EXPERT REPORT OF
DIMITRIOS VLASSOPOULOS

Pakootas et al. v. Teck Cominco Metals Ltd
United States District Court for the Eastern District of Washington

Prepared for

The Confederated Tribes of the Colville Reservation

Prepared by

Dimitrios Vlassopoulos, Ph.D.
Anchor QEA, LLC
421 SW Sixth Avenue, Suite 750
Portland, Oregon 97204

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ACRONYMS AND ABBREVIATIONS

^{137}Cs	cesium-137 (radioactive isotope)
^{204}Pb	lead-204 (stable isotope)
^{206}Pb	lead-206 (stable isotope)
^{207}Pb	lead-207 (stable isotope)
^{208}Pb	lead-208 (stable isotope)
^{210}Pb	lead-210 (radioactive isotope)
^{232}Th	thorium-232 (radioactive isotope)
^{235}U	uranium-235 (radioactive isotope)
^{238}U	uranium-238 (radioactive isotope)
µg/L	micrograms per liter
CIC	constant initial concentration
cm	centimeters
CRS	constant rate of supply
DGT	diffusive gradient in thin-film
Ecology	Washington State Department of Ecology
EGL	Environmental Geochemistry Laboratory
mg/kg	milligrams per kilogram
Teck	Teck Cominco Metals Ltd.

1 INTRODUCTION

1.1 Retention and Assignment

I have been retained by the Confederated Tribes of the Colville Reservation to render opinions in regard to the release of hazardous substances from the Teck Metals Ltd. (Teck) smelter located in Trail, British Columbia, Canada, into the United States. Specifically, I was asked to opine on impacts in northeastern Washington from smelter metals emissions. Lake sediments have been widely studied as environmental archives; therefore, my evaluations focused on atmospheric transport, deposition, and subsequent re-release of metals to lakes in this region.

The opinions presented here are based on review of pertinent reports, data, publications, and other documents, as well as results of field and laboratory investigations conducted in support of my evaluations.

1.2 Qualifications

I am a Principal Scientist with Anchor QEA, LLC, a privately owned environmental science and engineering consulting firm with corporate headquarters in Seattle, Washington. I am based in the firm's office in Portland, Oregon. In this capacity, I conduct scientific investigations for various clients and provide expert consultant services. Prior to joining Anchor QEA in 2010, I was an Associate with S.S. Papadopulos and Associates, Inc., where I had been employed since 1992.

My education and experience encompasses the fields of geochemistry, geology, and hydrology. I hold a Ph.D. in Environmental Sciences with a specialty in geochemistry from the University of Virginia, a M.S. in Geochemistry from the California Institute of Technology, a M.Sc. in Geological Sciences from McGill University, and a B.Sc. in Geology (with Honors) from Concordia University in Montreal, Canada. Additional details of my credentials, professional experience, publication record, and previous depositions and testimony can be found in my resume, which is provided as Appendix A.

1.3 Analysis

As part of my assignment, I reviewed various reports, publications, and other documents, and analyzed data published by the Washington State Department of Ecology (Ecology) to establish the footprint of atmospheric metals deposition from the Trail smelter as recorded in recent lake sediments across northeastern Washington.

In addition, I also designed and participated in a sampling and analysis program to collect sediment cores from selected lakes across the region to:

- Determine the source and chronology of smelter-emitted metals deposition and enrichment of lake sediments
- Characterize hazardous metals concentrations in porewater of lake sediments impacted by smelter-derived atmospheric metals deposition
- Assess the potential for ongoing releases of smelter-emitted metals from sediment to porewater and the overlying lake water column

1.4 Compensation

Anchor QEA is being compensated at my current billing rate of $337.50 per hour for my work as a testifying expert.

2 SUMMARY OF OPINIONS

2.1 Opinion 1

Hazardous metals present in Trail smelter air emissions, including antimony, arsenic, cadmium, lead, mercury and zinc, have been transported and deposited across northeast Washington. Smelter-emitted metals are detected in bottom sediments of lakes more than 60 miles from Trail.

2.2 Opinion 2

Smelter-emitted metals that have accumulated in northeast Washington lake sediments are released to porewater and are therefore mobile and bioavailable.

2.3 Opinion 3

Smelter-emitted metals in older as well as more recently deposited sediments continue to be released to porewater. The release of smelter-emitted metals to sediment porewaters and the overlying lake water column is an ongoing process.

3 BASIS OF OPINIONS

3.1 Opinion 1

Hazardous metals present in Trail smelter air emissions, including antimony, arsenic, cadmium, lead, mercury and zinc, have been transported and deposited across northeast Washington. Smelter-emitted metals are detected in bottom sediments of lakes more than 60 miles from Trail.

3.1.1 Trail Smelter Emissions

The Teck smelter has been in operation at Trail since 1896. While lead and zinc production have been the primary operations at Trail, several other materials and metals have also been produced throughout the years. Queneau (2010) provides a summary of the operations history. Copper production occurred from 1896 to the late 1930s. By 1902, lead was being produced using the Betts electrolytic process. Electrolytic zinc refining came online by 1916. Cadmium recovery began in 1927, and antimony recovery began in 1939. Lead, zinc, and cadmium production at the facility continue to the present time. Over time, technological improvements were made to convert wastes into materials that could be reprocessed or sold (e.g., cadmium and sulfuric acid). During the 1930s to 1960s, equipment was installed throughout the facility to recover potentially useful materials, including metals. For example, by 1931 electrostatic precipitators were in service for the sintering machines, zinc roasters, an acid plant, and a silver refinery. Baghouses were installed following slag fuming in 1930, lead blast furnace smelting in 1951, and zinc roasting in 1962. By the 1970s, the equipment at the facility was aging and numerous process upgrades were installed between the 1970s and 1990s. In 1997, the sinter plant, blast furnaces, and slag fuming furnaces were replaced by a Kivcet smelter, which resulted in significant reductions in particulate and metals air emissions (Queneau 2010).

Numerous studies and reports have documented and discussed the emissions of metals from the Trail smelter, their atmospheric transport, and deposition (Ecology 1998; Goodarzi et al. 2001, 2002a, 2002b, and 2003; ICF 2011; Landis 2014; Queneau 2010, 2011, and 2014; Sanei et al. 2007; Teck Cominco 2001).

Smelter smoke from Trail containing sulfur dioxide caused adverse impacts on livestock, crops, and forests in the Upper Columbia River Valley and was the basis of litigation between farmers in northern Washington and the Consolidated Mining & Smelting Co., Teck's predecessor, during the late 1920s and 1930s. The matter eventually became an international dispute and was decided by arbitration, which resulted in economic compensation for the local farmers of Steven's County and establishing laws for transboundary air pollution issues, which required the Consolidated Mining & Smelting Co. to monitor and control its emissions.

Goodarzi et al (2001, 2002a, 2002b and 2003, 2006) documented atmospheric transport and deposition of arsenic, cadmium, copper, mercury, lead, and zinc in the vicinity of Trail comparing results from moss-monitoring stations with surficial soil data, and found that deposition is highest along the Columbia River valley, which correlates with the prevailing wind directions.

Queneau (2010, 2011, and 2014) presented a summary of air emissions for several metals from the smelter between 1923 and 2002. The emissions were based on actual facility data collected between 1980 and 2002 and extrapolated for previous years based on mass balance analysis of the operations. Queneau (2014) updated his earlier emissions estimates by incorporating additional data that were available for some parts of the facility before 1980. As such, these estimates are considered to be minimum estimates for years prior to 1980, with uncertainties due to incomplete records and potential variation in plant operations. Queneau's (2014) emissions estimates for arsenic, cadmium, lead, mercury and zinc are shown in Figures 1 through 5, respectively.

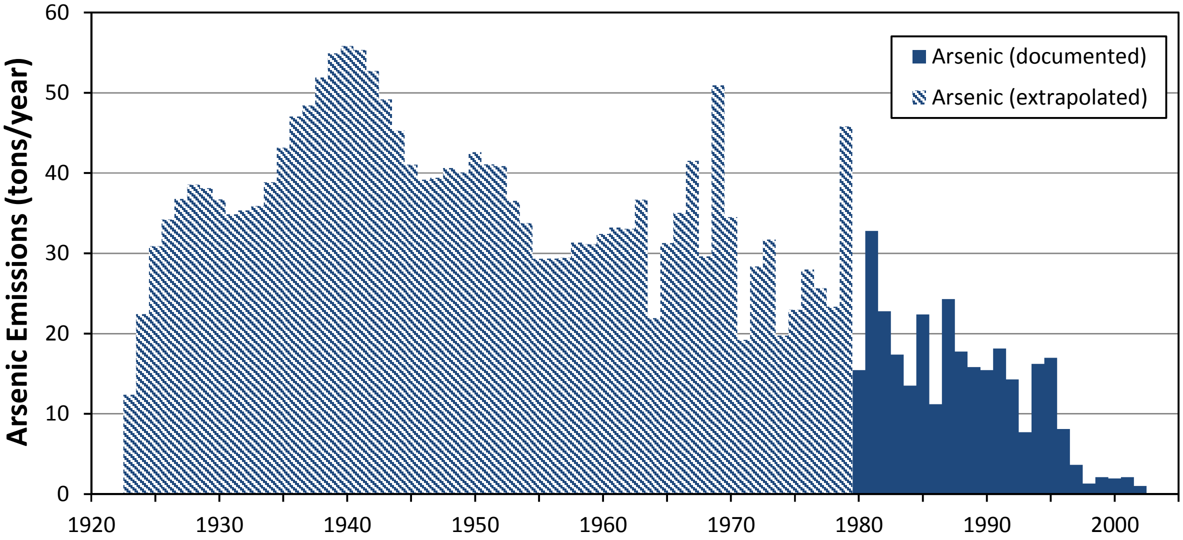


Figure 1. Estimated arsenic emissions from the Trail Facility, 1923 to 2002.

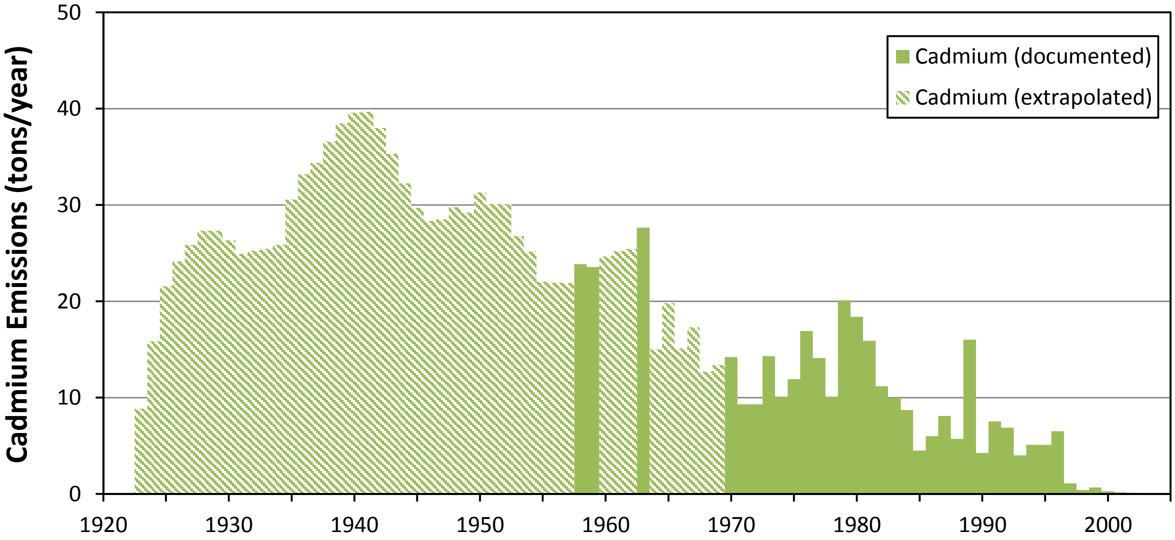


Figure 2. Estimated cadmium emissions from the Trail Facility, 1923 to 2002.

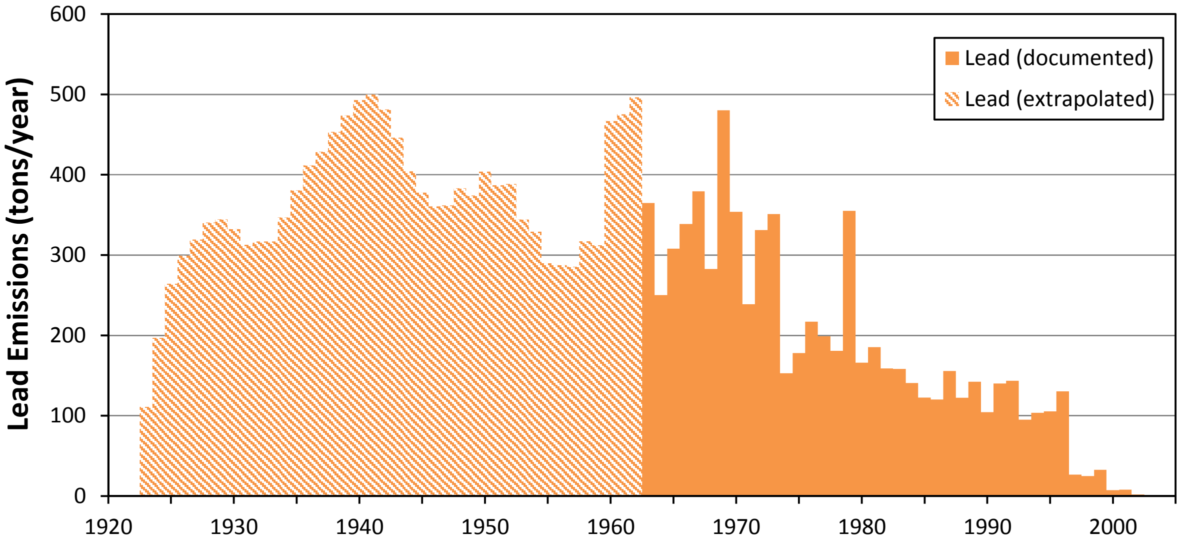


Figure 3. Estimated lead emissions from the Trail Facility, 1923 to 2002.

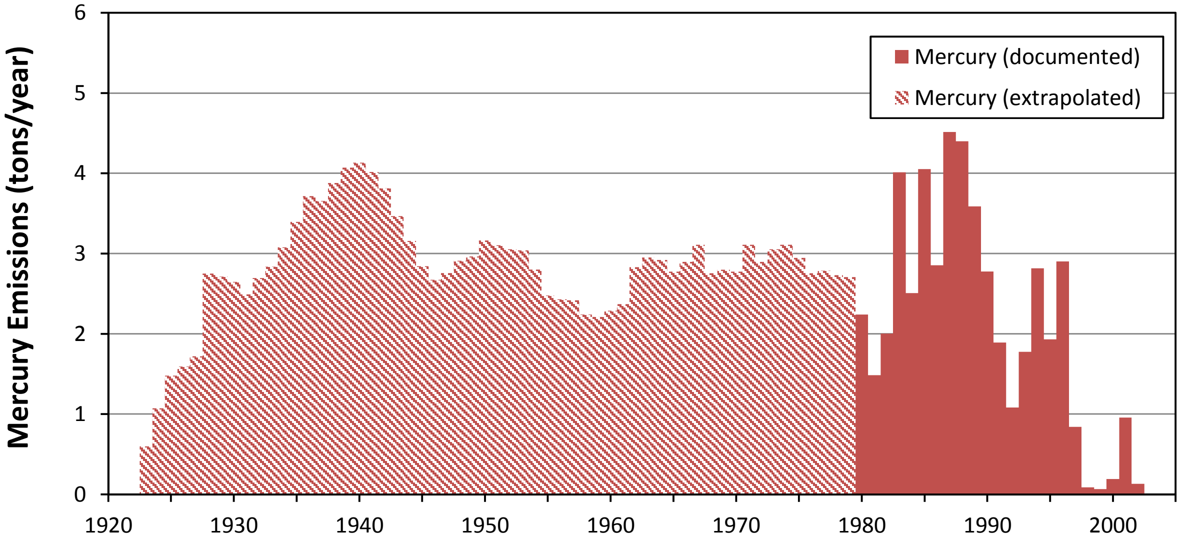


Figure 4. Estimated mercury emissions from the Trail Facility, 1923 to 2002.

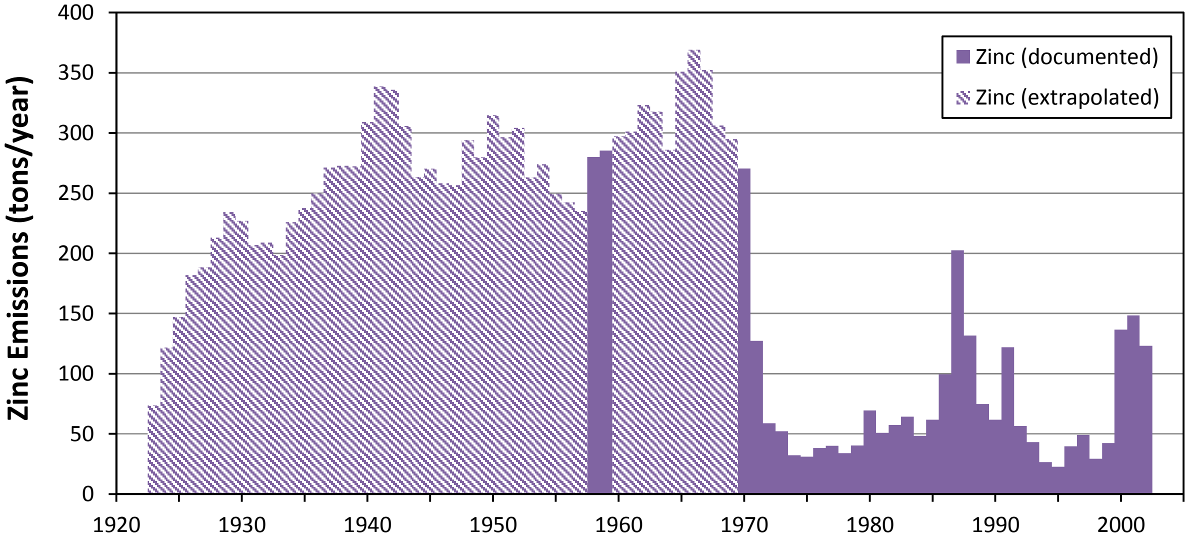
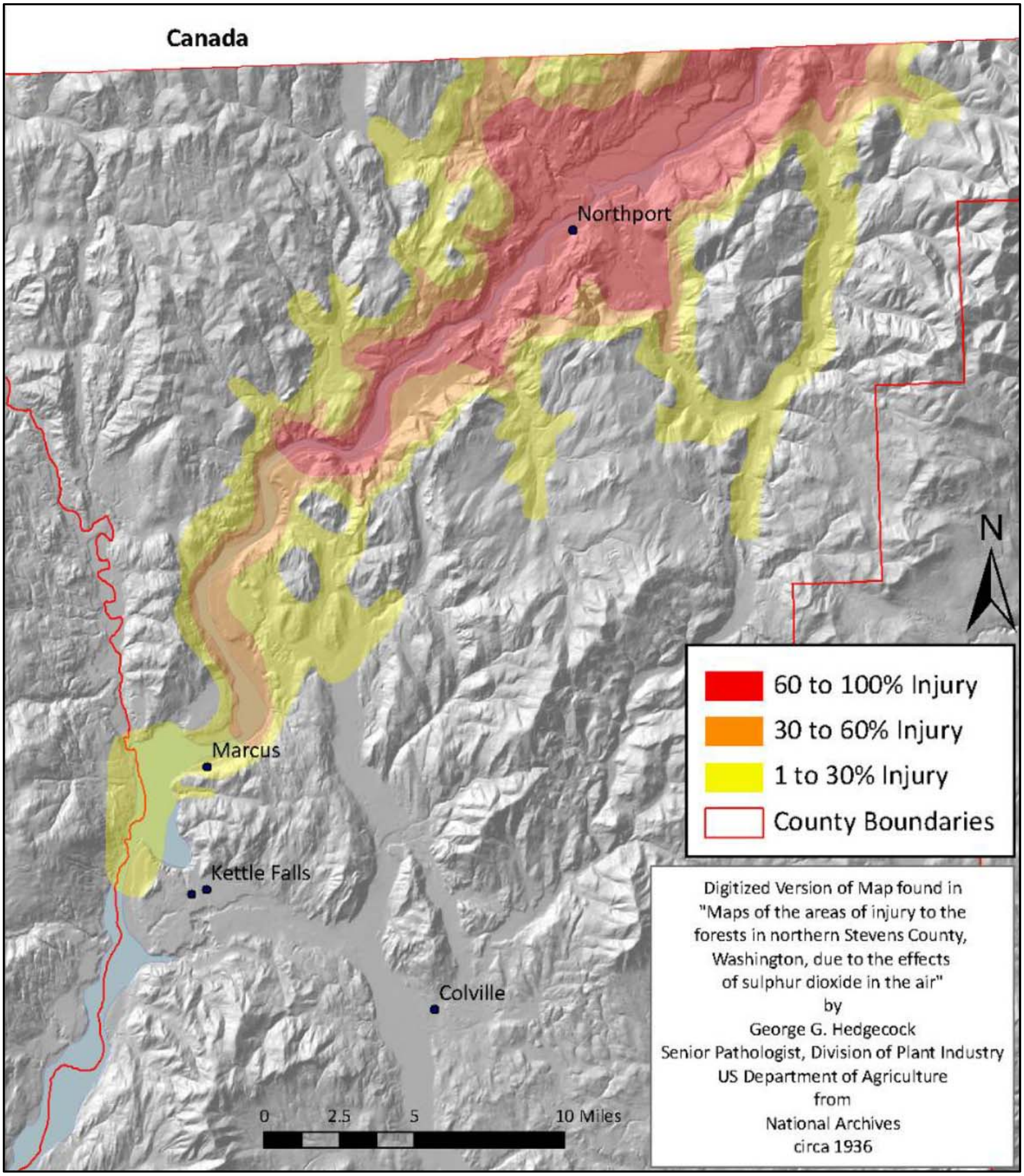


Figure 5. Estimated zinc emissions from the Trail Facility, 1923 to 2002.

The transport of smelter emissions from Trail downwind into the state of Washington is supported by ample physical and historical evidence. The local weather in Trail is influenced by continental air masses dropping down from northern Canada as well as systems moving eastward across southern Canada from the northern Pacific Ocean. Local winds in the Trail area are strongly influenced by the terrain of the Columbia River Valley. Daytime winds reflect up-valley (southerly) flow at the surface while nighttime winds reflect down-valley (northerly) flow induced by radiative cooling and sinking of air on the steep slopes of the river valley resulting in “drainage” of air down the valley until flow reversal commences sometime after sunrise the following morning (ICF 2011).

Smelter smoke containing sulfur dioxide caused adverse impacts on livestock, crops, and forests in the Upper Columbia River Valley and was the basis of litigation between farmers in northern Washington and the Consolidated Mining & Smelting Co., Teck’s predecessor, during the late 1920s and 1930s. The matter eventually became an international dispute and was decided by arbitration, which resulted in economic compensation for the local farmers of Steven's County and establishing laws for transboundary air pollution issues, which required the Consolidated Mining & Smelting Co. to monitor and control its emissions.

Maps of forest injury produced from surveys conducted by the U.S. Department of Agriculture during this period provide snapshots of the path of Trail smelter fumes and the extent of their visible impacts (Figure 6). The "footprint" of the sulfur dioxide plume on the vegetation also provides an indication of the primary path for atmospheric transport and deposition of smelter-emitted metals, although metals may be transported to a different extent than sulfur before being deposited due to differences in physical and chemical properties. As pointed out by Landis (2014), deposition of atmospherically transported metals emitted from the Trail smelter complex impacted a larger area in northeastern Washington than the area defined by visible injury to vegetation.



Digitized Version of Map found in
"Maps of the areas of injury to the
forests in northern Stevens County,
Washington, due to the effects
of sulphur dioxide in the air"
by
George G. Hedgecock
Senior Pathologist, Division of Plant Industry
US Department of Agriculture
from
National Archives
circa 1936

Figure 6. Extent of forest injury from Trail smelter smoke in 1930 (ICF 2011).

3.1.2 Lake Sediment Sampling and Analysis

Bottom sediments from selected lakes and wetlands across northeast Washington were sampled and analyzed to identify impacts from atmospheric deposition of smelter metals. The samples available included archived grab and core samples collected by Ecology, as well as sediment cores from selected lakes collected as part of the present investigation. The locations of the sampled waterbodies are shown in Figure 7.

The Ecology studies included bottom sediment grab samples from 19 lakes and 2 wetlands ranging in distance from approximately 10 to 65 miles from Trail. The Ecology studies also included 50 centimeter (cm) long cores from three lakes (Phillips Lake, Silver Crown Lake, and Phalon Lake) on a transect along the Upper Columbia River Valley. Metals concentrations and other information related to the Ecology samples are reported in Johnson et al. (2011, 2013).

In February 2014, I collected sediment cores from three lakes for detailed analysis, in collaboration with Professor Joel Blum and with field support from Environment International Ltd. The lakes included Cedar Lake in Stevens County, Ellen Lake in Ferry County, and Bonaparte Lake in Okanogan County. Cedar Lake and Ellen Lake were selected because they are located, respectively, within and just beyond the southernmost extent of the historic smelter smoke injury zone (Figure 6). Bonaparte Lake, located in Okanogan County about 65 miles west-by-southwest of Trail, was initially selected as a reference lake because it is separated from the Upper Columbia River Valley by several mountain ranges including the Kettle River Range. These three lakes were selected for study because they are relatively remote and undeveloped, have a small surface area (50-150 acres), and a small catchment area (less than 10 times the lake surface area), so that the metals influx to the lake is predominantly from atmospheric deposition rather than weathering and runoff. Cores were obtained using a gravity corer with 7.6 cm diameter by 60 cm long core tubes. Four undisturbed cores, including the sediment-water interface, were obtained from each lake. The cores were transported on dry ice to Anchor QEA's Environmental Geochemistry Laboratory (EGL) in Portland, Oregon, for processing.

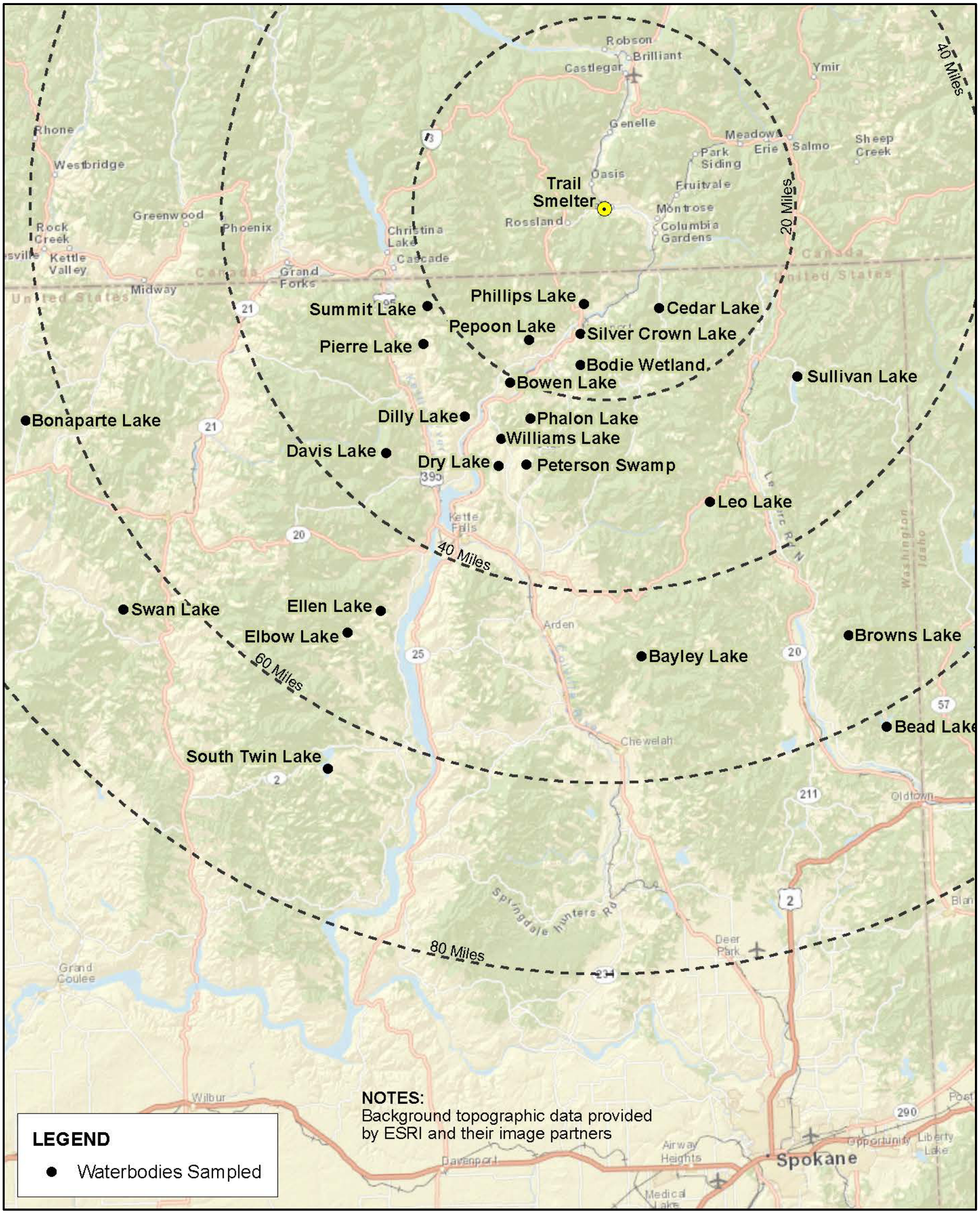


Figure 7. Location map of waterbodies sampled for this study.

At the EGL, one of the cores from each lake was sectioned and processed for chemical and isotopic analyses. The upper 20 cm of each core was sectioned at 1-cm intervals, and at 2-cm intervals below that. Moisture content of each core interval was determined by drying at 60° C, and aliquots of the dried samples were sent to: 1) Professor Mark Baskaran at Wayne State University for age dating by ^{210}Pb and ^{137}Cs; 2) Apex Laboratory for total metals and loss on ignition; 3) Professor Joel Blum at the University of Michigan for mercury and mercury isotope analyses; and 4) Professor Bruce Nelson at the University of Washington for stable lead isotope analysis. Archived split samples from the Ecology studies were also submitted to Professor Bruce Nelson for lead isotope analysis. Analytical results, except for mercury data, are provided in Appendix B. Mercury concentration and isotope data are given in Blum (2014).

3.1.3 Stable Lead Isotope Analysis

3.1.3.1 Lead Isotope Ratios as Source Indicators

Individual atoms of the same element can have different masses depending on the number of neutrons. These different versions of an element with different masses are called isotopes. Isotopes can be stable or unstable (radioactive). Naturally occurring lead has four stable isotopes: ^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb. The latter three are called radiogenic because they are produced by the radioactive decay of uranium (^{238}U and ^{235}U) and thorium (^{232}Th), respectively. ^{204}Pb is not radiogenic and is considered to be a stable reference isotope. The three radioactive parent elements, ^{238}U, ^{235}U and ^{232}Th, decay at different rates, with half lives of 4.468 billion years, 704 million years, and 14.01 billion years, respectively (Dickin 1995; Faure and Mensing 2005).

The isotopic composition of lead in geological materials is commonly expressed in terms of isotope ratios (e.g., normalized to ^{204}Pb) and is widely used in geological and environmental investigations for various purposes, including geochronology (age determination of rocks), mineral exploration, and contaminant source fingerprinting. The isotope ratios of lead ores are unaltered by smelting and other manufacturing processes (Flegal and Smith 1995; Shiel et al. 2010); therefore, they retain the original lead isotope ratios of the ore from which the lead was derived.

The isotopic composition of lead in an ore deposit depends on a number of factors, but in simplest terms it can be understood in terms of the geologic age of the ore deposit. The isotope ratios of $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ in the Earth have been steadily increasing throughout the Earth's history due to radioactive decay of uranium and thorium. Because of the chemical differences between these elements, lead is effectively separated from uranium and thorium during the formation of a lead ore mineral such as galena (lead sulfide), and the isotopic ratios of lead in the galena are frozen in at the time of its formation. Geologically older lead ores tend to have lower lead isotope ratios (less radiogenic lead) than more recently formed ores. Therefore, different lead deposits can have distinctive lead isotopic compositions, and lead isotope signatures can be used as tracers to identify the different natural and industrial contributions of lead in the environment (Sangster et al. 2000).

3.1.3.2 Lead Sources in Northeast Washington Lake Sediments

Lead isotope data for the main ores historically processed at the Trail smelter (Sullivan, Red Dog, and Pine Point mines), as well as from various mining districts in northeast Washington and south-central British Columbia, were compiled from published literature sources (Ayuso et al. 2004; Beaudoin 1997; Church 2010; Cumming et al. 1990; Godwin and Sinclair 1982; Godwin et al. 1982, 1988; Shiel et al. 2010; Small 1973).

Figure 8 is a scatter plot of $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ ratios for lead from the Trail smelter, the Leroi smelter in Northport, Washington (based on analyses of slag; Nelson 2011), and local geologic sources (based on data for mineral deposits in northeastern Washington). As can be seen on this plot, the smelter lead signatures are readily distinguishable from local geologic sources and each other.

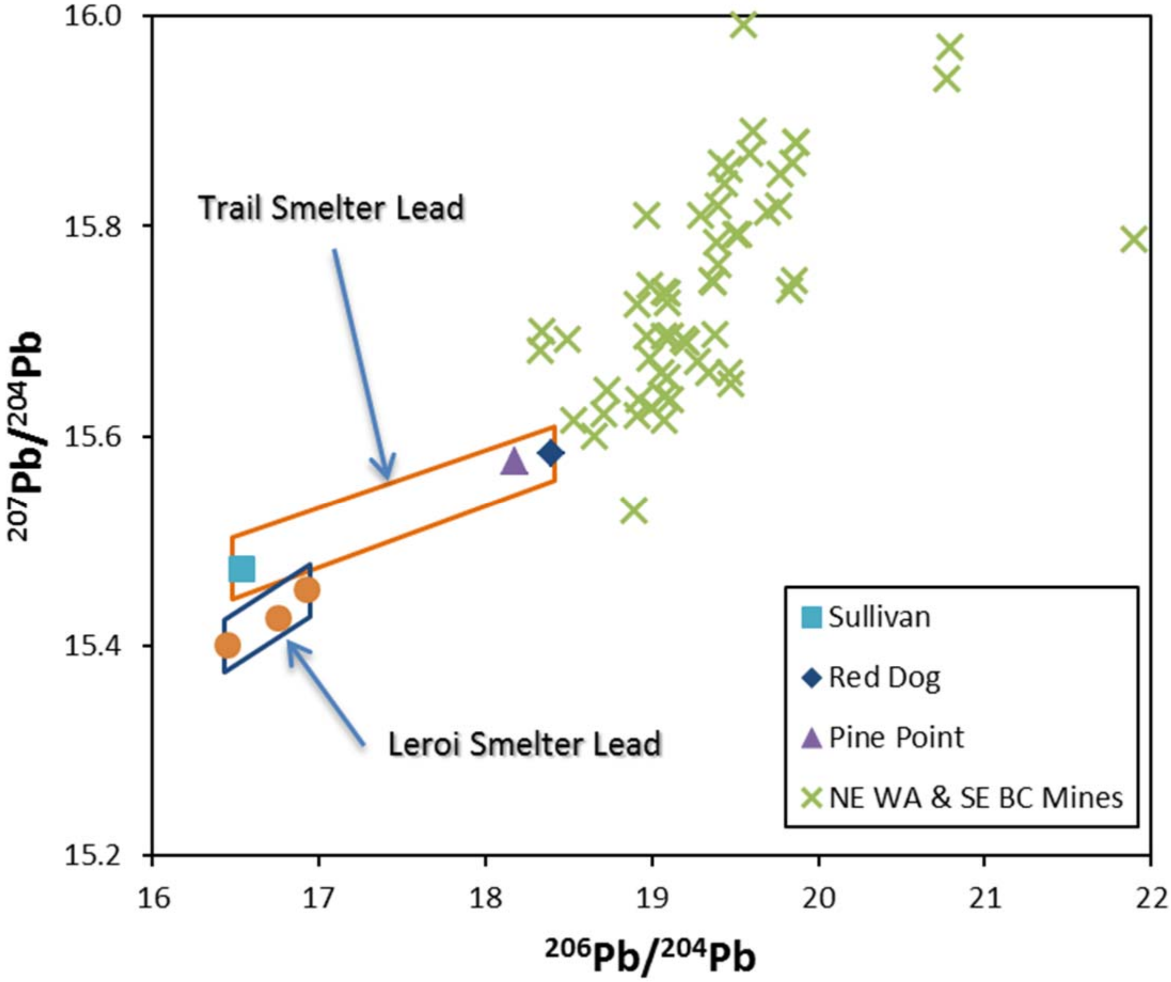


Figure 8. Lead isotope ratio plot showing signatures of regional geogenic and smelter-derived lead sources.

Queneau (2010) provides information on the major ore concentrates historically processed at the Trail smelter. Between 1921 and 1992, 85% of the lead concentrates came from the Sullivan Mine. From 1993 to 2001, close to 50% came from the Sullivan Mine and almost 40% came from the Red Dog Mine. Sullivan supplied almost 90% of the zinc concentrates until 1962. After 1963, about half of the zinc feeds came from Pine Point Mine, until it was shut down in 1989, with about 35% coming from the Sullivan Mine. Between 1990 and 2001, Red Dog Mine accounted for 55% of zinc feed and the Sullivan Mine for 40%. Since 2001, Red Dog Mine has been the main source of lead and zinc concentrates. These ores were imported from other regions (the Sullivan Mine is located in southeastern

British Columbia, the Red Dog Mine is located in Alaska, and Pine Point is located in the Northwest Territories), and the lead from these deposits is generally isotopically distinct from local geogenic lead sources in northeast Washington. The Sullivan Mine ores, for example, which were formed approximately 1.5 billion years ago, are much older than any of the rocks exposed within the study area, and their exotic lead isotope signature is easily distinguished from local sources.

The field labelled "Trail smelter lead" in Figure 8 represents the range of possible compositions of mixtures of concentrates from the Sullivan, Red Dog, and Pine Point mines used as ore feed for the Trail smelter. Air emissions generated during the processing of these feeds would have the same isotopic composition. In the earlier years, emissions from processing feeds with a higher proportion of Sullivan ore would have been less radiogenic (i.e., lower isotope ratios) than later periods when a higher percentage of Red Dog or Pine Point ore was processed. While changes in the proportions of different ore sources used in the smelter feed would produce variations in isotope ratios of lead emissions over time, these would all fall within the range delineated by the three main ore sources. Similarly, in lake sediments impacted by atmospheric deposition of smelter metals, lead isotope ratios would also be expected to fall within the range defined by the ore concentrates. The field for the Leroi smelter lead is based on analyses of slag samples collected from the former Leroi smelter site in Northport, Washington in 2011 (Riese 2011, Nelson 2011). The Northport smelter operated sporadically from 1898 until 1921, initially as a copper smelter. Coeur d'Alene lead ores were processed at Northport between 1916 and 1921.

Figure 9 plots the entire northeast Washington lake sediment lead isotope dataset and shows the surficial lake sediment in almost all of the lakes sampled in the study area is impacted by Trail smelter lead. The one exception is Sullivan Lake in Pend Oreille County, about 27 miles southeast of Trail. Lead isotope signatures in the Sullivan Lake sediment sample are clearly distinct from the Trail smelter lead and consistent with a local geogenic source. Bead Lake and Browns Lake, also in Pend Oreille County but farther south (approximately 50 and 60 miles from Trail, respectively), and the uppermost samples from the Bonaparte Lake core, plot near the upper limit of the Trail smelter lead envelope. These lakes are located the farthest east and west from Trail and appear to define the easterly and westerly extent of recent impacts from the smelter.

Several samples of the high-resolution cores from Cedar Lake, Ellen Lake, and Bonaparte Lake also plot well outside the smelter lead field. These samples are all from the deeper sections of the cores and represent pre-smelter sediments. None of the samples analyzed appear to plot within the Leroi smelter lead field, indicating that atmospheric lead deposition from the Leroi smelter is not a significant component of the lead in these samples.

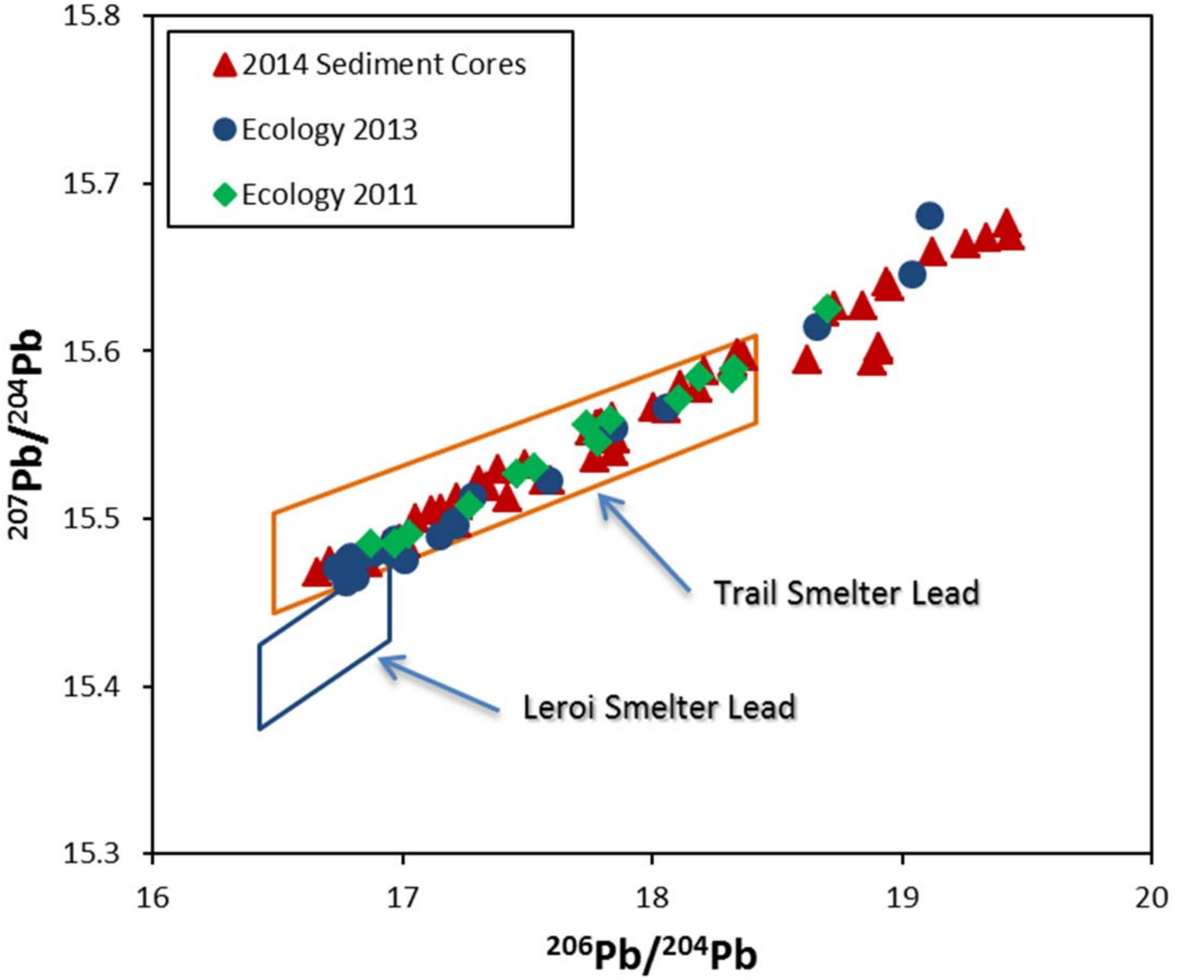


Figure 9. Lead isotope signatures of northeast Washington lake bottom sediments in relation to smelter-derived lead sources.

3.1.4 Identification of Trail Smelter-emitted Metals in Lake Sediments

The relationship between lead isotope signatures and metal concentrations in lake sediment samples was used to infer similar origins of specific metals and smelter lead. Figures 10 through 12 show profiles of lead isotope ratios and metals concentrations in cores from Silver Crown, Phillips, and Phalon lakes. In these plots, the shaded regions in the lead isotope profiles represent the range for Trail smelter emissions. The sediment profiles in all three lakes show strong enrichments in antimony, arsenic, cadmium, lead, mercury, and zinc within the upper 20 cm associated with less radiogenic lead isotope ratios characteristic of Trail smelter lead. Metals concentrations also decrease substantially with depth, mirroring the increasingly radiogenic lead profiles, indicating metals enrichment in the upper part of the profile in each lake is attributable to atmospheric deposition of metals emitted from the Trail smelter. The proximity of Silver Crown Lake to Northport, the site of the former Leroi smelter, suggests that a portion of the metals enrichment observed in the Silver Crown core could be derived from the Leroi smelter. The relatively short operation history of the Leroi smelter compared to Trail, and the absence of a clear Leroi smelter lead isotope signature in the Silver Crown samples indicates that metals indicate that atmospheric inputs of metals from the Leroi smelter are of smaller magnitude and duration than those from Trail. The spatial gradient in metals enrichment also corroborates a Trail source, with peak concentrations consistently higher in Silver Crown and Phillips lakes than in Phalon Lake, which is located farther south.

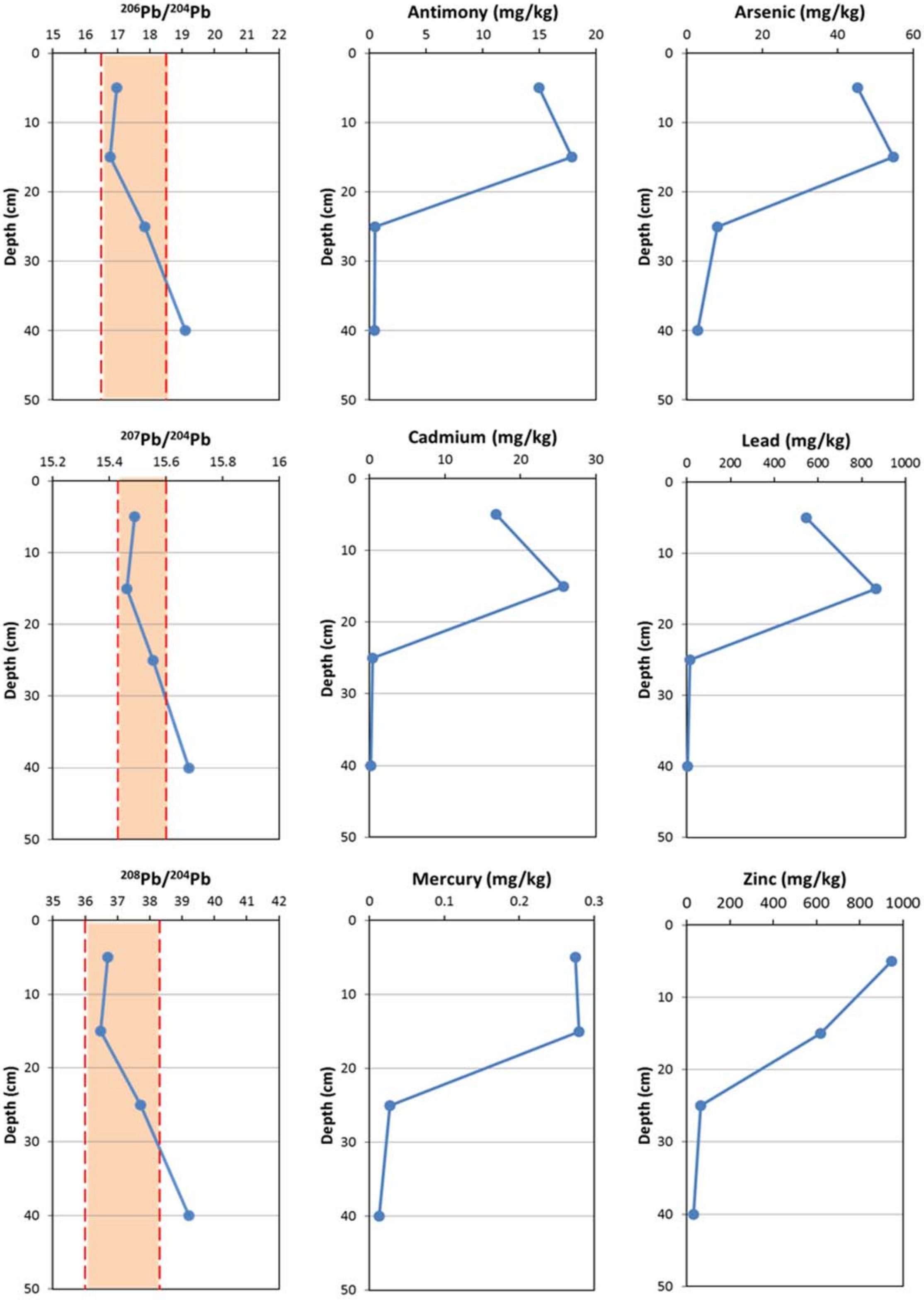


Figure 10. Lead isotope ratios and metals concentration profiles in Silver Crown Lake core.

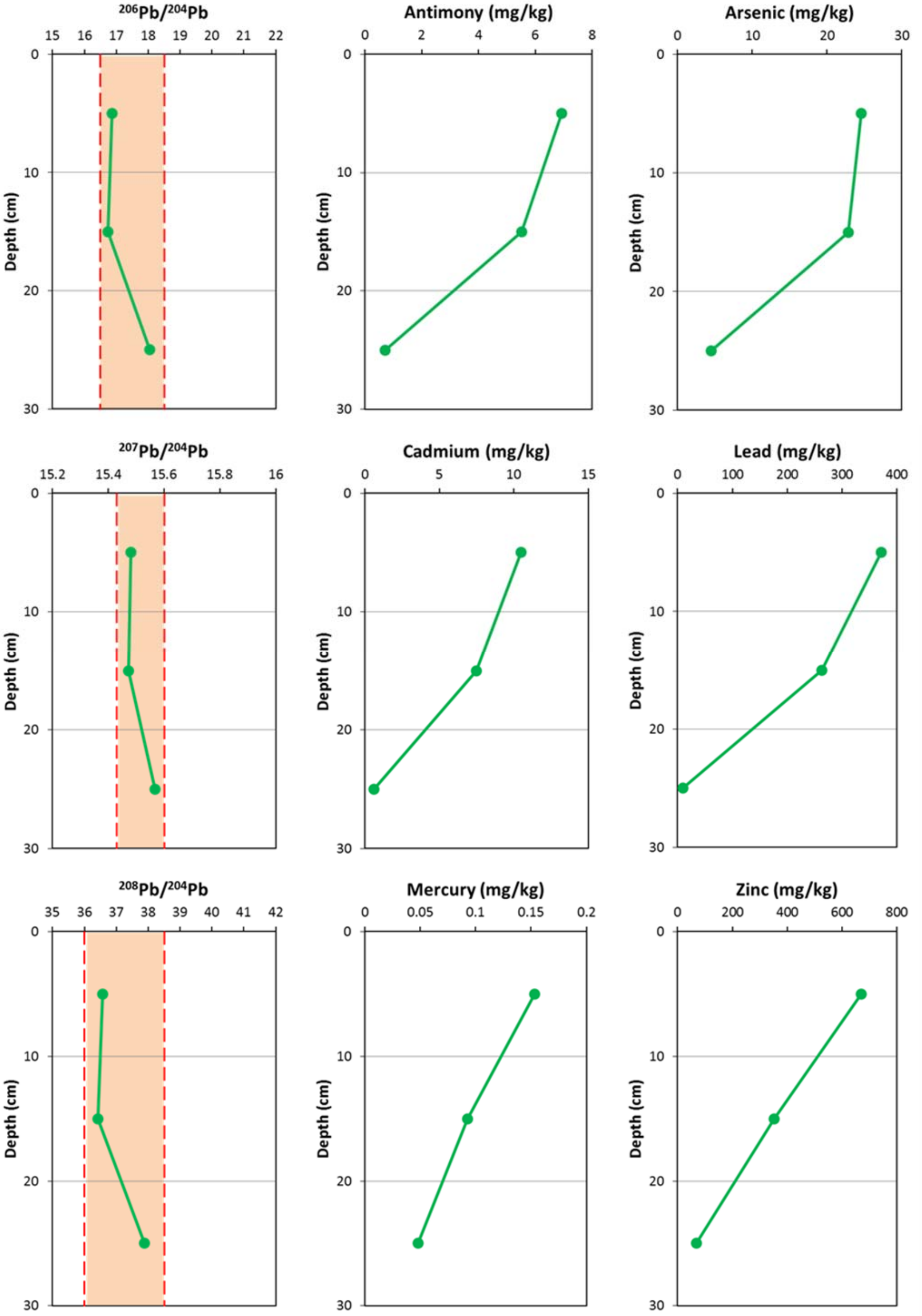


Figure 11. Lead isotope ratios and metals concentration profiles in Phillips Lake core.

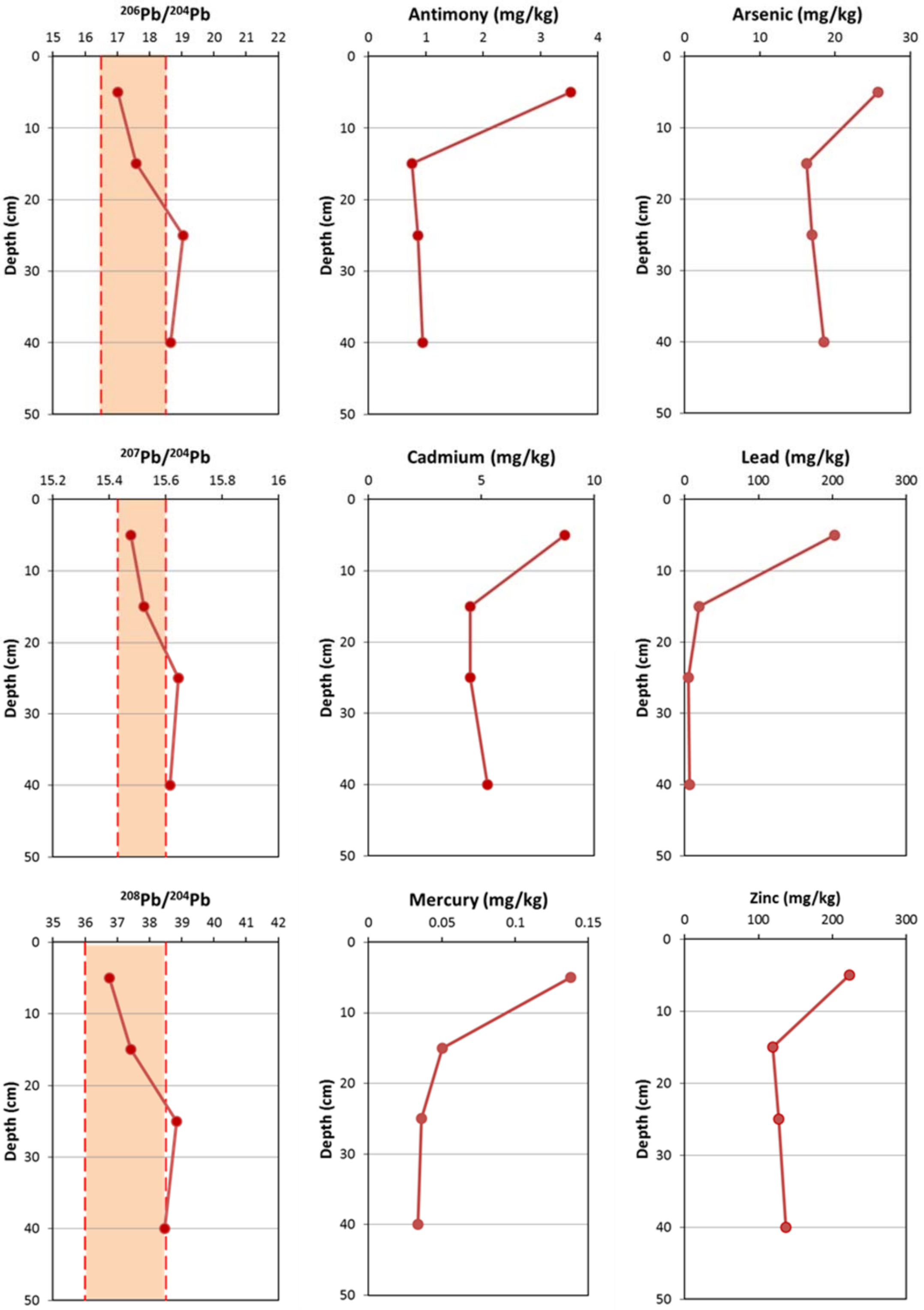
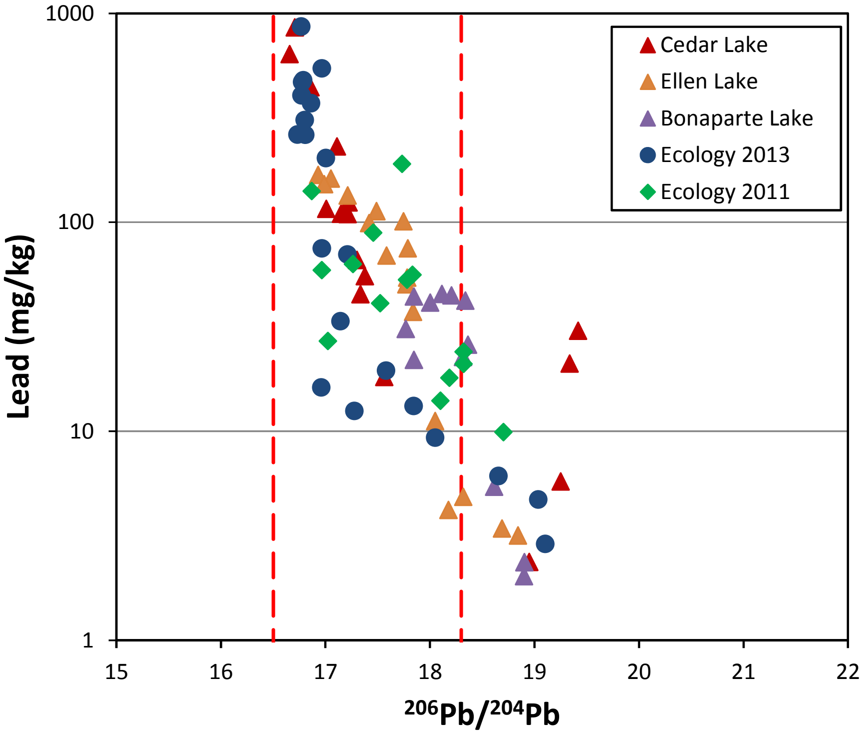


Figure 12. Lead isotope ratio and metals concentration profiles in Phalon Lake core.

Figure 13 illustrates the relationship between lead concentrations and lead isotope ratios in the entire dataset. The lead isotope ranges for Trail smelter lead are defined by the vertical dashed lines. The dataset encompasses a range of lead concentrations of almost three orders of magnitude. Lead concentrations greater than 10 milligrams per kilogram (mg/kg) have isotopic compositions that are indicative of Trail lead, and the highest concentrations are exclusively in the lower end of the range, indicating a Sullivan ore source. This plot shows conclusively that enrichment of lake sediments across the region in lead at concentrations greater than 10 mg/kg is primarily due to atmospheric deposition of Trail lead.

Figures 14 through 18 are similar plots for antimony, arsenic, cadmium, zinc, and mercury. These plots also show the highest levels of these metals are always associated with Trail lead, although the data suggest that non-Trail geogenic and/or anthropogenic sources of arsenic and perhaps zinc may also contribute locally to elevated levels of these metals in the investigated lake sediments.



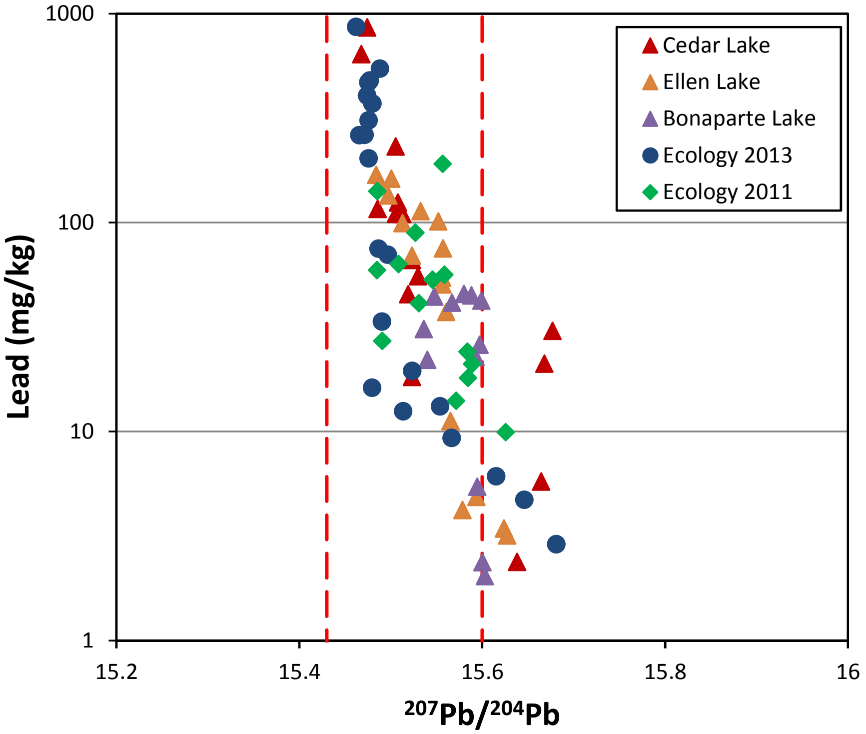


Figure 13. Relationship between lead concentration and lead isotope ratios in northeast Washington lake sediments.

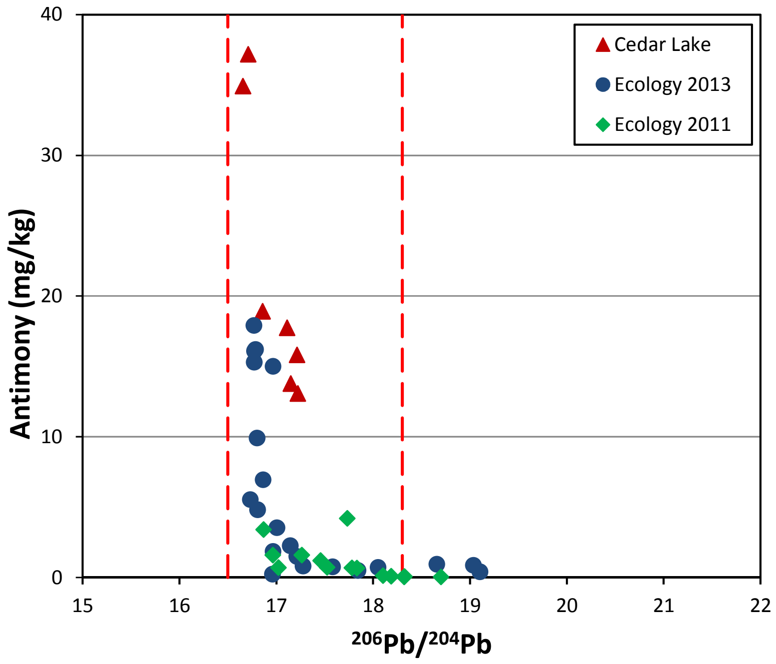


Figure 14. Relationship between antimony concentrations and lead isotope ratios in northeast Washington lake sediments.

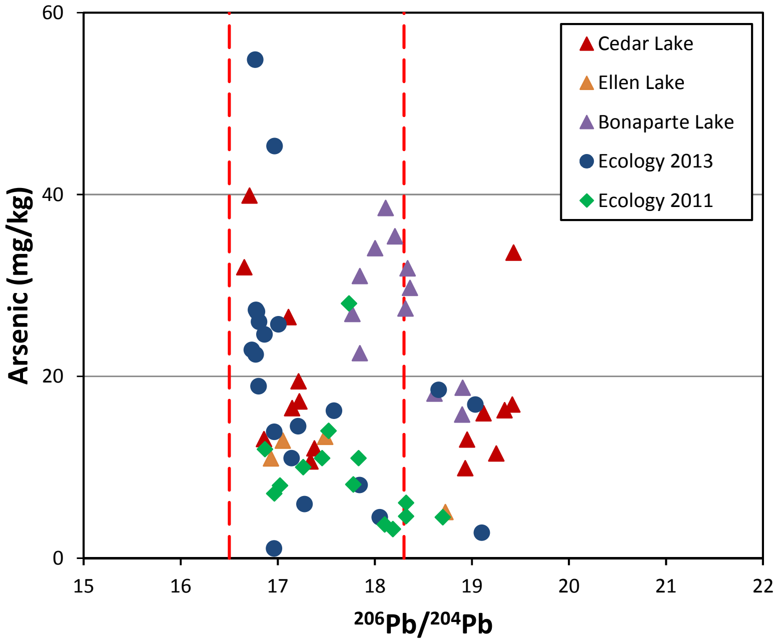


Figure 15. Relationship between arsenic concentrations and lead isotope ratios in northeast Washington lake sediments.

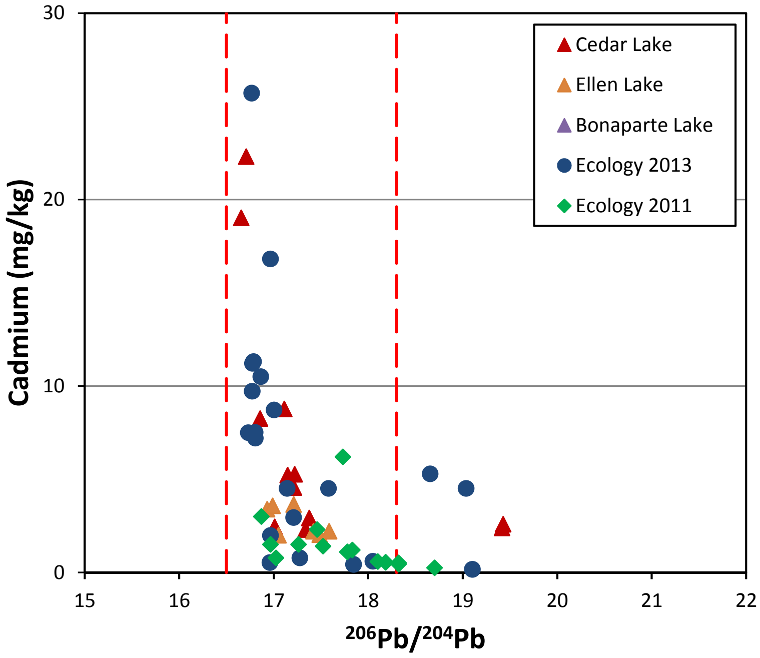


Figure 16. Relationship between cadmium concentrations and lead isotope ratios in northeast Washington lake sediments.

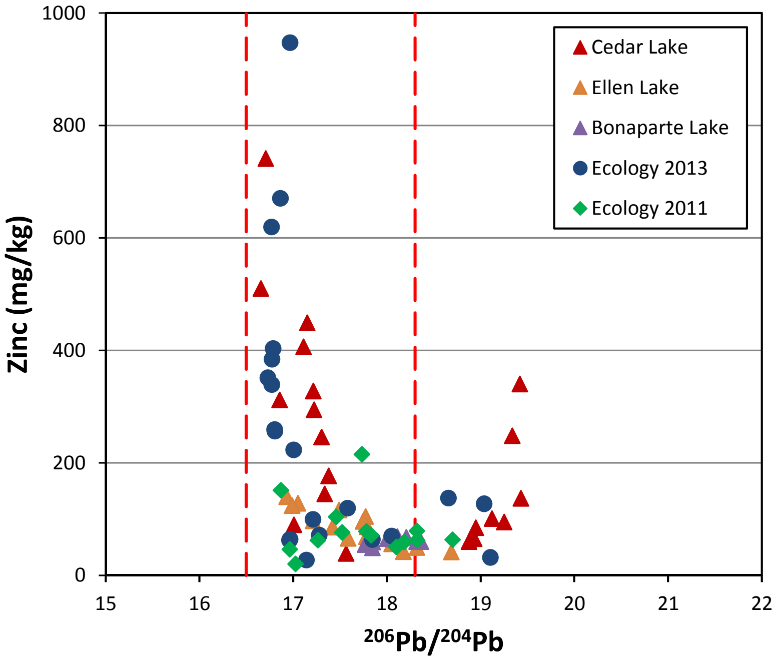


Figure 17. Relationship between zinc concentrations and lead isotope ratios in northeast Washington lake sediments.

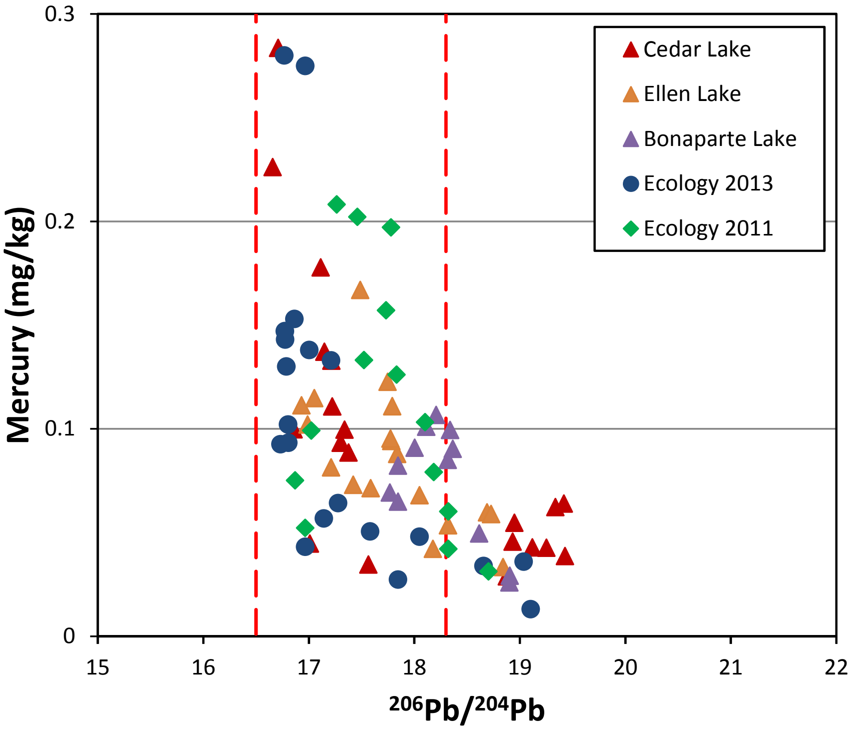


Figure 18. Relationship between mercury concentrations and lead isotope ratios in northeast Washington lake sediments.

3.1.5 Areal Extent of Smelter Impacts

The distribution of metals concentrations in lake sediments impacted by Trail lead with distance from Trail provides an additional line of support for identifying the source of elevated metals. Figure 19 shows lead concentrations and ^{206}Pb/^{204}Pb ratios, respectively for all surficial lake sediment samples and subsurface samples impacted by Trail-emitted lead. The peak concentrations decrease (exponentially with distance) up to 65 miles, while the lead isotope ratio gradually increases, indicating mixing with local geogenic lead. Antimony, cadmium, and zinc (Figures 20, 21 and 22) exhibit spatial profiles which are generally similar to lead, implying a common source, although the maximum concentration and rate of decrease is different for each metal. Landis (2014) discusses the effect of dispersion in decreasing airborne metals concentrations with increasing distance from a point source. The concentration-distance patterns in the lake sediments impacted by Trail smelter metals are also consistent with atmospheric transport and deposition of metals from the Trail source (Landis 2014).

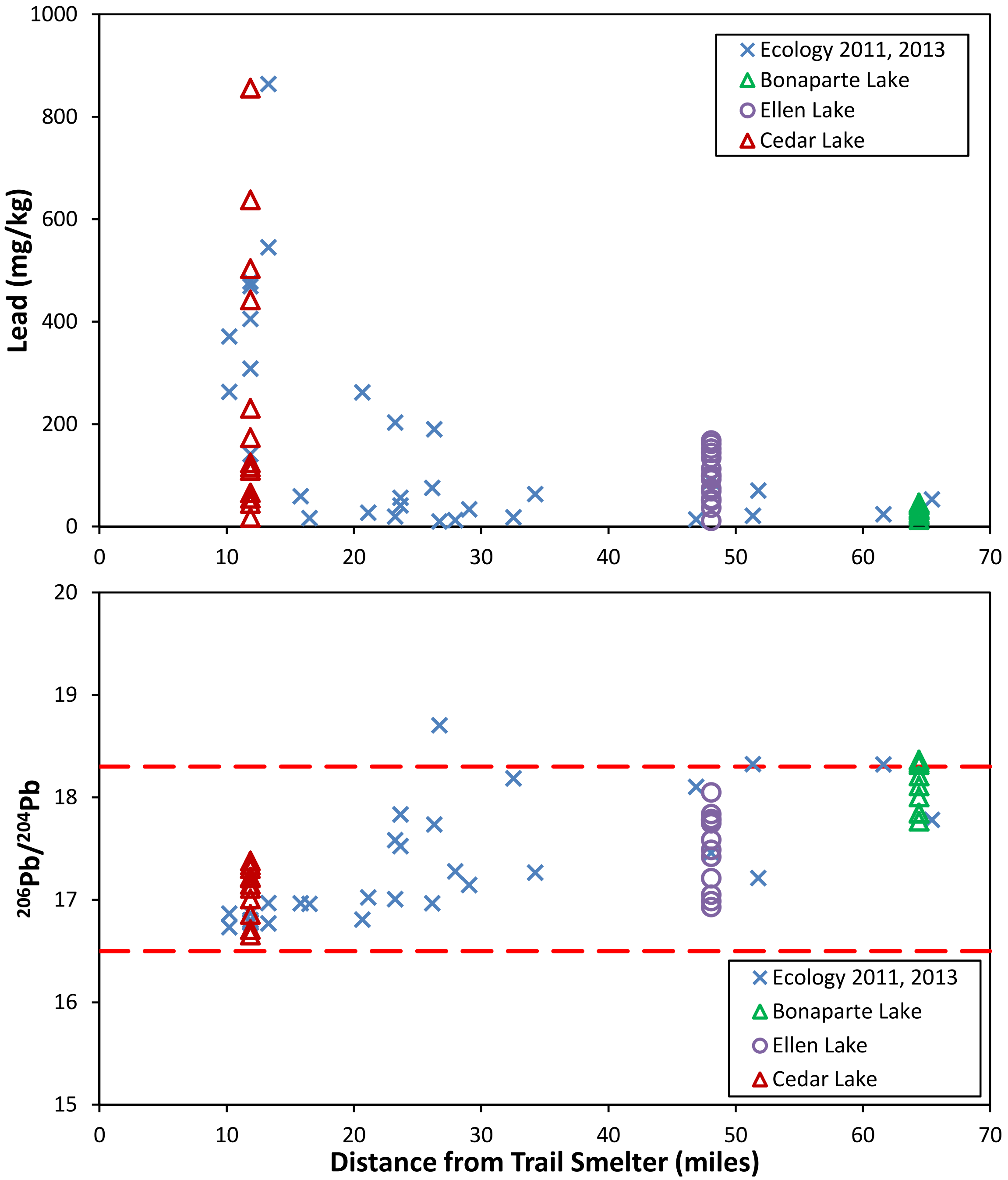


Figure 19. Relationship between and distance from Trail and lead concentrations (top) and lead isotope ratios (bottom) in lake sediments impacted by atmospheric deposition of Trail-emitted lead.

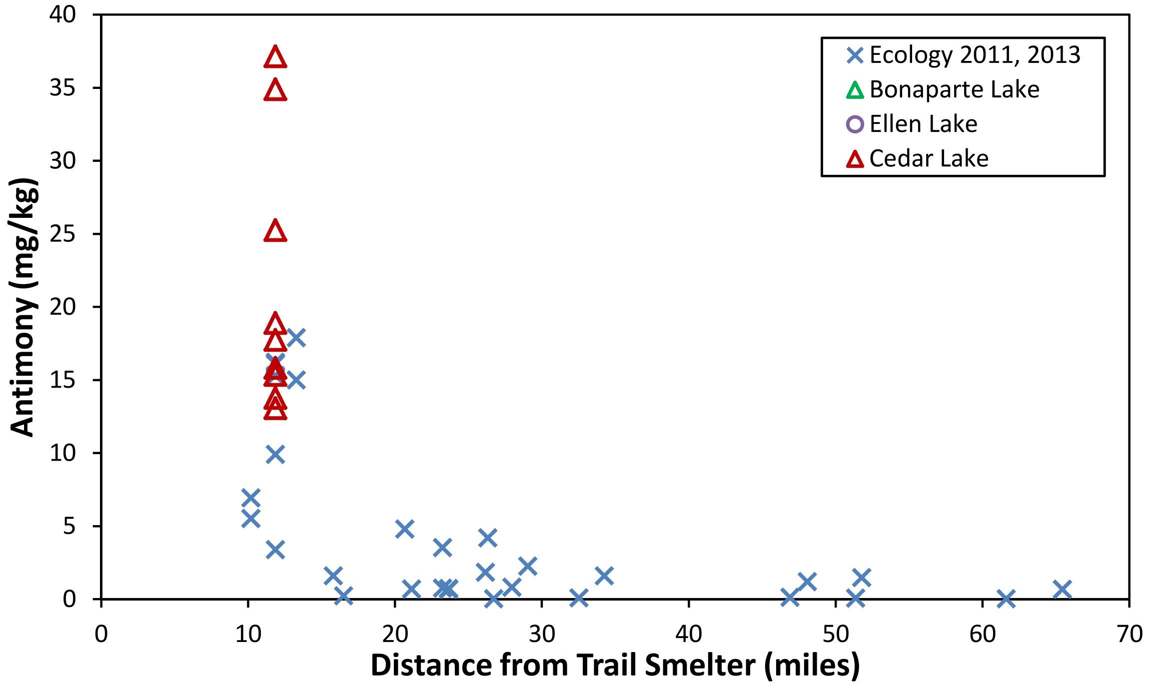


Figure 20. **Relationship between distance from Trail and antimony concentrations in lake sediments impacted by atmospheric deposition of Trail-emitted lead.**

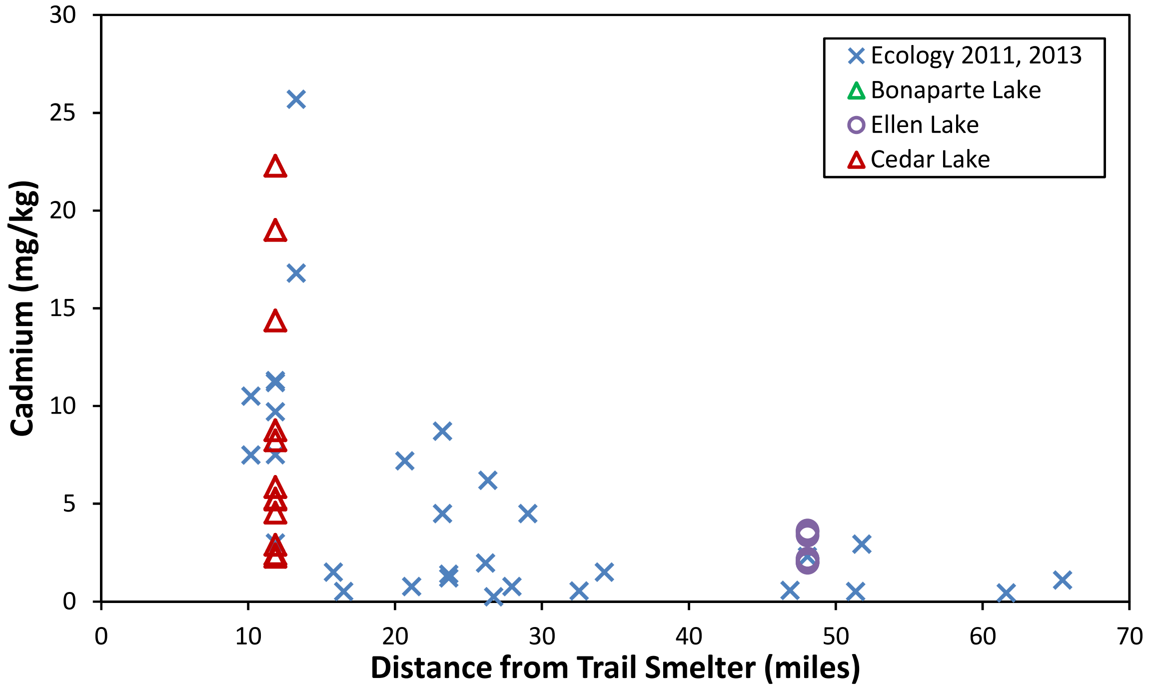


Figure 21. Relationship between distance from Trail and cadmium concentrations in lake sediments impacted by atmospheric deposition of Trail-emitted lead.

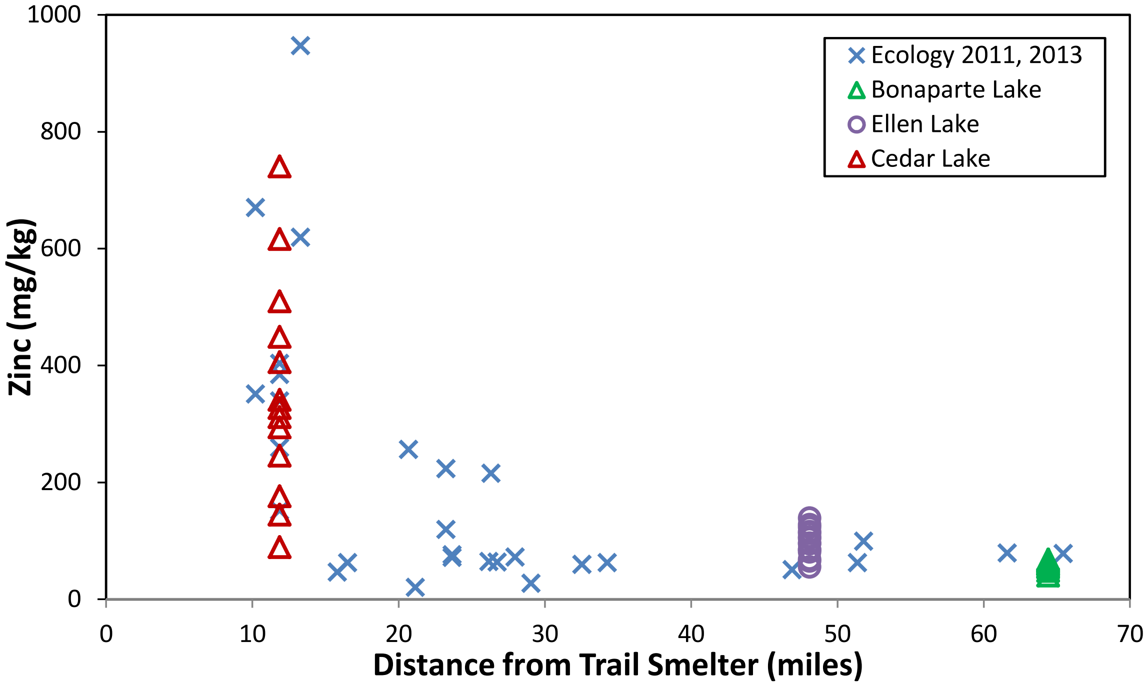


Figure 22. Relationship between distance from Trail and zinc concentrations in lake sediments impacted by atmospheric deposition of Trail-emitted lead.

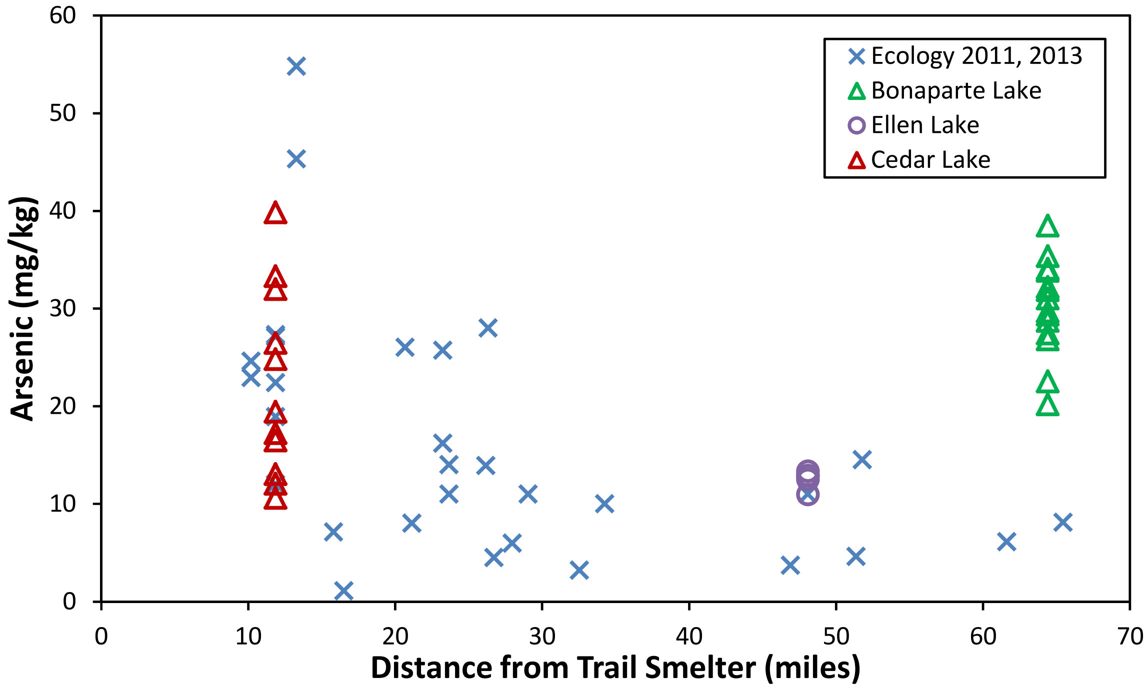


Figure 23. Relationship between distance from Trail and arsenic concentrations in lake sediments impacted by atmospheric deposition of Trail-emitted lead.

Arsenic, on the other hand, shows a more complex pattern (Figure 23). Bonaparte Lake, at a distance of 65 miles, is noticeably higher in arsenic than other lakes at similar distance. This is due to the local geology of the Bonaparte Lake watershed, which includes granitic and metamorphic rocks known to be naturally enriched in arsenic. With the exception of arsenic in Bonaparte Lake, concentrations show a generally decreasing trend with distance.

3.1.6 Timing of Metals Deposition

The deposition ages of the Cedar Lake, Lake Ellen, and Bonaparte Lake sediment cores were determined by fitting unsupported ^{210}Pb activities with depth with the constant initial concentration (CIC) and constant rate of supply (CRS) models. The calculated age-depth curves were checked against specific horizons based on ^{137}Cs activity (1954 onset and 1963 peak). Both models gave similar age-depth curves for the Cedar and Ellen lake cores, which were confirmed with ^{137}Cs. Average sedimentation rates of 10.7 and 12.7 milligrams per square centimeter per year (mg cm^{-2} yr^{-1}) were found for the Cedar and Ellen lake cores, respectively. The CIC model was considered appropriate for the Bonaparte core, which showed a lower sedimentation rate (4.2 mg cm^{-2} yr^{-1}). The age-depth curves were used as an aid to help interpret the metals concentration and lead isotope profiles in these cores in context of the local history and Trail smelter operations history.

Figures 24 through 29 show profiles of lead isotope ratios and concentrations of lead and selected metals for each of the sediment cores. In the lead isotope profiles, the range for Trail lead is shaded. The approximate depths (from top to bottom) of the year 2000, 1950, and 1900 date horizons in each core are shown as horizontal dotted lines. Detection limits for some metals were elevated due to the small sample size available; therefore, metals with low background concentrations (e.g., antimony and cadmium) have a higher incidence of non-detect results. Non-detect results are plotted with open symbols at half the detection limit.

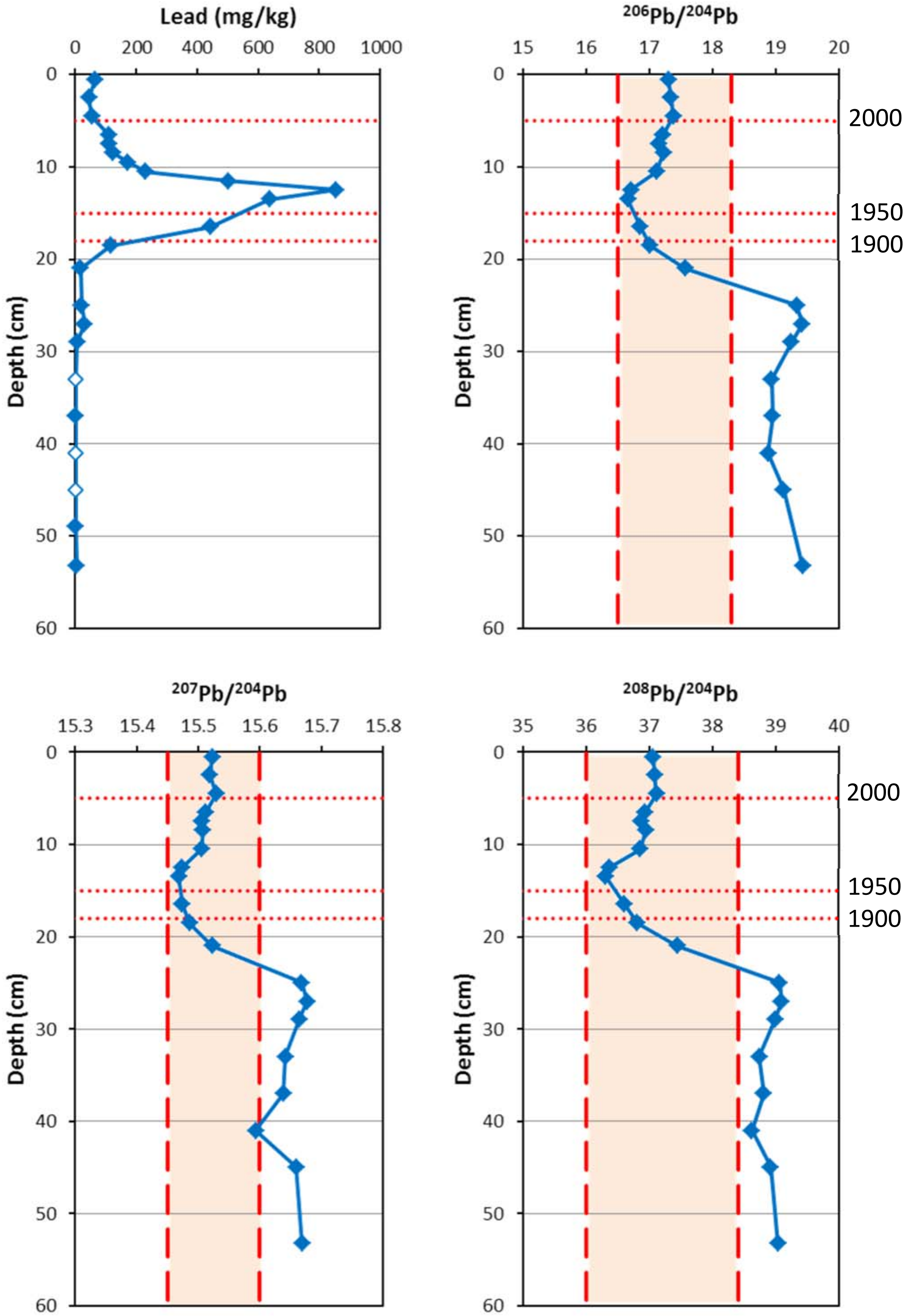


Figure 24. Vertical profiles of lead concentrations and lead isotope ratios in Cedar Lake core.

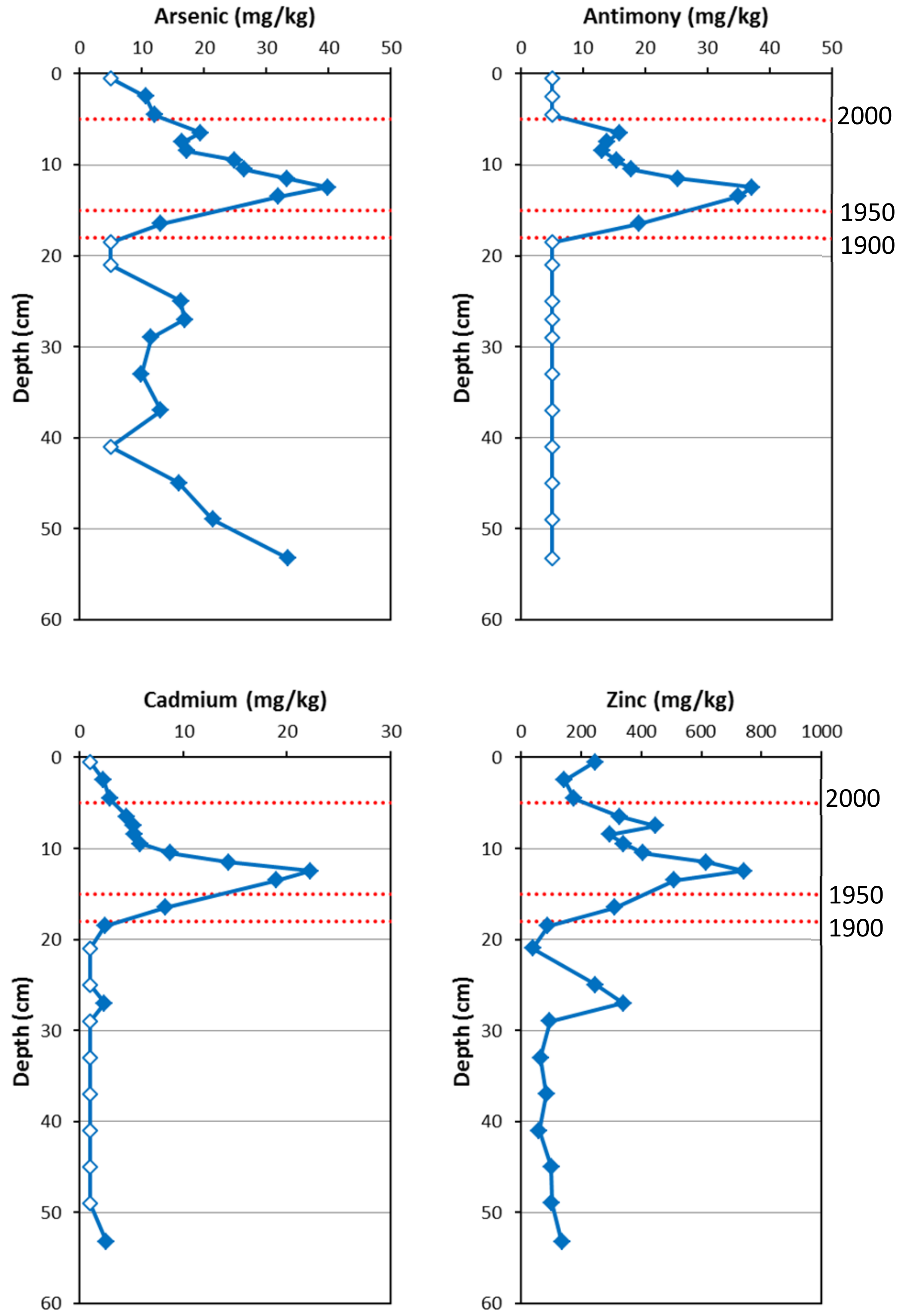


Figure 25. Vertical profiles of antimony, arsenic, cadmium and zinc concentrations in Cedar Lake core.

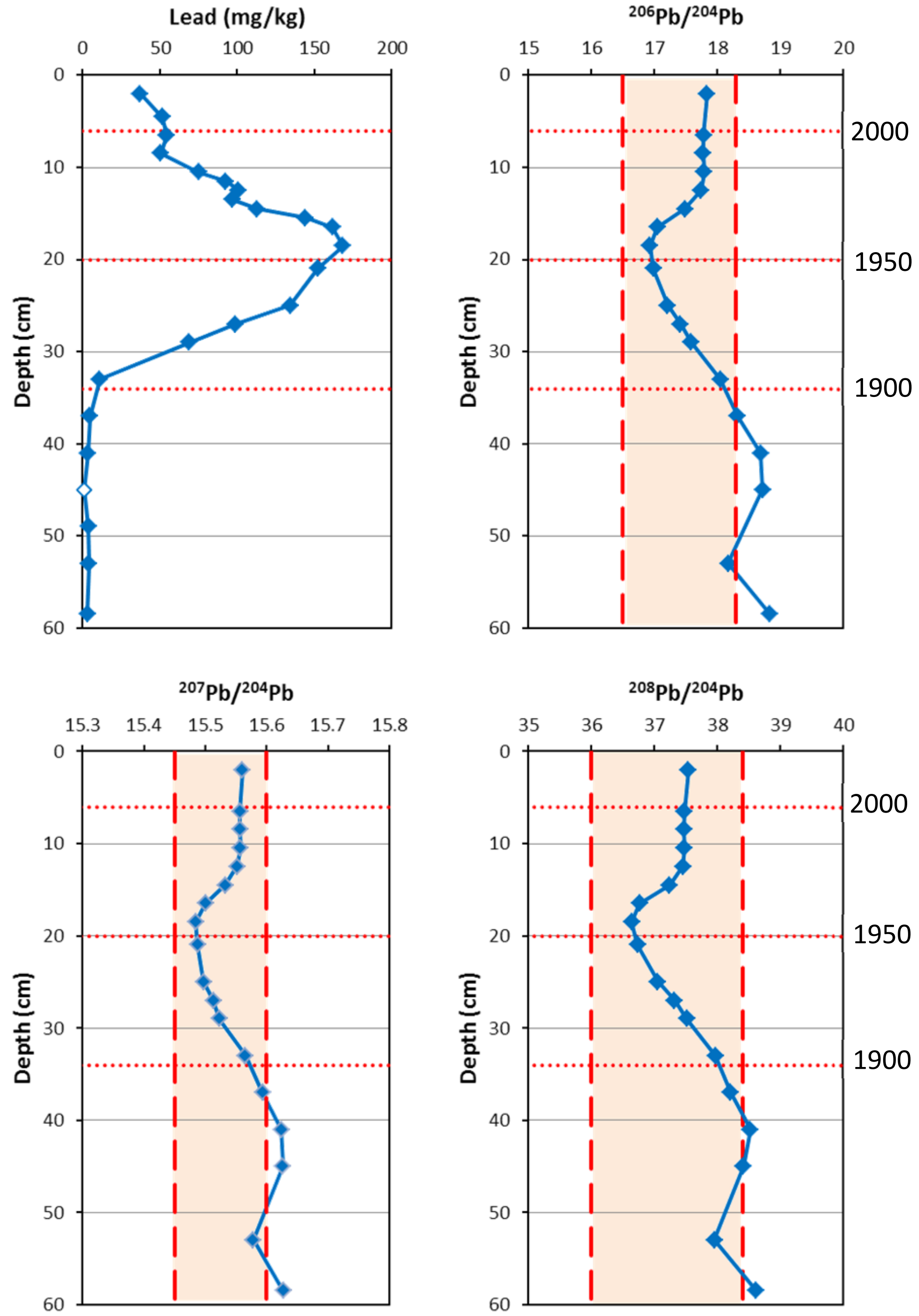


Figure 26. Vertical profiles of lead concentrations and isotope ratios in Ellen Lake core.

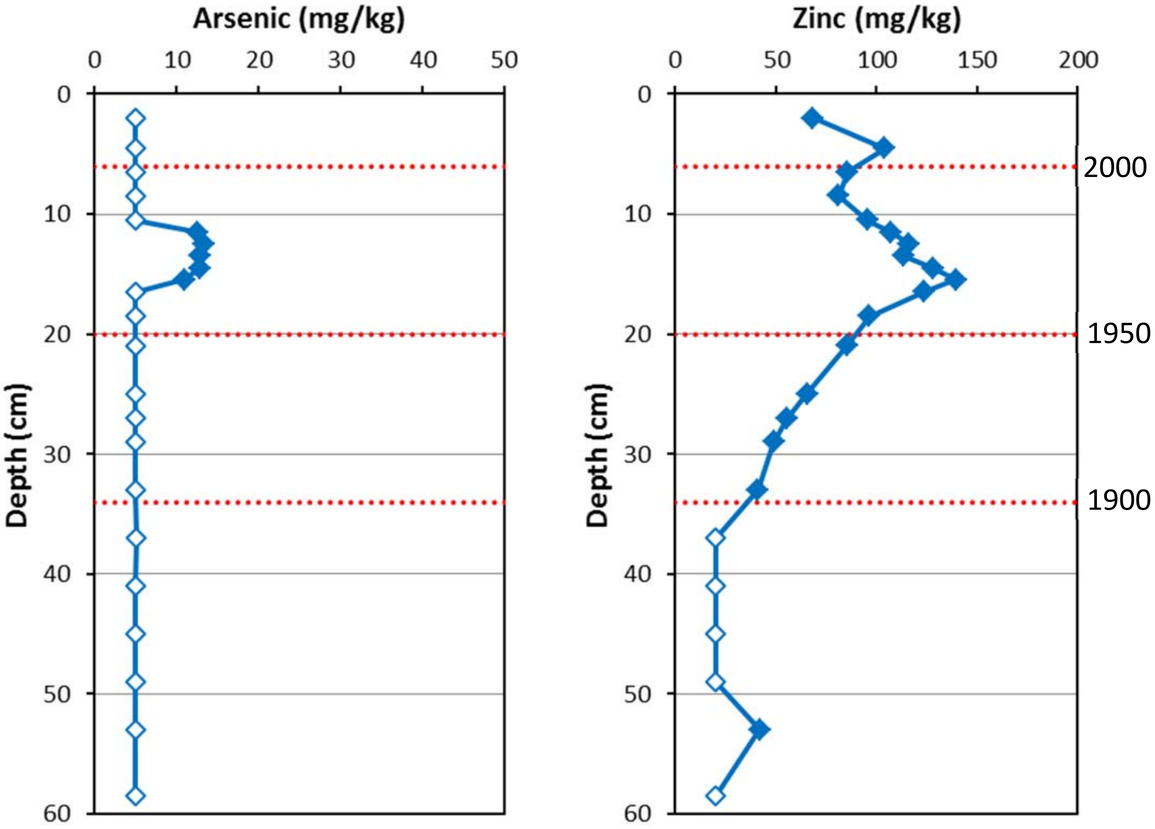


Figure 27. Vertical profiles of arsenic and zinc concentrations in Ellen Lake core.

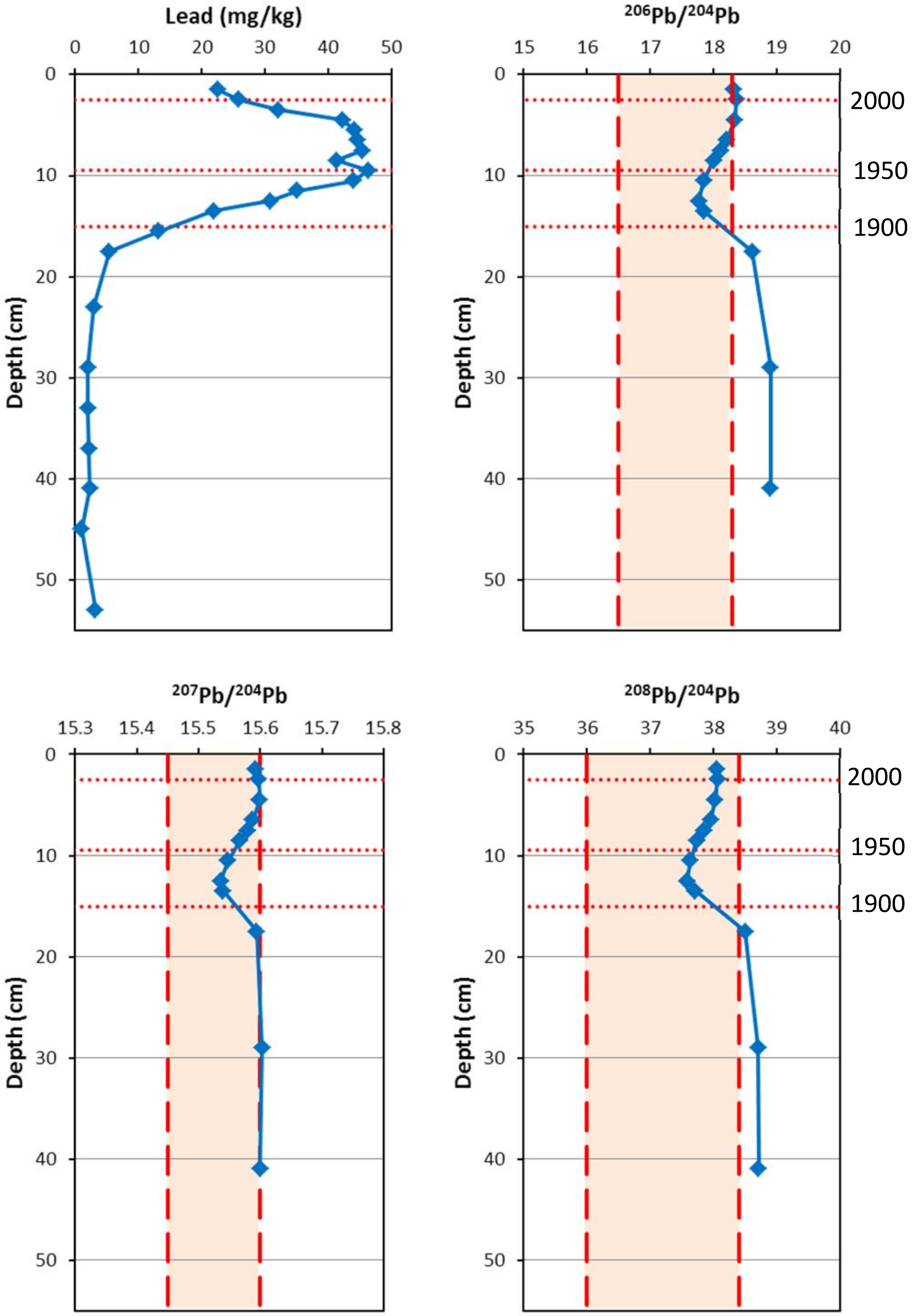


Figure 28. Vertical profiles of lead concentrations and isotope ratios in Bonaparte Lake core.

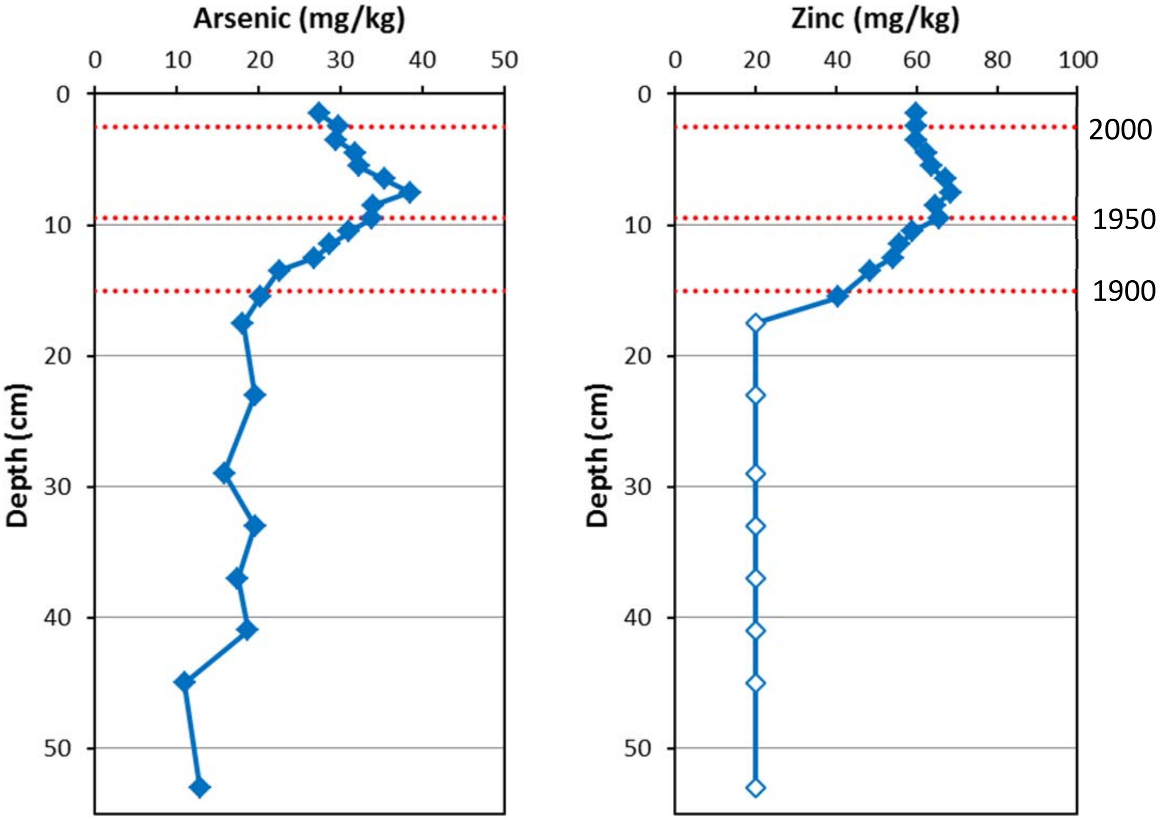


Figure 29. Vertical profiles of arsenic and zinc concentrations in Lake Ellen core.

Figures 24 and 25 show results for Cedar Lake. The increase in lead corresponds to the startup of lead operations at the start of the twentieth century, ramps up to a peak of 850 mg/kg in the late 1960s, and then drops rapidly during the 1970s to around 100 mg/kg during the 1980s and 1990s and a further decrease to level out at about 50 mg/kg since 2000. Compared to Queneau's emission estimates (Figure 3), the initial increase in lead concentrations is consistent with increasing atmospheric deposition following startup of the Trail smelter at the turn of the twentieth century, followed by reduced emissions during the 1980s and 1990s. The most recent decrease is consistent with the switch to the KIVCET smelter in the late 1990s. Although the lead concentrations in the core prior to the 1970s do not appear to match the emissions closely and are higher than might be expected from Figure 3, it is important to note that Queneau's emissions values prior to 1980 are minimum estimates and actual emissions were likely significantly higher. The lead isotopes also paint a consistent picture of a shift from mostly local geogenic lead prior to the twentieth century, followed by a shift to lower non-radiogenic values as the smelter came online, and a shift over time from processing mostly Sullivan ores to a mixture of the more radiogenic Pine Point and Red Dog lead ores. The apparent discrepancy in the peak may also be due in part to post-depositional mobilization. Evidence for this is apparent in the presence of slightly elevated lead concentrations and low lead isotope ratios in the one or two core intervals beneath the 1900 date marker. Arsenic, antimony, cadmium, and zinc show similar peaks and declines during the twentieth century, with a few notable differences. Arsenic and, to a lesser extent zinc concentrations, appear to have been somewhat variable prior to 1900. The peaks at 27 cm depth are associated with elevated aluminum, indicating a greater influx of terrigenous clay minerals, possibly reflecting a period of deposition of volcanic ash associated with Cascades eruptive activity (http://volcanoes.usgs.gov/observatories/cvo/Historical/timeline.shtml) or increased erosion associated with historical wildfires (Wright and Agee 2004; Nesbitt 2010). Despite these complexities, the highest concentrations recorded generally occurred during the twentieth century and are consistent with deposition of emissions from the Trail facility.

The Ellen Lake profiles show a very similar record during the twentieth century (Figures 26 and 27), albeit with lower peak concentrations, and slightly more subdued isotopic shifts, which is to be expected due to the greater distance from the source of the emissions at Trail. Zinc and arsenic, like lead, show highest concentrations during the twentieth century, although again lower than peak concentrations in the Cedar Lake core by a factor of 4 to 6.

The Bonaparte Lake core also records some evidence of deposition of Trail smelter metals (Figures 28 and 29). There is a distinct increase in lead concentrations at the start of the twentieth century that peaks at around 45 mg/kg in 1950 (about 20 times lower than the peak lead concentration in the Cedar Lake core) and then remains close to that level until the 1990s, before decreasing to about half that concentration during the following decade. The isotopic composition during the increasing leg is consistent with a Trail source, but the post-1950 data suggest additional inputs from other anthropogenic sources in the latter part of the twentieth century. The finding of a Trail lead signature in lake sediments at this location is somewhat surprising, given that it was originally selected to serve as a reference site, and demonstrates the large spatial extent of atmospheric metal deposition from the Trail smelter.

The overall consistency between sediment lead isotope signatures establishing the presence of Trail smelter lead in bottom sediments of lakes at distances more than 60 miles from Trail, the close association and enrichment of other toxic metals present in smelter emissions, including antimony, arsenic, cadmium, mercury and zinc, and sediment chronologies that place the timing of deposition in context of the smelter operations during the twentieth century provide compelling evidence that hazardous metals emitted from the Trail facility have been and continue to be transported to and deposited across the northeast Washington landscape since the beginning of the twentieth century.

3.2 Opinion 2

Smelter-emitted metals that have accumulated in northeast Washington lake sediments are released to porewater and are therefore mobile and bioavailable.

Dissolved concentrations in interstitial water provide a measure of the partitioning and relative mobility of metals accumulated in lake sediments. Vertical porewater concentration profiles in sediments are also useful for evaluating release and flux of metals to the overlying water column. To evaluate porewater concentration profiles for smelter metals, sediment cores from Cedar Lake and Lake Ellen were processed for porewater extraction and analysis.

3.2.1 Porewater Processing

All handling of cores and porewater samples was done under a nitrogen atmosphere. The cores were sectioned in 5-cm intervals, which were collected in centrifuge tubes. The tubes were centrifuged at 5,000 rounds per minute for 30 minutes, and then the supernatants were filtered through 0.45 micron membrane filters, collected into pre-cleaned polyethylene sample bottles, acidified, and submitted for metals analysis. The remaining sediment was retained for subsequent use in passive release testing.

3.2.2 Porewater Profiles

The porewater analysis results are provided in Appendix C. Figures 30 and 31 summarize porewater concentration profiles for antimony, arsenic, cadmium, lead, and zinc in the Cedar and Ellen lake cores. Also shown is the estimated depth of the 1900 time horizon in each core, which approximately separates the sediment column into pre- and post-Trail smelter periods. In both cores, peak porewater concentrations for antimony, arsenic, cadmium, lead, and zinc occur within the smelter-impacted sediment section, which also shows higher concentrations overall.

In most cases, the peak porewater concentration does not occurs in the shallowest interval below the sediment-water interface, but occurs at a deeper interval such that a concentration gradient is apparent between the deeper porewater and the porewater adjacent to the sediment-water interface indicating that freely dissolved metals in sediment porewater are transported upward by diffusion. Specifically, this is observed in the porewater profiles for antimony, arsenic, cadmium, lead, and zinc in the Cedar Lake core and for antimony, arsenic, cadmium, and zinc in the Ellen Lake core.

Sediment porewater represents the primary route of exposure for metals and therefore metals in porewater are considered bioavailable (Winger et al 2003).

These observations indicate the smelter-impacted sediment layer in these lakes is a source of smelter metals to porewater. The concentration profiles also demonstrate that smelter-emitted metals partitioned to porewater are transported upward by diffusion through the sediment column and released into the overlying water column.

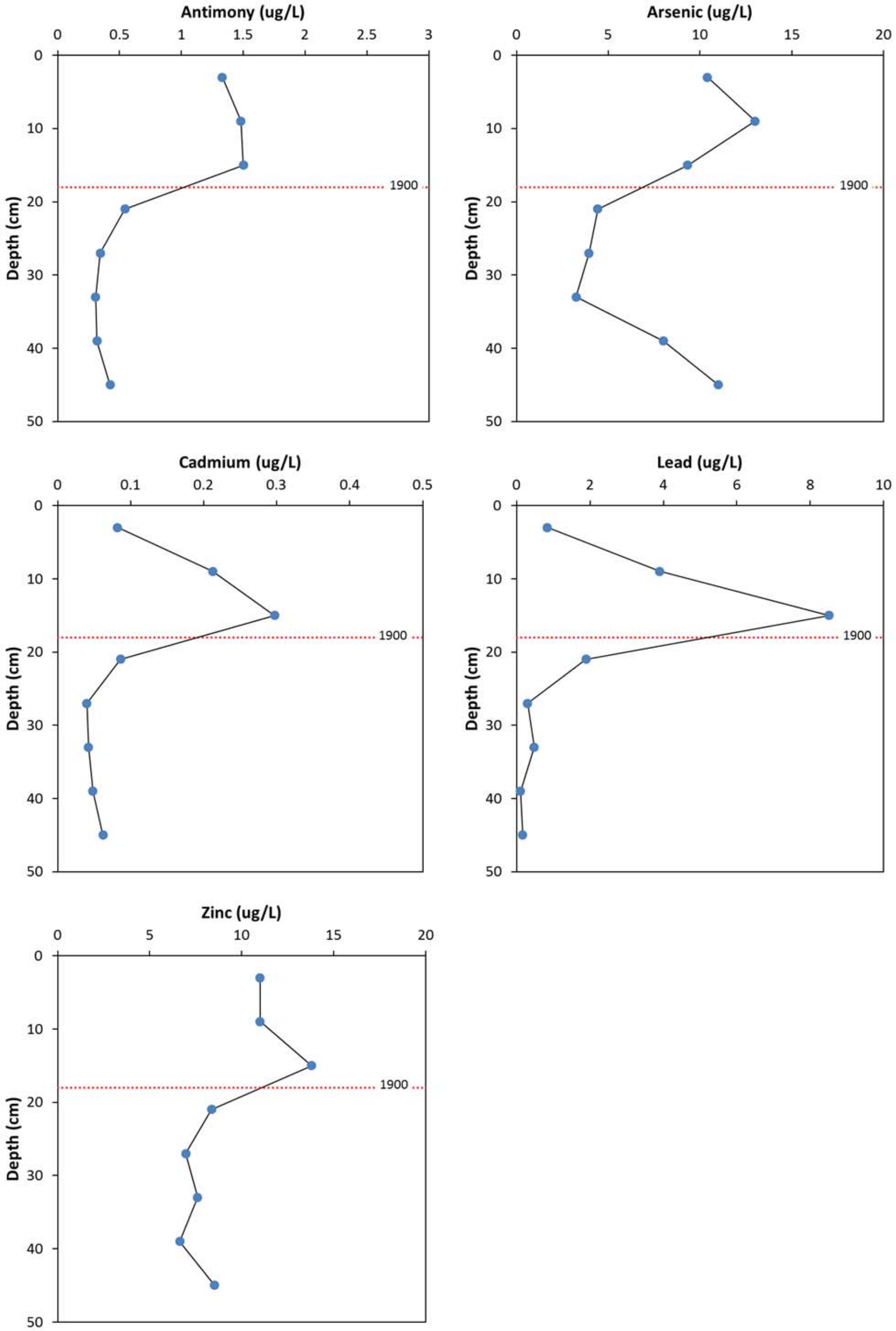


Figure 30. Porewater metals concentration profiles in Cedar Lake core.

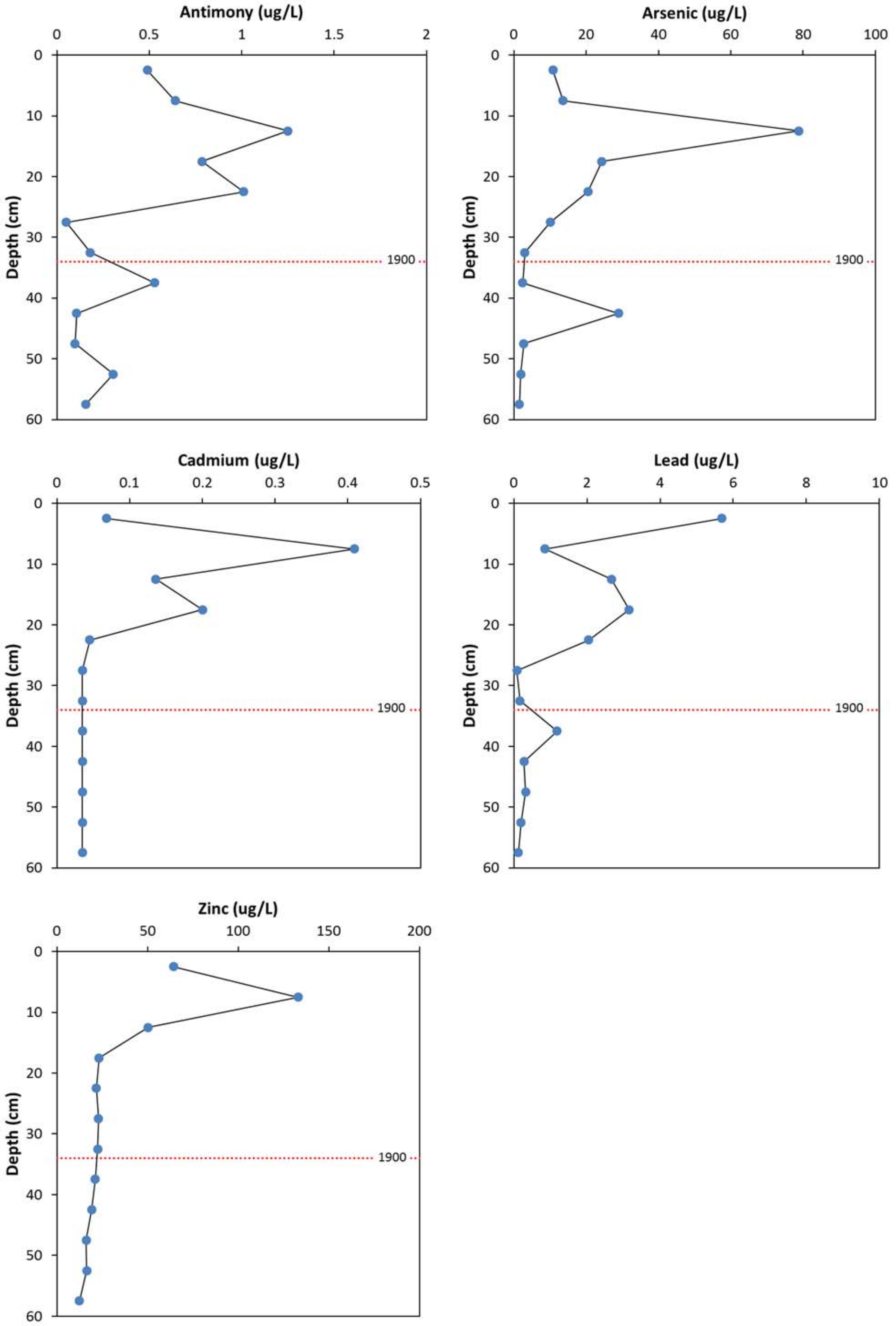


Figure 31. Porewater metals concentration profiles in Ellen Lake core.

3.3 Opinion 3

Smelter-emitted metals in older as well as more recently deposited sediments continue to be released to porewater. The release of smelter-emitted metals to sediment porewaters and the overlying lake water column is an ongoing process.

3.3.1 Passive Metals Release Tests

A series of laboratory tests were conducted to evaluate the release of metals from smelter-impacted sediments. The experiments were designed to quantify the cumulative mass release of several metals (antimony, arsenic, cadmium, lead, and zinc) from bottom sediment to lake water over time under conditions approximating the lake bottom environment, using an adaptation of the diffusive gradient in thin-film (DGT) methods.

The DGT probe passively accumulates dissolved metals from solution when deployed in situ. DGT utilizes a three-layer system consisting of a resin-impregnated hydrogel layer, a hydrogel diffusion-layer, and a filter membrane. The filter membrane isolates the gel surface from particles in the water. Dissolved metal ions in solution diffuse across the filter and gel layers and accumulate on the resin.

The passive metals release test involves placing a known mass of sediment in a reaction vessel with a known volume of lake water. A new DGT probe is suspended in the solution above the sediment. The vessel is then sealed, and the sediment is allowed to react with the water for a predetermined length of time during which the DGT is exposed to the water, calculated to be short enough to prevent saturating the DGT resin with metals. At the end of the exposure period, the DGT probe is removed and replaced with a new DGT device. The recovered probe is extracted in acid and the extract analyzed for the mass of metals accumulated during the exposure period. After the second exposure period, the second DGT probe is recovered and again replaced with a new probe, and the recovered probe is again extracted and analyzed for total mass of metals. The total mass of each metal recovered from the DGTs with cumulative exposure time represents the cumulative mass release.

The objectives of the release tests were to directly evaluate hazardous metals release from lake sediments impacted to different degrees by Trail smelter-emitted metals and to compare mass release from more recently deposited versus older sediments. Metals release tests were set up for three depth intervals of the Cedar Lake core and two depth intervals of the Ellen Lake core as follows.

Core	Depth Interval (centimeters)	Estimated Age of Deposition (years)
Cedar Lake	0 to 6	2000 to 2014
	6 to 18	1900 to 2000
	18 to 24	Before 1900
Ellen Lake	0 to 10	1990 to 2014
	10 to 30	1920 to 1990

Replicate tests were also conducted for Cedar (6 to 18 cm) and Ellen (10 to 30 cm) to assess reproducibility. In addition, two controls containing only lake water (one for each lake) were also run. All water used was filtered and degassed, and the tests were set up in a nitrogen atmosphere. The release tests were run for three reaction cycles (of duration 8, 10, and 20 days) for a total DGT exposure time of 38 days.

3.3.2 Passive Metals Release Test Results

Figure 32 summarizes the total metals masses accumulated in the DGTs during the 38-day duration of the tests. For each test, the results for the sediment-water tests are compared to the relevant water-only test to confirm the mass of metals accumulated in the DGTs was greater than what was initially present in the water and was therefore released from sediment. Results for copper (not shown) were considered unreliable due to elevated copper levels in the DGT blanks and controls. Cadmium was generally close to or below detection limits in the tests with Lake Ellen sediment. The other metals (antimony, arsenic, lead, and zinc) registered significant releases from the smelter-impacted sediments from both lakes.

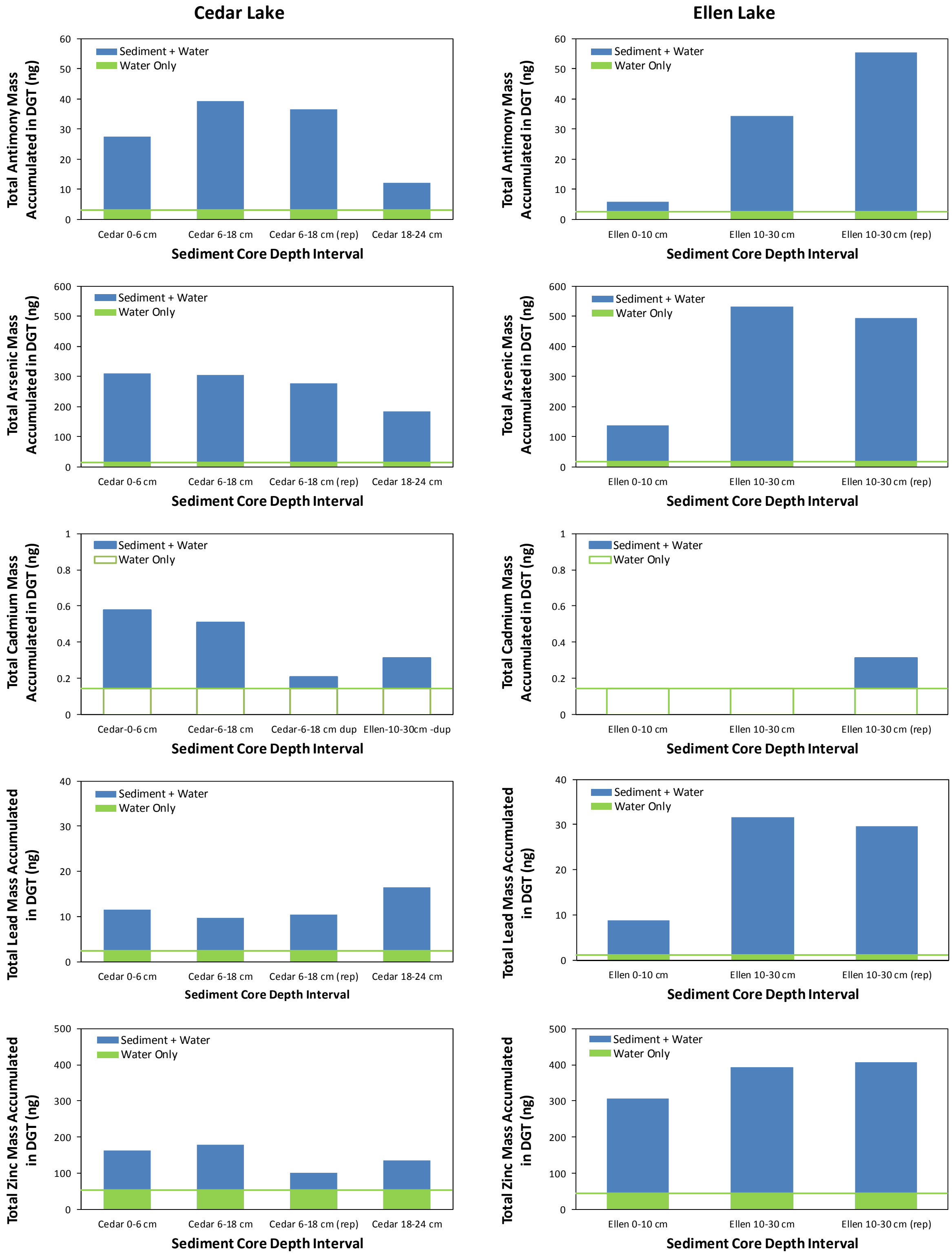


Figure 32. Cumulative metals mass accumulated in DGT cells during 38 days in passive release experiments with Cedar Lake and Lake Ellen sediments.

To facilitate comparison between tests, cumulative releases of antimony, arsenic, lead, and zinc from the sediments during the course of the 38-day test duration are shown in Figure 33 as a percentage of the total metal mass. Two types of release patterns are exhibited by the four metals. Arsenic and antimony show a rapid initial release during the first 18 days (0.3 to 1.7% for arsenic and 0.1 to 0.4% for antimony) followed by a slower release during the subsequent 20 days of the tests. Lead and zinc exhibit a slower but more continuous release during the entire 38 days (0.001 to 0.022% for lead and 0.01 to 0.11% for zinc).

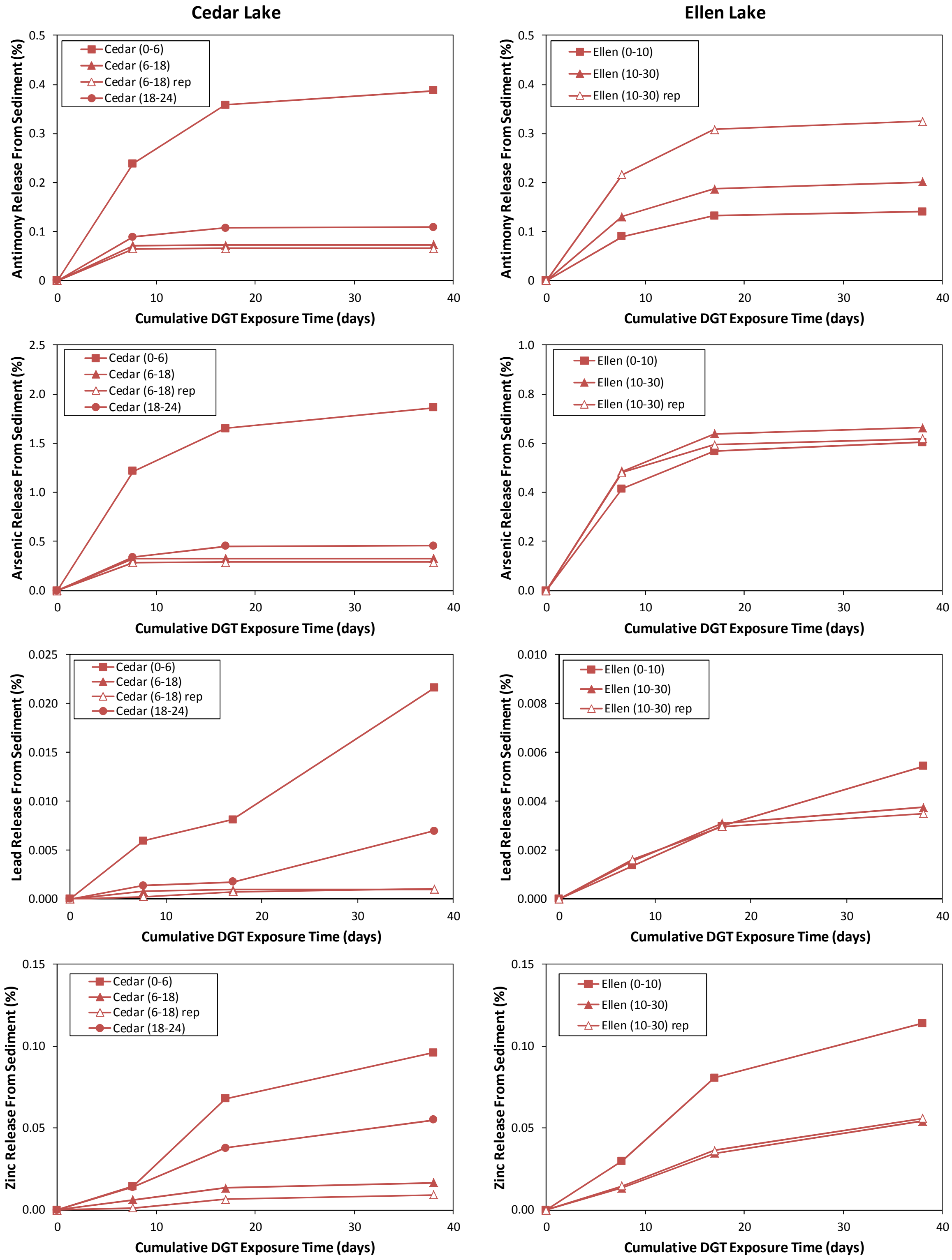


Figure 33. Fraction of metals released from Cedar Lake and Lake Ellen sediment as a function of time.

The metals release rates for Cedar Lake sediment were generally higher than for Ellen Lake sediment. This is likely due in part to the higher concentrations of smelter-emitted metals in the Cedar Lake sediment, which are relatively mobile as indicated by the porewater data presented in section 3.2.2. In the Cedar Lake sediments, the shallowest (0 to 6 cm) interval consistently showed the highest release rates for all four metals, while the deeper intervals were generally characterized by slower release rates. The Ellen Lake sediments similarly showed higher release rates for lead and zinc in the shallower interval, but less pronounced differences with depth for the other elements.

The generally higher hazardous metals release rates exhibited by the more recently deposited shallow sediment intervals indicate the release of smelter-emitted metals from impacted lake sediments in northeast Washington is greatest soon after deposition. In addition, the significant release of metals from the deeper, older sediment layers of both lakes also indicates metals release to water can continue for decades after deposition. This demonstrates that as long as smelter emissions to the atmosphere continue, hazardous metals will continue to be deposited in lakes across northeast Washington, where they accumulate in lake sediments, are subsequently re-released to sediment porewaters and the overlying lake water column.

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APPENDIX A
RESUME

DIMITRIOS VLASSOPOULOS, Ph.D.

Partner/Principal Scientist

PROFESSIONAL HISTORY

Anchor QEA, LLC, Principal Scientist, January 2011 to 2014
Anchor QEA, LLC, Senior Managing Scientist, July 2010 to December 2010
S.S. Papadopulos & Associates, Inc., Senior Staff Geochemist to Associate, 1992 to June 2010
University of Virginia, Doctoral Fellow, 1995 to 1998
California Institute of Technology, Graduate Research Assistant, 1989 to 1992
Mineral Exploration Research Institute, Research Associate, 1988 to 1990
McGill University Department of Geological Sciences, Research Assistant, 1985 to 1988
Quebec Ministry of Energy and Natural Resources, Senior Field Geologist, 1985
Concordia University, Department of Geology, Research Assistant, 1984 to 1989

EDUCATION

University of Virginia, Ph.D., Environmental Sciences, 2000
California Institute of Technology, M.S., Geochemistry, 1993
McGill University, M.S., Geological Sciences, 1989
Concordia University, B.S., Geology (Honors), 1986

EXPERIENCE SUMMARY

Dr. Vlassopoulos has more than 25 years of experience in contaminant hydrology and environmental geochemistry with a focus on evaluation and remediation of soil, sediment, groundwater, and surface water quality in aquatic and terrestrial systems. His areas of expertise include multimedia fate and transport modeling, environmental forensics, applied isotope geochemistry, and in situ remediation strategies. He has extensive litigation support and expert witness experience, including trial testimony.

AWARDS AND HONORS

Pegau Geology Award, University of Virginia, 1997
Dupont Fellowship, University of Virginia, 1996 to 1998
University of Virginia President's Fellowship, 1995 to 1998
Reinhardt Research Fellowship, McGill University, 1986 to 1987

PROFESSIONAL SOCIETIES

American Geophysical Union
Geochemical Society
Geological Society of America
International Association of GeoChemistry
International Mine Water Association
National Ground Water Association

EXPERT WITNESS EXPERIENCE

Trial Testimony

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Emeryville Redevelopment Agency v. Howard F. Robinson, Jr., et al. Superior Court of the State of California for the County of Alameda. Case No. RG-06-267594 (Consolidated with RG-06-267600 and RG-07-332012). November 19, 2010.

Abarca, Raul Valencia, et al., v. Merck & Co., Inc., et al. U.S. District Court for the Eastern District of California, Fresno Division. Case No. 1:07-CV-0388 OWW DLB. April 26, 2010.

United States v. Washington State Department of Transportation, et al. U.S. District Court for the Western District of Washington at Tacoma. Case No. 05-5447RJB. June 29, 2006.

Port of Vancouver v. Cadet Manufacturing Company. U.S. Bankruptcy Court for the Western District of Washington at Tacoma. Case No. 99-30304T. December 7, 2004, and June 15, 2005.

Domingo Aragon and Eva Aragon et al. v. Department of the Air Force, ex rel United States of America et al. U.S. District Court for the District of New Mexico. Case No. CIV 94-592 JP/LCS. July 25, 1995.

REPRESENTATIVE PROJECT EXPERIENCE

Penobscot River Litigation, Maine

Dr. Vlassopoulos served as a testifying expert for the defendants in a lawsuit regarding mercury contamination of a major estuary in Maine. His work involved critical review of investigations and recommendations submitted by a court-appointed expert panel regarding the extent of ecological harm and need for remedial action. His focus was on geochemical aspects of fate and transport of mercury and methylmercury and implications on the feasibility of in situ remediation. His testimony pointed out a number of shortcomings of the study panel investigation.

Pakootas et al. v. Teck, Upper Columbia River, Washington, Confederated Colville Tribes and State of Washington

Dr. Vlassopoulos served as a testifying expert for the plaintiffs in a lawsuit regarding trans-boundary contamination of a major river system by metals originating from a smelter in Canada. He established that the smelter operator was liable under the Comprehensive Environmental Response, Compensation, and Liability Act by proving that smelter slag and metal-bearing wastes were released, accumulated at the site, and continued to release hazardous constituents to the environment. The multiple lines of evidence developed include chemometric analysis and spatial mapping of heavy metals signatures, lead isotope fingerprinting, pre-smelter sediment baseline concentrations, laboratory leaching studies, and porewater sampling of smelter impacted sediments.

Dry Cleaner Contamination, Shoreline, Washington, Confidential Client

Dr. Vlassopoulos was retained as a testifying expert for the defendant in an environmental liability lawsuit regarding soil and groundwater contamination by perchloroethylene (PCE) releases at a dry cleaning facility sited on fractured till. He was able to establish the sources and recent timing of releases using compound-specific carbon and chlorine isotope analysis of PCE, evaluation of subsurface conditions, and solute transport modeling.

Emeryville Site B Redevelopment, Emeryville, California, Sherwin Williams

Dr. Vlassopoulos served as a testifying expert for the defendant in a remedial cost recovery lawsuit regarding arsenic, metals, and hydrogen sulfide contamination discovered in fill soils during redevelopment of a neighboring property. He was able to demonstrate to the court through historical topographic maps that a large portion of the contamination predated the defendant's occupation of the site.

Palermo Wellfield Superfund Site, Tumwater, Washington, U.S. Department of Justice

Dr. Vlassopoulos testified in a remediation cost recovery case on the origin of groundwater contamination by chlorinated solvents based on compound-specific stable isotope signatures.

Commingled Groundwater Plume Allocation, Port of Vancouver, Washington

Dr. Vlassopoulos was retained as an expert witness for environmental remediation cost recovery litigation. He used ambient stable isotope tracers to evaluate the role of surface water on a groundwater flow system as well as chemical signatures and compound-specific stable isotope analyses to allocate groundwater contamination from multiple chlorinated solvent sources.

Groundwater Plume Allocation, Elmira, Ontario, Crompton Corporation

Dr. Vlassopoulos was retained as an expert witness in environmental liability allocation for a commingled groundwater ammonia plume originating from two adjacent facilities. He allocated ammonia among the multiple sources based on nitrogen isotope signatures, chemical tracers and mass balance analyses. The matter was settled to the satisfaction of the client.

Environmental Torts Litigation Support, Roswell, New Mexico, U.S. Department of Justice

Dr. Vlassopoulos was retained as an expert witness for environmental torts claims related to groundwater contamination by chlorinated solvents at military installations and other government facilities.

Scope of Work Negotiation, Higgins Farm Superfund Site, Franklin Township, New Jersey, NCH Corporation

Dr. Vlassopoulos was retained initially to review the design, construction and operation of a pump-and-treat system for remediation of contaminated groundwater in a fractured rock aquifer. Subsequently, his role shifted to negotiating a scope of work for remedial system takeover from USEPA by NCH. The project involved compilation and analysis of a multi-year groundwater quality database, including data collected by multiple entities, and development and application of an automated process for evaluating and reporting robust trend statistics for constituent concentrations in monitoring wells over time. The results of this analysis provided the technical basis for reducing long-term monitoring efforts and associated costs.

Remedial System Evaluation, Chem-Dyne Superfund Site, Hamilton, Ohio, Chem-Dyne Trust

Dr. Vlassopoulos supervised performance evaluations of a groundwater pump-and-treat system operating for over 25 years. The evaluations included estimation of subsurface VOC mass distributions over time from historical extraction data and development and application of a solute transport model to forecast time remaining to attainment of cleanup levels and adaptive management of extraction well operation.

SECARB Phase III, Cranfield, Mississippi, Texas Bureau of Economic Geology

Dr. Vlassopoulos developed and applied a regional groundwater model for the SECARB geologic carbon sequestration pilot study site using the MODFLOW/MT3DMS-based reactive transport simulator PHT3D to evaluate potential groundwater quality impacts from a geogenic metals release associated with CO_2 leakage from a geologic carbon sequestration site to into overlying shallow drinking water aquifers to support groundwater monitoring design.

Remedial Investigation/Feasibility Study, Former Reynolds Metals Aluminum Smelter, Longview, Washington, ALCOA

Dr. Vlassopoulos designed and conducted field and laboratory investigations and groundwater modeling to evaluate the fate and transport of fluoride in support of the RIFS at a former aluminum smelter plant. The investigations included soil geochemical and mineralogical characterization to elucidate controls on groundwater fluoride concentrations, development of a site conceptual model, and numerical reactive transport modeling using MODFLOW and PHAST to assess the long-term effectiveness of remedial alternatives.

Natural Gas Exploration, Gilliam and Morrow Counties, Oregon, Confidential Client

Dr. Vlassopoulos supervised a hydrochemical prospecting program to locate natural gas accumulations underlying several thousand feet of Columbia River Basalt. Investigations included sampling and analysis of groundwater in fractured basalt aquifers to evaluate the source and origin of dissolved methane in water wells using a suite of tools including gas and groundwater geochemistry, stable isotope signatures, and groundwater age dating methods.

Seattle-Tacoma International Airport Third Runway, SeaTac, Washington, Port of Seattle

In support of water quality permit applications, Dr. Vlassopoulos conducted a vadose zone fate and transport modeling analysis to develop quality criteria for metals in fill materials used to construct a runway embankment that would be protective of surface water quality in adjacent wetlands.

Basalt Aquifer Assessment, Eastern Washington, Columbia Basin GWMA

Dr. Vlassopoulos performed an evaluation of regional and locally enhanced groundwater recharge to fractured basalt aquifers through multivariate statistical analysis of regional hydrochemistry data, collection, and interpretation of ambient geochemical and isotope tracer data, and groundwater age dating.

Onondaga Lake Cap and Dredge Design, Syracuse, New York, Honeywell International

Dr. Vlassopoulos evaluated geochemical speciation and controls on mercury fate and transport in sediment porewater, and assessed effectiveness of capping as an in situ remediation option. He developed an innovative approach for pH control using mineral-based amendments which was incorporated into the design of a multilayer reactive sediment cap.

WAC Bennett Dam Cementation Potential Evaluation, Peace River, British Columbia, BC Hydro

Dr. Vlassopoulos developed a conceptual model for internal cementing of earth-fill dams and carried out field and laboratory investigations to evaluate the cementing potential and status of a large embankment dam in Canada. The methodologies relied on carbonate system chemical and isotope mass balance analysis of seepage waters and archived embankment materials to quantify current conditions and development of a geochemical cementation model to assess future evolution.

Factory Lane Site, Middlesex, New Jersey, Rhone Poulenc

Dr. Vlassopoulos designed and pilot-tested an in situ treatment system based on zero-valent iron for shallow groundwater contaminated with high levels of arsenic.

1980 Bay Road Site, East Palo Alto, California, Rhone Poulenc

Dr. Vlassopoulos evaluated natural attenuation of a groundwater arsenic plume in a tidally influenced aquifer, developed an in situ chemical fixation process for arsenic contaminated soil, and pilot-tested an in situ groundwater treatment system using zero-valent iron.

Geochemical Evaluation of Groundwater Impacts at Oregon Steel Mill, Portland, Oregon, Evraz North America

Dr. Vlassopoulos conducted a geochemical evaluation of impacts from slag fill on shallow groundwater quality and demonstrated to the Oregon Department of Environmental Quality that natural attenuation was mitigating off-site migration of dissolved metals.

Geochemical Modeling Database Development, Electric Power Research Institute

Dr. Vlassopoulos developed and calibrated a thermodynamic database for geochemical modeling of adsorption of antimony, arsenic, boron, chromium, molybdenum, selenium, sulfate, and vanadium on iron hydroxides based on the CD-MUSIC surface complexation model.

Mercury Remediation Using Chemical Amendments at Sulphur Bank Mercury Mine Superfund Site, Clear Lake, California

Dr. Vlassopoulos collaborated in a research project to evaluate chemical amendments for sequestering mercury in situ in contaminated sediments. The study characterized mercury speciation in surface waters and sediments using X-ray absorption spectroscopy and complementary techniques (e.g., water chemistry, sediment composition, and mineralogy) to determine factors influencing mercury methylation and partitioning between aqueous and solid phases. The project was supported by funding from the National Institutes of Health's National Institute of Environmental Health Sciences Superfund Research Program.

Natural Resource Damage Litigation Support, Clark Fork River, Montana, Atlantic Richfield Company

Dr. Vlassopoulos provided technical support for natural resource damage litigation at historical mining and smelting operations. His evaluations included field sampling; characterization and modeling studies of metals (arsenic and cadmium) attenuation in groundwater; estimation of background (pre-mining) groundwater quality in the Butte mining district; and identification and separation of mining waste-related sulfate from natural geothermal sulfate loading to the Clark Fork River using stable isotope signatures.

Berkeley Pit, Butte, Montana, Atlantic Richfield Company

Dr. Vlassopoulos provided technical support for litigation involving the allocation of liability to cleanup costs among potentially responsible parties. He evaluated the impact of historical and ongoing mining operations on pit-lake water quality and cleanup costs based on field, laboratory, and geochemical modeling studies.

Seattle-Tacoma International Airport Third Runway, SeaTac, Washington, Port of Seattle

Dr. Vlassopoulos conducted detailed biogeochemical investigations to develop a conceptual understanding of sources and fate and transport of arsenic and mercury in groundwater. He evaluated the potential for methylmercury impacts on wetland sediments and surface water. Through integration of data analysis with biogeochemical reaction modeling, the origin of the metals was demonstrated to be from natural background sources; he documented the influence of seasonal redox dynamics and dissolved organic matter generation from local peat deposits on increased arsenic and mercury mobility.

Former Chlor-Alkali Plant Remediation, Port of Bellingham, Washington

Dr. Vlassopoulos provided technical support for the Whatcom Waterway Cleanup and Marina Development project. He developed geochemical conceptual models for mercury methylation and fate and transport in marine sediments impacted by a former chlor-alkali facility. He evaluated fate and transport of mercury in uplands groundwater and conducted laboratory treatability testing of in situ technologies for contaminated groundwater.

Des Moines Creek Regional Stormwater Detention Facility, King County, Washington

Dr. Vlassopoulos provided technical oversight and guidance to mitigate potential environmental impacts from arsenic-bearing soils at a stormwater detention facility construction site. His services included development of sampling and monitoring plans, evaluation of arsenic mobility data, and development and treatability testing of the in situ process for soil amendments to mitigate arsenic mobility during construction and subsequent operation of the facility. He continues to review long-term monitoring at the site.

Groundwater Investigation and Remediation, Former Gaylord Container Mill, Antioch, California, Forestar Group

Dr. Vlassopoulos conducted a fate and transport evaluation for metals in groundwater at a former Kraft mill, including use of molecular biological tools to evaluate the potential for in situ bioremediation. He performed treatability testing of chemical oxidation, aerobic biodegradation, and sorptive chemical amendments for in situ attenuation of arsenic plume.

Groundwater Remediation, Renton, Washington, Barbee Mill Company, Inc.

Dr. Vlassopoulos provided technical guidance and remedial design assistance for arsenic-contaminated groundwater at a former industrial site undergoing restoration for residential redevelopment. His work included evaluation of site conditions and remedial alternatives, including in situ redox manipulation and permeable reactive barriers to ensure restoration within the client's required timeframe.

Berry's Creek Study Area RI/FS Support, Hackensack Meadowlands, New Jersey, Dow

Dr. Vlassopoulos provides technical guidance in developing work plans and evaluating data to support remedial investigation efforts. This work has focused on a variety of issues germane to remedial decision-making, such as mercury fate, transport, and bioaccumulation, including understanding mercury methylation and the factors limiting bioavailability at this site.

Soda Lake Special Selenium Study, Casper, Wyoming, BP

Dr. Vlassopoulos developed and applied a selenium fate and transport and ecotoxicology model to an artificially maintained playa lake in support of water management decision analyses. His work included developing a site conceptual model for selenium, which was based on detailed characterization of selenium speciation and biogeochemical cycling.

Abandoned Coal Mine Drainage Investigation, Big South Fork National River and Recreation Area, Tennessee-Kentucky, National Park Service

Dr. Vlassopoulos designed and implemented an extensive field investigation at a historic coal mining district to identify and characterize multiple mine drainage sources discharging to a designated Wild and Scenic River in support of U.S. National Park Service restoration activities. The project included evaluation of pollutant loadings (metals and acidity) through long-term and storm-event monitoring and prioritizing point sources for remediation. Isotope tracers were used to estimate seepage rates from coal spoil piles.

Groundwater Resource Evaluation, Eastern Washington, Confederated Tribes of the Colville Reservation

As part of a groundwater resource areas study, Dr. Vlassopoulos conducted a geochemical evaluation of sources and controls on arsenic concentrations in groundwater on the Colville

Indian Reservation. He developed site selection guidelines to minimize the potential risk of arsenic exceedances in future supply wells.

PCB Partitioning Study, Rome, Georgia, General Electric

Dr. Vlassopoulos developed and implemented laboratory soil-water partitioning studies to derive site-specific, risk-based soil cleanup levels for PCBs for groundwater quality protection.

Agrico Chemical Site, Pensacola, Florida, Confidential Client

Dr. Vlassopoulos provided technical support for litigation involving groundwater contamination from a former phosphate fertilizer plant. He reconstructed historical fluoride concentrations in wastewater through geochemical modeling and used radioisotope data to evaluate sources of radium in groundwater.

Groundwater Contamination Evaluations at Natural Gas Transmission Facilities, Multiple Sites, Eastern United States, Duke Energy

Dr. Vlassopoulos evaluated nature, sources, and reconstructed release histories at several sites affected by petroleum hydrocarbons using hydrocarbon fingerprinting techniques, stable isotope signatures, and multicomponent simulation modeling.

Remedial Investigation of Transco Pipeline Facilities, Multiple Sites, Eastern United States, Williams

Dr. Vlassopoulos provided technical support for remedial investigations at a large number of natural gas transmission facilities from Texas to New York. The project involved developing a detailed compositional fate and transport model for petroleum hydrocarbon fractions to support definition of risk-based action levels.

Mamm Creek Hydrogeologic Evaluation, Garfield County, Colorado, Colorado Oil and Gas Conservation Commission

Dr. Vlassopoulos conducted a critical review of a Garfield County consultant report on groundwater quality impacts related to gas drilling and production activities on behalf of the Colorado Oil and Gas Conservation Commission (COGCC). The review evaluated the report's conclusions by analyzing an updated groundwater quality database for the study area provided by COGCC to assess whether dissolved methane and chloride concentrations showed statistically significant trends over time. The findings were presented to the COGCC.

Groundwater Baseline Evaluation, Garfield County, Colorado, Colorado Oil and Gas Conservation Commission

Dr. Vlassopoulos conducted geochemical evaluations of groundwater and recharge sources in the Piceance Basin as part of a baseline water quality study prior to the start of coalbed methane production in a 30-square-mile study area.

Natural Gas Exploration, Western Snake River Plain, Malheur County, Oregon, Confidential Client

Dr. Vlassopoulos supervised a hydrochemical prospecting program to locate potential drilling targets for unconventional shallow bacterial gas accumulations. Investigations included sampling and analysis to evaluate the source and origin of dissolved methane in groundwater using stable isotopes, noble gases, and groundwater age dating methods.

Vapor Intrusion Evaluation, Union Pacific Railyard, Eugene, Oregon, Union Pacific Railroad

Dr. Vlassopoulos evaluated the potential for chlorinated volatile organic compound (CVOC) exposure through soil vapor intrusion pathways in homes adjacent to a railyard. He successfully demonstrated to the Oregon Department of Environmental Quality that CVOCs in ambient air, and not groundwater, were responsible for the majority of the contamination detected in crawl space air samples.

Wah Chang Superfund Site, Albany, Oregon, ATI Metals

Dr. Vlassopoulos evaluated the effectiveness of natural attenuation in meeting a Record of Decision required cleanup timeframe for chlorinated solvents in groundwater. The analysis was accepted by USEPA Region 10.

Groundwater Remediation, Emerald Kalama Chemical, Kalama, Washington, BF Goodrich and Rogers Sugar

Dr. Vlassopoulos conducted an evaluation of natural and enhanced attenuation for diphenyl ether and other organic chemicals in groundwater at an operating chemical plant as part of a Corrective Action Plan (CAP) under the State's Voluntary Cleanup Program (VCP). He also developed and piloted an in situ bioremediation scheme using Waterloo Emitters to shorten the cleanup timeframe.

Systematic Approach to In Situ Bioremediation, Interstate Technology Regulatory Council

Dr. Vlassopoulos was part of a team that developed and co-authored the technical and regulatory guidance document, *A Systematic Approach to In Situ Bioremediation, Including Nitrate, Carbon Tetrachloride and Perchlorate.* He also served as instructor for a training class based on this document.

Groundwater Investigations, Multiple Sites, Panhandle Eastern Pipeline Company

Dr. Vlassopoulos developed a protocol for evaluating subsurface natural attenuation of PCBs and petroleum hydrocarbons at multiple sites along a major pipeline system. He developed a specialized field filtration technique for sampling dissolved PCBs in groundwater.

Pier 64 Groundwater Investigation, Mission Bay Redevelopment, San Francisco, California, Catellus Development Corporation

Dr. Vlassopoulos evaluated the natural attenuation potential of petroleum hydrocarbons associated with former bulk fuel storage and distribution facilities impacting groundwater along the shore of San Francisco Bay. The study involved dissolved gas sampling and use of stable isotope signatures to identify sources and hydrocarbon biodegradation pathways and rates, and a mass flux analysis to demonstrate assimilative capacity, enhanced by sulfate from tidal pumping into the coastal aquifer, was sufficient to reduce contaminant concentrations in groundwater to acceptable levels prior to discharge to the Bay.

Nitrate in Groundwater, Eastern Washington, Columbia Basin GWMA

Dr. Vlassopoulos evaluated seasonal, geologic, and hydrologic controls on nitrate concentration trends in domestic wells completed in the sedimentary aquifers of the Pasco and Quincy Basins. The study demonstrated the importance of recharge from canal leakage in mitigating nitrate levels in parts of the Columbia Basin Irrigation Project.

Aquifer Conditioning Feasibility Evaluation, City of Meridian, Idaho

Dr. Vlassopoulos evaluated geochemical controls on iron, manganese and uranium concentrations in city supply wells as part of a feasibility study of aquifer conditioning for in situ iron and manganese removal. He performed reactive transport modeling in support of pilot test design.

Risk Evaluation of Geologic Carbon Sequestration Projects, U.S. Environmental Protection Agency, Underground Injection Control Program

Dr. Vlassopoulos developed framework for characterizing and assessing risks of exposure and environmental effects risk associated with geologic carbon sequestration in support of regulatory guidance development.

Groundwater Quality Evaluation, Mexicali Valley, Mexico, Confidential Client

Dr. Vlassopoulos evaluated geochemical relationships between groundwater and surface water in a regional aquifer. The effect of surface water recharge from the All American Canal on regional groundwater quality was investigated by examining geospatial distributions of groundwater chemistry; using multivariate statistical methods to identify sources of water and solutes; and geochemical modeling to understand chemical evolution in the regional flow system.

Evaluation of Manganese in Groundwater, Portland, Oregon, City of Portland Bureau of Water Works

Dr. Vlassopoulos evaluated occurrence, origin, and treatment options for manganese in the City's well field.

Aquifer Storage Recovery Water Quality Evaluation, City of Tigard, Oregon

Dr. Vlassopoulos conducted a water quality and compatibility evaluation for an operating aquifer storage recovery (ASR) system.

Aquifer Storage Recovery Water Quality Evaluation, Sunrise Water Authority, Oregon

Dr. Vlassopoulos conducted a water quality compatibility evaluation for an ASR pilot study.

Aquifer Storage Recovery Water Quality Evaluation, City of Salem, Oregon

Dr. Vlassopoulos evaluated disinfection by-product formation potential during the storage phase in an operating ASR system.

Aquifer Storage Recovery Water Quality Evaluation, Baker City, Oregon

Dr. Vlassopoulos evaluated water quality compatibility for an ASR project by using geochemical modeling to predict potential effects of subsurface mixing of source water with native groundwater.

Spring Water Quality Assessments, Michigan, Nestlé Waters America

Dr. Vlassopoulos conducted water quality evaluations related to development and production quality control of spring water bottling operations.

Radionuclide Rule Compliance Support, Town of Poolesville, Maryland

Dr. Vlassopoulos investigated causes of elevated gross alpha radioactivity in several of the community's water supply wells and developed a monitoring and treatment plan to ensure compliance with federal drinking water regulations.

Review of EPA Risk Assessment for Silver-Bearing Wastes, Photographic Imaging Manufacturers Association

Dr. Vlassopoulos conducted an independent review of the USEPA's human health exposure risk assessment for silver-bearing wastes.

Evaluation of Water Quality Impacts from Perchlorate in Safety Flares, California, Orion Safety Products

Dr. Vlassopoulos conducted an evaluation of the potential for water quality impacts from perchlorate present in safety flares used on California highways.

PUBLICATIONS

Book

O'Day, P., D. Vlassopoulos, X. Meng, and L.G. Benning, editors, 2005. *Advances in Arsenic Research: Integration of Experimental and Observational Studies and Implications for*

Mitigation. ACS Symposium Series Vol. 915. Washington, DC: American Chemical Society/Oxford University Press.

Articles and Book Chapters

Wallis I., H. Prommer, D. Vlassopoulos, 2014. Numerical modelling. In *In-Situ Remediation of Arsenic-Contaminated Sites.* J. Bundschuh, H. Hollander, and L. Ma, editors. *CRC Press.*

Serrano S., D. Vlassopoulos, F. Garrido, and P.A. O'Day, 2013. A combined site-specific metals sorption and transport model for intact soil columns. *Vadose Zone Journal* doi:10.2136/vzj2012.0152.

Serrano S., D. Vlassopoulos, B. Bessinger, and P.A. O'Day, 2012. Immobilization of Hg(II) by co-precipitation in sulfate-cement systems. *Environmental Science & Technology* dx.doi.org/10.1021/es202939v.

Bessinger, B.A., D. Vlassopoulos, S. Serrano, and P.A. O'Day, 2012. Reactive transport modeling of subaqueous sediment caps and implications for the long-term fate of arsenic, mercury, and methylmercury. *Aquatic Geochemistry* dx.doi.org/10.1007/s10498-012-9165-4.

O'Day, P. A., and D. Vlassopoulos, 2010. Mineral-based amendments for remediation. *Elements* 6: 375-381.

Vlassopoulos, D., B. Bessinger, and P. O'Day, 2010. Aqueous solubility of As_2S_3 and thermodynamic stability of thioarsenites. Birkle, P., and I.S. Torres-Alvarado, editors. Boca Raton: CRC Press. *In Water-Rock Interaction* 823-826.

Root, R.A, D. Vlassopoulos, N.A. Rivera, M.T. Rafferty, C. Andrews, and P.A. O'Day, 2009. Speciation and natural attenuation of arsenic and iron in a tidally influenced shallow aquifer. *Geochimica et Cosmochimica Acta* 73: 5528-5553.

Serrano, S., P.A. O'Day, D. Vlassopoulos, M.T. Garcia-Gonzalez, and F. Garrido, 2009. A surface complexation and ion exchange model of Pb and Cd competitive sorption on natural soils. *Geochimica et Cosmochimica Acta* 73:543-558.

Adams, D.J., B. Faris, and D. Vlassopoulos, 2006. Evaluating in situ bioremediation for groundwater cleanup. *Chemical Engineering Progress* 102, no. 2:20-28.

Vlassopoulos, D., N. Rivera, P.A. O'Day, M.T. Rafferty, and C.B. Andrews, 2005. Arsenic removal by zero-valent iron: a field study of rates, mechanisms, and long-term performance. In *Advances in Arsenic Research: Integration of Experimental and Observational Studies and Implications for Mitigation*. O'Day, P.A., D. Vlassopoulos, X. Meng, and L.G. Benning, editors. *ACS Symposium Series, American Chemical Society* 915:344-360.

O'Day, P.A., D. Vlassopoulos, R. Root, and N. Rivera, 2004. The influence of sulfur and iron on dissolved arsenic concentrations in the shallow subsurface under changing redox conditions. *Proceedings of the National Academy of Sciences of the United States of America* 101:13703-13708.

Faris, B., and D. Vlassopoulos, 2003. A systematic approach to in situ bioremediation in groundwater. *Remediation* 13:27-52.

Raffensperger, J.P., and D. Vlassopoulos, 1999. The potential for free and mixed convection in sedimentary basins. *Hydrogeology Journal* 7:505-520.

Wood, S.A., C.D. Tait, D. Vlassopoulos, and D.R. Janecky, 1994. Solubility and spectroscopic studies of the interaction of palladium with simple carboxylic acids and fulvic acid at low temperature. *Geochimica et Cosmochimica Acta* 58:625-637.

Vlassopoulos, D., G.R. Rossman, and S.E. Haggerty, 1993. Coupled substitution of H and minor elements in rutile and implications of high OH contents in Nb- and Cr-rich rutile from the upper mantle. *American Mineralogist* 78:1181-1191.

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St-Seymour, K., D. Vlassopoulos, T.H. Pearce, and C. Rice, 1990. The record of magma chamber processes in plagioclase phenocrysts at Thera Volcano, Aegean Volcanic Arc, Greece. *Contributions to Mineralogy and Petrology* 104:73-84.

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Wood, S.A., and D. Vlassopoulos, 1990. The dispersion of Pt, Pd, and Au in surficial media about two PGE-Cu-Ni prospects in Quebec. *Canadian Mineralogist* 28:649-663.

Wood, S.A., D. Vlassopoulos, and A. Mucci, 1990. Effects of concentrated matrices on the determination of trace levels of palladium and gold in aqueous samples using solvent extraction-Zeeman effect graphite furnace atomic absorption spectrometry and inductively coupled plasma-mass spectrometry. *Analytica Chimica Acta* 229:227-318.

St-Seymour, K., and D. Vlassopoulos, 1989. The potential for future explosive volcanism associated with dome growth at Nisyros, Aegean Volcanic Arc, Greece. *Journal of Volcanology and Geothermal Research* 37:351-364.

Wood, S.A., and D. Vlassopoulos, 1989. Experimental determination of the hydrothermal solubility and speciation of tungsten at 500° C and 1 kbar. *Geochimica et Cosmochimica Acta* 53:303-312.

St-Seymour, K., S. Kumarapeli, and D. Vlassopoulos, 1988. Petrotectonics of Achaean Yasinski Metabasalts, Superior Province, Canada: Implications for genesis of Achaean greenstone belts. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* 177:165-183.

Theses

Vlassopoulos, D., 2000. *The Origins of Molecular Nitrogen in the Subsurface: Thermodynamic, Kinetic and Isotopic Constraints*. PhD dissertation. University of Virginia, Virginia.

Vlassopoulos, D., 1989. *Some Experimental Studies Bearing on the Solubility and Speciation of Gold in Natural Waters*. MS thesis. McGill University, Montreal, Quebec, Canada.

Selected Conference Presentations

Vlassopoulos, D., J. Goin, E.A. Henry, and D. Glaser, 2014. Suppression of Methylmercury in Sediments by Manganese(IV) Oxide. Presented at Goldschmidt 2014, Sacramento, California, June 2014.

Goin J., D. Vlassopoulos, M. Larsen, and S. Germiat, 2014. Soil and Groundwater Mercury Remediation at a Former Chlor Alkali Plant. Presented at the Ninth International

Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 2014.

Vlassopoulos, D., J. Goin, and M. Carey, 2013. Siderite amendment for in situ pH control in hyperalkaline environments. Presented at Goldschmidt 2013, Florence, Italy, August 2013.

O'Day, P.A., S. Serrano, V. Illera and D. Vlassopoulos, 2013. Remediation strategies for redox-active elements using combined experimental, spectroscopic, and computational approaches. Invited presentation at Goldschmidt 2013, Florence, Italy, August 2013.

Vlassopoulos, D., M. Carey, B. Henry, D. Glaser, S.S. Brown and E. Tokarski, 2013. Remediation of mercury-contaminated sediments: a mechanistic analysis of in situ treatment alternatives. Presented at International Conference on Mercury as a Global Pollutant, Edinburgh, Scotland, July 2013.

Vlassopoulos, D., 2013. Effective Use of Environmental Experts: A Practitioner’s Perspective. Invited lecture presented at Washington State Bar Association Environmental and Land Use Law Section Midyear Meeting and Seminar, Alderbrook Resort, Union, Washington, May 2013.

Vlassopoulos, D., M. Carey, and P. Royer, 2013. Multitracer models of groundwater age, mixing, and renewal in the Columbia Basin GWMA. Presented at the Ninth Washington Hydrogeology Symposium, Tacoma, Washington, April 2013.

Carey, M., D. Vlassopoulos, C. Patmont, and J. Laplante, 2013. Groundwater-surface water interactions and sulfide toxicity in marine sediments – a reactive transport modeling approach. Presented at the Ninth Washington Hydrogeology Symposium, Tacoma, Washington, April 2013.

Goin, J., D. Vlassopoulos, J. Mak, and M. Riley, 2013. Geochemical and isotopic evaluation of a potential subsurface combustion event. Presented at the Ninth Washington Hydrogeology Symposium, Tacoma, Washington, April 2013.

Vlassopoulos, D., M. Swanson-Theisen, J. Goin, G.R. Johnson, C. Kiehl-Simpson, and E. Glaza, 2013. A siderite-amended reactive cap for high pH sediments of Onondaga Lake, New York. Presented at Seventh International Conference on Remediation of Contaminated Sediments, Dallas, Texas, February 2013.

Vlassopoulos, D., D. Glaser, and B. Henry, 2013. Biogeochemical framework for design and assessment of in situ remediation strategies for mercury-contaminated sediments. Seventh International Conference on Remediation of Contaminated Sediments, Dallas, Texas, February 2013.

Serrano, S., D. Vlassopoulos, B. Bessinger, and P.A. O’Day, 2011. Hg(II) Sequestration by Ettringite-Type Phases, A Geochemical Modeling and EXAFS Study. Presented at Goldschmidt 2011, Prague, Czech Republic, August 2011.

O'Day, P.A., S. Serrano, T. Stilson, and D. Vlassopoulos, 2011. Mercury Distribution and Speciation in a Seasonal Wetland Impacted by Mine Waste. Presented at Goldschmidt 2011, Prague, Czech Republic, August 2011.

Vlassopoulos, D., and P.A. O’Day, 2011. Approaches to In Situ Remediation of Mercury and Arsenic-Contaminated Soils and Sediments Using Mineral Amendments. Invited presentation at the Mineralogical Society Annual Meeting 2011: Frontiers in Environmental Geoscience, Aberystwyth, Wales, June 2011.

Bessinger, B., and D. Vlassopoulos, 2011. A Reactive Transport Model of Mercury Fate in Sediment. Presented at the Eighth Washington Hydrogeology Symposium, Tacoma, Washington, April 2011.

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APPENDIX B
SEDIMENT ANALYTICAL RESULTS

Appendix B-1
Total Metals in Sediment

ID	Start Depth (cm)	End Depth (cm)	Midpoint (cm)	Aluminum (mg/kg)	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Cadmium (mg/kg)	Calcium (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Iron (mg/kg)	Lead (mg/kg)	Magnesium (mg/kg)	Manganese (mg/kg)	Nickel (mg/kg)	Potassium (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Sodium (mg/kg)	Thallium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
Method Blank				<500	<10	<10	<10	<2	<2	<1000	<10	<2	<10	<500	<2	<500	<10	<10	<1000	<10	<2	<1000	<2	<10	<40
BON2-0102	1.0	2.0	1.5	8,657	<10	27.45	97.19	<2	<2	9,198	26.45	3.61	22.44	9,880	22.65	2,445	442.9	65.33	<1000	<10	<2	<1000	<2	24.45	59.92
BON2-0203	2.0	3.0	2.5	9,277	<10	29.72	99.20	<2	<2	8,614	42.57	4.02	21.29	11,205	25.90	2,369	443.8	50.60	<1000	<10	<2	<1000	<2	23.09	59.84
BON2-0304	3.0	4.0	3.5	9,053	<10	29.39	97.63	<2	<2	8,481	43.00	3.55	19.92	11,854	32.15	2,387	435.9	59.76	<1000	<10	<2	<1000	<2	24.65	59.96
BON2-0405	4.0	5.0	4.5	9,183	<10	31.87	92.63	<2	<2	8,347	55.78	3.59	26.10	12,311	42.23	2,410	428.3	74.50	<1000	<10	<2	<1000	<2	24.50	62.35
BON2-0506	5.0	6.0	5.5	9,060	<10	32.20	92.00	<2	<2	8,080	32.40	3.40	21.60	12,000	44.20	2,320	414.0	48.80	<1000	<10	<2	<1000	<2	24.00	63.60
BON2-0607	6.0	7.0	6.5	9,763	<10	35.38	99.21	<2	<2	8,814	54.35	3.95	24.31	13,577	44.66	2,411	460.5	47.83	<1000	<10	<2	<1000	<2	26.09	67.19
BON2-0708	7.0	8.0	7.5	10,040	<10	38.49	101.2	<2	<2	9,087	30.56	3.37	21.03	14,087	45.44	2,401	478.2	50.60	<1000	<10	<2	<1000	<2	25.99	68.45
BON2-0809	8.0	9.0	8.5	9,699	<10	34.07	92.59	<2	<2	8,617	60.32	3.81	22.04	12,565	41.28	2,204	444.9	56.91	<1000	<10	<2	<1000	<2	25.65	64.73
BON2-0910	9.0	10.0	9.5	9,743	<10	33.86	90.69	<2	<2	8,733	45.15	3.37	20.00	12,535	46.34	2,257	437.6	44.36	<1000	<10	<2	<1000	<2	26.34	65.54
BON2-1011	10.0	11.0	10.5	9,783	<10	31.03	86.96	<2	<2	8,893	51.58	3.75	19.76	11,324	44.07	2,154	426.9	49.41	<1000	<10	<2	<1000	<2	25.89	58.89
BON2-1112	11.0	12.0	11.5	9,441	<10	28.74	84.43	<2	<2	8,762	37.13	2.99	16.97	10,299	35.13	2,076	415.2	46.11	<1000	<10	<2	<1000	<2	25.35	55.89
BON2-1213	12.0	13.0	12.5	9,479	<10	26.85	83.17	<2	<2	8,858	62.32	2.61	17.23	10,020	30.86	2,024	410.8	46.69	<1000	<10	<2	<1000	<2	25.05	54.11
BON2-1314	13.0	14.0	13.5	9,376	<10	22.54	79.68	<2	<2	8,974	67.40	3.02	17.30	8,954	21.93	1,970	398.4	62.98	<1000	<10	<2	<1000	<2	23.14	48.49
BON2-1516	15.0	16.0	15.5	8,920	<10	20.20	76.00	<2	<2	9,200	73.20	3.00	16.60	7,860	13.20	1,834	398.0	55.40	<1000	<10	<2	<1000	<2	21.00	40.60
BON2-1718	17.0	18.0	17.5	9,237	<10	18.07	77.11	<2	<2	9,217	108.8	3.21	20.08	8,153	5.42	1,795	407.6	112.0	<1000	<10	<2	<1000	<2	18.67	<40
BON2-2224	22.0	24.0	23.0	10,579	<10	19.56	76.85	<2	<2	9,461	73.45	2.59	16.17	9,481	2.99	1,762	361.3	43.11	<1000	<10	<2	<1000	<2	19.16	<40
BON2-2830	28.0	30.0	29.0	7,854	<10	15.79	61.54	<2	<2	8,117	28.54	2.23	11.54	8,866	2.02	1,543	249.0	32.39	<1000	<10	<2	<1000	<2	18.62	<40
BON2-3234	32.0	34.0	33.0	7,863	<10	19.56	63.71	<2	<2	9,093	69.15	2.62	15.12	10,262	2.02	1,589	314.5	35.08	<1000	<10	<2	<1000	<2	17.74	<40
BON2-3638	36.0	38.0	37.0	7,816	<10	17.43	63.93	<2	<2	8,898	35.67	2.40	10.62	8,758	2.20	1,633	302.6	30.86	<1000	<10	<2	<1000	<2	18.24	<40
BON2-4042	40.0	42.0	41.0	9,487	<10	18.74	70.61	<2	<2	8,343	103.4	3.35	19.33	10,769	2.37	1,606	268.2	46.75	<1000	<10	<2	<1000	<2	22.09	<40
BON2-4446	44.0	46.0	45.0	7,645	<10	10.98	54.89	<2	<2	6,846	96.21	3.19	16.37	7,325	<2	1,387	223.6	61.88	<1000	<10	<2	<1000	<2	19.76	<40
BON2-5254	52.0	54.0	53.0	9,540	<10	12.80	71.20	<2	<2	8,500	87.40	4.00	17.40	8,480	3.20	2,040	264.0	110.6	<1000	<10	<2	<1000	<2	32.00	<40
CDR3-0001*	0.0	1.0	0.5	2,043	<36.2	<36.2	130.4	<7.25	<7.25	73,913	<36.2	<7.25	<36.2	11,304	65.94	3,435	289.9	48.55	<3625	42.75	<7.25	<3625	<7.25	<36.2	245.7
CDR3-0203	2.0	3.0	2.5	1,731	<10	10.63	133.8	<2	2.29	125,000	13.75	2.50	10.42	9,333	45.21	2,896	302.1	25.00	<1000	32.50	<2	<1000	<2	17.71	144.6
CDR3-0405	4.0	5.0	4.5	1,830	<10	12.06	166.3	<2	2.91	184,823	<10	3.53	12.68	16,674	55.09	3,015	453.2	20.58	<1000	39.50	<2	<1000	<2	19.75	176.5
CDR3-0607	6.0	7.0	6.5	2,545	15.82	19.45	177.8	<2	4.55	66,364	15.64	3.45	19.64	12,145	109.5	2,345	285.5	24.91	<1000	62.18	<2	<1000	<2	27.09	327.3
CDR3-0708	7.0	8.0	7.5	2,568	13.78	16.49	217.1	<2	5.22	83,507	<10	2.51	16.08	10,313	109.6	2,255	304.8	17.75	<1000	59.71	<2	<1000	<2	24.63	448.9
CDR3-0809	8.0	9.0	8.5	2,795	13.07	17.24	237.7	<2	5.26	115,971	10.34	2.90	19.06	11,561	124.1	2,613	384.8	23.23	<1000	47.91	<2	<1000	<2	21.78	294.0
CDR3-0910	9.0	10.0	9.5	3,394	15.35	24.85	164.0	<2	5.86	95,960	12.73	3.64	21.01	12,566	173.5	2,667	371.7	28.08	<1000	51.31	<2	<1000	<2	24.65	341.4
CDR3-1011	10.0	11.0	10.5	3,932	17.74	26.50	111.3	<2	8.76	64,530	14.74	3.63	20.30	12,393	230.8	2,628	320.5	27.14	<1000	41.88	<2	<1000	<2	25.21	406.0
CDR3-1112	11.0	12.0	11.5	4,183	25.27	33.33	84.75	<2	14.38	38,562	12.20	3.70	48.15	13,355	503.3	2,331	296.3	25.05	<1000	49.67	<2	<1000	<2	24.18	616.6
CDR3-1213	12.0	13.0	12.5	4,347	37.16	39.86	97.75	<2	22.30	47,973	18.47	4.95	23.87	15,541	855.9	2,365	353.6	30.86	<1000	65.54	<2	<1000	<2	24.10	741.0
CDR3-1314	13.0	14.0	13.5	3,557	34.90	31.99	119.9	<2	19.02	84,116	<10	4.25	16.55	11,521	637.6	2,260	337.8	17.45	<1000	55.70	<2	<1000	<2	23.71	510.1
CDR3-1617	16.0	17.0	16.5	3,320	18.91	13.08	215.3	<2	8.25	201,207	<10	2.21	18.11	5,996	442.7	2,857	346.1	14.49	<1000	26.96	<2	<1000	<2	13.88	311.9
CDR3-1819	18.0	19.0	18.5	1,823	<10	<10	260.4	<2	2.43	269,097	<10	1.74	<10	4,479	116.0	2,899	343.8	9.38	<1000	9.90	<2	<1000	<2	<10	89.24
CDR3-2022	20.0	22.0	21.0	1,365	<10	<10	214.7	<2	<2	216,514	<10	1.83	<10	4,954	18.17	2,514	282.6	<10	<1000	<10	<2	<1000	<2	<10	38.53
CDR3-2426	24.0	26.0	25.0	18,056	<10	16.27	365.1	<2	<2	17,401	55.95	12.10	43.25	29,762	21.03	8,790	446.4	56.15	4,167	17.06	<2	<1000	<2	89.48	248.0
CDR3-2628	26.0	28.0	27.0	27,435	<10	16.90	548.7	<2	2.39	12,346	75.75	15.51	61.83	36,779	30.22	12,545	536.8	77.14	6,600	22.27	<2	<1000	<2	138.6	340.0
CDR3-2830	28.0	30.0	29.0	6,230	<10	11.51	151.2	<2	<2	14,742	39.29	4.76	13.69	10,714	5.75	4,087	254.0	28.57	1,508	14.09	<2	<1000	<2	34.33	94.64
CDR3-3234	32.0	34.0	33.0	2,495	<10	9.90	84.75	<2	<2	15,723	74.46	3.96	12.28	9,960	<2	2,297	281.2	28.32	<1000	14.46	<2	<1000	<2	12.08	64.75
CDR3-3638	36.0	38.0	37.0	3,261	<10	13.04	91.11	<2	<2	14,664	48.62	4.55	16.01	12,352	2.37	2,055	304.3	27.47	<1000	16.80	<2	<1000	<2	20.16	84.58
CDR3-4042	40.0	42.0	41.0	4,591	<10	<10	71.86	<2	<2	10,798	135.3	5.59	22.95	13,174	<2	1,645	303.4	69.86	<1000	15.97	<2	<1000	<2	15.37	59.88
CDR3-4446	44.0	46.0	45.0	3,088	<10	15.94	114.1	<2	<2	18,665	32.47	4.58	15.34	14,622	<2	2,052	406.4	26.10	<1000	21.51	<2	<1000	<2	16.93	100.4
CDR3-4850	48.0	50.0	49.0	3,480	<10	21.40	111.0	<2	<2	18,080	25.20	5.60	18.20	19,320	2.20	2,240	412.0	28.20	<1000	33.00	<2	<1000	<2	18.60	102.6
CDR3-5254.5	52.0	54.5	53.3	4,941	<10	33.60	159.1	<2	2.57	24,901	21.94	6.92	27.67	27,470	4.15	2,332	671.9	32.61	<1000	45.26	<2	<1000	<2	43.28	136.6
ELN2-0004	0.0	4.0	2.0	9,333	<10	<10	100.4	<2	<2	7,010	26.46	3.23	14.34	14,101	37.17	2,081	497.0	30.71	<1000	<10	<2	<1000	<2	22.42	68.48
ELN2-0405	4.0	5.0	4.5	11,042	<10	<10	102.6	<2	<2	7,395	23.85	3.81	16.23	16,954	51.70	2,265	448.9	59.12	1,002	<10	<2	<1000	<2	25.05	104.2
ELN2-0607	6.0	7.0	6.5	11,784	<10	<10	102.6	<2	<2	8,016	35.87	4.41	18.44	16,733	54.31	2,445	446.9	37.88	1,018	<10	<2	<1000	<2	27.25	85.57
ELN2-0809	8.0	9.0	8.5	10,938	<10	<10	98.00	<2	<2	7,405	30.54	3.79	15.77	14,571	50.50	2,236	439.1	42.32	<1000	<10	<2	<1000	<2	25.35	81.24
ELN2-1011	10.0	11.0	10.5	11,680	<10	<10	103.0	<2	<2	7,720	40.20	4.00	20.00	20,000	75.00	2,280	438.0	41.60	1,100	<10	<2	<1000	<2	30.40	95.40
ELN2-1112	11.0	12.0	11.5	12,525	<10	12.53	110.3	<2	<2	8,040	45.86	4.24	21.62	22,626	92.53	2,444	454.5	40.20	<1000	<10	<2	<1000	<2	32.73	106.9

Appendix B-1
Total Metals in Sediment

ID	Start Depth (cm)	End Depth (cm)	Midpoint (cm)	Aluminum (mg/kg)	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Cadmium (mg/kg)	Calcium (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Iron (mg/kg)	Lead (mg/kg)	Magnesium (mg/kg)	Manganese (mg/kg)	Nickel (mg/kg)	Potassium (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Sodium (mg/kg)	Thallium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
ELN2-1213	12.0	13.0	12.5	12,429	<10	13.36	111.5	<2	2.02	7,530	59.72	4.45	25.91	23,482	101.0	2,409	429.1	88.06	<1000	<10	<2	<1000	<2	34.21	116.0
ELN2-1314	13.0	14.0	13.5	12,702	<10	12.90	114.9	<2	2.02	6,875	40.52	4.44	18.95	21,371	97.18	2,399	387.1	58.87	1,123	<10	<2	<1000	<2	34.88	113.5
ELN2-1415	14.0	15.0	14.5	13,459	<10	12.92	114.1	<2	1.99	7,952	46.72	4.97	20.68	23,857	112.9	2,505	427.4	70.18	1,191	<10	<2	2,883	<2	35.19	127.8
ELN2-1516	15.0	16.0	15.5	12,635	<10	10.98	99.40	<2	3.39	7,864	51.30	4.19	21.96	22,954	144.3	2,196	423.2	63.47	1,002	<10	<2	<1000	<2	34.33	139.3
ELN2-1617	16.0	17.0	16.5	10,733	<10	<10	88.12	<2	3.56	7,089	54.06	3.56	19.21	17,683	161.6	1,921	388.1	53.86	<1000	<10	<2	<1000	<2	28.71	123.6
ELN2-1819	18.0	19.0	18.5	10,141	<10	<10	80.61	<2	3.64	7,030	60.40	3.84	17.17	14,848	168.3	1,820	379.8	52.12	<1000	<10	<2	<1000	<2	25.05	96.36
ELN2-2022	20.0	22.0	21.0	9,740	<10	<10	75.20	<2	2.20	7,040	49.20	3.60	16.80	13,100	152.0	1,868	362.0	52.40	<1000	<10	<2	<1000	<2	22.60	85.20
ELN2-2426	24.0	26.0	25.0	8,802	<10	<10	70.06	<2	2.20	7,086	55.29	2.79	15.77	10,599	134.1	1,721	337.3	25.75	<1000	<10	<2	<1000	<2	21.16	65.47
ELN2-2628	26.0	28.0	27.0	7,619	<10	<10	61.90	<2	<2	7,202	49.01	2.58	13.29	9,127	99.01	1,585	333.3	21.63	<1000	<10	<2	<1000	<2	18.65	55.56
ELN2-2830	28.0	30.0	29.0	7,480	<10	<10	58.20	<2	<2	7,240	54.40	2.40	15.00	8,360	69.20	1,508	330.0	24.60	<1000	<10	<2	<1000	<2	18.60	49.00
ELN2-3234	32.0	34.0	33.0	5,689	<10	<10	49.70	<2	<2	7,246	25.95	<2	<10	6,707	11.18	1,162	301.4	12.38	<1000	<10	<2	<1000	<2	13.77	41.12
ELN2-3638	36.0	38.0	37.0	4,352	<10	5.06	40.08	<2	<2	6,599	17.81	<2	<10	4,150	4.86	959.5	273.3	<10	<1000	<10	<2	<1000	<2	10.12	<40
ELN2-4042	40.0	42.0	41.0	4,547	<10	<10	40.64	<2	<2	7,062	18.91	<2	<10	4,849	3.42	998.0	269.6	<10	<1000	<10	<2	<1000	<2	<10	<40
ELN2-4446	44.0	46.0	45.0	4,137	<10	<10	41.97	<2	<2	7,129	23.69	<2	<10	5,602	<2	1,028	277.1	11.65	<1000	<10	<2	<1000	<2	<10	<40
ELN2-4850	48.0	50.0	49.0	4,016	<10	<10	41.16	<2	<2	7,309	15.06	<2	<10	3,695	3.82	1,050	273.1	<10	<1000	<10	<2	<1000	<2	<10	<40
ELN2-5254	52.0	54.0	53.0	4,208	<10	<10	45.09	<2	<2	8,397	18.44	<2	10.82	4,088	4.21	1,170	304.6	<10	<1000	<10	<2	<1000	<2	<10	41.88
ELN2-5661	56.0	61.0	58.5	4,158	<10	<10	42.18	<2	<2	6,772	20.99	<2	<10	5,505	3.17	940.6	279.2	17.23	<1000	<10	<2	<1000	<2	<10	<40
ELN2-4850 rep	48.0	50.0	49.0	4,045	<10	<10	47.38	<2	<2	8,052	25.66	<2	<10	6,423	3.93	1,105	325.8	18.54	<1000	<10	<2	<1000	<2	11.05	<40
ELN2-5254 rep	52.0	54.0	53.0	4,288	<10	<10	32.71	<2	<2	5,864	10.34	<2	<10	3,220	<2	796.6	220.3	<10	<1000	<10	<2	<1000	<2	8.98	<40
MS2711	Standard			23,228	<19.7	99.21	211.0	<3.9	41.73	19,488	23.23	8.27	103.1	25,039	1,161	8,386	566.9	<19.7	5,433	<19.7	<8.66	<1970	<3.94	58.66	328.0
MS2711	Standard			21,583	18.35	100.00	208.3	<3.6	41.37	19,281	23.38	9.35	96.04	24,748	1,151	8,165	554.0	<18.0	5,036	<18.0	<9.35	<1800	<3.60	56.12	330.2
MS2711	Standard			20,568	18.94	100.00	205.7	<3.8	40.91	19,015	23.11	8.33	100.8	24,318	1,144	7,917	545.5	<18.9	4,848	<18.9	<9.09	<1900	<3.79	56.06	325.0

Note:
CDR3-0001* - elevated MDLs due to low sample mass

Appendix B-2
Sediment Core Radioisotope Data

Sample	Depth Interval	210Pb	error	137Cs	error	226Ra	error
Units:	cm	dpm/g		dpm/g		dpm/g	
BON-2-0102	1-2 cm	49.49	2.51	4.78	0.31	0.71	0.32
BON-2-0203	2-3 cm	40.56	1.67	5.44	0.23	0.56	0.21
BON-2-0304	3-4 cm	44.35	1.51	6.84	0.22	1.34	0.21
BON-2-0405	4-5 cm	44.34	2.18	10.14	0.35	2.02	0.31
BON-2-0506	5-6 cm	41.44	2.29	14.46	0.43	0.78	0.21
BON-2-0607	6-7 cm	29.56	1.37	9.26	0.54	0.96	0.30
BON-2-0708	7-8 cm	30.90	1.37	9.15	0.27	1.41	0.23
BON-2-0809	8-9 cm	16.34	1.13	4.39	0.20	0.79	0.10
BON-2-0910	9-10 cm	19.33	1.26	6.27	0.21	0.35	0.11
BON-2-1011	10-11 cm	10.09	0.83	4.36	0.15	1.38	0.17
BON-2-1112	11-12 cm	11.00	1.02	3.47	0.17	1.24	0.17
BON-2-1213	12-13 cm	5.92	0.74	0.85	0.08	1.06	0.14
BON-2-1314	13-14 cm	5.06	0.59	0.60	0.06	1.08	0.12
BON-2-1516	15-16 cm	3.10	0.53	0.38	0.07	0.74	0.10
BON-2-1718	17-18 cm	3.33	0.71	0.41	0.08	1.03	0.15
BON-2-2224	22-24 cm	0.99	0.48	0.25	0.05	0.87	0.08
BON-2-2830	28-30 cm	1.77	0.39	0.16	0.04	0.94	0.08
BON-2-3234	32-34 cm	0.96	0.36	0.12	0.04	0.95	0.08
BON-2-3638	36-38 cm	0.98	0.43	0.16	0.05	0.90	0.09
BON-2-4042	40-42 cm	0.54	0.34	0.00	0.00	6.06	0.58
BON-2-4446	44-46 cm	0.87	0.30	0.00	0.00	0.94	0.06
BON-2-5254	52-54 cm	0.94	0.29	0.00	0.00	1.05	0.06
ELN-2-0004	0-4 cm	70.05	1.07	4.44	0.09	1.69	0.08
ELN-2-0405	4-5 cm	47.07	1.58	4.38	0.18	1.03	0.21
ELN-2-0607	6-7 cm	59.42	1.57	5.69	0.20	1.57	0.17
ELN-2-0809	8-9 cm	52.29	1.36	5.02	0.14	1.39	0.14
ELN-2-1011	10-11 cm	32.29	1.00	6.65	0.17	1.40	0.15
ELN-2-1112	11-12 cm	33.48	1.15	9.76	0.24	1.98	0.18
ELN-2-1213	12-13 cm	32.66	1.25	10.18	0.25	1.58	0.22
ELN-2-1314	13-14 cm	27.79	0.85	13.74	0.23	1.98	0.17
ELN-2-1415	14-15 cm	24.82	0.90	14.42	0.28	2.10	0.21
ELN-2-1516	15-16 cm	29.16	1.10	8.12	0.20	1.96	0.17
ELN-2-1617	16-17 cm	22.73	1.09	2.28	0.12	1.84	0.15
ELN-2-1819	18-19 cm	14.91	0.91	1.96	0.13	1.94	0.16
ELN-2-2022	20-22	8.83	0.55	0.41	0.06	1.31	0.10
ELN-2-2426	24-26	7.80	0.58	0.54	0.07	1.38	0.10
ELN-2-2628	26-28	6.10	0.51	0.33	0.06	0.84	0.09
ELN-2-28-30	28-30	4.83	0.54	0.25	0.05	1.14	0.09
ELN-2-3234	32-34	3.12	0.36	0.15	0.03	0.91	0.07
ELN-2-3638	36-38	3.58	0.52	0.14	0.04	0.77	0.09
ELN-2-4042	40-42	2.11	0.46	0.00	0.00	0.72	0.09
ELN-2-4446	44-46	1.36	0.39	0.00	0.00	0.59	0.00
ELN-2-4850	48-50	4.39	0.58	0.00	0.00	0.75	0.11

Appendix B-2
Sediment Core Radioisotope Data

Sample	Depth Interval	210Pb	error	137Cs	error	226Ra	error
Units:	**cm**	**dpm/g**		**dpm/g**		**dpm/g**	
CDR3-0001	0-1 cm	51.16	3.29	0.91	0.25	2.27	0.46
CDR3-0203	2-3 cm	31.75	1.59	0.64	0.15	1.12	0.28
CDR3-0405	4-5 cm	33.57	1.21	0.53	0.08	0.87	0.13
CDR3-0405-D	4-5 cm	34.44	1.34	0.51	0.09	0.82	0.14
CDR3-0607	6-7 cm	33.48	1.31	1.03	0.12	0.59	0.06
CDR3-0708	7-8 cm	43.14	1.76	2.26	0.17	0.65	0.16
CDR3-0809	8-9 cm	26.01	1.52	3.09	0.17	0.89	0.08
CDR3-0809-D	8-9 cm	23.68	1.35	2.82	0.16	0.54	0.08
CDR3-0910	9-10 cm	28.30	1.22	8.32	0.25	0.87	0.12
CDR3-1011	10-11 cm	23.61	1.45	10.83	0.31	0.94	0.15
CDR3-11-12	11-12 cm	22.19	1.59	7.04	0.26	0.00	0.13
CDR3-1213	12-13 cm	13.43	1.46	2.53	0.19	0.87	0.09
CDR3-1314	13-14 cm	9.32	1.13	0.70	0.12	0.67	0.17
CDR3-1617	16-17 cm	3.75	0.57	0.35	0.07	0.93	0.10
CDR3-1819	18-19 cm	2.29	0.30	0.04	0.82	0.87	0.41
CDR3-20-22	20-22 cm	1.43	0.28	0.09	0.03	0.70	0.06
CDR3-2426	24-26 cm	2.15	0.37	0.28	0.05	2.23	0.09
CDR3-2426-D	24-26 cm	2.38	0.52	0.35	0.06	2.56	0.11
CDR3-2830	28-30 cm	0.00	0.00	0.00	0.00	1.47	0.17
CDR3-4850	48-50 cm	0.00	0.00	0.00	0.00	0.86	0.08
CDR3-52-54	52-54 cm	0.00	0.00	0.00	0.00	1.32	0.07

Pb Isotope Compositions:
Core Sediment Samples from Cedar, Ellen and Bonaparte Lakes (Washington) – Sample Suite #2 and Compilation of Previous Data

for

ANCHOR QEA, LLC and
Short Cressman & Burgess PLLC

Dr. Bruce K. Nelson
Isotope Geochemistry Laboratory
Dept. of Earth & Space Sciences
University of Washington

July 20, 2014

Introduction:

Samples from deep sediment cores were provided to the UW Isotope Geochemistry Laboratory from three northern Washington Lakes: Cedar, Ellen and Bonaparte. This report details the results of the Pb isotope analyses of a second subset of the core samples from each lake. Results of analyses of the previous sample suites were originally presented in a report dated June 13, 2014, and those results are incorporated here to provide a summary of all lake sediment core samples analyzed to date.

Accompanying this report is an electronic file that contains the Pb isotope analyses, isotope standard data, and the graphics presented below [Excel file: "Cedar Ellen Bonaparte core data sent July 20 2014"].

Pb Isotope Analyses:

The samples that were analyzed since the previous report of June 13, 2014, and first reported here, are listed in Table 1. In all other tables and figures in this report, data from all samples analyzed to date are compiled.

After chemical purification of Pb, the samples were analyzed for Pb isotope composition on a Nu Plasma, multiple-collector inductively coupled plasma mass spectrometer at the University of Washington over four sessions: Cedar Lake samples on May 30, 2014, Ellen Lake samples on May 31, 2014, Bonaparte Lake samples on June 13, 2014 and a total of 20 samples selected from all three lakes on July 18, 2014.

The compiled Pb isotope compositions of all analyzed samples are presented in Table 2.

NIST 981 (NBS 981) Pb isotope standard was run before and after every two or three samples. Data for 17 analyses of internal laboratory rock standard (UWBCR-1) are also provided in Table 3. Typically, the rock standard was run at the beginning and end of each daily session. Isotopic compositions of the rock standard analyses define the quoted error of ±350 ppm (2 sigma). The measured Pb isotope values of the rock standards are well within 350 ppm of the average of all previous runs (n=23) of the rock standard that accompanied previous analytical work. Consequently, the measured ratios of samples reported here are directly comparable to values of all previously analyzed samples from this laboratory.

All samples were prepared according to previously documented standard analytical procedures.

Table 1: Pb Isotope Compositions of Sediment Core Samples Analyzed July 18, 2014

Sample	Average depth (cm)	^{206}Pb/^{204}Pb	^{207}Pb/^{204}Pb	^{208}Pb/^{204}Pb
Cedar Lake				
Cedar(1) CDR3-0001	*0.5*	*17.303*	*15.523*	*37.058*
Cedar(3) CDR3-0405	*4.5*	*17.379*	*15.530*	*37.109*
Cedar(4) CDR3-0607	*6.5*	*17.215*	*15.513*	*36.932*
Cedar(5) CDR3-0708	*7.5*	*17.150*	*15.506*	*36.860*
Cedar(8) CDR3-1011	*10.5*	*17.112*	*15.505*	*36.853*
Cedar(16) CDR3-2628	*27.0*	*19.418*	*15.677*	*39.095*
Cedar(17) CDR3-2830	*29.0*	*19.252*	*15.664*	*38.992*
Cedar(18) CDR3-3234	*33.0*	*18.934*	*15.642*	*38.739*
Cedar(20) CDR3-4042	*41.0*	*18.877*	*15.594*	*38.619*
Cedar(21) CDR3-4446	*45.0*	*19.121*	*15.659*	*38.920*
Ellen Lake				
Ellen(1) ELN2-0004	*2.0*	*17.839*	*15.561*	*37.545*
Ellen(4) ELN2-0809	*8.5*	*17.775*	*15.557*	*37.475*
Ellen(5) ELN2-1011	*10.5*	*17.790*	*15.557*	*37.479*
Ellen(7) ELN2-1213	*12.5*	*17.747*	*15.552*	*37.456*
Ellen(11) ELN2-1617	*16.5*	*17.052*	*15.501*	*36.765*
Ellen(12) ELN2-1819	*18.5*	*16.931*	*15.484*	*36.640*
Ellen(13) ELN2-2022	*21.0*	*16.989*	*15.488*	*36.733*
Ellen(14) ELN2-2426	*25.0*	*17.213*	*15.498*	*37.061*
Bonaparte Lake				
Bonaparte(7) BON2-0708	*7.5*	*18.114*	*15.580*	*37.859*
Bonaparte(13) BON2-1314	*13.5*	*17.846*	*15.540*	*37.712*

University of Washington Isotope Geochemistry Laboratory.

Error on Pb analyses is ±350 ppm (2 sigma) or ±0.035% for 206Pb/204 and 207Pb/204Pb, and ±400 ppm (2 sigma) or ±0.040% for 208Pb/204Pb.

Pb normalized to 205Tl/203Tl = 2.38714 and then to NIST 981 = 16.9356, 15.4891, 36.7006 (Todt et al., 1996) for 206Pb/204, 207Pb/204Pb and 208Pb/204Pb, respectively, by sample-standard bracketing.

Isotopic analyses conducted on July 18, 2014; analyst B.K.Nelson.

Compiled Results:

Table 2: Pb Isotope Compositions of Sediment Core Samples

Sample	**Average depth (cm)**	**^{206}Pb/^{204}Pb**	**^{207}Pb/^{204}Pb**	**^{208}Pb/^{204}Pb**
Cedar Lake				
Cedar(1) CDR3-0001	*0.5*	*17.303*	*15.523*	*37.058*
Cedar(2) CDR3-0203	2.5	17.338	15.519	37.078
Cedar(3) CDR3-0405	*4.5*	*17.379*	*15.530*	*37.109*
Cedar(4) CDR3-0607	*6.5*	*17.215*	*15.513*	*36.932*
Cedar(5) CDR3-0708	*7.5*	*17.150*	*15.506*	*36.860*
Cedar(6) CDR3-0809	8.5	17.223	15.508	36.942
Cedar(8) CDR3-1011	*10.5*	*17.112*	*15.505*	*36.853*
Cedar(10) CDR3-1213	12.5	16.709	15.474	36.370
Cedar(11) CDR3-1314	13.5	16.657	15.468	36.308
Cedar(12) CDR3-1617	16.5	16.858	15.474	36.607
Cedar(13) CDR3-1819	18.5	17.010	15.486	36.805
Cedar(14) CDR3-2022	21.0	17.564	15.523	37.443
Cedar(15) CDR3-2426	25.0	19.337	15.668	39.059
Cedar(16) CDR3-2628	*27.0*	*19.418*	*15.677*	*39.095*
Cedar(17) CDR3-2830	*29.0*	*19.252*	*15.664*	*38.992*
Cedar(18) CDR3-3234	*33.0*	*18.934*	*15.642*	*38.739*
Cedar(19) CDR3-3638	37.0	18.951	15.638	38.811
Cedar(20) CDR3-4042	*41.0*	*18.877*	*15.594*	*38.619*
Cedar(21) CDR3-4446	*45.0*	*19.121*	*15.659*	*38.920*
Cedar(23) CDR3-5254.5	53.3	19.430	15.669	39.038
Ellen Lake				
Ellen(1) ELN2-0004	*2.0*	*17.839*	*15.561*	*37.545*
Ellen(3) ELN2-0607	6.5	17.783	15.556	37.482
Ellen(4) ELN2-0809	*8.5*	*17.775*	*15.557*	*37.475*
Ellen(5) ELN2-1011	*10.5*	*17.790*	*15.557*	*37.479*
Ellen(7) ELN2-1213	*12.5*	*17.747*	*15.552*	*37.456*
Ellen(9) ELN2-1415	14.5	17.489	15.533	37.242
Ellen(11) ELN2-1617	*16.5*	*17.052*	*15.501*	*36.765*
Ellen(12) ELN2-1819	*18.5*	*16.931*	*15.484*	*36.640*
Ellen(13) ELN2-2022	*21.0*	*16.989*	*15.488*	*36.733*
Ellen(14) ELN2-2426	*25.0*	*17.213*	*15.498*	*37.061*
Ellen(15) ELN2-2628	27.0	17.420	15.513	37.321
Ellen(16) ELN2-2830	29.0	17.587	15.523	37.520
Ellen(17) ELN2-3234	33.0	18.051	15.565	37.977
Ellen(18) ELN2-3638	37.0	18.321	15.594	38.219
Ellen(19) ELN2-4042	41.0	18.689	15.624	38.527
Ellen(20) ELN2-4446	45.0	18.728	15.627	38.423
Ellen(22) ELN2-5254	53.0	18.177	15.578	37.961
Ellen(23) ELN2-5661	58.5	18.843	15.627	38.624

Bonaparte Lake				
Bonaparte(1) BON2-0102	1.5	18.318	15.593	38.059
Bonaparte(2) BON2-0203	2.5	18.364	15.597	38.071
Bonaparte(4) BON2-0405	4.5	18.340	15.599	38.025
Bonaparte(6) BON2-0607	6.5	18.208	15.588	37.956
Bonaparte(7) BON2-0708	*7.5*	*18.114*	*15.580*	*37.859*
Bonaparte(8) BON2-0809	8.5	18.004	15.567	37.736
Bonaparte(10) BON2-1011	10.5	17.847	15.548	37.640
Bonaparte(12) BON2-1213	12.5	17.769	15.536	37.582
Bonaparte(13) BON2-1314	*13.5*	*17.846*	*15.540*	*37.712*
Bonaparte(15) BON2-1718	17.5	18.616	15.595	38.503
Bonaparte(17) BON2-2830	29.0	18.902	15.603	38.712
Bonaparte(17r) BON2-2830	29.0	18.905	15.604	38.718
Bonaparte(20) BON2-4042	41.0	18.905	15.600	38.718

University of Washington Isotope Geochemistry Laboratory; “r” suffix indicates repeat analysis.
Error on Pb analyses is ±350 ppm (2 sigma) or ±0.035% for 206Pb/204 and 207Pb/204Pb, and ±400 ppm (2 sigma) or ±0.040% for 208Pb/204Pb.
Pb normalized to 205Tl/203Tl = 2.38714 and then to NIST 981 = 16.9356, 15.4891, 36.7006 (Todt et al., 1996) for 206Pb/204, 207Pb/204Pb and 208Pb/204Pb, respectively, by sample-standard bracketing.
Isotopic analyses conducted on May 30-31, June 13, and July 18, 2014; analyst B.K.Nelson.
Italicized entries are those samples analyzed on July 18, 2014, newly reported here.

Table 3: Pb Isotope Compositions of UW Internal Rock Standard

Analysis Date		^{206}Pb/^{204}Pb	^{207}Pb/^{204}Pb	^{208}Pb/^{204}Pb
March 18, 2014	08UW BCR-1	18.587	15.611	38.465
March 26, 2014	08UW BCR-1	18.586	15.613	38.473
April 8, 2014	08UW BCR-1	18.592	15.617	38.484
May 30, 2014	08UW BCR-1	18.582	15.607	38.457
May 30, 2014	08UW BCR-1	18.587	15.613	38.473
May 31, 2014	08UW BCR-1	18.582	15.608	38.461
May 31, 2014	08UW BCR-1	18.586	15.611	38.467
June 13, 2014	08UW BCR-1	18.589	15.613	38.471
June 13, 2014	08UW BCR-1	18.588	15.614	38.475
July 18, 2014	08UW BCR-1	18.589	15.615	38.479
July 18, 2014	08UW BCR-1	18.582	15.609	38.462
July 18, 2014	08UW BCR-1	18.582	15.613	38.471
July 18, 2014	08UW BCR-1	18.587	15.614	38.475
July 18, 2014	08UW BCR-1	18.590	15.616	38.481
July 18, 2014	08UW BCR-1	18.592	15.615	38.481
July 18, 2014	08UW BCR-1	18.584	15.615	38.474
July 18, 2014	08UW BCR-1	18.589	15.614	38.476
Average	(n=17)	**18.587**	**15.613**	**38.472**
2 Std Dev		**0.003**	**0.003**	**0.008**

University of Washington Isotope Geochemistry Laboratory

Error on Pb analyses is ±350 ppm (2 sigma) or ±0.035% for 206Pb/204 and 207Pb/204Pb, and ±400 ppm (2 sigma) or ±0.040% for 208Pb/204Pb.

Pb normalized to 205Tl/203Tl = 2.38714 and then to NIST 981 = 16.9356, 15.4891, 36.7006 (Todt et al., 1996) for 206Pb/204, 207Pb/204Pb and 208Pb/204Pb, respectively, by sample-standard bracketing.

Analyst: B.K.Nelson.

The isotopic compositions of lake sediment samples are shown in Figure 1. The lake sediment core samples are compared to previous analyses of Cedar and other lakes in northern Washington in Figure 2 (from report submitted on May 15, 2014). Compositions and sample names of the selected slag samples and the other lakes are provided in the accompanying Excel data sheet.

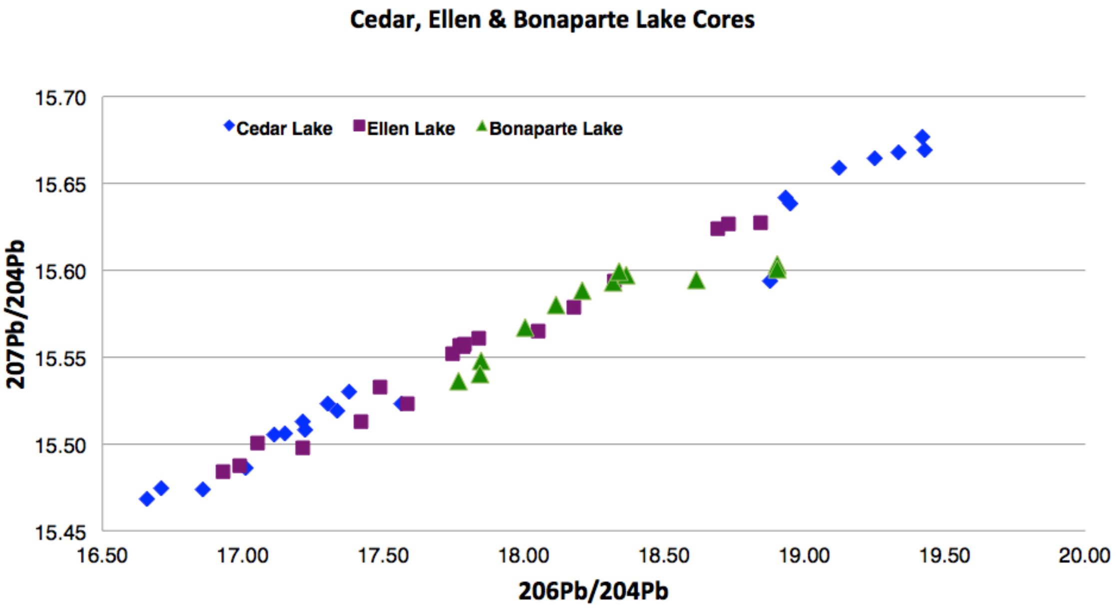

Fig 1. ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{204}Pb for cored sediment samples from Ellen, Cedar and Bonaparte Lakes.

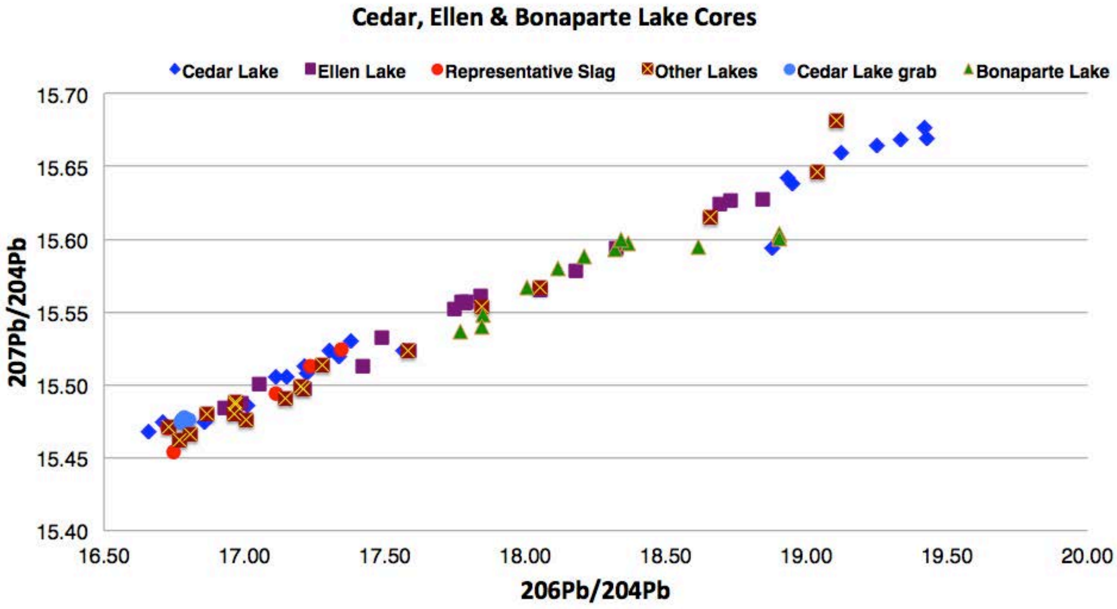

Fig 2. ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{204}Pb for cored sediment samples from Ellen, Cedar and Bonaparte Lakes compared to data obtained from earlier studies, including: Cedar Lake grab samples, which all plot in a cluster near the low isotope limit of the Cedar trend; samples from Silver, Phalon, Phillips, Dry, Elbow, Dilly, Bowen, Peterson, Bowie lakes; representative samples of slag from the Columbia River.

The trends of isotopic composition with depth (age) among the three cores are illustrated in Figure 3, in which the ordinate represents the average depth (cm) of the sampled core interval. The variation with depth in Cedar and Ellen lakes are quite consistent; however, note that the depths are not calibrated for age in these figures. The highest Pb isotope ratios for Bonaparte Lake are similar to the highest ratios for Cedar and Ellen. The lowest Pb isotope ratios observed in Cedar and Ellen are markedly less radiogenic than the lowest values measured for Bonaparte (figure 3d).

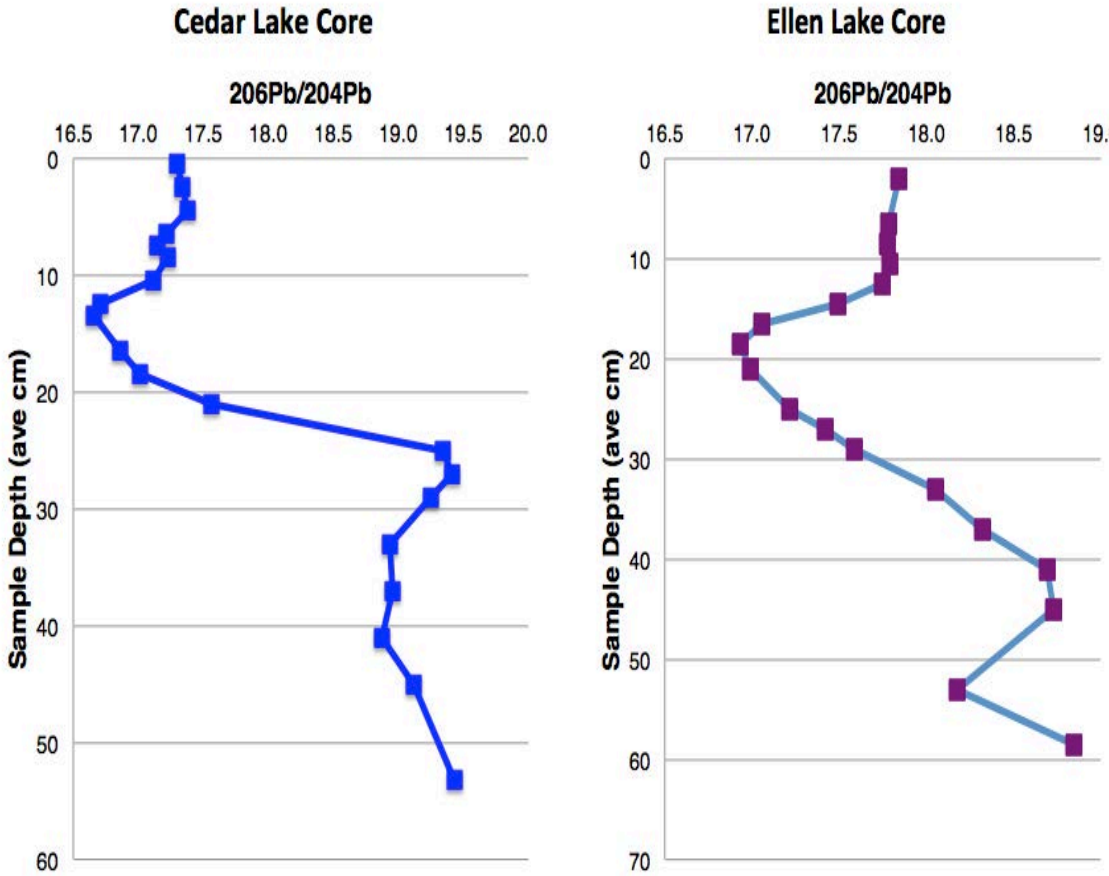

Fig 3. ^{206}Pb/^{204}Pb isotope variation of Cedar and Ellen Lake sediment with depth.

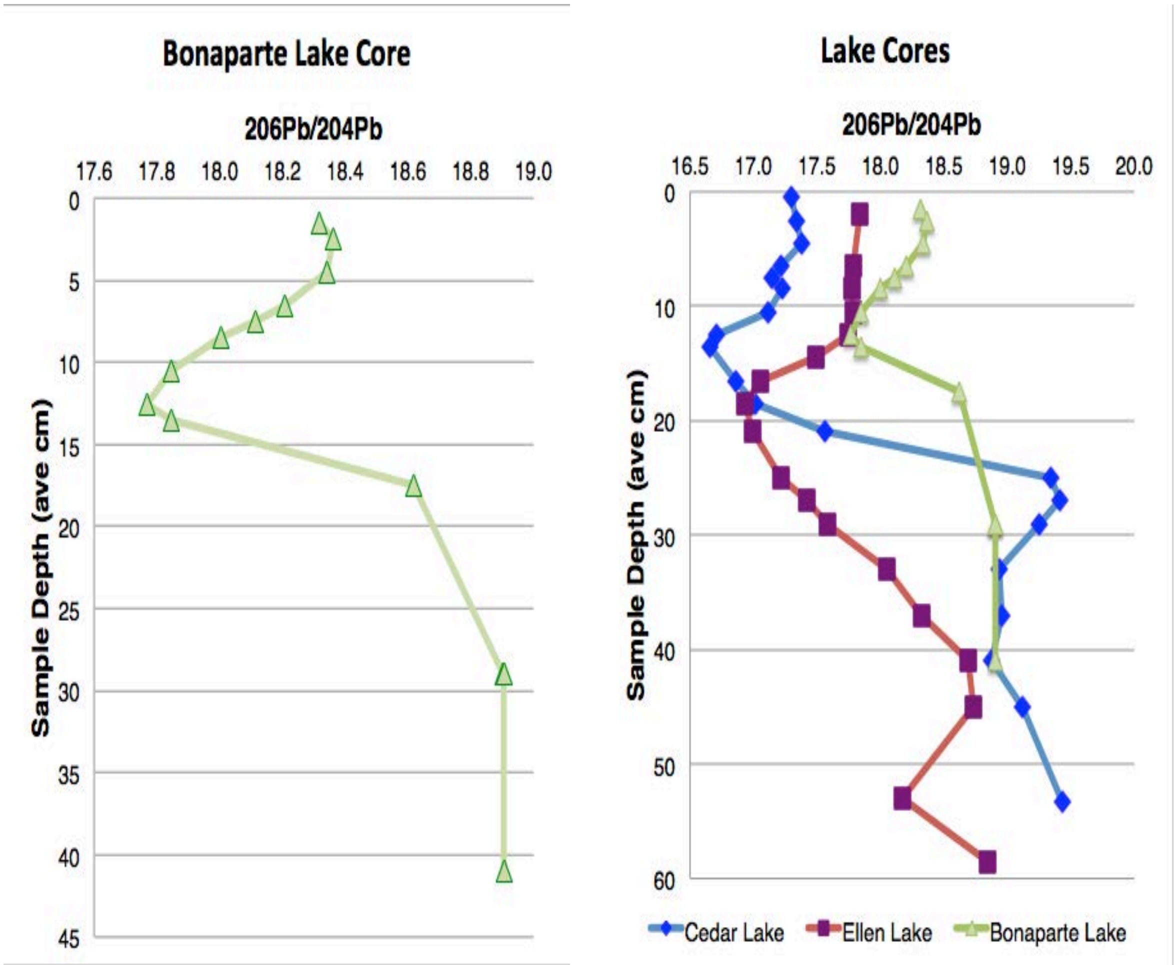

Fig 3 (continued). ^{206}Pb/^{204}Pb isotope variation of Bonaparte Lake sediment with depth, and all three lake cores superposed on the same isotope and depth scale.

Pb Isotope Compositions
Northeast Washington Lake Sediment
Core and Grab Samples

for

Washington State Dept. of Ecology
and
Short Cressman & Burgess PLLC

Dr. Bruce K. Nelson
Isotope Geochemistry Laboratory
Dept. of Earth & Space Sciences
University of Washington

May 15, 2014

Introduction

I report on the Pb isotope analyses of a suite of samples provided by Washington Department of Ecology. A total of 22 samples were analyzed. They include core samples from Silver, Phalon and Phillips lakes, and grab samples from Cedar, Dry, Elbow, Dilly, Bowen, Peterson, and Bowie lakes.

Accompanying this report is an electronic file that contains the Pb isotope analyses and the graphics reproduced in this report.

Pb Isotope Analyses

Pb isotope analyses of all analyzed samples are presented in Table 1. All sediment samples were analyzed during a single analytical session. Data for three analyses of internal laboratory rock standard (UWBCR-1) are also provided in Table 2 and in the spreadsheet. Standard deviation of the rock standard analyses is well within the quoted error of ±250 ppm (2 sigma). The measured Pb isotope values of the rock standards are well within 250 ppm of the average of all previous runs (n=23) of the standard runs that accompanied previous analytical work. Consequently, the measured ratios of samples reported here are directly comparable to values of all previously analyzed samples.

All samples were prepared according to previously documented standard procedures.

Table 1: Pb Isotope Compositions of Sediment Samples

Sample		$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$
Core sample 1	Cedar Lake grab 1	16.803	15.476	36.513
Core sample 2	Cedar Lake grab 3	16.788	15.477	36.496
Core sample 3	Cedar Lake grab 3	16.773	15.474	36.473
Core sample 4	Cedar Lake grab 2	16.777	15.476	36.480
Core sample 10	Silver Lake 0-10cm	16.967	15.488	36.695
Core sample 11	Silver Lake 10-20cm	16.769	15.462	36.484
Core sample 12	Silver Lake 20-30cm	17.845	15.554	37.720
Core sample 13	Silver Lake 30-50cm	19.104	15.681	39.211
Core sample 15	Phalon Lake 0-10cm	17.007	15.476	36.756
Core sample 16	Phalon Lake 10-20cm	17.582	15.524	37.426
Core sample 17	Phalon Lake 20-30cm	19.037	15.646	38.832
Core sample 18	Phalon Lake 30-50cm	18.658	15.615	38.462
Core sample 20	Phillips Lake 0-10cm	16.865	15.480	36.576
Core sample 21	Phillips Lake 10-20cm	16.733	15.472	36.419
Core sample 22	Phillips Lake 20-30cm	18.051	15.567	37.876
Core sample 24	Dry Lake 0-10cm	17.144	15.490	36.925
Core sample 50	Elbow Lake	17.211	15.497	36.985
Core sample 50B	Elbow Lake	17.203	15.499	36.952
Core sample 51	Dilly/Glasgo	16.966	15.487	36.717
Core sample 52	Bowen	16.808	15.466	36.526
Core sample 53	Peterson	17.278	15.514	37.022
Core sample 55	Bodie	16.961	15.480	36.686

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Centimeter ranges indicate depth of sample from lake bottom.
Error on Pb analyses is ±250 ppm (2 sigma) or ±0.025%.
Pb normalized to 205Tl/203Tl = 2.38714 and then to NIST 981 = 16.9356, 15.4891, 36.7006 (Todt et al., 1996) for 206Pb/204, 207Pb/204Pb and 208Pb/204Pb, respectively, by sample-standard bracketing.
Isotopic analyses conducted on March 18, 2014; analyst B.K.Nelson.

Table 2: Long-Term Pb Isotope Compositions of UW Internal Rock Standard

Sample		$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$
March 18, 2014	'UW BCR-1'	18.587	15.611	38.465
March 26, 2014	'UW BCR-1'	18.586	15.613	38.473
April 8, 2014	'UW BCR-1'	18.592	15.617	38.484

University of Washington Isotope Geochemistry Laboratory
Error on Pb analyses is ±250 ppm (2 sigma) or ±0.025%.
Pb normalized to 205Tl/203Tl = 2.38714 and then to NIST 981 = 16.9356, 15.4891, 36.7006 (Todt et al., 1996) for 206Pb/204, 207Pb/204Pb and 208Pb/204Pb, respectively, by sample-standard bracketing.
Isotopic analyses conducted on March 18, 2014; analyst B.K.Nelson.

The isotopic compositions of lake sediment samples are compared graphically with previous results from this laboratory in Figures 1 and 2. Compositions and sample names of the selected slag samples are provided in the accompanying Excel data sheet.

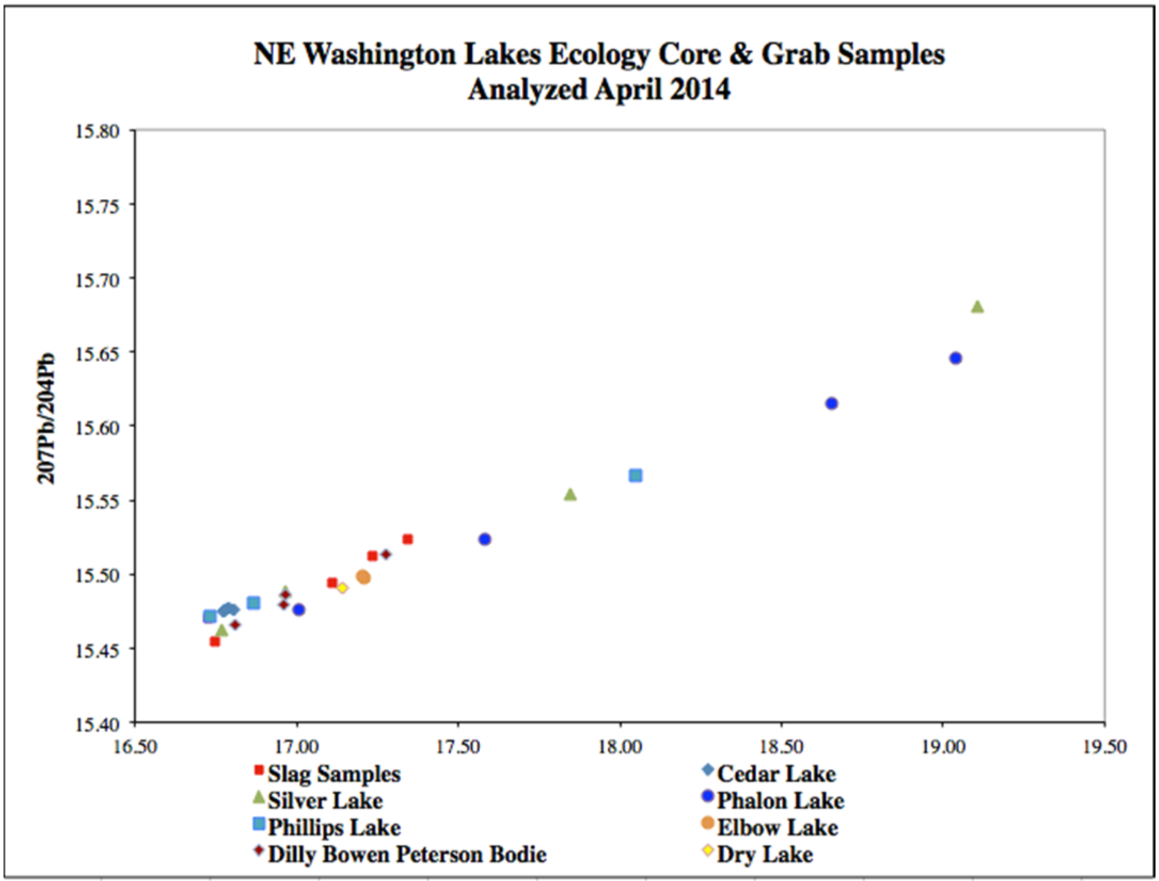

Fig 1. ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{204}Pb for all samples analyzed in this study, with a selection of slag compositions analyzed (and reported to EI) previously.

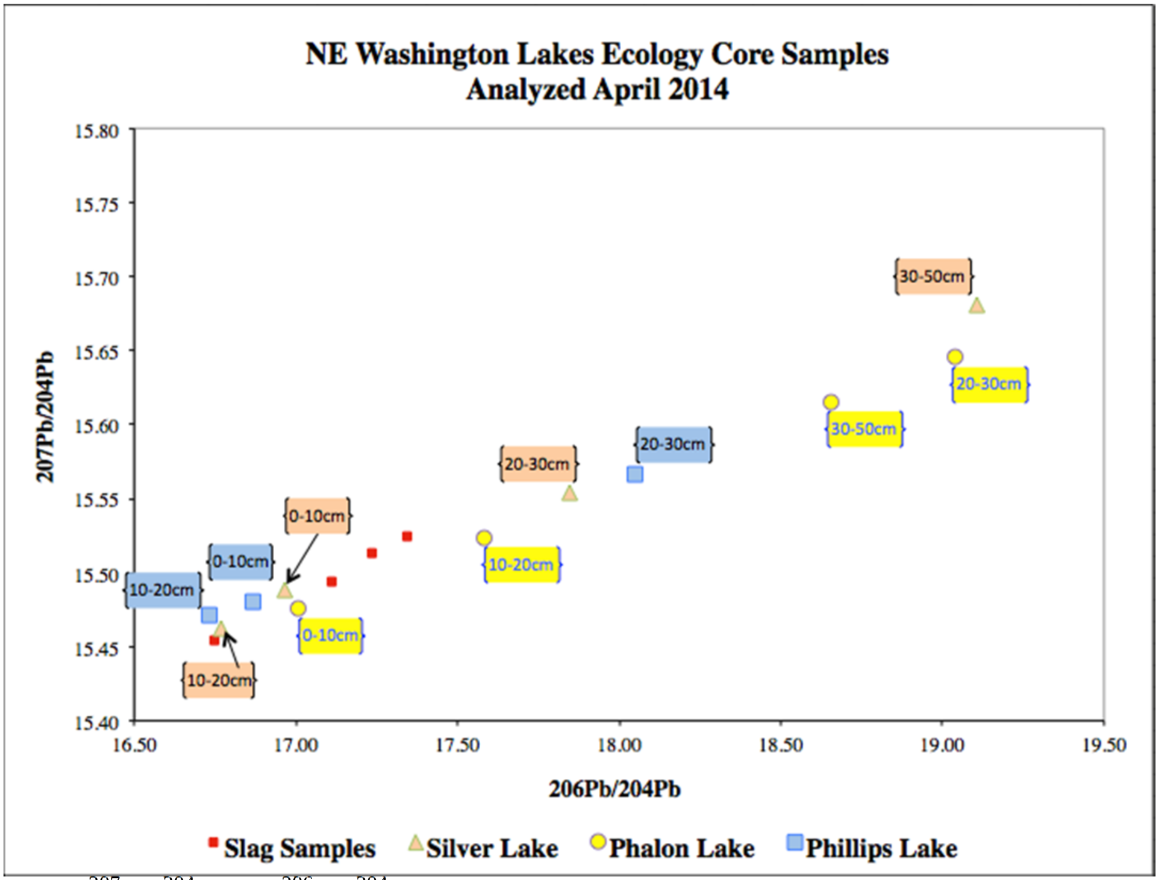

Fig 2. ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{204}Pb for those samples that were taken from sediment cores. Core depth is indicated for each sample. Also shown for reference is a selection of slag compositions analyzed (and reported to EI) previously.

APPENDIX C
POREWATER CHEMISTRY RESULTS

Appendix C
Porewater Chemistry Results

Porewater Samples	ID	pH	ORP (mV)	Arsenic (µg/L)	Cadmium (µg/L)	Copper (µg/L)	Lead (µg/L)	Antimony (µg/L)	Zinc (µg/L)
Cedar 0-6	C 0-6	6.06	-130.1	10.40	0.082	0.605	0.837	1.33	11.00
Cedar 6-12	C 6-12	6.07	-137.2	13.00	0.212	0.731	3.90	1.48	11.00
Cedar 12-18	C 12-18	6.12	-60	9.32	0.297	0.960	8.51	1.50	13.80
Cedar 18-24	C 18-24	5.46	-150	4.43	0.086 J	0.995	1.89	0.543	8.36
Cedar 24-30	C 24-30	5.11	-128	3.95	0.04 J	0.564	0.299	0.344	6.96
Cedar 30-36	C 30-36	5.76	-168.7	3.25	0.042 J	0.657	0.481	0.306	7.60
Cedar 36-42	C 36-42	5.57	100	8.01	0.048 J	1.01	0.108 J	0.317	6.63
Cedar 42-48	C 42-48	5.81	69.1	11.00	0.062 J	1.27	0.163	0.424	8.53
Ellen 0-5	E 0-5	5.99	-140	10.8	0.068 J	26.30	5.69	0.489	64.4
Ellen 5-10	E 5-10	6.37	-150	13.6	0.409	1.33	0.85	0.64	133.0
Ellen 10-15	E 10-15	6.47	-149	78.8	0.136	2.89	2.67	1.25	50.3
Ellen 15-20	E 15-20	5.51	-153.5	24.3	0.200	1.50	3.15	0.785	23.3
Ellen 20-25	E 20-25	5.87	-145	20.5	0.045 J	1.13	2.05	1.01	21.8
Ellen 25-30	E 25-30	6.15	-140.5	10.1	0.035 U	1.85	0.087 J	0.051 U	23.0
Ellen 30-35	E 30-35	6.28	-142.5	3.04	0.035 U	1.56	0.164	0.18 J	22.5
Ellen 35-40	E 35-40	6.42	-152	2.42	0.035 U	1.73	1.18	0.529	21.1
Ellen 40-45	E 40-45	6.44	-23.2	28.90	0.035 U	1.99	0.277	0.107 J	19.2
Ellen 45-50	E 45-50	6.1	-55.4	2.76	0.035 U	1.51	0.320	0.098 J	16.2
Ellen 50-55	E 50-55	6.26	-69	1.90	0.035 U	1.99	0.198	0.304	16.5
Ellen 55-61	E 55-61	6.56	-71.0	1.54	0.035 U	1.31	0.12 J	0.156 J	12.4

Notes:

U = Below the method detection limit (MDL)

J = Between the MDL and the method reporting limit

µg/L = microgram per liter

mV = millivolt

ORP = oxidation-reduction potential