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Observations on sediment chemistry of the Slave River Delta, Northwest Territories, Canada

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Abstract A study was conducted to examine sediment chemistry in the outer, mid and apex areas of the Slave River Delta, Northwest Territories, Canada. Delta sediments consisted primarily of quartz (60–82%) with lesser amounts of calcite (2–6%), feldspars (8–15%), micas (3–7%), montmorillonite (2–9%), dolomite/ankerite (2–4%) and kaolinite (3–5%). The mineralogy and major element composition was remarkably similar in the outer, mid and apex areas of the delta. Concentrations of Cu, Cd, Cr, Pb, As and Hg were significantly higher in the mid-delta. Elevated metal concentrations in this section of the delta are related to geomorphic and hydraulic controls, which cause selective sorting and fining of sediment in smaller mid-delta channels where vegetation is important for sediment trapping and metal cycling. Concentrations of Hg, Cd and As in all samples exceeded the Potential Effect Level of the Canadian Sediment Guidelines for the Protection of Aquatic Life.

INTRODUCTION

The Slave River Delta is a biologically diverse and highly productive ecosystem in a remote part of Canada's north (English *et al.*, 1997). Plant assemblages are dominated by various macrophytes including *Equisetum fluviatile, Equisetum arvense* and *Carex aquatilis*. These plants have adventitious rooting systems that trap sediment in many sections of the delta (English, 1984) and may influence the fate and distribution of particle-associated contaminants. Milburn & Prowse (1998) reported the presence of organic contaminants, such as PAHs, dioxins, furans and PCBs in channel-bottom sediments in the delta under ice and just before ice-on conditions. Other studies have identified sediment-bound contaminants upstream of the delta (McCarthy *et al.*, 1997) and in lake bed sediments immediately offshore of the delta (Allan, 1979; Mudroch *et al.*, 1992). However, relatively little is known about the quality of sediment deposited in the delta from upstream sources and its potential to impact the biological community (Carson & Hudson, 1997).

The principal pathway for metal movement from aquatic sediments to vegetation such as rooted macrophytes is by root uptake and subsequent translocation to above ground tissues. Plant metal concentrations are generally proportional to the metal content of underlying sediments, although the phase partitioning and bioavailability of metals is governed by sediment properties such as sediment pH, redox potential and organic matter content (Jackson, 1998). Given the importance of vegetation for sediment trapping and its potential to influence the distribution of sediment bound contaminants, this paper is a preliminary examination of sediment quality in the Slave River Delta. Mineralogy and trace metal distribution of sediment collected from deposition zones in three morphological areas of the delta (outer, mid and apex) are presented and discussed in the context of potential uptake by rooted macrophytes. Sediment metal concentrations are compared to the Canadian Sediment Guidelines for the Protection of Aquatic Life (CCME, 1999) to assess the quality and potential environmental significance of delta sediment.

MATERIALS AND METHODS

Study area

The Slave River Delta is located in the Northwest Territories at the confluence of the Slave River with Great Slave Lake (Vandenburgh & Smith, 1988). Three morphological areas of the delta (outer, mid and apex) are distinguished by increasing levee height, plant assemblages and geomorphology (English *et al.*, 1997). The outer delta is a large marsh flat, which serves as an important staging, breeding and feeding ground for migratory bird species. *Equisetum fluviatile* and other emergent species of aquatic vegetation attract a diverse range of wildlife including muskrat and moose. Cleavage bar islands are the principal depositional features in the outer delta where emergent plant species such as *Equisetum fluviatile*, *Carex rostra* and *Carex aquatilis* invade and enhance sediment trapping (English, 1984). The mid delta is a transitional area between the water-dominated landscape of the outer delta and the elevated, relatively dry apex area. Lateral accretion bars in mid-delta channels are inundated by rooted macrophytes that serve to trap sediment and stabilize these depositional features. The mid delta represents 45% of the active delta and has an average levee height of 1 m above Great Slave Lake summer water levels. The mid delta supports plant species adapted to a mesic environment including *Equisetum arvense*, *Cornus stolonifera*, *Salix* spp, *Alnus tenuifolia* and *Populus balsamifera*. The *Alnus–Salix* plant assemblage is by far the most representative in the mid-delta zone. In the apex zone, the average elevation of levees above summer water levels is approximately 2 m. Flood frequency in the apex is approximately 35 years (English, 1984). About 6% of the apex is classified as aquatic and most of these areas are elevated and cut off from the Slave River flow. A significant portion of this zone has reached the climax forest stage of *Picea glauca*, which is underlain by permafrost.

Sediment sampling and preparation

A total of 31 sediment samples were collected at 26 sites in representative portions of the outer, mid and apex areas of the delta where vegetation plays an important role in sediment trapping. Sample locations shown in Fig. 1 include marsh flats in the outer delta (S1–S7), lateral accretion bars in mid delta (S8–S10), as well as channel entrance and lateral accretion bars in the apex (S11–S26). Surface sediment was collected in the outer and mid delta with hand corers. Chemistry of the top 2 cm of each core is reported. In the apex, sediment was collected in lateral accretion bars, channel entrance bars and the bottom of Middle Channel West and Old Steamboat Channel (Fig. 1). All sediment samples were freeze dried and homogenized by grinding prior to geochemical and chemical analysis.

Sediment chemistry

The concentrations of major elements (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, TiO_2, MnO and P_2O_5) and trace elements (Cr, Cu, As, Cd, Hg, Pb) were determined using a Philips PW1480 XRF spectrometer in the Geology Department at McMaster University, Hamilton, Ontario. Practical detection limit of the instrument is 50 ppm. Precision of the analysis was determined by analysing three pellets made from a

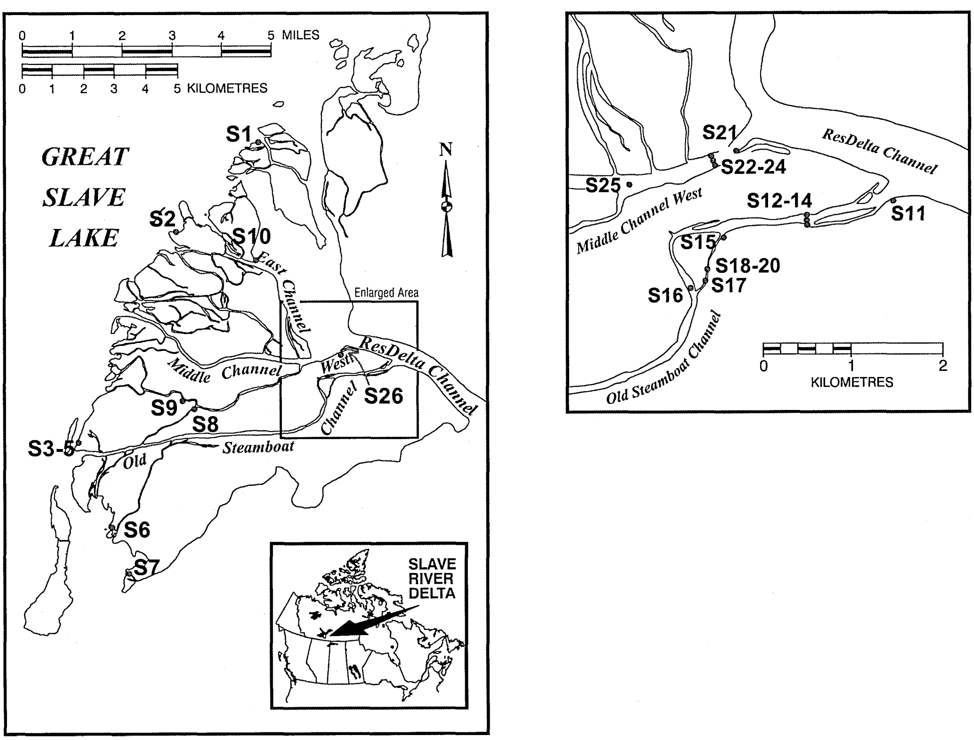

Fig. 1 Study area and sample locations.

homogenized sediment sample. Accuracy of the analysis was verified by running Canadian Reference Standards and comparing the results with the stated reference values for major and trace elements. The mineralogical composition of sediments was investigated by powder X-ray diffraction using Cu-target with a Ni-filter. Mineralogy is reported as percent dry weight.

According to the Canadian Sediment Guidelines for the Protection of Aquatic Life (CCME, 1999), Interim Sediment Quality Guidelines (ISQG) are metal levels at which adverse effects occur rarely and Probable Effects Levels (PEL) are concentrations at which effects are expected to occur frequently. Sediment metal concentrations are compared to the CCME (1999) Guidelines to assess the quality and potential environmental significance of delta sediment.

RESULTS AND DISCUSSION

Mineralogy and major element composition

The mineralogy of delta sediment was relatively consistent in the three morphological areas of the delta. Sediments across the delta were composed of quartz (60–82%) with lesser proportions of calcite (2–6%), feldspars (8–15%), micas (3–7%), montmorillonite (2–9%), dolomite/ankerite (2–4%) and kaolinite (3–5%). Differences in mineralogy are attributed to variation in the textural composition of the samples. Finer grained deposits contained less quartz but higher percentages of feldspar and montmorillonite.

Concentrations of major elements in morphological zones of the delta sediments are summarized in Table 1. Despite differences in sediment texture, both the mean and range of major element concentrations are relatively uniform across the delta. The texture of deposited sediment in the delta is a function of the energy conditions and suspended solids concentrations in the Slave River as well as the morphology and distribution of vegetation in each channel. Correlation coefficients between sediment chemistry and grain size (D_{50}, % clay) show that Al_2O_3, Fe_2O_3 and MnO, which are associated with clay minerals, increase with decreasing grain size (Table 2).

Table 1 Concentration of major elements (% dry weight) in morphological zones of the delta.

	Outer delta:			Mid delta:			Apex:		
	Mean	Range	*CV*	Mean	Range	*CV*	Mean	Range	*CV*
SiO_2	74.3	69.4–77.3	3.80	72.9	71.1–76.2	3.89	72.8	67.7–80.5	5.41
Al_2O_3	10.9	9.1–14	16.67	11.1	8.4–13	21.73	11.8	6.9–15.8	23.59
Fe_2O_3	3.5	2.9–4.8	20.47	3.8	3.2–4.2	14.37	3.9	2.2–5.6	28.50
MgO	2.3	2.1–2.7	9.81	2.3	1.9–2.6	16.23	2.4	1.8–2.8	11.26
CaO	4.4	3.9–4.7	7.38	4.8	4.3–5.6	14.58	4.2	2.8–5.6	20.53
Na_2O	0.53	0.41–0.63	15.81	0.49	0.44–0.57	14.29	0.49	0.34–0.72	23.87
K_2O	2.1	1.8–2.5	12.82	2.1	1.8–2.3	12.18	2.2	1.5–2.8	18.44
TiO_2	0.71	0.58–0.86	14.94	0.62	0.41–0.76	29.74	0.7	0.5–0.88	18.05
MnO	0.059	0.043–0.084	26.05	0.047	0.0025–0.074	82.67	0.057	0.031–0.11	41.20
P_2O_5	0.30	0.27–0.32	6.09	0.29	0.27–0.32	9.12	0.29	0.27–0.32	5.34

Table 2 Correlation coefficients between sediment properties.

Parameter	D_{50}		% clay	
SiO_2	0.954	*	−0.796	*
Al_2O_3	−0.955	*	0.812	*
Fe_2O_3	−0.879	*	0.898	*
MgO	−0.926	*	0.730	*
CaO	0.760	*	−0.878	*
Na_2O	0.925	*	−0.713	*
K_2O	−0.929	*	0.857	*
TiO_2	−0.810	*	0.760	*
MnO	−0.767	*	0.850	*
Co	−0.630	*	0.533	†
Cr	−0.599	*	0.558	†
V			0.672	*

* significant at the 0.01 level (2-tailed).
† significant at the 0.05 level (2-tailed).

Trace elements

The mean and range of trace element concentrations in three morphological zones within the delta are presented in Fig. 2 and compared to the Canadian Sediment Guidelines for the Protection of Aquatic Life (CCME, 1999). According to the CCME Guidelines, Interim Sediment Quality Guidelines (ISQG) are metal levels at which adverse effects occur rarely and Probable Effects Levels (PEL) are concentrations at which effects are expected to occur frequently. In Fig. 2, the ISQG level for each metal is indicated by a dashed horizontal line and the PEL by a solid horizontal line. The PEL values for Hg and Cd are 0.486 $\mu g\ g^{-1}$ and 3.5 $\mu g\ g^{-1}$, respectively.

Levels of Cr, Hg, As and Cd exceeded the PEL for all samples in each of the morphological zones. Concentrations of Cu, Cd, Pb, As and Hg are significantly greater ($p \leq 0.05$) in the mid-delta area than in either of the other two morphological zones. Elevated metal concentrations in the mid delta can be partly explained by the morphology and energy conditions of channels flowing through this section of the delta. Large portions of the outer delta are flooded during spring and significant quantities of sediment are deposited. Lateral accretion bars in the mid delta are flooded annually and sediment deposition is common in these deposition zones. As energy conditions of the Slave River and delta channels decrease, only finer sediment fractions remain suspended in the water column. During this period vegetation is important for trapping fine-grained sediment in lateral accretion bars and marsh flats in the outer delta.

Macrophytes affect the distribution and partitioning of trace metals in aquatic systems (McIntosh *et al.*, 1978). However, no information is currently available on the sediment trapping efficiency of macrophytes and their role in trace metal cycling within the Slave River Delta. Metal tissue concentrations in rooted macrophytes are generally a function of the sediment metal content and pore water chemistry (Jackson, 1998). Metals uptake is through the roots and stems with subsequent translocation to stem and shoots (Jackson *et al.*, 1993). Given the trace metal concentrations reported in this paper, it is likely that macrophytes will play a role in

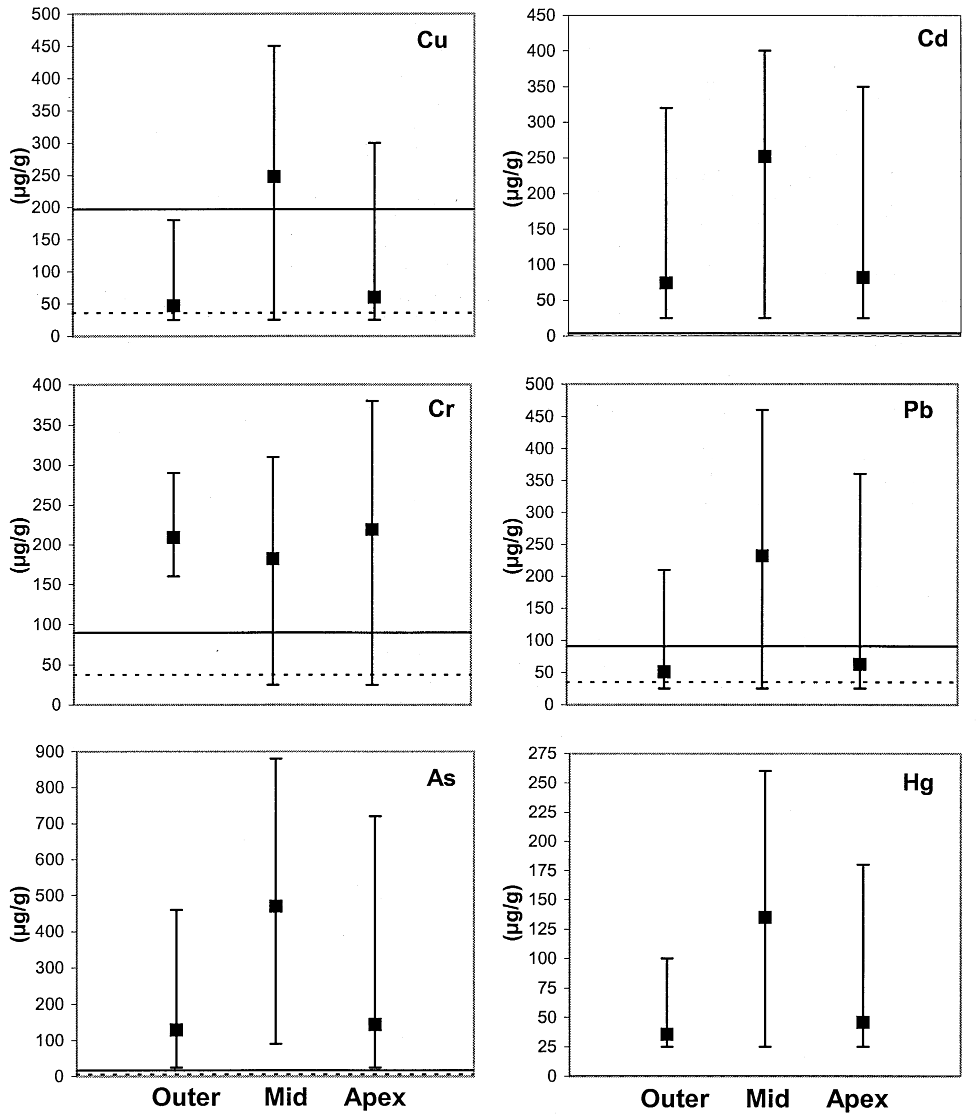

Fig. 2 Concentration of trace metals in morphological zones of the delta (dashed line: ISQG level, solid line: PEL level—see text for details).

the uptake and redistribution of metals in the delta. Four possible pathways for the fate of metals taken up by macrophytes include: gradual transfer to attached epiphytes, sudden release at senescence to the water column, sedimentation while bound to dead or dying shoot tissues, and transfer to grazers that ingest the tissue (Jackson, 1998). The present study has provided a first assessment of trace metal chemistry in sediment of the Slave River Delta. However, further studies are required to quantify the rates and magnitude of pathways for metal cycling in the delta and to determine the role of vegetation for metal bioaccumulation in this remote and ecologically important ecosystem.

REFERENCES

Allan, R. J. (1979) Heavy metals in the bottom sediments of Great Slave Lake, Canada. A Reconnaissance. *Environ. Geol.* **5**(3), 49–58.

Carson, M. A. & Hudson, H. R. (1997) Sediment dynamics and implications for sediment associated contaminants in the Peace, Athabaska and Slave River basins, *Northern River Basins Study Project Report no. 133, Northern River Basin Study, Edmonton, Alberta, Canada.*

CCME (Canadian Council of Ministers of the Environment) (1999) *Canadian Environmental Quality Guidelines*. CCME, Ottawa, Ontario, Canada.

English, M. C. (1984) Implications of upstream impoundment on the natural ecology and environment of the Slave River Delta, Northwest Territories. In: *Northern Ecology and Resource Management*, 311–336.

English, M. C., Hill, B., Stone, M. & Ormson, R. (1997) Geomorphological and plant assemblage change of Slave River Delta, NWT before and after impoundment of the Peace River. *Hydrol. Processes* **11**, 1707–1724.

Jackson, L. J. (1998) Paradigms of metal accumulation in rooted aquatic vascular plants. *Sci. Total Environ.* **219**, 223–231.

Jackson, L. J., Kalf, J. & Ramussen, J. B. (1993) Sediment pH and redox potential affect the bioavailability of Al, Cu, Fe, Mn and Zn to rooted aquatic macrophytes. *Can. J. Fish. Aquatic Sci.* **50**, 143–148.

McCarthy, L. H., Williams, T., Stephens, G., Peddle, J., Robertson, K. & Gregor, D. (1997) Baseline studies in the Lave River , NWT, 1990-1994, part 1: evaluation of the chemical quality of water and suspended sediments from the Slave River (NWT). *Sci. Total Environ.* **197**, 21–53.

McIntosh, A. W., Shepherd, B. K., Mayes R. A, Atchison, G. J. & Nelson, D. W. (1978) Some aspects of sediment distribution and macrophyte cycling of metals in a contaminated lake. *J. Environ. Qual.* **7**, 301–305.

Milburn, D. & Prowse, T. (1998) Sediment bound contaminants in a remote northern delta. *Nordic Hydrol.* **29**(4/5), 397–414.

Mudroch, A., Allan, R. J. & Joshi, S. R. (1992) Geochemistry and organic contaminants of the sediments of Great Slave lake, Northwest Territories, Canada. *Arctic* **45**(1), 10–19.

Vandenburgh, S. & Smith, D. (1988) Slave River delta: geomorphology, sedimentology and Holocene reconstruction. *Can. J. Earth Sci.* **25**, 1990–2004.