*1365.79*	68.03	11.60	86.54	1.86	4.23	6.29	0.58	-29.87	3.60	10.80858
34.0	*1349.25*	69.53	12.48	86.11	1.41	3.22	6.40	0.59	-29.88	3.90	10.74896
34.5	*1332.94*	69.52	12.98	85.35	1.68	3.81	6.66	0.62	-29.87	3.94	10.81877
35.0	*1316.65*	73.95	13.86	84.53	1.61	3.65	6.33	0.58	-29.87	3.70	10.8406
35.5	*1303.55*	72.11	13.62	84.82	1.56	3.55	6.20	0.57	-29.80	3.83	10.83302
36.0	*1289.89*	70.67	14.88	84.10	1.02	2.32	6.33	0.58	-29.77	3.88	10.92945
36.5	*1274.74*	73.03	12.56	85.60	1.84	4.17	6.11	0.57	-29.84	3.87	10.76358
37.0	*1259.97*	69.76	12.34	85.62	2.04	4.65	6.14	0.56	-29.76	3.78	10.87558
37.5	*1246.17*	69.15	12.00	86.46	1.54	3.50	6.02	0.56	-29.77	3.61	10.73385
38.0	*1231.69*	68.00	11.98	86.67	1.36	3.09	6.49	0.62	-29.66	3.96	10.53867
38.5	*1215.36*	68.01	12.26	86.45	1.29	2.93	6.66	0.64	-29.75	4.05	10.4105
39.0	*1200.13*	68.96	11.71	86.65	1.64	3.72	6.58	0.63	-29.61	3.73	10.36481
39.5	*1184.65*	67.04	11.72	86.59	1.69	3.85	6.48	0.62	-29.65	4.03	10.4886
40.0	*1167.14*	69.22	13.04	85.60	1.36	3.10	6.42	0.60	-29.69	4.12	10.7198
40.5	*1151.75*	72.08	13.06	85.04	1.91	4.33	6.09	0.56	-29.60	4.03	10.86014
41.0	*1136.39*	72.59	13.37	84.92	1.71	3.88	5.83	0.53	-29.49	3.68	10.96952
41.5	*1121.10*	72.97	12.69	85.63	1.68	3.81	5.70	0.52	-29.59	3.57	10.96955
42.0	*1107.60*	73.82	13.80	84.49	1.72	3.90	6.20	0.57	-29.68	4.00	10.90905
42.5	*1096.15*	70.23	12.84	85.22	1.94	4.41	6.53	0.60	-29.63	3.96	10.83402
43.0	*1080.64*	67.41	11.77	86.43	1.80	4.10	7.54	0.70	-30.01	3.85	10.76709
43.5	*1065.55*	67.46	12.65	85.89	1.46	3.32	7.89	0.74	-29.82	4.10	10.67167
44.0	*1047.71*	70.32	12.97	84.96	2.07	4.71					
44.5	*1034.36*	69.61	11.88	85.63	2.49	5.67					
45.0	*1019.64*	68.06	12.93	85.52	1.55	3.53					
45.5	*1003.50*	72.54	14.79	83.42	1.79	4.08					
46.0	*990.20*	73.03	14.20	83.81	1.99	4.52					
46.5	*977.91*	72.87	14.14	83.69	2.16	4.92					
47.0	*964.01*	72.49	15.60	82.67	1.73	3.92					
47.5	*949.38*	73.65	16.37	81.61	2.03	4.61					
48.0	*935.06*	75.73	16.99	80.98	2.03	4.62					
48.5	*922.59*	75.04	17.12	81.04	1.84	4.18					
49.0	*909.85*	75.93	16.72	81.72	1.56	3.54					
49.5	*898.81*	73.82	15.57	82.84	1.59	3.62					
50.0	*886.54*	71.72	15.38	83.13	1.48	3.37					
50.5	*872.06*	72.36	15.16	82.90	1.94	4.41					
51.0	*859.14*	71.33	14.64	83.14	2.22	5.05					
51.5	*845.66*	70.33	14.45	83.89	1.66	3.78					
52.0	*830.47*	73.12	14.74	83.94	1.33	3.01					
52.5	*816.39*	71.05	14.38	84.32	1.30	2.94					
53.0	*803.33*	71.37	14.75	83.99	1.25	2.85					
53.5	*789.43*	71.38	14.45	84.16	1.40	3.17					
54.0	*774.04*	71.33	14.95	83.59	1.46	3.32					
54.5	*759.74*	70.81	14.33	84.30	1.37	3.10					
55.0	*746.63*	69.39	13.16	85.47	1.36	3.10					
55.5	*733.32*	68.15	12.32	86.00	1.68	3.82					
56.0	*718.55*	65.68	11.75	86.76	1.49	3.39					
56.5	*700.42*	63.05	10.59	87.76	1.65	3.75					
57.0	*682.25*	64.13	11.24	87.39	1.37	3.12					
57.5	*657.99*	66.14	11.60	87.05	1.35	3.06					
58.0	*632.61*	67.91	12.32	86.33	1.35	3.07					

Nico Lake

Nico Lake											
Depth	Year CE	%H2O	%OM	%MM	LOI 1000	%CaCO3	%C	%N	δ13C	δ15N	C/N
0	2015	95.59	35.11	62.71	2.18	4.95	17.09	1.90	-31.27	3.96	10.41
0.5	2011.9	93.62	34.48	63.32	2.19	4.99	17.36	1.72	-31.18	4.38	10.11
1	2008.4	92.91	35.89	61.92	2.19	4.98	17.18	1.71	-31.08	4.20	10.02
1.5	2004.8	92.89	34.89	64.29	0.82	1.87	17.80	1.73	-30.91	4.22	10.28
2	2000.6	92.96	34.56	64.87	0.57	1.29	17.50	1.70	-30.82	3.85	10.27
2.5	1996.2	93.22	36.05	62.21	1.74	3.96	16.29	1.96	-30.80	4.26	10.11
3	1992.3	91.87	32.77	64.32	2.91	6.62	15.75	1.52	-30.62	3.73	10.37
3.5	1988	92.41	33.51	63.87	2.62	5.95	17.25	1.64	-30.46	3.73	10.52
4	1983.9	92.26	32.04	65.63	2.33	5.29	16.78	1.59	-30.46	3.73	10.56
4.5	1979.7	92.16	32.02	66.26	1.72	3.92	15.40	1.45	-30.24	3.89	10.62
5	1975.3	91.97	31.07	66.99	1.94	4.41	15.79	1.48	-29.95	3.77	10.67
5.5	1971.1	91.17	31.10	67.34	1.57	3.56	15.98	1.53	-29.95	4.08	10.48
6	1966	91.90	29.95	66.67	3.38	7.69	16.97	1.59	-29.94	3.96	10.71
6.5	1961.5	91.47	31.41	66.74	1.85	4.20	15.19	1.77	-30.00	3.89	10.81
7	1956.6	90.82	30.43	67.66	1.91	4.35	15.53	1.72	-29.85	4.26	10.07
7.5	1951.2	90.82	30.38	67.51	2.11	4.79	15.69	1.47	-29.92	3.73	10.65
8	1944.9	89.88	29.49	68.36	2.15	4.88	15.73	1.46	-29.69	3.70	10.75
8.5	1939.4	90.77	29.72	67.73	2.55	5.79	15.83	1.47	-29.85	4.00	10.73
9	1934.6	90.42	29.46	68.46	2.07	4.72	15.25	1.41	-29.56	3.84	10.82
9.5	1930.9	89.98	28.34	70.26	1.40	3.18	14.35	1.33	-29.57	3.71	10.76
10	1925.6	90.46	28.57	68.91	2.52	5.73	15.07	1.38	-29.51	3.92	10.90
10.5	1919.1	89.73	28.32	69.56	2.12	4.82	14.47	1.34	-29.51	3.74	10.84
11	1911.3	89.82	27.76	69.88	2.36	5.37	14.59	1.35	-29.42	4.05	10.82
11.5	1902.6	89.75	26.53	71.56	1.91	4.34	12.99	1.22	-29.26	3.92	10.67
12	1896.3	89.19	27.83	71.45	0.72	1.63	13.03	1.58	-29.01	3.70	10.82
12.5	1890.9	89.19	26.90	71.66	1.44	3.28	13.50	1.25	-29.03	3.81	10.81
13	1885.3	89.37	27.07	71.99	0.94	2.14	13.82	1.28	-28.89	3.90	10.80
13.5	1879.4	88.49	25.93	72.54	1.53	3.47	13.69	1.26	-28.86	3.85	10.83
14	1872.6	88.42	27.03	71.79	1.18	2.69	13.15	1.21	-29.07	4.16	10.86
14.5	1866.1	87.04	26.76	70.80	2.45	5.56	13.73	1.28	-29.06	3.64	10.76
15	1860.3	87.88	26.39	71.54	2.07	4.70	13.80	1.27	-28.87	3.66	10.86
15.5	1852.8	89.47	27.90	70.60	1.50	3.40	13.84	1.28	-29.06	4.05	10.79
16	1847.1	88.36	24.79	72.82	2.39	5.44	13.44	1.25	-29.17	3.77	10.78
16.5	1840.1	88.65	26.07	71.18	2.74	6.24	14.17	1.34	-29.22	4.54	10.54
17	1833.9	87.10	26.73	71.27	2.00	4.54	14.64	1.38	-28.97	3.94	10.64
17.5	1825.8	90.52	28.45	69.67	1.88	4.28	15.06	1.44	-28.84	4.24	10.49
18	1820.3	89.08	27.19	70.66	2.15	4.88	14.02	1.35	-28.91	3.74	10.41
18.5	1813.8	88.62	26.86	70.61	2.53	5.76	14.09	1.36	-28.91	3.50	10.36
19	1807.3	88.53	25.60	72.68	1.72	3.91	14.30	1.37	-29.12	3.73	10.42
19.5	1801.2	87.99	27.15	70.73	2.11	4.80	14.43	1.40	-29.12	3.78	10.32
20	1793.9	88.19	27.51	70.68	1.81	4.12	15.35	1.51	-28.87	3.82	10.16
20.5	1787.4	89.57	25.86	71.26	2.87	6.53	14.94	1.46	-28.86	3.79	10.26
21	1780.5	88.51	27.67	70.29	2.04	9.03	15.85	1.57	-28.92	3.89	10.10
21.5	1773.8	88.36	28.71	69.12	2.17	4.93	15.39	1.52	-29.25	3.97	10.10
22	1767	89.29	29.85	68.84	1.31	2.97	15.58	1.55	-29.27	3.77	10.03
22.5	1761.2	88.24	31.24	66.94	1.82	4.13	16.93	1.68	-29.05	3.90	10.07
23	1754.1	88.89	32.85	65.89	1.26	2.86	17.30	1.72	-28.93	4.19	10.04
23.5	1746.6	89.29	29.55	68.47	1.98	4.50	17.93	1.80	-28.91	4.00	9.98
24	1739.7	89.56	30.93	67.96	1.11	2.53	18.23	1.86	-28.93	3.66	9.82
24.5	1733.9	88.39	31.33	67.17	1.50	3.41	17.83	1.78	-29.36	3.60	10.04
25	1727.1	88.97	31.97	67.85	0.18	0.40	17.62	1.74	-29.51	3.65	10.11

Nico continued.



25.5	1720.3	88.78	29.37	68.36	2.27	5.17	17.10	1.69	-29.53	3.60	10.15
26	1714.2	89.46	30.29	66.97	2.74	6.22	17.39	1.72	-29.38	3.61	10.09
26.5	1707	89.54	30.78	66.98	2.24	5.09	16.95	1.67	-29.40	3.75	10.15
27	1701.1	87.83	30.19	67.73	2.08	4.72	17.39	1.72	-29.24	3.91	10.10
27.5	1692.4	87.99	30.35	68.16	1.49	3.39	16.16	1.58	-29.29	3.97	10.23
28	1686.3	88.41	30.52	67.41	2.07	4.70	15.89	1.55	-29.46	3.59	10.22
28.5	1678.8	88.23	29.26	68.56	2.17	4.94	15.50	1.50	-29.51	3.71	10.34
29	1672.1	87.79	29.12	68.80	2.08	4.73	16.33	1.57	-29.61	3.75	10.39
29.5	1663.4	88.02	28.64	69.89	1.47	3.35	16.37	1.59	-29.40	3.73	10.33
30	1656.8	87.79	28.15	69.72	2.13	4.84	16.40	1.59	-29.08	3.52	10.30
30.5	1648.7	87.85	27.85	69.87	2.28	5.18	15.30	1.49	-29.09	3.59	10.28
31	1641.1	86.87	28.94	69.70	1.36	3.10	16.16	1.60	-28.97	3.57	10.09
31.5	1633.5	88.03	29.07	69.10	1.83	4.15	14.67	1.40	-29.08	3.79	10.51
32	1626.1	87.91	29.15	69.38	1.47	3.33	16.62	1.61	-28.76	3.68	10.30
32.5	1618.7	87.49	28.82	69.29	1.89	4.29	15.99	1.52	-28.80	3.63	10.51
33	1610.4	88.20	27.85	69.87	2.28	5.18	16.35	1.58	-28.79	3.82	10.37
33.5	1603.5	87.06	27.79	70.85	1.36	3.09	13.57	1.26	-29.17	3.83	10.80
34	1595.5	86.32	26.55	71.86	1.59	3.61	13.32	1.21	-29.13	3.36	10.97
34.5	1587.8	87.30	26.28	72.64	1.08	2.46	13.38	1.21	-29.18	3.65	11.07
35	1580.3	85.26	25.17	73.49	1.35	3.06	13.45	1.21	-28.99	3.47	11.09
35.5	1569.8	86.75	25.98	72.21	1.81	4.12	13.73	1.24	-29.44	3.59	11.11
36	1561.2	86.29	23.18	73.18	3.64	8.28	14.77	1.34	-29.21	3.65	11.05
36.5	1551.5	86.04	25.95	72.36	1.69	3.85	15.41	1.39	-29.17	3.63	11.06
37	1543.7	86.34	26.37	72.48	1.15	2.62	14.58	1.33	-29.09	4.07	10.99
37.5	1535	84.63	26.04	72.57	1.39	3.16	12.90	1.17	-29.17	3.76	11.05
38	1525	84.56	26.57	71.30	2.13	4.84	14.98	1.34	-29.46	3.93	11.17
38.5	1515.8	86.54	25.96	72.42	1.62	3.69	14.84	1.32	-29.40	3.73	11.21
39	1508.5	86.78	27.11	71.41	1.48	3.37	15.11	1.35	-29.51	3.86	11.23
39.5	1500.4	85.73	26.34	71.86	1.79	4.08	15.06	1.34	-29.68	3.91	11.26
40	1491.7	85.17	26.66	71.35	1.99	4.52	15.21	1.35	-29.57	4.08	11.23
40.5	1482.1	86.10	27.17	71.43	1.40	3.18	15.39	1.36	-29.79	3.64	11.31
41	1473.4	85.26	26.81	70.91	2.28	5.18	15.73	1.39	-29.71	3.80	11.34
41.5	1464.3	85.05	26.97	71.45	1.58	3.59	14.68	1.31	-29.62	3.59	11.24
42	1454.9	85.38	25.76	72.51	1.73	3.92	14.77	1.32	-29.45	3.50	11.21
42.5	1446.1	84.73	26.90	71.43	1.67	3.80	14.84	1.34	-29.51	3.96	11.11
43	1436.7	85.87	26.88	71.27	1.85	4.20	14.41	1.29	-29.50	3.21	11.19
43.5	1428.3	83.89	24.01	73.47	2.52	5.73	14.63	1.33	-29.51	4.00	10.97
44	1418	84.50	25.85	72.27	1.88	4.28	15.36	1.42	-29.57	3.99	10.83
44.5	1408.4	85.03	25.33	72.02	2.65	6.03	15.16	1.40	-29.34	4.15	10.81
45	1398.2	83.98	25.76	72.03	2.20	5.01	15.14	1.41	-29.29	3.71	10.75
45.5	1386	84.21	25.96	72.17	1.86	4.23	14.58	1.36	-29.26	3.93	10.70
46	1376.7	84.12	25.90	71.98	2.12	4.81	14.27	1.36	-29.26	3.98	10.52
46.5	1366.8	83.69	27.40	70.43	2.16	4.92	14.92	1.42	-29.16	3.97	10.49
47	1354.8	84.69	26.11	71.46	2.42	5.50	14.91	1.39	-29.04	4.12	10.69
47.5	1343.2	84.31	25.86	72.18	1.96	4.46	13.71	1.29	-29.26	4.31	10.63
48	1332.8	83.33	25.12	73.37	1.51	3.44	13.99	1.32	-29.32	3.64	10.63
48.5	1320.6	82.71	23.61	74.23	2.16	4.90	15.09	1.42	-29.17	3.67	10.64
49	1310.2	84.18	23.40	74.21	2.39	5.43	13.27	1.25	-29.15	4.25	10.64
49.5	1299.9	82.91	23.99	74.51	1.51	3.42	14.93	1.40	-29.37	4.14	10.68
50	1289.8	83.08	23.62	74.31	2.07	4.71	14.22	1.32	-29.36	4.27	10.75
50.5	1277.2	82.44	24.83	73.83	1.34	3.04	11.90	1.09	-29.46	4.26	10.92
51	1266.1	83.04	24.30	74.07	1.64	3.72	12.81	1.18	-29.40	3.67	10.88
51.5	1256	84.11	25.57	72.67	1.76	4.01	13.01	1.19	-29.28	4.57	10.97
52	1245.8	84.38	26.42	71.81	1.77	4.02	12.99	1.19	-29.34	4.42	10.88
52.5	1234.6	84.94	25.96	71.15	2.90	6.59	13.29	1.25	-29.35	4.29	10.68
53	1226.2	84.26	25.76	71.31	2.93	6.66	13.74	1.27	-29.23	4.47	10.82
53.5	1214.9	85.18	28.63	69.41	1.96	4.46	13.95	1.30	-29.08	3.88	10.77
54	1209.2	87.26	29.29	68.25	2.45	5.58	15.36	1.44	-29.07	3.82	10.69
54.5	1201.2	85.70	26.99	69.73	3.29	7.47	18.72	1.76	-29.28	3.82	10.66
55	1193.4	85.64	27.94	69.71	2.35	5.34	16.63	1.57	-29.40	4.47	10.58
55.5	1184.5	85.36	27.20	69.51	3.29	7.47	16.77	1.60	-29.47	4.29	10.48
56	1174.9	84.87	27.92	69.07	3.01	6.85	16.17	1.53	-29.60	4.29	10.55
56.5	1165.1	85.49	27.42	70.12	2.46	5.58	15.96	1.51	-29.56	4.11	10.58
57	1157.3	84.27	26.88	69.81	3.31	7.53	16.07	1.50	-29.75	4.38	10.68
57.5	1148.4	85.14	26.61	70.49	2.90	6.59	15.47	1.46	-29.61	4.62	10.61
58	1139.8	84.30	28.44	70.03	1.53	3.48	16.02	1.50	-29.53	4.44	10.65
58.5	1128.5	84.84	26.96	70.55	2.49	5.65	16.08	1.52	-29.53	4.42	10.60
59	1119.5	84.66	26.80	71.05	2.15	4.88	15.32	1.44	-29.52	4.26	10.66
59.5	1109	84.93	26.74	70.82	2.44	5.55	15.78	1.50	-29.65	3.93	10.55

Grid Lake

Grid Lake											
Depth	Year CE	%H2O	%OM	%MM	LOI 1000	%CaCO3	%C	%N	δ13C	δ15N	C/N
0.0	2015.0	97.41	45.80	47.71	6.49	14.75	28.38	2.52	-30.41	1.81	11.25
0.5	2013.48	94.11	46.89	47.20	5.90	13.41	27.19	2.55	-30.45	2.09	10.66
1.0	2006.72	93.38	45.78	46.69	7.53	17.11	26.85	2.50	-30.48	2.21	10.75
1.5	1995.60	92.72	43.63	50.97	5.40	12.27	26.33	2.35	-30.44	2.10	11.18
2.0	1981.08	92.69	42.60	51.02	6.38	14.49	27.14	2.52	-30.07	2.00	10.76
2.5	1962.98	93.16	42.98	52.34	4.68	10.64	27.14	2.48	-30.05	1.55	10.95
3.0	1942.28	93.27	38.71	50.15	11.14	25.33	23.99	2.02	-30.30	1.97	11.89
3.5	1916.98	91.65	41.56	51.59	6.85	15.56	25.05	2.13	-30.58	2.45	11.78
4.0	1888.88	91.82	40.00	54.39	5.61	12.75	23.51	1.96	-30.76	2.71	12.02
4.5	1874.84	90.68	38.12	56.32	5.57	12.65	24.29	1.98	-30.77	3.04	12.27
5.0	1854.84	90.85	39.19	55.25	5.57	12.65	22.43	1.83	-30.75	2.57	12.26
5.5	1838.84	89.70	38.89	56.13	4.98	11.32	22.22	1.82	-30.72	2.73	12.23
6.0	1816.27	89.86	37.67	57.36	4.97	11.30	20.71	1.66	-30.41	2.43	12.46
6.5	1794.84	89.93	37.16	57.09	5.75	13.06	22.33	1.75	-30.28	2.49	12.76
7.0	1773.73	88.56	37.97	57.97	4.07	9.24	21.06	1.65	-30.24	2.29	12.74
7.5	1747.46	88.66	36.49	58.07	5.44	12.36	19.60	1.51	-30.19	2.13	12.95
8.0	1720.62	88.51	37.46	57.80	4.75	10.79	20.94	1.60	-30.20	2.14	13.06
8.5	1697.59	88.44	37.79	56.69	5.52	12.54	18.25	1.38	-30.08	1.77	13.25
9.0	1669.85	88.45	39.21	55.79	5.01	11.38	21.97	1.68	-30.08	1.94	13.07
9.5	1643.76	88.30	38.83	56.83	4.33	9.85	22.73	1.73	-29.94	1.44	13.14
10.0	1619.52	88.62	38.07	56.14	5.79	13.16	25.53	1.97	-30.02	1.71	12.97
10.5	1595.18	88.81	40.35	54.34	5.31	12.07	23.21	1.81	-30.11	1.65	12.80
11.0	1571.79	88.57	40.17	55.52	4.31	9.80	22.68	1.76	-30.03	1.93	12.88
11.5	1545.79	87.63	40.82	54.75	4.43	10.07	23.59	1.84	-30.08	1.75	12.80
12.0	1518.59	90.04	43.17	51.88	4.95	11.25	24.01	1.90	-30.16	1.73	12.66
12.5	1498.08	89.00	42.60	51.81	5.60	12.72	25.19	1.99	-29.91	1.55	12.69
13.0	1474.47	89.69	41.32	52.59	6.09	13.84	24.88	1.96	-29.75	1.55	12.70
13.5	*1452.56*	88.56	41.17	53.69	5.15	11.69	23.31	1.81	-29.59	1.05	12.88
14.0	*1427.68*	88.26	42.46	52.79	4.75	10.80	25.25	1.96	-29.54	1.04	12.86
14.5	*1400.93*	90.00	43.50	52.76	3.74	8.50	23.80	1.84	-29.49	0.93	12.95
15.0	*1377.16*	88.40	41.37	52.60	6.03	13.70	25.11	1.93	-29.61	1.21	12.98
15.5	*1351.33*	87.66	43.13	52.92	3.95	8.98	25.73	1.97	-29.55	1.17	13.04
16.0	*1326.20*	86.92	40.70	54.57	4.73	10.74	24.86	1.89	-29.59	0.96	13.18
16.5	*1299.86*	85.06	36.01	59.30	4.69	10.65	25.81	1.98	-29.43	0.96	13.06
17.0	*1262.37*	85.41	41.08	54.86	4.05	9.21	24.64	1.87	-29.65	1.10	13.17
17.5	*1224.66*	85.79	40.44	55.30	4.26	9.69	24.89	1.87	-29.68	0.96	13.34
18.0	*1195.27*	85.13	41.00	55.19	3.81	8.66	23.53	1.71	-29.84	0.92	13.77
18.5	*1161.50*	85.44	40.76	55.62	3.61	8.22	23.77	1.70	-30.04	1.24	13.96
19.0	*1127.71*	82.22	36.56	59.00	4.44	10.10	23.34	1.65	-30.10	1.14	14.12
19.5	*1085.12*	83.35	37.63	58.66	3.70	8.42	23.67	1.67	-30.10	1.33	14.17
20.0	*1047.50*	84.27	39.35	57.16	3.49	7.92	23.95	1.69	-30.09	1.34	14.15
20.5	*1011.70*	83.98	37.16	59.05	3.79	8.61	23.11	1.57	-30.17	0.97	14.74
21.0	*977.67*	82.92	36.46	60.23	3.31	7.53	22.71	1.55	-30.14	1.39	14.61
21.5	*939.45*	82.95	36.01	60.21	3.78	8.60	22.16	1.49	-30.15	1.16	14.92
22	*906.47*	85.40	37.55	58.64	3.81	8.66	22.34	1.50	-30.12	1.38	14.92
22.5	*874.61*	84.27	35.80	60.34	3.86	8.77	21.35	1.40	-29.98	1.01	15.22
23.0	*834.66*	83.59	36.31	59.59	4.10	9.32	21.96	1.48	-30.14	1.56	14.86
23.5	*794.94*	84.87	37.32	58.69	3.99	9.06	22.24	1.47	-30.07	1.21	15.12
24.0	*761.22*	82.90	37.99	58.31	3.70	8.40	21.98	1.47	-30.15	1.10	14.99
24.5	*724.41*	83.58	38.17	57.68	4.15	9.42	22.96	1.58	-30.23	2.51	14.56
25.0	*686.69*	85.29	37.97	58.02	4.01	9.12	22.39	1.52	-30.14	1.26	14.75

Grid Lake continued

25.5	*656.26*	81.61	35.95	59.53	4.52	10.27	22.21	1.48	-30.11	1.29	15.01
26.0	*616.24*	83.10	36.38	59.10	4.52	10.27	21.25	1.41	-30.16	1.11	15.09
26.5	*580.71*	82.19	35.56	60.61	3.83	8.70	21.98	1.45	-30.07	1.24	15.14
27.0	*541.60*	82.00	35.05	60.02	4.93	11.20	21.78	1.45	-30.11	1.48	15.04
27.5	*500.32*	82.39	36.32	59.30	4.37	9.94	21.71	1.44	-30.22	1.32	15.07
28.0	*455.26*	82.47	34.58	60.35	5.07	11.51	21.47	1.40	-30.02	1.00	15.36
28.5	*409.94*	83.10	36.01	60.57	3.42	7.78	21.34	1.38	-30.09	1.15	15.46
29.0	*375.22*	82.74	35.62	60.73	3.65	8.29	21.74	1.42	-30.10	1.27	15.33
29.5	*333.76*	81.64	35.36	60.28	4.37	9.92	19.82	1.28	-29.99	1.11	15.47
30.0	*292.85*	83.46	36.43	58.26	5.31	12.06	21.70	1.43	-30.14	1.39	15.14
30.5	*258.21*	84.43	36.62	59.47	3.91	8.90	21.69	1.42	-30.21	1.17	15.32
31.0	*220.60*	83.71	36.84	59.85	3.30	7.51	21.50	1.41	-30.20	1.18	15.22
31.5	*185.73*	83.53	35.96	59.74	4.30	9.78	21.79	1.43	-30.23	1.65	15.21
32.0	*146.97*	84.30	36.05	59.57	4.38	9.96	21.55	1.40	-30.19	1.33	15.37
32.5	*108.61*	84.75	35.40	59.43	5.17	11.75	21.86	1.43	-30.26	1.29	15.32
33.0	*72.10*	83.55	37.30	58.97	3.73	8.48	22.30	1.45	-30.24	1.32	15.41
33.5	*38.76*	83.40	34.29	60.81	4.90	11.13	21.42	1.37	-30.09	1.43	15.67
34.0	*1.47*	81.36	35.51	60.27	4.21	9.58	21.55	1.38	-30.23	1.39	15.65
34.5	*-39.74*	81.46	33.79	61.74	4.46	10.14	20.52	1.29	-30.10	1.36	15.91
35.0	*-85.20*	80.60	34.01	62.73	3.26	7.41	19.99	1.25	-30.08	1.18	15.94
35.5	*-129.06*	80.29	34.06	61.71	4.23	9.62	20.06	1.26	-30.11	1.53	15.98
36.0	*-175.47*	81.00	34.33	61.94	3.72	8.46	19.57	1.22	-30.09	1.12	16.05
36.5	*-219.35*	81.65	33.30	63.38	3.32	7.54	20.46	1.27	-30.09	1.28	16.10
37.0	*-259.81*	81.14	34.85	62.14	3.01	6.84	20.48	1.28	-30.20	1.62	15.95
37.5	*-300.81*	81.04	34.02	62.89	3.09	7.03	20.10	1.25	-30.17	1.39	16.09
38.0	*-344.35*	79.83	32.25	64.03	3.72	8.46	20.14	1.25	-30.33	1.68	16.16
38.5	*-386.89*	81.83	33.63	62.87	3.50	7.97	20.79	1.29	-30.19	1.68	16.06
39.0	*-426.95*	82.03	33.89	61.89	4.22	9.60	20.21	1.27	-30.17	1.52	15.88
39.5	*-468.50*	81.72	32.90	62.76	4.34	9.87	21.22	1.33	-30.44	1.42	15.97
40.0	*-510.91*	82.03	33.15	62.58	4.27	9.70	21.62	1.37	-30.40	1.43	15.83
40.5	*-551.55*	82.86	33.48	62.42	4.10	9.33	20.20	1.29	-30.38	1.32	15.70
41.0	*-592.76*	81.09	32.82	63.60	3.58	8.13	20.72	1.32	-30.44	1.88	15.75
41.5	*-637.74*	81.64	32.70	63.63	3.67	8.34	20.14	1.26	-30.43	1.37	15.95
42.0	*-679.44*	79.79	32.41	63.86	3.73	8.47	19.70	1.26	-30.47	1.67	15.63
42.5	*-723.35*	80.43	33.71	63.03	3.26	7.41	20.30	1.27	-30.41	1.52	15.96
43.0	*-768.94*	80.84	33.33	62.44	4.23	9.61	20.02	1.25	-30.44	1.34	15.98

Appendix 5. Sediment metals concentrations (µg g^{-1}) by depth (cm) and Year CE with MEI plotted by date.

Lake MW01

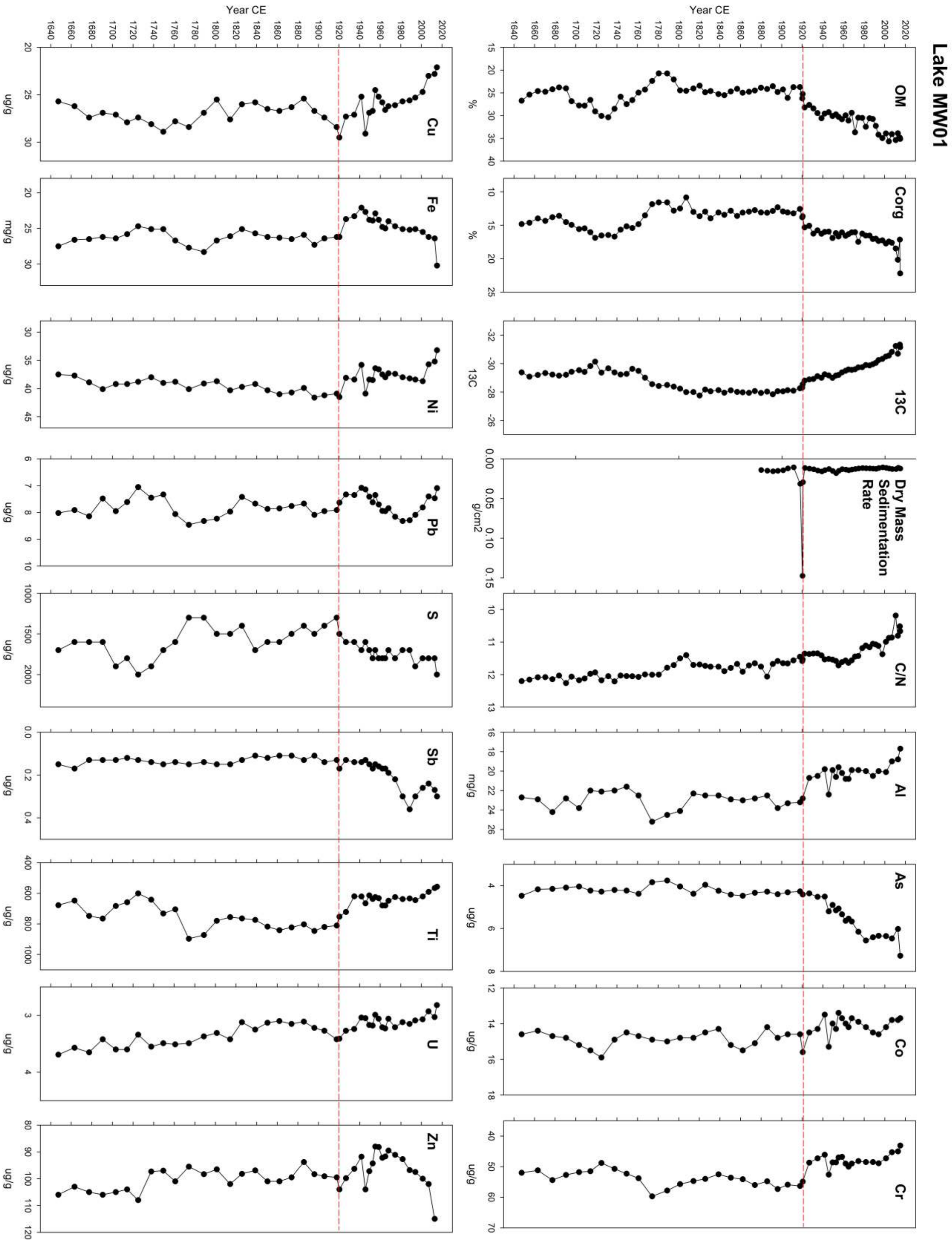
Lake MW01

Date	Depth	Aluminum (	Antimony	Arsenic (A	Barium (B	Beryllium	Bismuth (	Boron (B)	Cadmium	Calcium (	Chromiu	Cobalt (C	Copper (C	Iron (Fe)	Lead (Pb)	Lithium (L	Magnesiu
2015	0	17.70	0.30	7.27	150.00	0.61	0.24	12.40	0.20	7140.00	43.10	13.70	22.10	30.20	7.09	32.80	7170.00
2012.751	1	18.80	0.27	6.02	149.00	0.63	0.23	11.50	0.21	5590.00	45.00	13.80	22.80	26.40	7.47	33.20	7440.00
2006.901	2	19.00	0.24	6.46	146.00	0.61	0.22	12.10	0.22	5270.00	45.30	13.80	23.00	26.20	7.40	34.20	7370.00
2001.14	3	20.10	0.26	6.35	150.00	0.63	0.23	12.50	0.22	4770.00	47.30	14.20	24.70	25.50	7.81	35.30	7610.00
1993.926	4	20.00	0.30	6.34	151.00	0.65	0.24	11.10	0.23	4510.00	48.90	14.60	25.30	25.10	8.09	35.40	7970.00
1988.444	5	20.50	0.36	6.41	152.00	0.65	0.24	12.40	0.22	4360.00	48.50	14.50	25.60	25.20	8.29	35.50	7940.00
1981.624	6	20.00	0.30	6.56	154.00	0.66	0.25	10.00	0.21	4910.00	48.50	14.20	25.70	25.10	8.32	36.00	7950.00
1974.302	7	19.90	0.22	6.15	153.00	0.67	0.25	9.70	0.21	4150.00	48.20	13.90	26.10	24.70	8.16	36.10	7970.00
1967.9	8	19.90	0.19	5.67	155.00	0.66	0.25	9.80	0.20	4090.00	49.00	13.70	26.20	24.00	7.84	36.10	7910.00
1964.781	8.5	20.80	0.17	5.54	157.00	0.68	0.26	10.00	0.21	4540.00	50.00	14.20	26.60	25.00	7.95	36.30	8160.00
1961.963	9	20.80	0.17	5.64	158.00	0.66	0.26	12.30	0.21	4270.00	49.00	14.00	25.80	24.80	7.94	36.10	7960.00
1958.383	9.5	20.20	0.16	5.34	154.00	0.66	0.25	10.50	0.20	3990.00	46.80	13.70	25.20	23.80	7.70	34.60	7780.00
1955.08	10	19.60	0.15	5.07	151.00	0.63	0.24	9.40	0.19	3820.00	47.00	13.40	24.50	22.90	7.35	33.90	7630.00
1952.543	10.5	20.60	0.17	5.15	157.00	0.66	0.26	9.80	0.21	3990.00	48.60	14.30	26.70	23.90	7.62	35.50	8020.00
1949.272	11	19.90	0.15	4.90	150.00	0.66	0.24	9.60	0.22	3940.00	48.60	14.00	26.90	23.80	7.41	34.90	7690.00
1945.568	11.5	22.40	0.13	5.20	164.00	0.65	0.23	10.80	0.23	3920.00	52.60	15.30	29.10	22.70	7.14	34.20	8470.00
1941.667	12	19.80	0.14	4.51	147.00	0.69	0.23	10.30	0.21	3890.00	46.10	13.50	25.20	22.10	7.08	35.30	7400.00
1934.679	13	20.50	0.14	4.52	154.00	0.65	0.24	9.90	0.22	3880.00	47.30	14.30	27.10	23.30	7.35	36.20	7810.00
1926.616	14	20.70	0.13	4.36	153.00	0.67	0.24	9.50	0.23	3830.00	48.70	14.50	27.30	23.70	7.33	36.80	7620.00
1920.281	15	22.80	0.17	4.41	167.00	0.72	0.27	10.40	0.22	3900.00	54.90	15.60	29.50	26.20	7.63	39.70	8640.00
1917.654	16	23.20	0.13	4.27	174.00	0.74	0.29	9.80	0.21	3870.00	56.30	14.60	28.40	26.20	7.91	40.70	8740.00
1905.691	17	23.30	0.14	4.31	172.00	0.74	0.28	10.20	0.19	3890.00	55.90	14.60	27.40	26.40	7.95	40.50	8800.00
1895.949	18	23.80	0.11	4.40	174.00	0.76	0.29	10.30	0.19	3960.00	57.30	14.80	26.70	27.30	8.09	40.30	8990.00
1885.729	19	22.50	0.13	4.28	164.00	0.74	0.27	9.40	0.18	3680.00	54.80	14.20	25.40	25.90	7.67	38.10	8690.00
1873.813	20	22.80	0.11	4.33	165.00	0.76	0.27	9.50	0.20	3840.00	56.00	15.10	26.30	26.50	7.76	39.50	8700.00
1862.024	21	23.00	0.11	4.47	165.00	0.73	0.27	10.00	0.21	3860.00	54.10	15.50	26.70	26.30	7.85	39.00	8730.00
1850.448	22	22.90	0.12	4.42	170.00	0.73	0.27	11.30	0.21	3890.00	53.60	15.20	26.50	26.20	7.87	38.70	8390.00
1838.527	23	22.50	0.11	4.24	164.00	0.74	0.26	9.50	0.21	3810.00	52.50	14.30	25.80	25.70	7.67	38.50	8260.00
1825.653	24	22.50	0.13	3.96	161.00	0.71	0.26	9.60	0.21	3710.00	54.00	14.50	26.00	25.10	7.42	37.10	8320.00
1814.207	25	22.30	0.15	4.38	166.00	0.74	0.27	9.80	0.23	3950.00	54.70	14.80	27.60	26.10	7.97	38.50	8380.00
1801.209	26	24.10	0.15	4.04	170.00	0.75	0.29	9.10	0.22	3930.00	55.70	14.80	25.50	26.70	8.23	41.90	8560.00
1788.651	27	24.50	0.14	3.76	178.00	0.77	0.29	9.20	0.20	3920.00	57.80	15.00	26.90	28.30	8.32	43.90	9270.00
1774.09	28	25.20	0.15	3.84	178.00	0.77	0.29	9.50	0.20	3940.00	59.70	14.90	28.40	27.70	8.46	42.60	9120.00
1760.877	29	22.50	0.14	4.38	158.00	0.67	0.28	7.80	0.22	3820.00	53.80	14.70	27.80	26.70	8.06	36.70	8230.00
1749.258	30	21.60	0.15	4.23	154.00	0.69	0.26	9.50	0.21	3770.00	52.30	14.50	28.90	25.10	7.33	36.00	8010.00
1737.573	31	22.00	0.14	4.20	162.00	0.71	0.25	8.40	0.24	4080.00	50.70	14.90	28.10	25.10	7.45	36.20	7850.00
1724.862	32	22.10	0.13	4.28	151.00	0.70	0.24	8.00	0.25	4110.00	48.80	15.90	27.40	24.70	7.05	33.20	7550.00
1714.139	33	22.00	0.12	4.23	160.00	0.71	0.26	10.60	0.27	4120.00	51.50	15.50	27.90	25.80	7.61	39.40	7750.00
1703.135	34	23.80	0.13	4.04	163.00	0.73	0.27	8.70	0.25	4290.00	51.80	15.20	27.10	26.40	7.95	39.10	8050.00
1690.435	35	22.80	0.13	4.09	164.00	0.72	0.26	9.70	0.23	3750.00	52.70	14.80	26.90	26.20	7.48	38.70	8410.00
1677.283	36	24.20	0.13	4.15	166.00	0.73	0.28	8.40	0.22	3950.00	54.40	14.70	27.40	26.50	8.14	41.00	8320.00
1663.075	37	22.90	0.17	4.17	162.00	0.67	0.28	7.00	0.22	3840.00	51.20	14.40	26.20	26.60	7.91	33.40	8120.00
1647.37	38	22.70	0.15	4.47	166.00	0.69	0.28	7.80	0.23	4020.00	52.00	14.60	25.70	27.50	8.02	35.00	7980.00
	19R	23100.00	0.15	4.29	168.00	0.76	0.26	10.50	0.18	3720.00	55.50	14.60	25.90	26300.00	7.57	40.00	8660.00
	22R	22100.00	0.12	4.28	158.00	0.73	0.25	9.40	0.19	3720.00	52.60	14.50	25.50	25700.00	7.54	38.20	8260.00
	24R	22200.00	0.13	4.01	163.00	0.75	0.26	10.20	0.20	3780.00	53.20	14.10	25.70	25400.00	7.51	39.40	8380.00

Lake MW01 continued

Lake MW01 continued

Date	Depth	Manganes	Molybden	Nickel (Ni	Phosphor	Potassium	Selenium	Silver (Ag	Sodium (N	Strontium	Sulfur (S)	Thallium (	Tin (Sn)	Titanium (	Tungsten	Uranium (	Vanadium	Zinc (Zn)	Zirconium
2015.00	0.00	611.00	0.64	33.20	1210.00	3650.00	0.33	<0.10	404.00	33.80	2000.00	0.21	<2.0	557.00	<0.50	2.82	42.00		2.70
2012.75	1.00	422.00	0.67	35.20	949.00	3710.00	0.32	<0.10	321.00	29.40	1800.00	0.23	<2.0	566.00	<0.50	3.03	43.50	115.00	3.60
2006.90	2.00	446.00	0.70	35.70	936.00	3740.00	0.31	<0.10	326.00	27.40	1800.00	0.22	<2.0	591.00	<0.50	2.93	43.90	102.00	3.40
2001.14	3.00	382.00	0.73	38.70	861.00	3960.00	0.36	<0.10	328.00	26.90	1800.00	0.23	<2.0	621.00	<0.50	3.07	45.50	100.00	3.80
1993.93	4.00	368.00	0.81	38.40	825.00	4050.00	0.35	<0.10	321.00	26.20	1900.00	0.24	<2.0	645.00	<0.50	3.09	45.50	97.50	4.30
1988.44	5.00	368.00	0.82	38.20	773.00	4050.00	0.33	<0.10	330.00	25.90	1700.00	0.24	<2.0	634.00	<0.50	3.15	45.20	96.80	4.30
1981.62	6.00	364.00	0.84	38.00	822.00	4020.00	0.31	<0.10	324.00	27.30	1700.00	0.24	<2.0	638.00	<0.50	3.12	45.70	92.70	4.60
1974.30	7.00	348.00	0.82	37.40	730.00	4060.00	0.34	<0.10	298.00	24.50	1800.00	0.25	<2.0	625.00	<0.50	3.21	46.40	91.10	4.50
1967.90	8.00	341.00	0.77	37.30	736.00	4110.00	0.33	<0.10	303.00	24.00	1700.00	0.25	<2.0	649.00	<0.50	3.06	46.70	89.50	4.40
1964.78	8.50	350.00	0.79	38.00	767.00	4220.00	0.34	<0.10	317.00	25.00	1800.00	0.25	<2.0	680.00	<0.50	3.23	48.30	91.70	4.50
1961.96	9.00	362.00	0.77	37.50	775.00	4180.00	0.35	<0.10	319.00	25.30	1800.00	0.26	<2.0	680.00	<0.50	3.21	48.20	92.20	4.40
1958.38	9.50	317.00	0.74	36.60	716.00	4050.00	0.31	<0.10	303.00	23.80	1800.00	0.24	<2.0	632.00	<0.50	3.06	45.90	88.20	4.40
1955.08	10.00	312.00	0.81	36.40	687.00	4020.00	0.35	<0.10	291.00	22.90	1700.00	0.23	<2.0	625.00	<0.50	2.99	45.50	88.00	4.30
1952.54	10.50	329.00	0.90	38.50	718.00	4060.00	0.35	<0.10	306.00	24.00	1800.00	0.25	<2.0	637.00	<0.50	3.18	46.70	94.30	4.50
1949.27	11.00	314.00	1.00	38.40	685.00	3960.00	0.33	<0.10	300.00	23.70	1700.00	0.25	<2.0	614.00	<0.50	3.17	45.50	97.20	4.40
1945.57	11.50	352.00	0.89	40.90	807.00	4560.00	0.31	<0.10	344.00	23.30	1600.00	0.23	<2.0	666.00	<0.50	3.05	50.50	104.00	3.60
1941.67	12.00	300.00	0.88	35.80	673.00	3910.00	0.34	<0.10	294.00	23.40	1700.00	0.24	<2.0	621.00	<0.50	3.04	45.30	91.80	3.50
1934.68	13.00	315.00	0.86	38.40	714.00	4140.00	0.31	<0.10	314.00	23.60	1600.00	0.25	<2.0	620.00	<0.50	3.24	45.30	96.30	3.90
1926.62	14.00	306.00	0.87	38.10	644.00	4020.00	0.29	<0.10	295.00	22.90	1600.00	0.25	<2.0	722.00	<0.50	3.27	46.90	99.80	4.50
1920.28	15.00	334.00	1.00	41.50	678.00	4560.00	0.32	<0.10	336.00	23.90	1500.00	0.27	<2.0	753.00	<0.50	3.41	51.70	104.00	4.70
1917.65	16.00	328.00	0.99	40.90	671.00	4670.00	0.30	<0.10	328.00	24.10	1300.00	0.29	<2.0	811.00	<0.50	3.42	52.80	99.50	4.80
1905.69	17.00	332.00	0.93	41.20	683.00	4730.00	0.28	<0.10	329.00	24.20	1400.00	0.28	<2.0	820.00	<0.50	3.27	53.10	99.10	5.10
1895.95	18.00	340.00	0.81	41.60	685.00	4750.00	0.31	<0.10	323.00	25.20	1500.00	0.30	<2.0	846.00	<0.50	3.22	55.10	98.30	5.30
1885.73	19.00	320.00	0.72	39.90	681.00	4530.00	0.30	<0.10	319.00	23.20	1400.00	0.28	<2.0	803.00	<0.50	3.11	52.30	93.80	5.40
1873.81	20.00	334.00	0.76	40.70	689.00	4560.00	0.29	<0.10	313.00	23.90	1500.00	0.28	<2.0	823.00	<0.50	3.15	53.60	99.50	5.70
1862.02	21.00	332.00	0.75	41.00	713.00	4620.00	0.32	<0.10	334.00	24.50	1600.00	0.29	<2.0	841.00	<0.50	3.10	54.70	101.00	5.10
1850.45	22.00	326.00	0.74	40.30	714.00	4530.00	0.30	<0.10	328.00	25.00	1600.00	0.29	<2.0	818.00	<0.50	3.13	54.30	101.00	5.10
1838.53	23.00	311.00	0.74	39.20	718.00	4340.00	0.32	<0.10	314.00	24.10	1700.00	0.27	<2.0	774.00	<0.50	3.25	51.90	96.90	5.20
1825.65	24.00	316.00	0.74	39.70	722.00	4420.00	0.31	<0.10	314.00	23.20	1400.00	0.27	<2.0	764.00	<0.50	3.12	51.10	98.20	5.20
1814.21	25.00	328.00	1.00	40.30	701.00	4380.00	0.31	<0.10	306.00	24.50	1500.00	0.28	<2.0	756.00	<0.50	3.42	51.60	102.00	5.40
1801.21	26.00	328.00	0.97	38.70	690.00	4750.00	0.28	<0.10	308.00	24.60	1500.00	0.30	<2.0	780.00	<0.50	3.31	51.40	96.50	6.20
1788.65	27.00	339.00	0.91	39.10	684.00	4930.00	0.30	<0.10	319.00	25.10	1300.00	0.30	<2.0	873.00	<0.50	3.37	54.20	98.30	6.90
1774.09	28.00	343.00	0.97	40.10	716.00	4950.00	0.29	<0.10	322.00	24.80	1300.00	0.31	<2.0	897.00	<0.50	3.49	54.80	95.50	6.60
1760.88	29.00	353.00	1.11	38.80	772.00	4420.00	0.32	<0.10	285.00	24.00	1600.00	0.28	<2.0	705.00	<0.50	3.51	51.00	101.00	6.40
1749.26	30.00	312.00	1.07	39.00	707.00	4150.00	0.37	<0.10	295.00	23.20	1700.00	0.26	<2.0	732.00	<0.50	3.49	50.10	97.00	5.40
1737.57	31.00	331.00	1.22	38.00	804.00	4150.00	0.36	<0.10	313.00	25.40	1900.00	0.26	<2.0	642.00	<0.50	3.55	48.40	97.30	5.80
1724.86	32.00	326.00	1.15	38.80	875.00	4080.00	0.40	<0.10	296.00	24.80	2000.00	0.27	<2.0	601.00	<0.50	3.34	48.20	108.00	5.20
1714.14	33.00	327.00	1.07	39.20	766.00	4090.00	0.36	<0.10	294.00	24.90	1800.00	0.29	<2.0	659.00	<0.50	3.60	48.20	104.00	6.00
1703.13	34.00	334.00	1.04	39.20	787.00	4330.00	0.36	<0.10	309.00	25.40	1900.00	0.29	<2.0	683.00	<0.50	3.60	49.80	105.00	6.10
1690.43	35.00	320.00	0.87	40.10	733.00	4390.00	0.35	<0.10	324.00	24.10	1600.00	0.28	<2.0	765.00	<0.50	3.42	51.40	106.00	5.40
1677.28	36.00	335.00	0.97	38.90	744.00	4590.00	0.30	<0.10	323.00	24.70	1600.00	0.29	<2.0	748.00	<0.50	3.65	51.90	105.00	6.10
1663.08	37.00	329.00	0.93	37.70	731.00	4340.00	0.28	<0.10	333.00	23.50	1600.00	0.28	<2.0	648.00	<0.50	3.57	49.10	103.00	6.60
1647.37	38.00	322.00	0.86	37.50	789.00	4280.00	0.34	<0.10	439.00	24.30	1700.00	0.29	<2.0	678.00	<0.50	3.69	49.70	106.00	6.10
	19R	331.00	0.70	39.90	697.00	4780.00	0.30	<0.10	339.00	24.00	1300.00	0.28	<2.0	855.00	<0.50	3.05	53.70	95.20	5.10
	22R	318.00	0.71	39.50	666.00	4430.00	0.31	<0.10	316.00	23.90	1600.00	0.28	<2.0	789.00	<0.50	3.01	51.90	96.10	5.10
	24R	316.00	0.76	39.20	679.00	4400.00	0.32	<0.10	310.00	24.00	1400.00	0.27	<2.0	762.00	<0.50	3.22	50.40	96.60	5.30



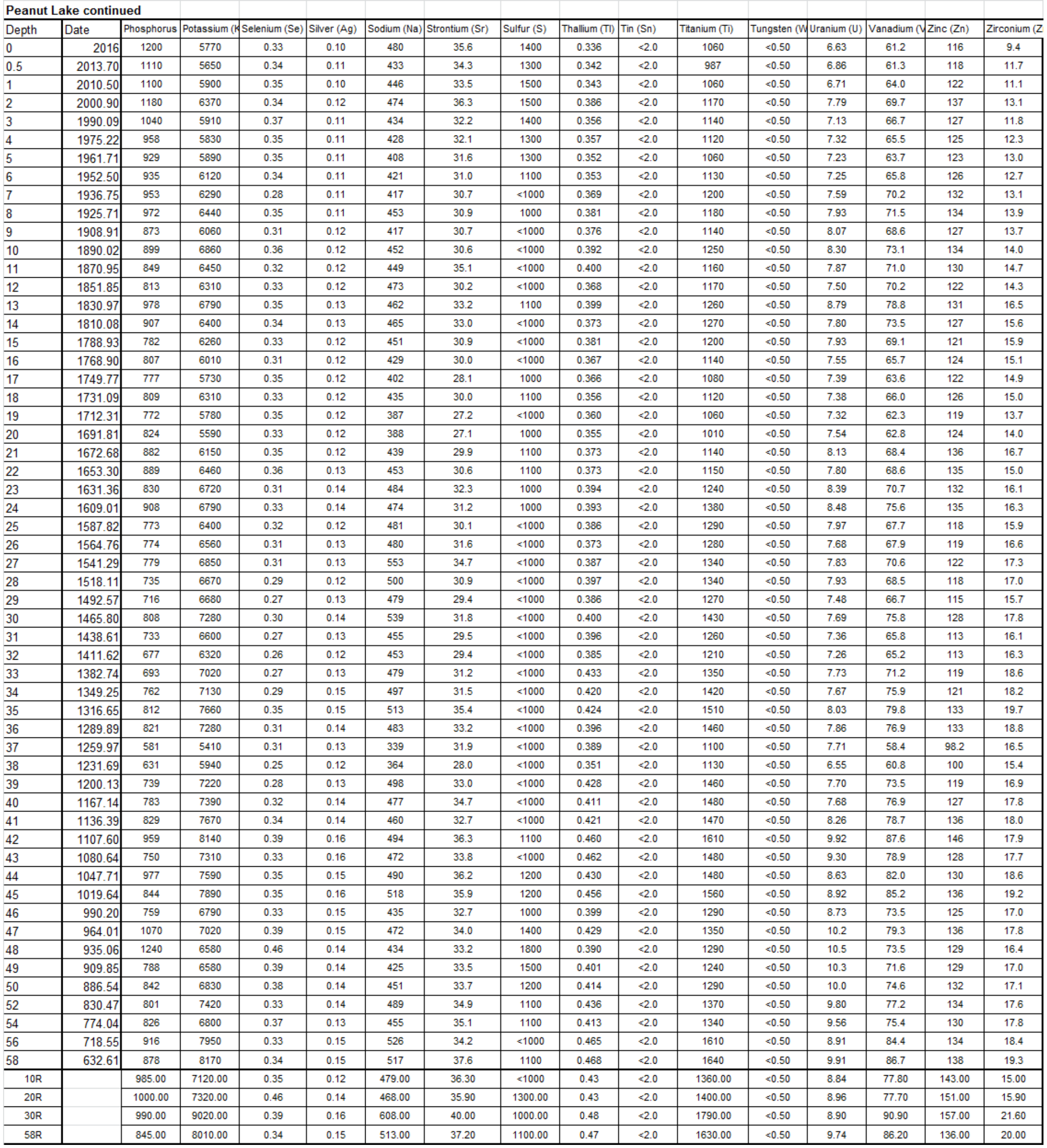
Lake MW01
Year CE
1640
1660
1680
1700
1720
1740
1760
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
OM
%
15
20
25
30
35
40
Corg
%
10
15
20
25
13C
13C
-32
-30
-28
-26
Dry Mass Sedimentation Rate
g/cm2
0.00
0.05
0.10
0.15
C/N
10
11
12
13
Al
mg/g
16
18
20
22
24
26
As
ug/g
4
6
8
Co
ug/g
12
14
16
18
Cr
ug/g
40
50
60
70
Cu
ug/g
20
25
30
Fe
mg/g
20
25
30
Ni
ug/g
30
35
40
45
Pb
ug/g
6
7
8
9
10
S
ug/g
1000
1500
2000
Sb
ug/g
0.0
0.2
0.4
Ti
ug/g
400
600
800
1000
U
ug/g
3
4
Zn
ug/g
80
90
100
110
120

Peanut Lake

Peanut Lake

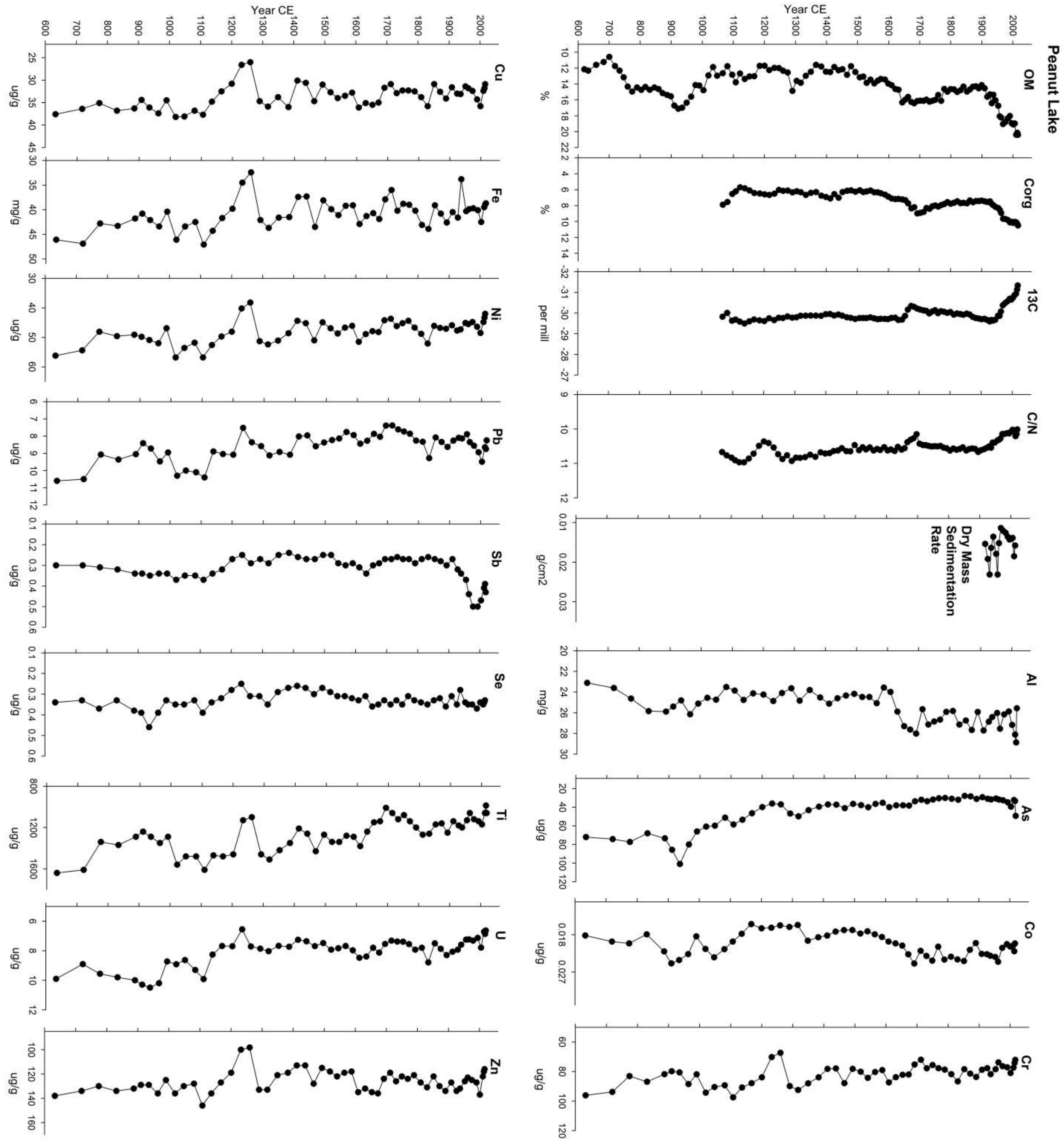
Depth	Date	Aluminum (Al)	Antimony (Sb)	Arsenic (As	Barium (Ba)	Beryllium (Be	Bismuth (Bi)	Boron (B)	Cadmium (Cd	Calcium (Ca)	Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Lithium (Li)	Magnesium (	Manganese (Mn)	Molybdenum (	Nickel (Ni)
0	2016	27100	0.43	49.3	230	0.92	0.45	13.6	0.182	6230	72.1	21.3	30.9	38700	8.25	57.6	10600	623	0.83	42.0
0.5	2013.70	28500	0.39	33.3	239	0.96	0.46	11.9	0.189	5620	74.1	21.7	31.8	38900	8.75	55.5	11000	545	0.86	43.3
1	2010.50	29800	0.41	32.2	235	0.92	0.45	12.8	0.200	5430	77.3	21.8	32.4	39500	8.65	58.1	11600	521	0.86	44.8
2	2000.90	31800	0.47	39.4	256	1.06	0.50	14.0	0.215	6050	81.0	24.4	35.8	42500	9.49	65.2	12000	603	1.01	48.5
3	1990.09	29500	0.50	34.6	243	0.92	0.46	12.8	0.192	5200	77.1	23.1	34.3	40100	8.94	54.0	11600	534	0.88	46.4
4	1975.22	29300	0.50	32.5	230	0.95	0.45	13.6	0.184	5080	76.4	23.7	32.4	39700	8.56	59.7	11100	507	0.88	44.8
5	1961.71	29200	0.44	31.7	228	0.94	0.44	12.9	0.177	5020	73.8	26.0	31.8	39900	8.35	55.8	11200	492	0.86	45.5
6	1952.50	29400	0.37	30.6	222	0.99	0.42	13.6	0.156	4840	78.4	26.4	31.4	40300	7.89	57.0	11100	483	0.76	45.1
7	1936.75	31700	0.34	31.6	251	0.97	0.45	12.9	0.175	4760	81.8	27.7	33.1	33800	8.14	57.6	12000	500	0.77	47.3
8	1925.71	31700	0.32	30.9	243	1.04	0.44	13.6	0.182	4690	77.7	26.8	33.0	41600	8.10	63.0	11600	493	0.83	47.7
9	1908.91	31600	0.27	29.2	241	1.03	0.45	13.1	0.178	4610	78.8	25.8	31.6	40500	8.26	63.0	11700	478	0.80	45.9
10	1890.02	32400	0.30	31.0	252	1.05	0.47	13.4	0.200	4770	83.7	25.0	34.1	42600	8.63	63.0	12500	511	0.89	47.1
11	1870.95	32100	0.28	28.3	243	1.04	0.45	12.8	0.199	4730	81.4	25.1	32.6	40800	8.34	59.5	12100	481	1.00	46.8
12	1851.85	31300	0.27	27.8	228	0.99	0.44	14.8	0.186	4470	78.4	28.5	30.9	39100	8.08	58.6	11400	447	1.15	46.1
13	1830.97	34200	0.26	31.9	266	1.12	0.52	13.6	0.197	4800	86.7	30.2	35.8	43900	9.28	59.0	13800	510	1.07	52.1
14	1810.08	32800	0.27	30.9	252	1.02	0.47	13.9	0.200	4720	81.8	29.6	33.8	43100	8.33	61.6	11800	490	1.08	48.8
15	1788.93	31100	0.29	30.0	227	1.04	0.46	14.0	0.190	4710	78.7	28.8	32.5	40200	8.26	62.0	11700	465	1.25	46.7
16	1768.90	30400	0.27	30.4	238	0.98	0.44	12.5	0.181	4570	77.7	23.8	32.3	39000	7.86	57.3	11100	476	1.06	44.4
17	1749.77	29000	0.27	31.7	226	0.93	0.44	11.4	0.168	4440	75.6	26.2	32.3	38800	7.73	58.0	11000	462	1.13	45.2
18	1731.09	30400	0.26	33.5	241	0.97	0.44	12.5	0.176	4630	77.8	25.9	32.9	40200	7.61	59.3	11400	463	1.26	46.2
19	1712.31	27200	0.27	32.0	220	0.87	0.43	12.0	0.169	4300	72.0	23.2	30.9	36000	7.38	49.7	10200	447	1.12	43.7
20	1691.81	28300	0.27	33.6	222	0.91	0.44	11.4	0.170	4300	75.2	25.2	31.7	37900	7.39	53.9	10800	455	1.22	44.2
21	1672.68	31500	0.29	38.2	244	1.03	0.47	11.6	0.185	4730	82.0	25.9	35.0	41900	8.04	58.3	11700	524	1.33	48.2
22	1653.30	31400	0.30	37.9	247	0.98	0.45	12.2	0.194	4630	82.2	23.7	35.5	40700	7.87	56.4	12200	501	1.25	47.9
23	1631.36	32100	0.34	37.9	256	1.02	0.46	14.2	0.198	4910	83.8	24.9	35.1	41300	8.27	63.0	11900	497	1.35	48.9
24	1609.01	33100	0.31	39.9	266	1.05	0.47	13.5	0.195	4760	87.4	27.1	36.1	42900	8.44	62.3	12500	534	1.41	51.5
25	1587.82	30400	0.29	35.2	237	0.98	0.43	13.6	0.169	4570	79.0	23.9	32.8	39100	7.94	59.3	11500	475	1.29	46.1
26	1564.76	32100	0.30	36.4	244	0.98	0.41	13.4	0.180	4550	80.3	22.9	33.5	39200	7.76	59.5	11800	484	1.28	46.7
27	1541.29	32800	0.29	40.0	261	1.03	0.43	13.7	0.183	4800	84.3	23.0	34.0	41100	8.14	63.0	12300	498	1.33	48.7
28	1518.11	32800	0.25	37.7	256	1.01	0.43	12.9	0.180	4520	80.1	23.7	32.7	39900	8.23	59.8	12200	487	1.27	46.9
29	1492.57	30700	0.25	36.4	241	0.92	0.43	11.5	0.171	4330	78.2	21.4	31.0	38100	8.37	53.2	11600	468	1.22	44.9
30	1465.80	34800	0.27	40.9	285	1.02	0.44	14.0	0.181	4710	87.9	24.1	34.7	43500	8.59	62.6	13100	508	1.32	51.0
31	1438.61	31000	0.27	37.2	235	0.95	0.42	12.2	0.164	4340	77.9	21.7	30.6	37300	7.96	56.9	11800	476	1.19	45.2
32	1411.62	30400	0.26	37.0	237	0.95	0.42	12.0	0.169	4150	78.2	22.0	30.1	37400	8.02	55.4	11300	466	1.24	44.4
33	1382.74	33100	0.24	39.4	263	1.02	0.48	12.1	0.171	4590	83.9	25.1	36.0	41500	9.08	67.3	12200	516	1.41	48.6
34	1349.25	33800	0.25	43.1	279	1.08	0.49	13.5	0.197	4650	88.0	27.6	33.8	41600	8.92	67.3	13200	519	1.51	51.1
35	1316.65	37500	0.29	49.7	291	1.14	0.49	14.5	0.225	5050	92.5	23.6	35.9	43700	9.12	67.3	13700	554	1.35	52.4
36	1289.89	34500	0.27	46.7	285	1.07	0.45	13.9	0.217	4860	89.9	23.5	34.7	42100	8.58	67.0	13500	549	1.14	51.3
37	1259.97	26500	0.29	36.9	208	0.98	0.44	11.6	0.159	4350	67.3	17.3	26.0	32400	8.36	59.3	9740	415	1.05	38.2
38	1231.69	28100	0.25	36.0	224	0.93	0.40	10.7	0.168	4000	70.2	18.4	26.6	34500	7.52	54.9	10700	449	1.09	40.2
39	1200.13	35400	0.27	39.8	267	1.03	0.48	14.4	0.188	4580	83.9	24.0	30.8	39800	9.08	62.0	13200	546	1.13	48.1
40	1167.14	35700	0.32	46.4	268	1.08	0.49	14.3	0.208	4760	87.9	22.8	32.5	41700	9.04	64.7	13400	549	1.27	49.7
41	1136.39	36400	0.34	53.4	294	1.13	0.49	13.6	0.225	4730	90.8	26.1	34.8	44300	8.89	62.7	13500	585	1.28	52.6
42	1107.60	38400	0.37	58.5	301	1.21	0.57	15.9	0.257	5140	97.5	31.6	37.7	47100	10.4	66.8	14300	647	1.61	56.8
43	1080.64	34800	0.35	51.2	274	1.13	0.57	14.4	0.221	4630	89.3	31.8	36.8	42500	10.1	64.7	12800	564	1.90	51.8
44	1047.71	36600	0.35	59.8	289	1.22	0.57	16.8	0.223	5000	90.5	34.7	38.1	43400	10.0	70.8	12900	598	2.40	53.6
45	1019.64	38300	0.37	60.8	296	1.19	0.58	15.8	0.229	5020	94.3	33.4	38.2	46100	10.3	67.9	14000	620	1.85	56.8
46	990.20	32400	0.34	66.0	255	1.12	0.51	14.0	0.231	4630	81.9	23.7	34.5	40400	8.95	62.0	12100	553	1.63	46.9
47	964.01	35300	0.34	80.0	270	1.14	0.54	14.1	0.219	4910	88.5	30.6	37.4	43400	9.47	62.2	13100	615	2.24	52.0
48	935.06	32000	0.35	101	256	1.09	0.49	14.2	0.210	4790	80.6	31.1	36.1	42100	8.72	58.9	11900	614	2.52	50.9
49	909.85	31500	0.34	85.7	257	1.15	0.48	14.7	0.224	4840	79.8	30.9	34.4	40800	8.41	62.7	11500	565	2.50	49.8
50	886.54	33400	0.34	73.4	270	1.12	0.51	14.6	0.230	4810	81.8	28.4	36.3	41800	9.05	63.6	12200	561	1.97	49.1
52	830.47	35400	0.32	68.0	279	1.11	0.51	14.8	0.237	4710	86.9	24.5	36.8	43300	9.36	63.1	12900	590	1.41	49.6
54	774.04	33000	0.31	77.3	276	1.11	0.49	14.2	0.232	4810	83.1	26.9	35.1	42800	9.07	61.7	12300	584	1.65	48.1
56	718.55	38000	0.30	74.2	313	1.15	0.57	14.7	0.238	4810	93.8	31.6	36.4	46900	10.5	68.1	13900	654	1.87	54.4
58	632.61	37900	0.30	72.0	309	1.23	0.56	16.1	0.246	5070	96.1	29.8	37.6	46100	10.6	67.7	14200	663	2.16	56.2
10R		36900.00	0.30	33.10	278.00	1.17	0.49	16.30	0.21	5310.00	88.90	26.30	35.70	45100.00	9.67	67.60	13000.00	557.00	0.92	49.80
20R		36200.00	0.33	41.40	274.00	1.15	0.52	15.10	0.20	5350.00	89.50	30.00	37.40	43800.00	8.83	63.50	12800.00	572.00	1.49	52.40
30R		43700.00	0.33	50.40	329.00	1.28	0.51	17.80	0.23	5620.00	106.00	28.60	41.10	50700.00	10.10	71.20	15700.00	663.00	1.54	59.90
58R		38300.00	0.30	71.60	314.00	1.19	0.57	15.50	0.25	5160.00	95.90	29.70	37.50	46300.00	10.60	74.10	14400.00	650.00	2.17	56.10

Peanut Lake continued



Peanut Lake continued

Depth	Date	Phosphorus	Potassium (K	Selenium (Se)	Silver (Ag)	Sodium (Na)	Strontium (Sr)	Sulfur (S)	Thallium (Tl)	Tin (Sn)	Titanium (Ti)	Tungsten (W	Uranium (U)	Vanadium (V	Zinc (Zn)	Zirconium (Z
0	2016	1200	5770	0.33	0.10	480	35.6	1400	0.336	<2.0	1060	<0.50	6.63	61.2	116	9.4
0.5	2013.70	1110	5650	0.34	0.11	433	34.3	1300	0.342	<2.0	987	<0.50	6.86	61.3	118	11.7
1	2010.50	1100	5900	0.35	0.10	446	33.5	1500	0.343	<2.0	1060	<0.50	6.71	64.0	122	11.1
2	2000.90	1180	6370	0.34	0.12	474	36.3	1500	0.386	<2.0	1170	<0.50	7.79	69.7	137	13.1
3	1990.09	1040	5910	0.37	0.11	434	32.2	1400	0.356	<2.0	1140	<0.50	7.13	66.7	127	11.8
4	1975.22	958	5830	0.35	0.11	428	32.1	1300	0.357	<2.0	1120	<0.50	7.32	65.5	125	12.3
5	1961.71	929	5890	0.35	0.11	408	31.6	1300	0.352	<2.0	1060	<0.50	7.23	63.7	123	13.0
6	1952.50	935	6120	0.34	0.11	421	31.0	1100	0.353	<2.0	1130	<0.50	7.25	65.8	126	12.7
7	1936.75	953	6290	0.28	0.11	417	30.7	<1000	0.369	<2.0	1200	<0.50	7.59	70.2	132	13.1
8	1925.71	972	6440	0.35	0.11	453	30.9	1000	0.381	<2.0	1180	<0.50	7.93	71.5	134	13.9
9	1908.91	873	6060	0.31	0.12	417	30.7	<1000	0.376	<2.0	1140	<0.50	8.07	68.6	127	13.7
10	1890.02	899	6860	0.36	0.12	452	30.6	<1000	0.392	<2.0	1250	<0.50	8.30	73.1	134	14.0
11	1870.95	849	6450	0.32	0.12	449	35.1	<1000	0.400	<2.0	1160	<0.50	7.87	71.0	130	14.7
12	1851.85	813	6310	0.33	0.12	473	30.2	<1000	0.368	<2.0	1170	<0.50	7.50	70.2	122	14.3
13	1830.97	978	6790	0.35	0.13	462	33.2	1100	0.399	<2.0	1260	<0.50	8.79	78.8	131	16.5
14	1810.08	907	6400	0.34	0.13	465	33.0	<1000	0.373	<2.0	1270	<0.50	7.80	73.5	127	15.6
15	1788.93	782	6260	0.33	0.12	451	30.9	<1000	0.381	<2.0	1200	<0.50	7.93	69.1	121	15.9
16	1768.90	807	6010	0.31	0.12	429	30.0	<1000	0.367	<2.0	1140	<0.50	7.55	65.7	124	15.1
17	1749.77	777	5730	0.35	0.12	402	28.1	1000	0.366	<2.0	1080	<0.50	7.39	63.6	122	14.9
18	1731.09	809	6310	0.33	0.12	435	30.0	1100	0.356	<2.0	1120	<0.50	7.38	66.0	126	15.0
19	1712.31	772	5780	0.35	0.12	387	27.2	<1000	0.360	<2.0	1060	<0.50	7.32	62.3	119	13.7
20	1691.81	824	5590	0.33	0.12	388	27.1	1000	0.355	<2.0	1010	<0.50	7.54	62.8	124	14.0
21	1672.68	882	6150	0.35	0.12	439	29.9	1100	0.373	<2.0	1140	<0.50	8.13	68.4	136	16.7
22	1653.30	889	6460	0.36	0.13	453	30.6	1100	0.373	<2.0	1150	<0.50	7.80	68.6	135	15.0
23	1631.36	830	6720	0.31	0.14	484	32.3	1000	0.394	<2.0	1240	<0.50	8.39	70.7	132	16.1
24	1609.01	908	6790	0.33	0.14	474	31.2	1000	0.393	<2.0	1380	<0.50	8.48	75.6	135	16.3
25	1587.82	773	6400	0.32	0.12	481	30.1	<1000	0.386	<2.0	1290	<0.50	7.97	67.7	118	15.9
26	1564.76	774	6560	0.31	0.13	480	31.6	<1000	0.373	<2.0	1280	<0.50	7.68	67.9	119	16.6
27	1541.29	779	6850	0.31	0.13	553	34.7	<1000	0.387	<2.0	1340	<0.50	7.83	70.6	122	17.3
28	1518.11	735	6670	0.29	0.12	500	30.9	<1000	0.397	<2.0	1340	<0.50	7.93	68.5	118	17.0
29	1492.57	716	6680	0.27	0.13	479	29.4	<1000	0.386	<2.0	1270	<0.50	7.48	66.7	115	15.7
30	1465.80	808	7280	0.30	0.14	539	31.8	<1000	0.400	<2.0	1430	<0.50	7.69	75.8	128	17.8
31	1438.61	733	6600	0.27	0.13	455	29.5	<1000	0.396	<2.0	1260	<0.50	7.36	65.8	113	16.1
32	1411.62	677	6320	0.26	0.12	453	29.4	<1000	0.385	<2.0	1210	<0.50	7.26	65.2	113	16.3
33	1382.74	693	7020	0.27	0.13	479	31.2	<1000	0.433	<2.0	1350	<0.50	7.73	71.2	119	18.6
34	1349.25	762	7130	0.29	0.15	497	31.5	<1000	0.420	<2.0	1420	<0.50	7.67	75.9	121	18.2
35	1316.65	812	7660	0.35	0.15	513	35.4	<1000	0.424	<2.0	1510	<0.50	8.03	79.8	133	19.7
36	1289.89	821	7280	0.31	0.14	483	33.2	<1000	0.396	<2.0	1460	<0.50	7.86	76.9	133	18.8
37	1259.97	581	5410	0.31	0.13	339	31.9	<1000	0.389	<2.0	1100	<0.50	7.71	58.4	98.2	16.5
38	1231.69	631	5940	0.25	0.12	364	28.0	<1000	0.351	<2.0	1130	<0.50	6.55	60.8	100	15.4
39	1200.13	739	7220	0.28	0.13	498	33.0	<1000	0.428	<2.0	1460	<0.50	7.70	73.5	119	16.9
40	1167.14	783	7390	0.32	0.14	477	34.7	<1000	0.411	<2.0	1480	<0.50	7.68	76.9	127	17.8
41	1136.39	829	7670	0.34	0.14	460	32.7	<1000	0.421	<2.0	1470	<0.50	8.26	78.7	136	18.0
42	1107.60	959	8140	0.39	0.16	494	36.3	1100	0.460	<2.0	1610	<0.50	9.92	87.6	146	17.9
43	1080.64	750	7310	0.33	0.16	472	33.8	<1000	0.462	<2.0	1480	<0.50	9.30	78.9	128	17.7
44	1047.71	977	7590	0.35	0.15	490	36.2	1200	0.430	<2.0	1480	<0.50	8.63	82.0	130	18.6
45	1019.64	844	7890	0.35	0.16	518	35.9	1200	0.456	<2.0	1560	<0.50	8.92	85.2	136	19.2
46	990.20	759	6790	0.33	0.15	435	32.7	1000	0.399	<2.0	1290	<0.50	8.73	73.5	125	17.0
47	964.01	1070	7020	0.39	0.15	472	34.0	1400	0.429	<2.0	1350	<0.50	10.2	79.3	136	17.8
48	935.06	1240	6580	0.46	0.14	434	33.2	1800	0.390	<2.0	1290	<0.50	10.5	73.5	129	16.4
49	909.85	788	6580	0.39	0.14	425	33.5	1500	0.401	<2.0	1240	<0.50	10.3	71.6	129	17.0
50	886.54	842	6830	0.38	0.14	451	33.7	1200	0.414	<2.0	1290	<0.50	10.0	74.6	132	17.1
52	830.47	801	7420	0.33	0.14	489	34.9	1100	0.436	<2.0	1370	<0.50	9.80	77.2	134	17.6
54	774.04	826	6800	0.37	0.13	455	35.1	1100	0.413	<2.0	1340	<0.50	9.56	75.4	130	17.8
56	718.55	916	7950	0.33	0.15	526	34.2	<1000	0.465	<2.0	1610	<0.50	8.91	84.4	134	18.4
58	632.61	878	8170	0.34	0.15	517	37.6	1100	0.468	<2.0	1640	<0.50	9.91	86.7	138	19.3
10R		985.00	7120.00	0.35	0.12	479.00	36.30	<1000	0.43	<2.0	1360.00	<0.50	8.84	77.80	143.00	15.00
20R		1000.00	7320.00	0.46	0.14	468.00	35.90	1300.00	0.43	<2.0	1400.00	<0.50	8.96	77.70	151.00	15.90
30R		990.00	9020.00	0.39	0.16	608.00	40.00	1000.00	0.48	<2.0	1790.00	<0.50	8.90	90.90	157.00	21.60
58R		845.00	8010.00	0.34	0.15	513.00	37.20	1100.00	0.47	<2.0	1630.00	<0.50	9.74	86.20	136.00	20.00


Peanut Lake
OM
%
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per mill
C/N
Dry Mass Sedimentation Rate
g/cm2
Al
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Co
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Cr
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Year CE
Cu
ug/g
Fe
mg/g
Ni
ug/g
Pb
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Sb
ug/g
Se
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Ti
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Zn
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600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000

Nico Lake

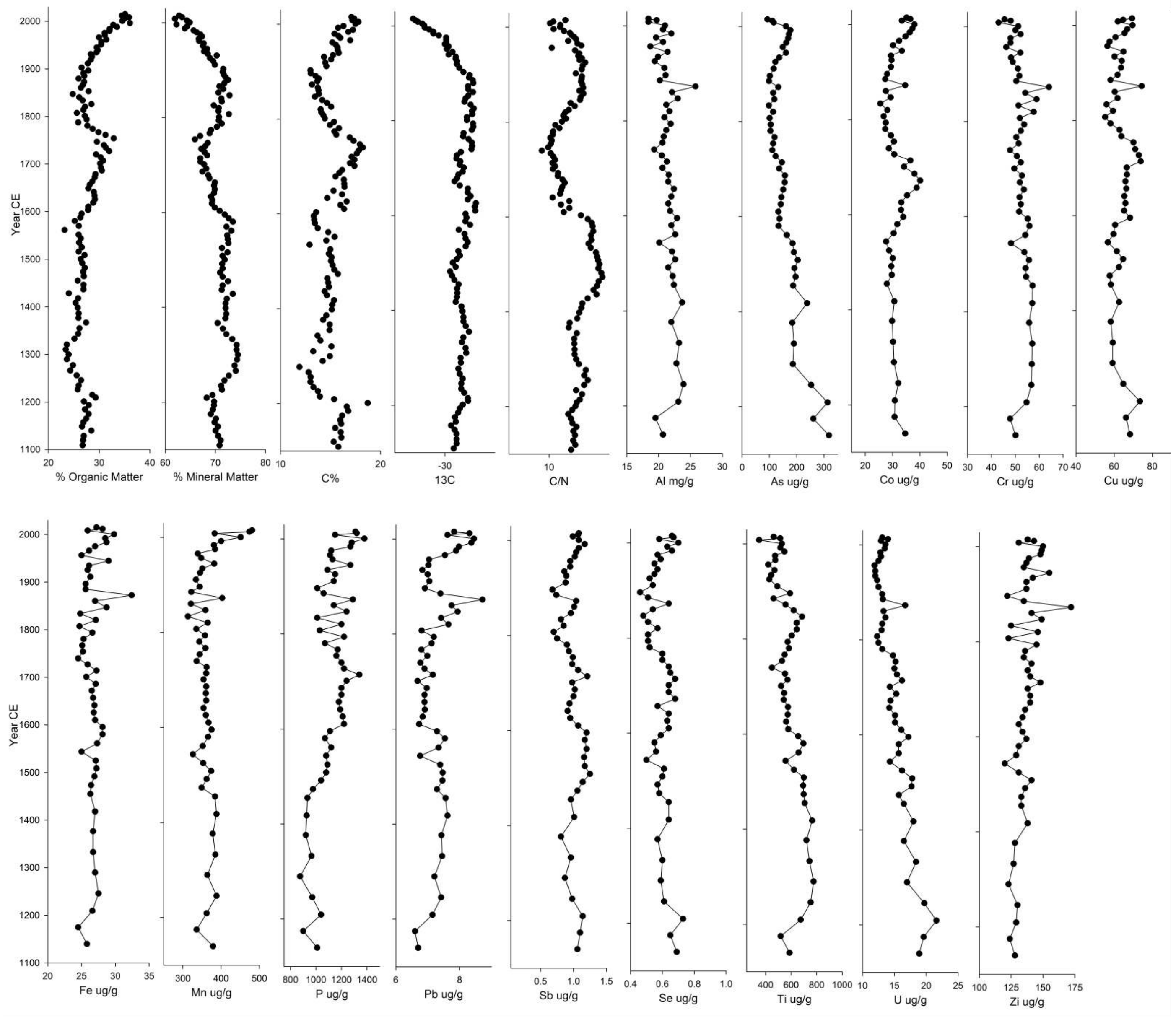
Nico Lake																				
Year CE	Depth	Aluminun	Antimony	Arsenic (A	Barium (B	Beryllium	Bismuth (	Boron (B)	Cadmium	Calcium ((	Chromiun	Cobalt (Cc	Copper (C	Iron (Fe)	Lead (Pb)	Lithium (L	Magnesiu	Manganes
2015.0	0.0	18400.0	1.1	93.1	166.0	0.7	0.5	10.5	0.3	7700.0	45.5	35.1	69.4	27200.0	7.8	28.6	6950.0	481.0
2011.9	0.5	19700.0	1.1	111.0	172.0	0.8	0.5	11.6	0.4	7480.0	48.1	36.5	64.7	28100.0	8.3	31.9	7230.0	474.0
2008.4	1	18400	0.99	116	156	0.74	0.43	9	0.281	7390	43	33.4	61.9	25900	7.62	28.2	6810	383
2000.6	2	21000	1.08	161	172	0.82	0.47	11.3	0.341	7430	51.2	38	69.6	29800	8.45	32.9	7760	451
1992.3	3.0	20700.0	1.2	177.0	166.0	0.8	0.5	10.3	0.3	7090.0	50.0	37.3	66.8	28500.0	8.4	31.6	7920.0	400.0
1983.9	4.0	22000.0	1.1	172.0	166.0	0.8	0.5	10.4	0.3	6690.0	52.2	36.3	65.4	28700.0	8.0	32.1	7920.0	381.0
1975.3	5	19600	1.04	169	154	0.81	0.44	9.5	0.295	6370	48	34.7	60.7	27000	7.89	32.1	7120	384
1966.0	6	20700	1.02	162	152	0.79	0.44	9.2	0.256	6000	48	32.4	57.6	26100	7.54	30.4	7670	339
1956.6	7.0	18700.0	1.0	149.0	141.0	0.8	0.4	9.1	0.3	6080.0	46.2	30.2	56.5	25000.0	7.0	32.4	6870.0	348.0
1944.9	8.0	21400.0	1.0	161.0	169.0	0.8	0.4	8.1	0.3	5750.0	52.1	33.4	64.9	29000.0	7.0	29.4	7840.0	382.0
1934.6	9	19900	0.86	136	150	0.86	0.42	8.6	0.273	6080	48.2	29.4	60.2	26100	6.83	32.4	6850	351
1925.6	10	19400	0.89	122	154	0.81	0.43	8.1	0.258	5770	48.9	29.6	64	25900	7	31.7	7070	345
1911.3	11.0	20900.0	0.9	116.0	151.0	0.8	0.4	8.6	0.3	5530.0	51.1	29.4	63.6	26300.0	7.1	31.3	7620.0	334.0
1896.3	12.0	21100.0	0.7	102.0	146.0	0.8	0.4	10.2	0.2	5420.0	51.7	28.0	61.8	25600.0	6.9	36.6	7550.0	344.0
1885.3	13	20200	0.74	98.7	156	0.82	0.45	7.6	0.254	5390	50.4	27.3	58.1	25600	7.4	32.7	7560	322
1872.6	14	25800	1.04	133	193	1.02	0.53	9.4	0.329	6860	64.1	34.6	74.4	32400	8.72	40.8	9600	403
1860.3	15.0	22100.0	1.0	114.0	169.0	0.9	0.5	10.5	0.3	5820.0	54.2	27.5	60.3	27000.0	7.8	35.7	8010.0	321.0
1847.1	16.0	23000.0	1.0	118.0	181.0	0.9	0.5	10.7	0.3	5840.0	58.9	29.3	61.8	28700.0	7.9	36.3	8350.0	359.0
1833.9	17	21200	0.81	98.1	146	0.78	0.43	11	0.257	5390	51.3	25.5	56	24800	7.42	35.1	7230	313
1820.3	18	21700	0.85	114	164	0.9	0.47	10.5	0.308	5910	57.7	28.1	59.4	27100	7.65	35.4	7870	365
1807.3	19.0	20900.0	0.7	101.0	151.0	0.8	0.4	9.9	0.9	5330.0	51.9	26.7	55.3	24700.0	6.8	34.4	7410.0	335.0
1793.9	20.0	21900.0	0.8	105.0	163.0	0.9	0.5	8.7	0.3	5690.0	53.7	27.5	58.1	26600.0	7.2	32.8	7760.0	358.0
1780.5	21	21200	0.9	104	156	0.79	0.44	8.8	0.289	5530	52.3	27.3	62.8	25300	7.12	33.7	7560	343
1767.0	22	20800	0.93	119	143	0.78	0.43	9.7	0.301	5690	50.4	29.4	63.8	25100	6.8	29.9	7210	359
1754.1	23.0	20600.0	1.0	114.0	150.0	0.8	0.5	9.7	0.3	5950.0	51.4	30.5	70.1	25200.0	7.0	32.6	7420.0	344.0
1739.7	24.0	19300.0	1.0	111.0	145.0	0.8	0.5	8.3	0.3	5830.0	47.8	28.6	71.0	24500.0	6.8	29.2	6750.0	336.0
1727.1	25	20500	1.07	123	145	0.81	0.46	9.5	0.306	5890	50.7	30.6	72.9	25900	6.9	29.8	7080	362
1714.2	26	21300	1.21	146	150	0.86	0.49	10.4	0.325	6190	52.3	36.5	73.9	27200	7.16	29.8	7480	361
1701.1	27.0	20600.0	1.0	136.0	151.0	0.8	0.5	9.0	0.3	5850.0	49.6	34.2	66.6	25700.0	6.7	30.0	7330.0	354.0
1686.3	28.0	21600.0	1.0	157.0	151.0	0.9	0.5	9.2	0.3	6010.0	52.8	38.0	66.7	27100.0	7.0	32.5	7410.0	361.0
1672.1	29	21500	1	156	157	0.83	0.46	9	0.307	5910	51.9	40.1	65.9	26500	6.9	31.2	7240	360
1656.8	30	22400	0.94	151	155	0.82	0.46	8.8	0.294	5810	53.6	38.8	66.4	26700	6.9	29.4	7510	361
1641.1	31.0	22000.0	0.9	144.0	154.0	0.8	0.5	8.7	0.3	5830.0	51.8	35.3	65.3	26900.0	6.9	30.5	7440.0	354.0
1626.1	32.0	21500.0	1.0	142.0	150.0	0.8	0.5	8.9	0.3	5920.0	52.3	33.2	65.9	26800.0	6.8	33.2	7370.0	360.0
1610.4	33	21800	1.07	133	151	0.81	0.46	9	0.285	5820	51.6	33.1	65.2	27000	6.73	31.6	7400	367
1595.5	34	22900	1.2	137	169	0.86	0.49	8.8	0.31	5720	55.2	33.9	68.3	28100	7.29	34.4	7750	375
1580.3	35.0	22000.0	1.2	134.0	161.0	0.9	0.5	8.7	0.3	5320.0	55.9	31.7	60.5	28100.0	7.5	36.0	8250.0	366.0
1561.2	36.0	22600.0	1.2	164.0	159.0	0.8	0.5	8.4	0.3	5500.0	54.2	30.4	59.7	27300.0	7.3	35.1	7750.0	352.0
1543.7	37	20100	1.16	185	147	0.76	0.44	7.2	0.256	5000	48.2	27.6	56.7	25000	6.76	32.2	7060	326
1525.0	38	22100	1.17	190	160	0.86	0.47	8.4	0.291	5450	53.8	28.7	61.4	27100	7.39	33.7	7620	353
1508.5	39.0	22600.0	1.3	204.0	165.0	0.8	0.5	8.9	0.3	5630.0	55.7	30.1	64.7	27200.0	7.5	34.8	8150.0	374.0
1491.7	40.0	21500.0	1.1	192.0	159.0	0.8	0.5	8.8	0.3	5660.0	54.3	29.5	62.5	26900.0	7.5	35.2	7880.0	362.0
1473.4	41	22200	1.06	196	156	0.82	0.46	8.7	0.316	5720	54.5	29.7	57.7	26400	7.29	35.4	7740	349
1454.9	42	22400	0.96	187	163	0.91	0.47	9.6	0.292	5780	57.2	27.9	58.3	26300	7.56	39.1	8280	384
1418.0	44.0	23700.0	1.0	238.0	176.0	0.9	0.5	9.8	0.3	5770.0	57.1	30.6	62.6	27000.0	7.6	33.4	8380.0	388.0
1376.7	46.0	22000.0	0.8	184.0	164.0	0.9	0.5	9.5	0.3	5710.0	55.8	29.8	58.2	26700.0	7.4	38.2	7980.0	378.0
1332.8	48	23200	0.96	190	164	0.81	0.47	9.2	0.291	5300	57.1	30.2	59.3	26700	7.45	35.2	8320	385
1289.8	50	22800	0.87	186	168	0.89	0.47	10.3	0.262	5350	56.9	30.5	59.2	27000	7.21	39.2	8240	364
1245.8	52.0	23900.0	1.0	253.0	170.0	0.9	0.5	9.7	0.3	5640.0	56.7	32.1	64.8	27500.0	7.4	38.3	8290.0	388.0
1209.2	54.0	23100.0	1.1	313.0	159.0	0.9	0.5	8.9	0.3	5640.0	54.7	30.8	73.5	26600.0	7.2	36.8	7930.0	362.0
1174.9	56	19500	1.1	261	145	0.73	0.43	6.9	0.293	5070	47.8	30.7	66.2	24500	6.6	30.5	6880	336
1139.8	58	20700	1.06	318	144	0.78	0.44	8	0.308	5350	50.1	34.6	68.3	25800	6.7	31.7	7420	379
	23R	19300.0	1.0	106.0	142.0	0.7	0.4	8.4	0.3	5450.0	47.9	29.1	66.9	24000.0	6.7	30.4	6820.0	328.0
	27R	19700.0	1.0	130.0	138.0	0.8	0.4	9.0	0.3	5690.0	47.4	32.9	64.6	24500.0	6.5	31.2	6800.0	336.0
	30R	19100	0.86	139	141	0.77	0.44	7.7	0.285	5270	47.4	35.2	61.3	24500	6.51	29.9	6710	321

Nico Lake continued

Nico Lake continued

Year CE	Depth	Molybden	Nickel (Ni	Phosphor	Potassium	Selenium	Silver (Ag	Sodium (N	Strontium	Sulfur (S)	Thallium (	Tin (Sn)	Titanium (	Uranium (	Vanadium	Zinc (Zn)	Zirconium
2015.0	0.0	3.3	35.7	1310.0	3380.0	0.7	<0.10	339.0	32.2	<5000	0.3	<2.0	463	13.1	42.9	138	5.2
2011.9	0.5	3.9	37.0	1320.0	3310.0	0.7	<0.10	323.0	32.4	<5000	0.3	<2.0	514	14	45	143	5.3
2008.4	1	3.59	33.6	1150	3200	0.58	<0.10	271	28.8	<5000	0.239	<2.0	349	12.9	40.8	131	5
2000.6	2	4.26	39.3	1380	3690	0.7	<0.10	317	30.5	<5000	0.27	<2.0	527	13.6	48.4	150	5.6
1992.3	3.0	4.2	39.4	1280.0	3520.0	0.6	0.1	310.0	30.7	<5000	0.3	<2.0	516	13.5	46.3	149	5.7
1983.9	4.0	3.8	39.2	1270.0	3730.0	0.7	0.1	312.0	29.6	<5000	0.3	<2.0	547	12.8	48.1	148	5.5
1975.3	5	3.55	37	1120	3400	0.57	0.11	284	29	<5000	0.268	<2.0	474	12.9	44.6	139	5.6
1966.0	6	3.47	36.1	1110	3570	0.59	0.1	288	27.6	<5000	0.27	<2.0	476	12.5	44.2	137	4.8
1956.6	7.0	3.8	34.8	1130.0	3010.0	0.6	<0.10	269.0	26.2	<5000	0.3	<2.0	420	11.9	43.4	135	4.4
1944.9	8.0	3.5	39.8	1270.0	3560.0	0.6	0.1	299.0	27.1	<5000	0.3	<2.0	469	12	48.7	155	4.3
1934.6	9	3.62	36	1090	3120	0.55	0.11	271	26.5	<5000	0.259	<2.0	443	12	44.9	142	4.3
1925.6	10	3.58	36.4	1150	3300	0.52	0.1	269	26.2	<5000	0.272	<2.0	428	12.3	44.9	137	4.6
1911.3	11.0	3.8	37.3	1140.0	3450.0	0.5	0.1	286.0	26.8	<5000	0.3	<2.0	491	12.5	46.9	137	4.2
1896.3	12.0	3.5	36.4	1010.0	3510.0	0.5	0.1	298.0	25.9	2800.0	0.3	<2.0	591	13.1	46.9	122	4.2
1885.3	13	3.42	36.6	1060	3480	0.51	0.11	273	25.5	<5000	0.275	<2.0	462	13.2	45.6	135	4.7
1872.6	14	4.94	46.2	1290	4090	0.64	0.13	331	31	<5000	0.333	<2.0	556	16.7	59.4	172	5.9
1860.3	15.0	4.5	38.2	1140.0	3870.0	0.5	0.1	315.0	27.9	<5000	0.3	<2.0	620	13.3	51.9	141	4
1847.1	16.0	4.0	40.8	1240.0	4050.0	0.5	0.1	339.0	28.8	<5000	0.3	<2.0	685	13.6	55.9	149	4
1833.9	17	4	35.7	1010	3540	0.51	0.12	321	27.5	2700	0.288	<2.0	644	13.1	46.9	125	4.1
1820.3	18	3.84	40	1200	3750	0.57	0.12	314	28.8	<5000	0.3	<2.0	645	13	44.9	146	4
1807.3	19.0	3.4	73.3	1030.0	3490.0	0.5	0.1	296.0	27.3	2700.0	0.3	<2.0	605	12.3	49.2	123	3.8
1793.9	20.0	3.2	38.1	1220.0	3580.0	0.5	0.1	298.0	28.0	<5000	0.3	<2.0	572	12.5	48.7	145	4.4
1780.5	21	3.55	37.3	1070	3460	0.52	0.13	278	26.2	3000	0.279	<2.0	583	13.1	50.3	136	4.1
1767.0	22	4.28	36.8	1170	3380	0.6	0.12	300	26.5	3400	0.283	<2.0	548	14.8	49.4	135	3.8
1754.1	23.0	4.1	37.9	1160.0	3330.0	0.6	0.1	289.0	29.3	3500.0	0.3	<2.0	528	15.2	48.6	141	3.9
1739.7	24.0	4.5	36.4	1200.0	3100.0	0.6	0.1	261.0	26.8	<5000	0.3	<2.0	449	15	49.3	138	4.7
1727.1	25	5.09	38.2	1220	3360	0.65	0.12	288	28.1	3600	0.284	<2.0	552	15.4	49.3	140	3.9
1714.2	26	5.02	39.5	1340	3490	0.68	0.13	296	29.8	3800	0.31	<2.0	571	16.2	52.4	148	4.1
1701.1	27.0	4.3	38.4	1240.0	3340.0	0.6	0.1	281.0	27.5	3500.0	0.3	<2.0	521	14.3	48.9	138	4.1
1686.3	28.0	4.4	39.6	1200.0	3370.0	0.6	0.1	280.0	28.8	3700.0	0.3	<2.0	545	15.3	51.1	140	4.4
1672.1	29	4.23	39.5	1200	3400	0.68	0.12	282	28.5	3600	0.28	<2.0	542	14.4	50.2	140	4.4
1656.8	30	3.73	40.1	1180	3410	0.57	0.12	291	28.5	3600	0.276	<2.0	575	14.2	50.2	136	4.3
1641.1	31.0	3.3	38.9	1190.0	3430.0	0.6	0.1	289.0	28.2	3500.0	0.3	<2.0	573	15.1	50.3	134	4.4
1626.1	32.0	3.3	38.3	1210.0	3370.0	0.6	0.1	283.0	28.9	3400.0	0.3	<2.0	561	15.1	50.8	131	4.3
1610.4	33	3.27	38.1	1220	3380	0.64	0.12	308	28.7	3400	0.277	<2.0	577	16.1	50	134	4.7
1595.5	34	3.64	39	1110	3830	0.59	0.12	302	29.2	3000	0.308	<2.0	655	17.2	53	137	5.2
1580.3	35.0	3.7	39.0	1070.0	3850.0	0.6	0.1	301.0	28.1	2600.0	0.3	<2.0	696	15.7	53.2	131	6.3
1561.2	36.0	4.5	38.2	1120.0	3570.0	0.6	0.1	286.0	28.6	2800.0	0.3	<2.0	658	15.7	53	129	5.4
1543.7	37	4.76	34.7	1080	3140	0.5	0.11	273	25.7	2700	0.278	<2.0	556	14.3	47.8	120	4.4
1525.0	38	4.69	38.3	1090	3510	0.61	0.12	290	28	2900	0.3	<2.0	622	16.2	52.2	131	5.3
1508.5	39.0	4.9	39.9	1080.0	3690.0	0.6	0.1	294.0	29.1	2900.0	0.3	<2.0	700	17.8	54.3	141	6.1
1491.7	40.0	4.4	38.9	1040.0	3560.0	0.6	0.1	285.0	27.8	2800.0	0.3	<2.0	694	17.7	53.1	136	6.3
1473.4	41	3.84	38.7	976	3580	0.58	0.12	284	28.3	2900	0.294	<2.0	698	15.7	52.8	133	6.1
1454.9	42	3.48	40.1	933	3770	0.64	0.13	301	29.3	2900	0.309	<2.0	706	16.5	53	133	6.7
1418.0	44.0	4.5	40.5	927.0	3920.0	0.6	0.1	322.0	29.6	3100.0	0.3	<2.0	765	18	54.3	138	6.9
1376.7	46.0	3.2	39.8	920.0	3790.0	0.6	0.1	305.0	29.3	3000.0	0.3	<2.0	720	16.5	52.3	128	7.5
1332.8	48	2.9	39.8	965	3860	0.6	0.13	307	27.9	2900	0.302	<2.0	744	18.4	53.6	127	7
1289.8	50	3.11	39.6	875	4180	0.59	0.13	309	28	2600	0.297	<2.0	776	17	53.6	123	8.3
1245.8	52.0	3.8	41.3	971.0	3860.0	0.6	0.1	316.0	29.7	3200.0	0.3	<2.0	753	19.7	54	130	7.4
1209.2	54.0	4.6	41.5	1040.0	3630.0	0.7	0.1	306.0	29.3	3800.0	0.3	<2.0	675	21.6	52.4	129	6.4
1174.9	56	4.32	39.1	900	3240	0.65	0.13	262	25.6	3900	0.242	<2.0	518	19.6	47.8	124	5.8
1139.8	58	5.11	39.7	1010	3480	0.69	0.13	287	28.2	4000	0.261	<2.0	587	18.9	48.5	128	6.1
	23R	3.7	35.7	1090.0	3110.0	0.5	0.1	269.0	25.6	3000.0	0.3	<2.0	460	14.7	46.5	132	3.3
	27R	4.1	36.7	1060.0	3140.0	0.6	0.1	269.0	27.2	3300.0	0.3	<2.0	461	13.8	47.6	131	3.9
	30R	3.35	36.8	1050	3080	0.52	0.11	257	25.7	3100	0.255	<2.0	464	13.5	45.4	124	3.5

Nico Lake HC1 Metals of Interest



Grid Lake

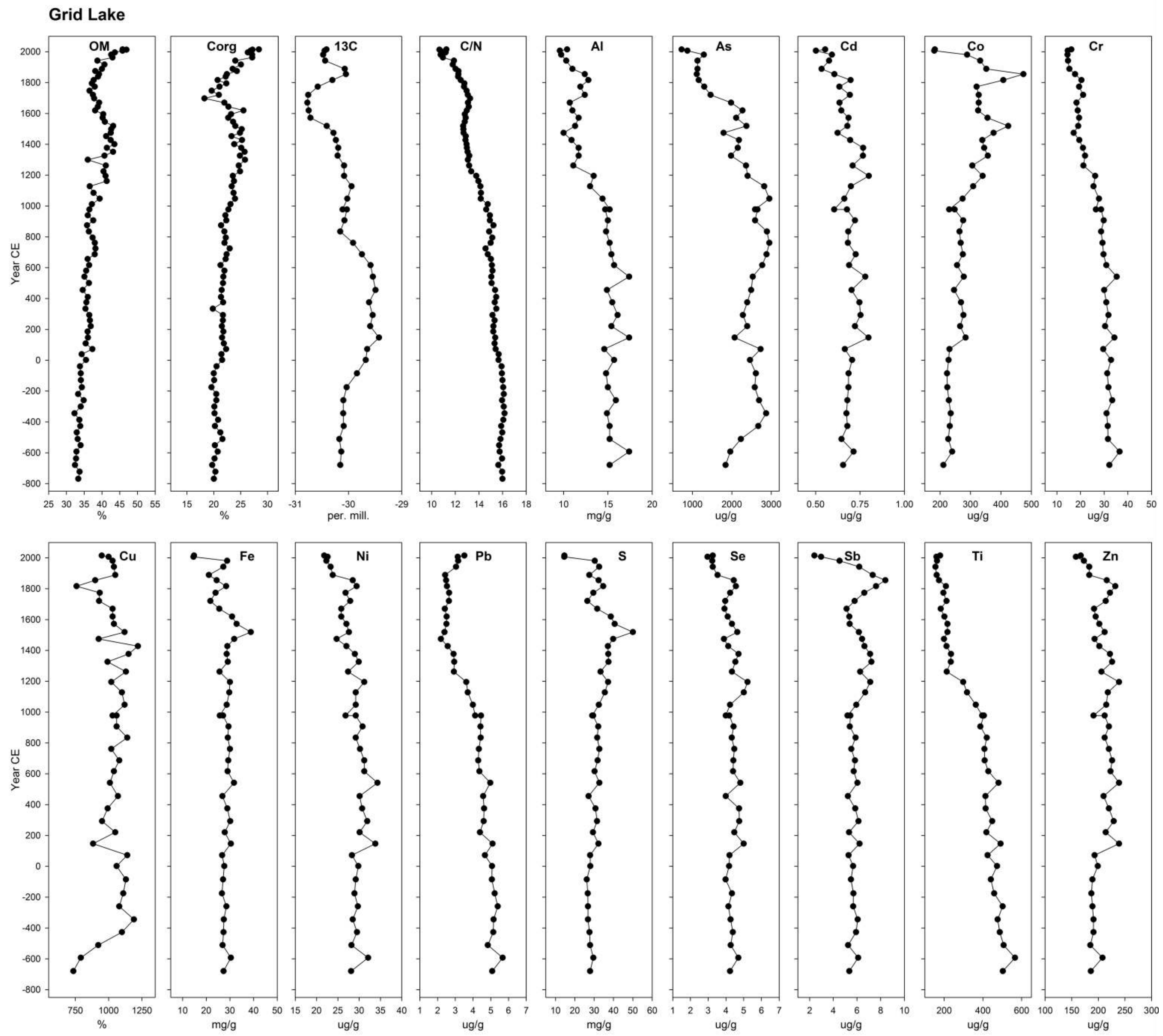
Grid Lake

Depth	Year	Aluminun	Antimony	Arsenic (A	Barium (B	Beryllium	Bismuth (	Boron (B)	Cadmium (	Calcium (	Chromiun	Cobalt (Co	Copper (C	Iron (Fe)	Lead (Pb)	Lithium (L	Magnesium
0.0	2015	10400	2.4	726	84.6	0.75	5.55	15.7	0.554	15600	16.1	183	948	14800	3.51	12.4	3750
1.0	2006.723	9580	2.97	872	73.3	0.69	5.29	14.9	0.502	13700	14.6	181	1000	14600	3.14	11.1	3330
2.0	1981.079	9730	4.53	1290	66.2	0.66	5.04	10.9	0.592	12400	14.5	289	1030	28800	3.16	11.1	3100
3.0	1942.277	10300	6.19	1130	66.9	0.7	5.03	10	0.576	11900	14.7	332	1040	27200	3.04	11.2	2910
4.0	1888.876	11000	7.33	1130	67.1	0.8	5.49	9.8	0.534	12100	15.3	352	1050	21100	2.43	11.8	3000
5.0	1854.837	12400	8.4	1110	79.3	0.86	6.33	9.6	0.606	12700	17.7	474	899	24400	2.48	13.2	3430
6.0	1816.267	12800	7.61	1160	87.4	0.86	6.36	8.5	0.697	11700	20.4	408	759	28400	2.53	13.9	3730
7.0	1773.727	11900	6.62	1300	82.1	0.83	6.41	7.5	0.634	11500	19.4	320	933	23900	2.65	14.3	3530
8.0	1720.616	12400	5.8	1460	88.3	0.83	6.36	7.1	0.693	11100	21.1	327	928	21700	2.64	14	3730
9.0	1669.85	10700	5.12	1980	78.5	0.73	5.73	5.3	0.635	10100	18.3	327	1030	25500	2.41	13.1	3330
10.0	1619.524	11000	5.35	2270	79.9	0.72	6.08	6	0.645	10300	18.8	325	1030	30900	2.51	13.2	3330
11.0	1571.79	11700	5.38	2110	86.2	0.72	6.25	8.3	0.686	10600	19.4	356	1040	32800	2.5	12.8	3500
12.0	1518.588	11300	6.16	2370	79.6	0.7	6.08	6.4	0.679	11000	19	424	1120	38800	2.39	12.6	3400
13.0	1474.473	10000	6.43	1790	73	0.59	5.31	<5.0	0.624	9310	17.1	376	925	31800	2.19	11.1	3100
14.0	1427.68	10900	6.63	2180	83.7	0.63	5.95	<5.0	0.695	10400	19.5	339	1220	28900	2.57	13.1	3530
15.0	1377.158	11700	7.11	2150	93.6	0.74	6.63	<5.0	0.768	11100	21	345	1150	28600	2.9	13.7	3900
16.0	1326.2	11700	7.22	1980	94.8	0.74	6.4	5.3	0.767	11200	21.9	357	992	29100	2.94	14	3990
17.0	1262.374	11100	6.27	2360	90.8	0.68	6.07	<5.0	0.709	9790	21.2	306	1130	25600	2.92	14.5	3880
18.0	1195.267	13400	7.12	2400	110	0.79	6.96	<5.0	0.8	10800	26.2	340	1020	30000	3.62	17.7	4820
19.0	1127.706	13000	6.69	2820	102	0.72	6.56	<5.0	0.699	9800	25.5	309	1100	29700	3.7	18	4710
20.0	1047.497	14400	5.94	2950	98.9	0.9	6.56	<5.0	0.662	9240	27.8	274	1120	28600	3.99	26.7	5110
21.0	977.67	15200	5.2	2590	102	0.91	6.52	6.2	0.605	9920	26.5	230	1030	25700	4.12	27.5	4790
22.0	977.6663	14700	5.44	2650	105	0.91	6.85	5.4	0.677	9600	28.7	248	1060	27100	4.45	27.4	5400
23.0	906.4667	15000	5.39	2590	103	0.92	6.88	<5.0	0.722	9530	29.8	276	1060	29400	4.42	26.7	5650
24.0	834.6571	14800	5.88	2890	106	0.89	6.76	6.1	0.684	9200	28.7	264	1140	29100	4.43	26.2	5380
25.0	761.2157	15200	5.52	2950	103	0.85	6.79	<5.0	0.682	9260	29.3	268	1020	30000	4.33	25.8	5520
26.0	686.6873	15400	5.83	2880	109	0.89	6.95	5.2	0.726	9520	29.7	275	1080	29300	4.29	25.8	5590
27.0	616.2351	15700	5.72	2770	109	0.85	6.7	<5.0	0.689	9020	30.9	256	1040	29000	4.36	25.6	5900
28.0	541.5987	17400	6.04	2530	118	0.94	7.28	5.9	0.78	9850	35.3	278	1010	31700	4.97	29.1	6630
29.0	455.2587	14900	5.23	2490	105	0.85	6.72	<5.0	0.703	8850	30	246	1070	26800	4.57	25.8	5850
30.0	375.2184	15500	5.85	2390	103	0.91	7.09	5.4	0.747	9400	30.9	269	993	28900	4.62	25.7	5750
31.0	292.8468	16100	6.13	2280	111	0.89	6.97	5.6	0.753	9540	31.8	277	951	30100	4.6	26.1	5930
32.0	220.6036	15400	5.33	2390	102	0.87	6.71	5.6	0.722	9280	30.4	266	1050	27800	4.39	24.9	5710
33.0	146.9675	17400	6.22	2070	120	0.97	7.51	6.5	0.798	10500	34.3	284	883	30400	5.1	28.9	6580
34.0	72.09599	14600	5.29	2730	99.6	0.82	6.36	5.4	0.665	8540	29.6	231	1140	26700	4.67	24.6	5650
35.0	1.46657	15700	5.67	2460	107	0.85	6.5	5.4	0.706	8470	32.9	228	1060	27600	5.07	27	6280
36.0	-85.1978	14800	5.49	2610	99.9	0.86	6.3	<5.0	0.686	8210	31.3	223	1130	27100	5.06	26	6060
37.0	-175.469	15000	5.7	2580	103	0.84	6.29	5.1	0.685	8150	31.8	224	1110	26600	5.22	26.4	6040
38.0	-259.805	15900	5.68	2690	102	0.86	6.16	5.2	0.679	8100	33.4	229	1080	28500	5.39	27.5	6390
39.0	-344.349	14900	6.06	2870	101	0.83	6.26	5.2	0.674	8230	31	235	1190	27400	5.16	26	5910
40.0	-426.951	15200	5.92	2670	99.5	0.84	6.12	5.3	0.679	8210	31.5	232	1100	27300	5.14	26.2	6150
41.0	-510.906	15200	5.25	2230	106	0.92	5.81	6.1	0.646	8790	31.6	227	922	26900	4.83	29.1	5930
42.0	-592.759	17400	6.1	1960	120	1.08	6.65	6.3	0.714	9960	36.5	240	791	30400	5.67	34.1	6930
43.0	-679.437	15200	5.35	1840	110	0.94	5.84	5.9	0.655	9010	32.2	211	735	27300	5.08	31	5980
19R		13800	6.07	2090	104	0.98	6.37	6.6	0.682	10500	25	288	840	28800	3.56	26.7	4550
28R		15200	4.89	1720	97.5	0.98	6.28	5.8	0.644	9570	29.6	229	693	27200	4.29	30.6	5520
38R		16800	5.73	2860	114	1.03	6.2	6.9	0.719	9490	34.9	226	1160	29200	5.41	33.7	6410

Grid Lake continued

Grid Lake continued

Depth	Year	Manganese	Molybdenu	Nickel (Ni	Phosphor	Potassium	Selenium	Silver (Ag	Sodium (N	Strontium	Sulfur (S)	Thallium (	Tin (Sn)	Titanium (	Tungsten	Uranium (	Vanadium	Zinc (Zn)	Zirconium
0.0	2015	93.4	6.65	21.8	1160	1280	3.26	0.13	350	44.7	14600	0.163	<2.0	179	1.44	25.1	10.5	167	2.8
1.0	2006.723	87.7	8.58	22.6	895	1020	2.96	0.11	221	39	14500	0.145	<2.0	160	1.53	28.9	9.52	158	2.6
2.0	1981.079	89.1	21.3	22.3	595	900	3.23	0.11	198	34.5	30300	0.181	<2.0	163	1.37	50.8	9.46	173	2.6
3.0	1942.277	96.3	20.8	23.3	574	900	3.26	0.11	187	31.8	32600	0.184	<2.0	155	1.05	46.6	9.23	183	2.5
4.0	1888.876	95.3	20.4	23.8	654	930	3.53	0.12	191	32.9	27500	0.179	<2.0	161	1.12	47.6	9.53	183	1.7
5.0	1854.837	102	22.5	28.5	725	1030	4.44	0.13	199	33.8	32300	0.214	<2.0	173	1.16	50.1	11.3	216	1.5
6.0	1816.267	108	18.1	29.4	716	1150	4.56	0.13	201	30.9	34700	0.227	<2.0	209	1.06	46.8	13.5	232	1.3
7.0	1773.727	101	13.9	26.8	630	1080	4.24	0.13	176	30.1	29600	0.232	<2.0	196	1.13	45.5	13.2	222	1.2
8.0	1720.616	105	14.5	27.9	619	1120	3.96	0.13	200	28.9	26500	0.228	<2.0	212	1.05	45.8	13.9	214	1.2
9.0	1669.85	94.8	12.8	25.8	523	980	3.92	0.12	158	26	31600	0.212	<2.0	182	0.91	42.5	12.4	192	1.3
10.0	1619.524	96.5	14.3	25.8	532	1010	4.1	0.12	157	26.3	38600	0.222	<2.0	201	0.99	43.5	12.4	195	1.5
11.0	1571.79	102	14.5	27	551	1060	4.34	0.13	174	26.6	40600	0.217	<2.0	217	1.07	44.4	12.7	202	1.4
12.0	1518.588	102	19.5	27.6	565	990	4.64	0.12	159	26.8	50000	0.233	<2.0	217	1.15	45.8	12.1	212	2.5
13.0	1474.473	93.1	18.3	24.7	454	920	3.89	0.11	157	23.3	39800	0.206	<2.0	199	1.04	39.5	11.4	193	1.8
14.0	1427.68	104	17.9	27	485	1000	4.13	0.12	147	25.4	37100	0.224	<2.0	212	1	43	12.8	202	2.7
15.0	1377.158	112	17.7	29	523	1070	4.71	0.14	160	27	37300	0.248	<2.0	235	1.09	47.6	14	222	2.3
16.0	1326.2	114	18.2	29.9	501	1090	4.53	0.14	168	26.6	37400	0.247	<2.0	234	1.05	47.4	14.6	226	2.3
17.0	1262.374	109	16.1	27.4	455	1070	4.34	0.13	139	24.1	33300	0.245	<2.0	213	1.17	46.6	14.2	206	2.9
18.0	1195.267	133	18	31.2	511	1410	5.22	0.14	168	26.2	37200	0.28	<2.0	298	1.85	53.3	18.2	239	3.2
19.0	1127.706	132	17.8	29.2	454	1450	5.01	0.14	167	24.3	35500	0.269	<2.0	318	1.2	50.8	18.2	218	3.3
20.0	1047.497	141	15.6	29.2	422	1520	4.23	0.14	156	22.8	32400	0.278	<2.0	363	1.18	52.6	19.4	215	4
21.0	977.67	143	15.2	26.8	413	1810	3.99	0.14	174	23.5	29000	0.273	<2.0	396	1.72	50.2	19.8	191	4.6
22.0	977.6663	148	14.4	29.2	397	1700	4.19	0.15	185	23.8	29500	0.289	<2.0	405	1.51	54	20.9	212	4.3
23.0	906.4667	152	15.3	30.8	447	1690	4.43	0.14	166	23.4	32100	0.293	<2.0	387	1.47	56.3	21.6	220	4.6
24.0	834.6571	149	16.1	29.2	453	1740	4.33	0.14	202	23.9	31600	0.297	<2.0	420	1.37	54.6	20.9	212	3.9
25.0	761.2157	153	14.4	30.2	450	1730	4.47	0.15	170	22.9	32700	0.28	<2.0	408	1.29	53	21.1	220	4.6
26.0	686.6873	156	14.9	31.2	444	1730	4.42	0.15	170	23.7	31800	0.283	<2.0	409	1.31	53.9	21.3	226	4.5
27.0	616.2351	160	13.7	31.2	445	1870	4.4	0.15	194	23	30200	0.271	<2.0	428	1.47	51.7	22.5	223	4.7
28.0	541.5987	182	15.5	34.3	460	2080	4.81	0.16	202	25	32700	0.312	<2.0	481	1.39	57.9	25.7	239	6
29.0	455.2587	159	14.2	30.1	399	1820	3.99	0.15	175	23	27100	0.29	<2.0	413	1.36	53.6	22.4	210	5.3
30.0	375.2184	162	16	30.7	451	1810	4.74	0.15	176	24.5	30700	0.308	<2.0	414	1.3	58	22.6	220	5
31.0	292.8468	168	16.2	31.9	450	1920	4.75	0.15	187	25	31500	0.312	<2.0	448	1.36	57.1	23.6	229	4.8
32.0	220.6036	162	15.3	30.1	432	1810	4.47	0.14	176	24.3	29400	0.291	<2.0	418	1.32	55.9	22.1	214	4.8
33.0	146.9675	180	17.4	33.8	503	2100	5	0.16	219	27.4	32200	0.347	<2.0	491	1.69	62.6	25.6	239	5.5
34.0	72.09599	158	14.7	28.3	407	1880	4.2	0.14	175	23	27900	0.297	<2.0	424	1.33	54	22.6	193	5.1
35.0	1.46657	173	15.3	29.8	410	2080	4.18	0.14	202	23.2	28000	0.307	<2.0	473	1.33	56.8	25.2	199	5.9
36.0	-85.1978	171	15.8	29.2	397	2030	3.98	0.14	173	22.6	26200	0.299	<2.0	441	1.29	56.8	24.3	189	6.1
37.0	-175.469	169	15.8	28.9	363	2020	4.34	0.14	192	22.9	26700	0.315	<2.0	458	1.36	57.4	24.8	187	6.2
38.0	-259.805	180	15.6	29.7	374	2220	4.14	0.14	201	23.3	26800	0.323	<2.0	502	1.33	56.9	26.1	189	6.3
39.0	-344.349	170	16.5	28.5	388	2050	4.26	0.14	194	23.1	26800	0.313	<2.0	476	1.27	56.7	24.4	191	6.3
40.0	-426.951	174	16.4	29.5	356	2130	4.39	0.14	190	23.7	27600	0.32	<2.0	487	1.72	55.4	25.2	191	6.6
41.0	-510.906	186	15.1	28.2	409	2210	4.27	0.13	222	23.2	27900	0.286	<2.0	507	1.28	53.2	24.4	185	5.5
42.0	-592.759	213	16.4	32.1	432	2510	4.7	0.15	219	26.4	29600	0.326	<2.0	566	1.45	61.3	29.1	208	6.6
43.0	-679.437	187	14.9	28.1	407	2250	4.23	0.14	212	23.7	27900	0.287	<2.0	503	1.22	54	24.9	186	5.7
19R		133	17.5	28.4	475	1560	4.97	0.14	179	24.6	35300	0.267	<2.0	360	1.38	51.8	18.5	218	3
28R		163	13.3	28.4	425	1970	4.54	0.14	187	23.4	29000	0.282	<2.0	454	1.37	52.1	22.3	201	4.7
38R		202	15.8	30.3	434	2490	4.73	0.15	234	25	30100	0.314	<2.0	567	1.44	58.2	27.7	198	5.9


Grid Lake
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