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LAKE SEDIMENT GRAB SAMPLING VERSUS CORING FOR ENVIRONMENTAL RISK ASSESSMENT OF METAL MINING

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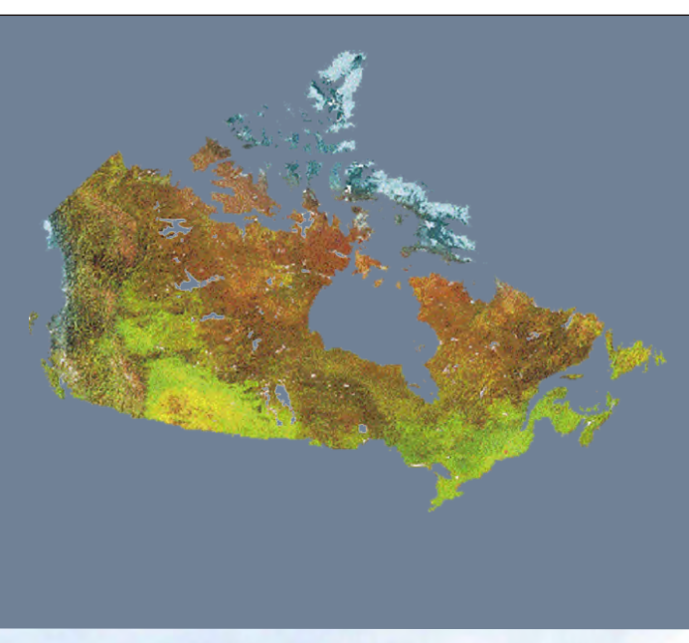


ABSTRACT

Current practices for baseline studies of sites to be developed for mining include surface grab sampling of sediments in aquatic receiving environments. In contrast, vertical sediment coring is a universal tool of paleolimnological research. This study evaluates the effectiveness of sediment grab sampling versus sediment coring for environmental risk assessment of metal mining. The former Aldermac mine (Cu, Zn, Au and Ag), 25 km west of Rouyn-Noranda in Abitibi, Quebec, operated from 1932-1943 and discharged acid mine drainage to the watershed downstream. The study site is representative of both a common mineral deposit and the legacy of historical mining practices. Contamination and adverse effects on aquatic habitats were demonstrated to the point where the government of Quebec led an environmental restoration of the Aldermac property (2008-11). Further mining development is foreseeable in the watershed. Surveys of sediment grab samples (2011-13) were done by Petite Ponar® with a penetration depth of approximately 5-10 cm at 32 sites. Co-located sediment coring surveys were conducted using a 10-cm diameter gravity corer, modified with extension rods, to a sediment depth of 30-45 cm. Cores were sub-sampled at discrete depth intervals in two exercises: one survey with a larger regional distribution and thicker sediment slices (32 sites) and the other at 1-cm interval sections at 5 sites for detailed study. Grab sampling generated rapid results that permitted estimates of the current environmental reference state (baseline before new development), metal contaminant sources, and the spatial extent of metal contamination. Sediment coring produced estimates of naturally-occurring metal concentrations (pre-industrial background), the current baseline metal concentrations, metal contaminant sources, the duration of contamination, and its spatial extent. Although surveys of surface sediment grabs are faster and simpler and provide more sample material, they are imprecise snapshots without temporal scales. Sediment coring offers chronology of metal contaminant deposition, more precision, and potential for more targeted data (e.g., to fingerprint metal contaminant sources, assess diagenetic metal mobility, determine stability of metal-bearing phases). Cores can be taken in a reasonably rapid and simple manner, but less efficiently than grab sampling with less sample material for each core slice if sub-sampled at high resolution. Grab sampling offers a first approximation that may be sufficient for an initial environmental risk assessment. However, when further investigation is warranted, sediment coring can be optimized for efficiency and provide insight into accumulated metal contamination over time and an estimate of the range of metal levels in a naturally mineralized region (natural background).

INTRODUCTION

The mining industry and environmental consultants routinely use dredge or grab sampling of surface sediments for environmental risk assessment. Sediment coring is recommended when further investigation warrants (e.g., EC, 2012a; US EPA, 2001) and can help fulfill the increasing requirement for cumulative effects assessment.

In this study, geochemical results from grab sampling of surface lake sediments and sediment coring are compared for risk assessment of metal mining based on findings downstream of a common mineral deposit with a legacy of metal contamination (Goulet & Couillard, 2009).

The Aldermac mine (Cu, Zn, Au and Ag), 25 km west of Rouyn-Noranda in Abitibi, Quebec, produced an estimated 1.5 Mt of mine tailings that discharged acid mine drainage to the adjacent Rivière Abitibi watershed which includes Lac Arnoux and Lac Dasserat (1932-1943; Figure 1). The Quebec government led an environmental restoration (2008-11) and follow-up monitoring (2013) of the former mining property that coincided with this complementary aquatic sediment study (2011-13) downstream. In addition to historical mining activities, the region remains a target for active exploration (massive sulphides, gold) that could lead to future development and necessitate further environmental risk assessment.

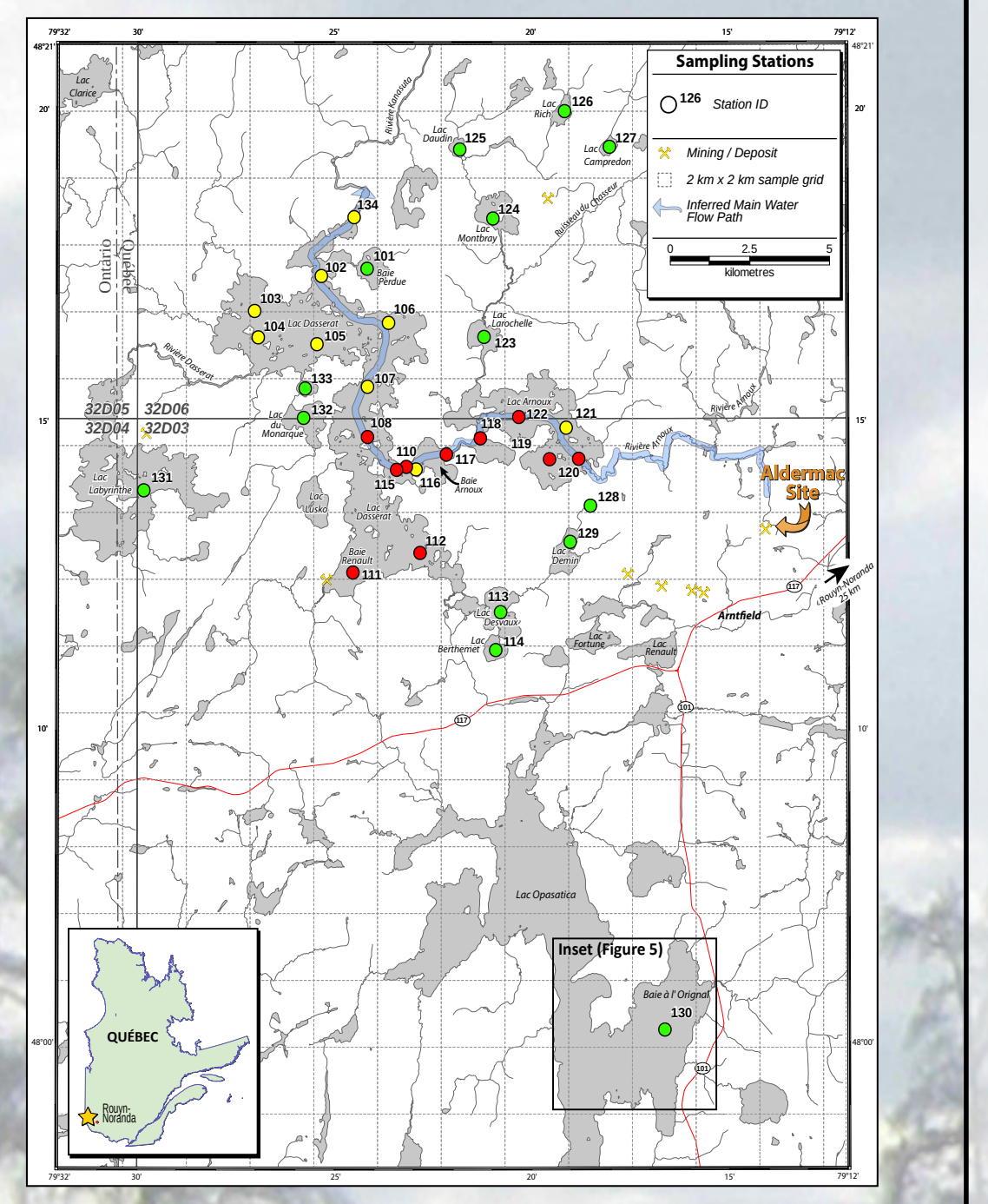


Figure 1. Sample location map of regional coring sites in the vicinity of the Aldermac site.

METHODS

Selection of sampling stations was based on their regional distribution (minimum of one station per 2 km² sampling grid), water depth, geochemical gradients and proximity to the primary contaminant source (Figure 1).

Surface sediment samples were taken by a Petite Ponar® grab sampler (6” X 6”) at 32 sites with a penetration depth of up to 10 cm, depending on sediment stiffness (Figure 2). Sediment cores were either taken by divers (4 sites in 2011) or by a modified gravity corer (2011-13) at the same stations as the grab samples. A 10-cm diameter gravity corer was modified with threaded rod extensions on the head assembly to allow hand-taken cores from the water surface that match the preservation of the nepheloid layer achieved by diver coring (Figure 3). Depth penetration of the core tube into the sediments was controlled by a perforated disk mounted on the outside of the coring assembly (Figure 3). Cores were extruded on site and sectioned at 0.5 to 5.0 cm depth intervals. Sediments from five stations were sectioned at 1.0 cm intervals for detailed study. Sediments cored in this study were either organic-rich (Lac Arnoux gyjtta or dy) or mixed glaciolacustrine clays from glacial Lake Barlow-Ojibway.

All sediment samples were freeze-dried and sieved (<177 µm) before a modified aqua-regia digestion after which, major and minor trace elements were analysed by ICP-MS and -ES at ACME Labs (McNeil *et al.*, in prep). Zn concentrations are demonstrated here as an example.

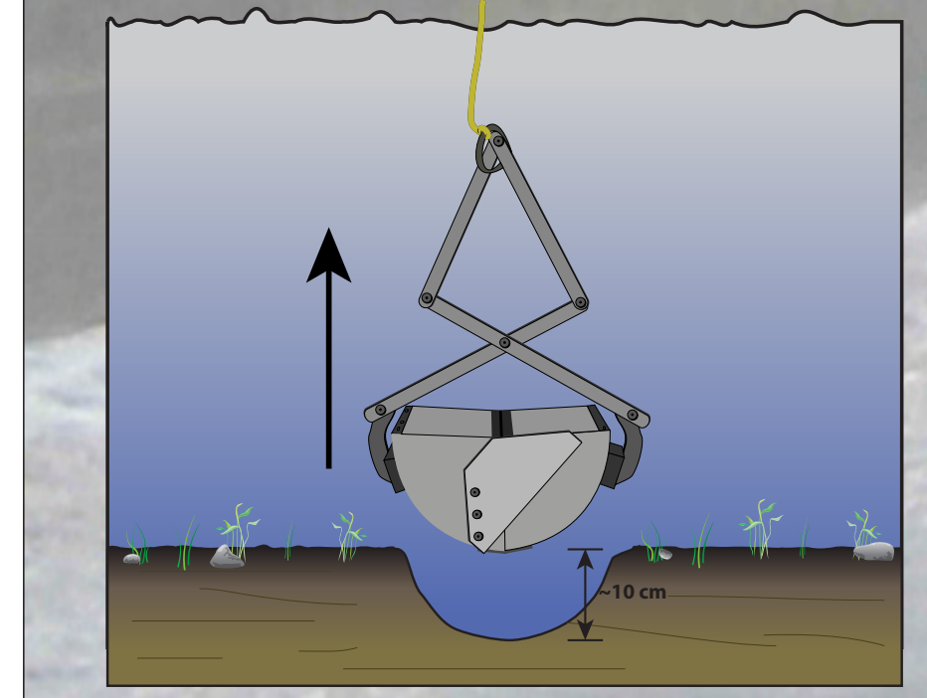
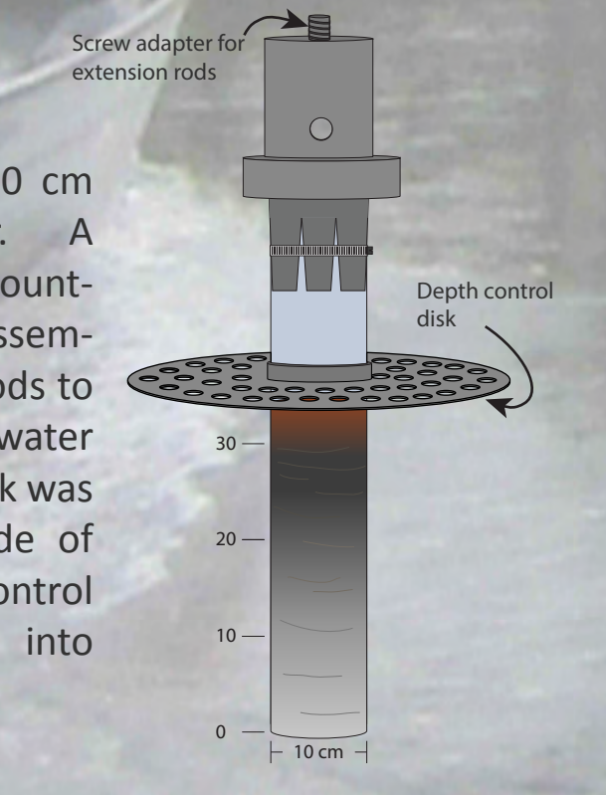


Figure 2. Petite Ponar® grab sampler with up to 10 cm penetration depth into the sediments.

Figure 3. Modified 10 cm diameter gravity corer. A threaded adapter was mounted on top of the head assembly to allow extension rods to be added (up to ~15 m water depth). A perforated disk was mounted on the outside of the coring assembly to control the penetration depth into the sediments.



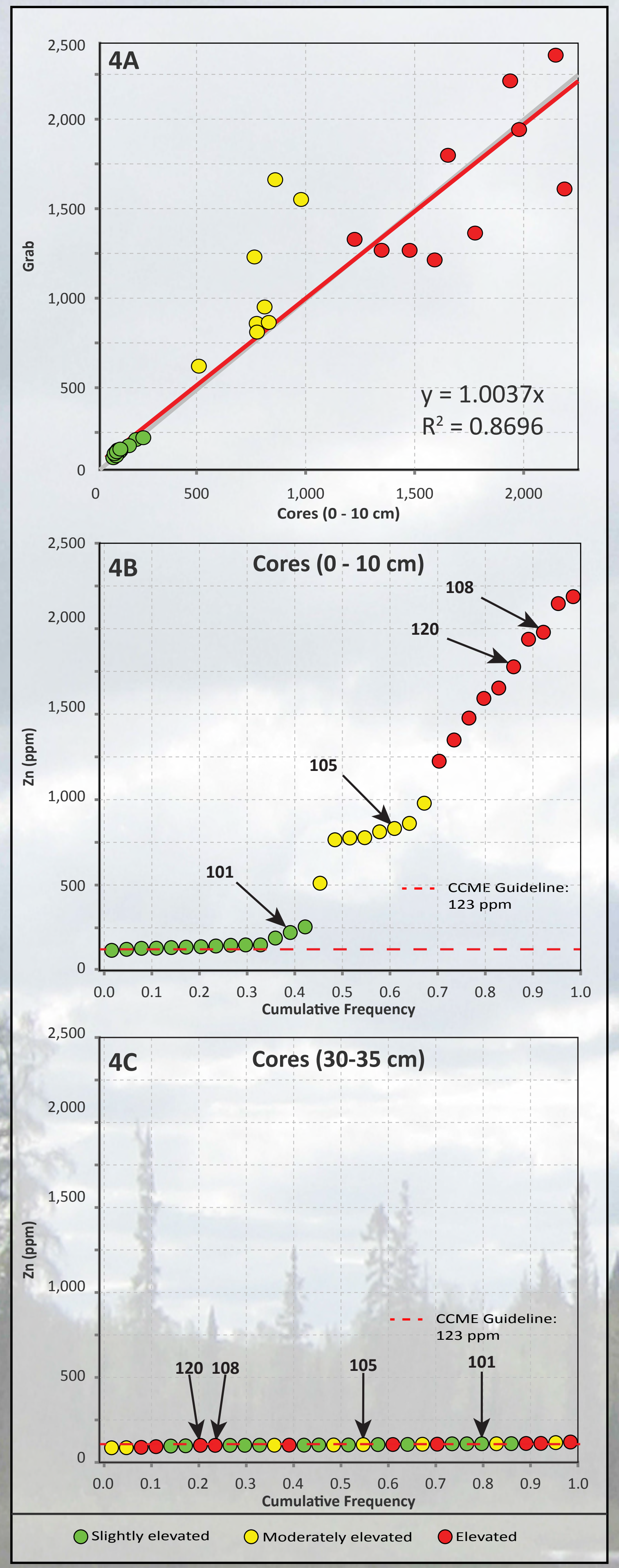


Figure 4A) X-Y plot of zinc concentrations in grab versus core (0-10 cm) samples **B)** Cumulative frequency plot of zinc concentrations in cores (0-10 cm). **C)** Cumulative frequency plot of zinc concentrations in cores (30-35 cm). Colour coding of stations was assigned based on the separation in the cumulative frequency plot and was included in Figure 1.

Fe-precipitates forming along the rocky shores of Lac Arnoux

Tailings-rich river banks of Rivière Arnoux just upstream of the mouth of Lac Arnoux.

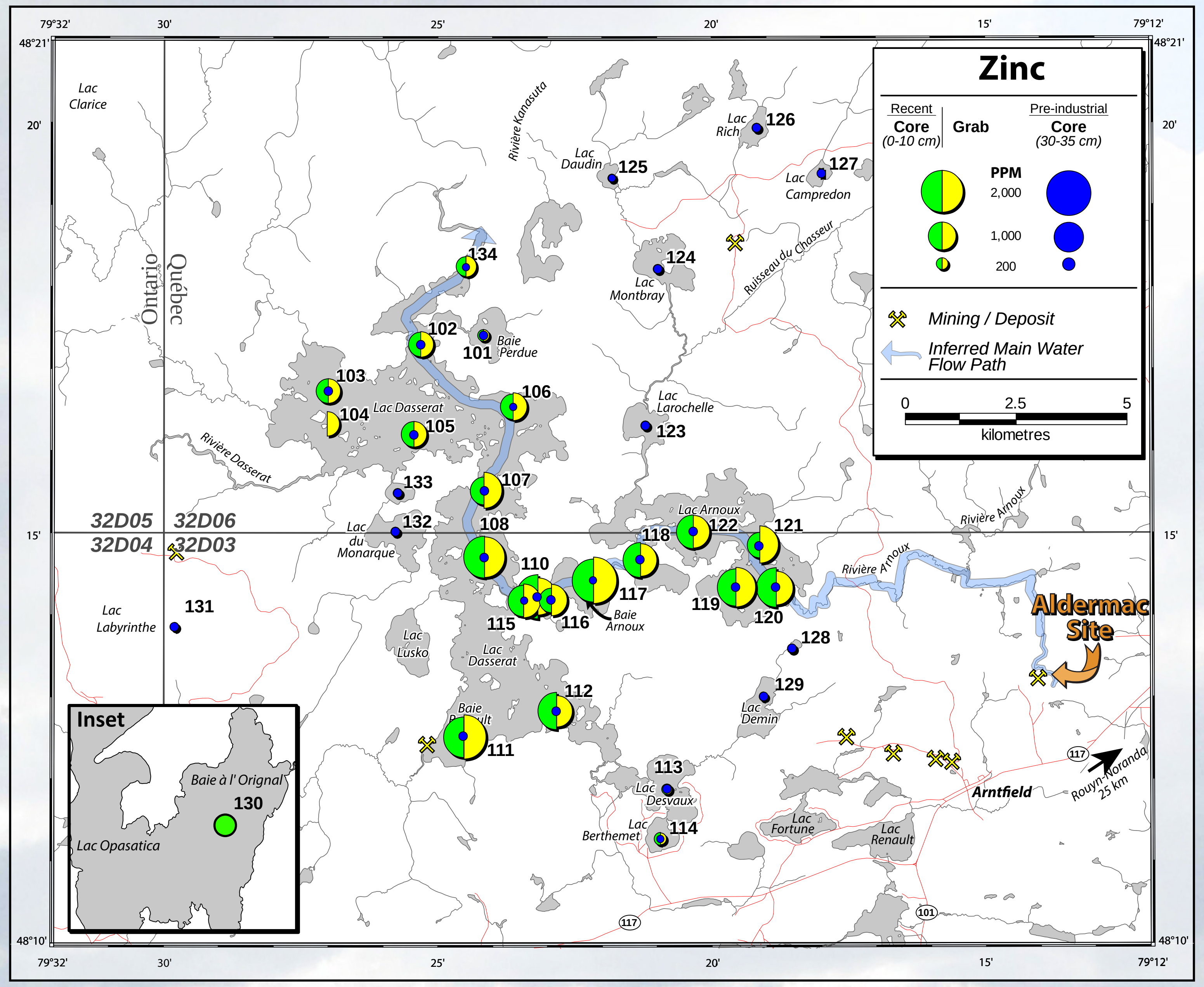


Figure 5. Map of zinc concentrations in recent (0-10 cm) and pre-industrial sediments (30-35 cm) from bulk sediment grab sampling and sediment coring.

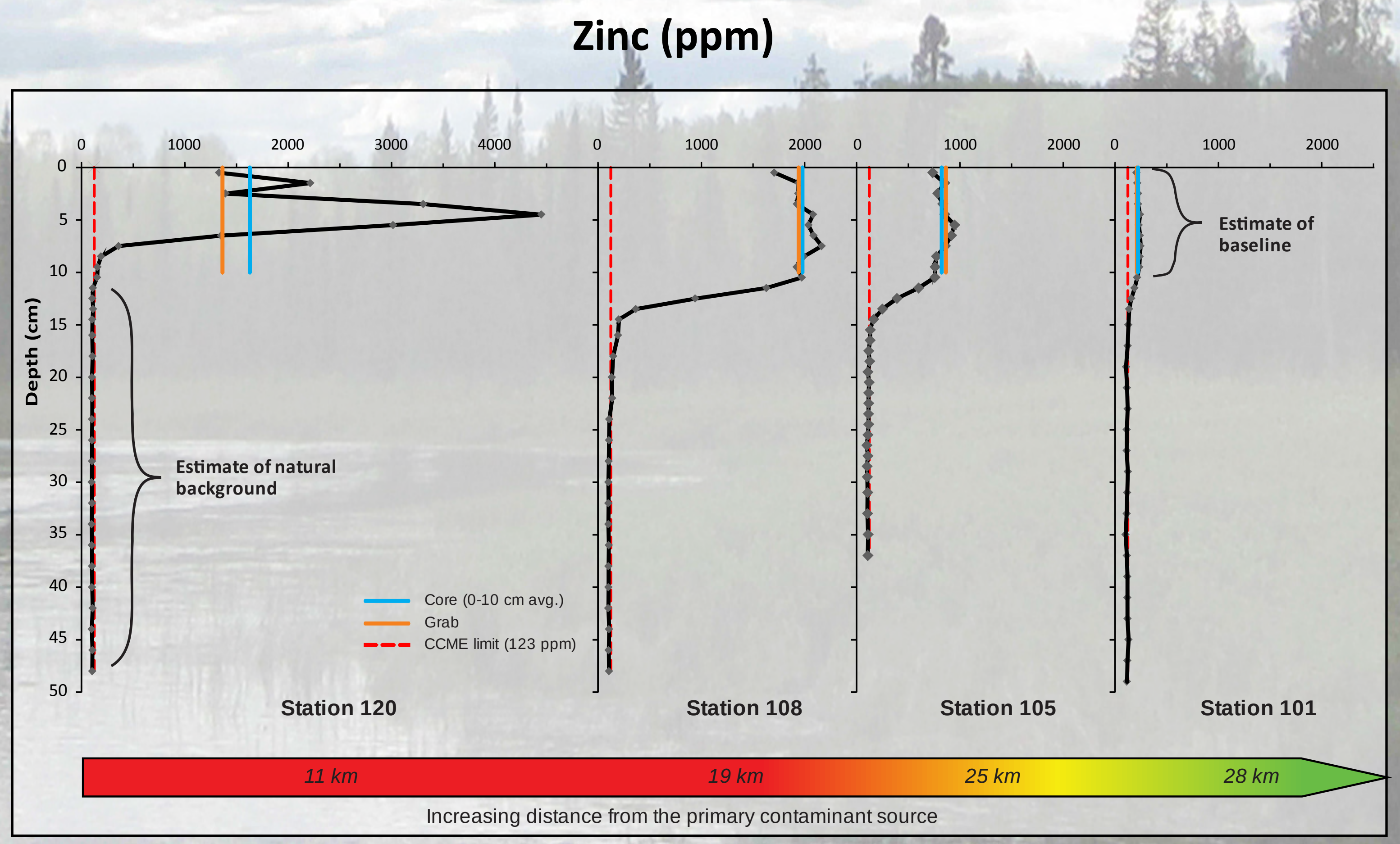


Figure 6. Zinc concentration profiles with depth in four sediment cores subsampled at 1.0 cm intervals.

Zinc (ppm)	Cores (0 - 10 cm)	Cores (30-35 cm)
Number of sites	32	32
Mean	806.6	103.5
Standard Deviation	710.2	7.8
Minimum	118.3	86.4
10 percentile	130.3	90.0
25 percentile	144.6	100.6
50 percentile	770.4	103.0
75 percentile	1,445.1	109.5
90 percentile	1,966.9	111.7
95 percentile	2,161.2	117.8
Maximum	2,187.5	120.0
CCME Guideline	123	123

Table 1. Summary statistiscs of zinc concentrations (ppm) in shallow (0-10 cm) and deeper (30-35 cm) sediment core intervals.

Grab	Coring
imprecise; penetration depth is a function of sediment stiffness, bottom debris and speed of descent; inconsistent	more precise; consistent control on depth penetration in sediments and intervals of core slices
preferential sampling of near surface sediments (Figure 2, 5)	representative samples
no temporal scale	temporal scale (age dating, e.g., ^{210}Pb), chronology of deposition
faster; simpler	fast, simple; extrusion and sectioning of core slices can be optimized
more sediment material in a bulk sample	less sediment material per slice, depending on thickness of core sections
identify general spatial distribution of recent contamination (Figures 4, 5)	delineate spatial distribution of recent and historical contamination (Figure 5)
bulk estimate of maximum contaminant concentration (Figure 5)	maximum contaminant concentration more precisely quantifiable
identify recent contaminant sources	identify recent and historical contaminant sources; with additional investigation, possible to identify geochemically distinct contaminant sources (Figure 6)
no estimate of natural background	estimate range of natural background concentrations (Figures 4, 5, 6 and Table 1)
estimate of baseline conditions (Figures 4, 5 and 6)	estimate of baseline conditions possible (Figures 4, 5 and 6)
duration of more recent contamination possibly identified by time-series sampling	duration of contamination identified through the time period represented in the sediment core (Figure 6)
bulk estimates only	oxygen penetration into the sediments can be limited and provide opportunity for research grade studies

Table 2. Capabilities of grab sampling versus coring of aquatic sediments for environmental risk assessment.

View of Baie Arnoux.

Accessing surrounding lakes as part of the regional study.

RESULTS

In both surface grab samples and shallow cored sediments (0-10 cm averaged), higher Zn concentrations are recorded at proximal sites to the Aldermac property (over 2000 ppm) and decrease with distance (to 118 ppm; Figures 4, 5, 6). Deeper in the cores (30-35 cm), lower Zn concentrations remain relatively invariant (86.4-120.0 ppm; SD=7.8; Figures 4, 5, 6 and Table 1). Detailed core profiles confirm elevated Zn concentrations at the surface and concentrations that decrease both with distance and depth (Figure 6). Of note, the lower 10th percentile of Zn concentrations in shallow sediments exceeded CCME guidelines for sediment quality (Figures 4, 5, 6 and Table 1).

DISCUSSION

Results from both grab sampling and the shallow sediment cores (0-10 cm) generally confirm the inferred surface water flow path from the Aldermac site to Rivière Arnoux, Lac Arnoux and northern Lac Dasserat (Figures 1, 5). Elevated Zn concentrations in southern Lac Dasserat (Stations 111 in Baie Renault and 112) could result from surface water flow reversals controlled by damming (MRN, pers.comm., 2013). In Lac Berthemet (Station 114), the slightly elevated Zn concentrations in surface sediments may be attributable to higher lake usage, traffic and erosion (marinas, boats, waterfront cottages, houses and roads).

Zinc concentrations deeper in the cores (30-35 cm) are consistently lower than the CCME guidelines for sediment quality (CCME, 2007) and show little variation within and among cores (Figures 4, 5, 6 and Table 1). If a typical sedimentation rate of approximately 1 mm/yr is assumed for Canadian shield lakes, then sediments deeper than about 10 cm represent pre-industrial time and can provide estimates for the range of natural background concentrations, barring post-depositional metal mobility (Figure 6).

Baie Perdue (Station 101) is not in the major flow direction of effluent from the Aldermac site. However, its shallow sediments are slightly elevated in Zn and higher than natural background (Figure 6). They may represent baseline conditions of cumulative effects over a significant period of industrialization. In this case, without other local contaminant sources, cumulative effects are likely caused by atmospheric transport from smelting in Rouyn-Noranda or Sudbury.

Although the general spatial patterns of metal distributions are demonstrated in both grab samples and shallow core sediments (Figures 4, 5), grab samples can serve as approximations which are less precise than sediment cores sectioned at high resolution. Capabilities of grab sampling and sediment coring are summarized in Table 2.

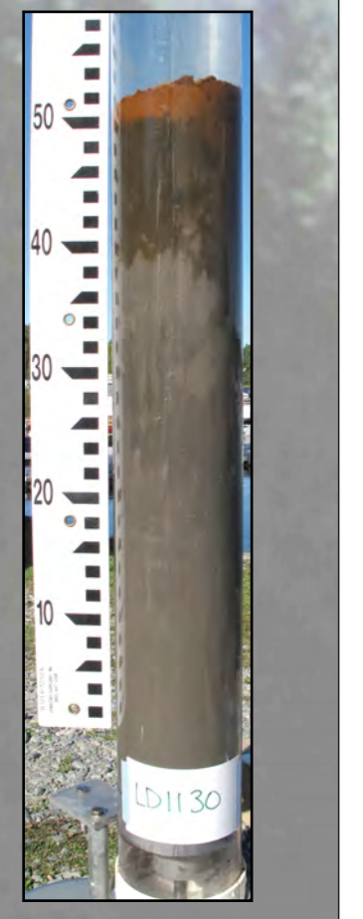
CONCLUSIONS

Quantifying historical contamination and natural variability are identified as challenges to environmental risk assessment of metal mining (e.g., EC, 2012b). The building blocks for environmental risk assessment include: (1) an understanding of natural background and natural processes, (2) the current environmental reference state or baseline, (3) sources, (4) spatial extent, (5) duration and (6) timing of perturbations, and (7) degradation or recovery of environmental conditions. Sediment grab sampling can contribute to building blocks 2, 3, 4 and perhaps 7. Sediment coring can contribute to all seven and is a practical option for more thorough investigation of environmental risk assessment when warranted.

Grab sample collection using Petite Ponar®.

Heterogeneity of grab sample in collection bag.

Lake sediment core collection using a modified gravity corer



Lake sediment core

REFERENCES

Canadian Council of Ministers of the Environment (CCME), 2007. Canadian Environmental Quality Guidelines, Chapter 6: Canadian Sediment Quality Guidelines for the Protection of Aquatic Life.

Environment Canada, 2012a. Metal Mining Technical Guidance for Environmental Effects Monitoring. Environment Canada, 550 pp.

Environment Canada, 2012b. Environmental Effects Monitoring, Investigation of Cause Workshop for Metal Mining, Proceedings, 101 pp.

Goulet, R.R. and Couillard, Y., 2009. Weight-of-evidence assessment of impacts from an abandoned mine site to the Dasserat Lake Watershed, Quebec, Canada. IN: Lake Pollution Research Progress. ED: F.R. Miranda and L.M. Bernard. Nova Science Publishers, Inc, 355-369 pp.

McNeil, R.J., Alpay, S. and Grenier, A., *in prep*. Environmental geoscience investigations surrounding the former Aldermac mine, Abitibi, Quebec: Regional surveys of surface water and sediment geochemistry. Geological Survey of Canada Open File No. 7595.

United States Environmental Protection Agency, 2001. Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual. Office of Science and Technology, Office of Water, US EPA, Washington, DC. EPA-823-B-01-002, 208 pp.

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