

Trace Metal Pollution from a Municipal Waste Disposal Site at Pangnirtung, Northwest Territories

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ABSTRACT. Water and sediment samples collected from a municipal waste disposal site near the Hamlet of Pangnirtung, Baffin Island, were analyzed for classical parameters and trace metals (Cd, Cu, Fe, Pb and Zn). Although all trace metal concentrations showed a considerable increase below the dump, only Pb and Fe in water samples from the main collector ditch and below the dump exhibited excessive levels, with 6.1 and 53.3 ppm respectively. The ratios between easily exchangeable metals and total metals ranged between 0.02 (Fe) and 18.7 (Cu), in accordance with related studies. There was no significant accumulation of any trace metal in the sediments below the disposal site, indicating rapid removal from the intertidal flats and subsequent accumulation in the bottom sediments.

Key words: Baffin Island, metal contamination, leachates, trace metals, waste disposal

RÉSUMÉ. On a analysé des échantillons d'eau et de sédiments recueillis à l'emplacement d'une décharge municipale près du hameau de Pangnirtung dans la terre de Baffin, pour savoir s'ils contenaient les paramètres et les oligo-éléments classiques (Cd, Cu, Fe, Pb et Zn). Bien que toutes les concentrations d'oligo-éléments aient montré une hausse considérable sous la décharge, seuls le plomb et le fer dans les échantillons d'eau du principal fossé collecteur et de sous la décharge, se sont montrés en quantités excessives, soit 6,1 et 53,3 ppm respectivement. Les rapports entre les métaux facilement échangeables et les métaux totaux variaient entre 0,02 (Fe) et 18,7 (Cu), en accord avec des études connexes. Il n'y avait pas d'accumulation importante d'aucun des oligo-éléments dans les sédiments sous l'emplacement de la décharge, ce qui indique un retrait rapide des zones plates de la laisse et une accumulation subséquente dans les sédiments du fond.

Mots clés: terre de Baffin, contamination par les métaux, percolats, oligo-éléments, décharge

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INTRODUCTION

Trace metal contamination in the eastern Canadian Arctic by mines and the subsequent impact on the marine environment have been studied for a long time (Bohn and McElroy, 1976; Bohn and Fallis, 1978; Fallis, 1982). The uptake and bioaccumulation of trace metals in biota (Muir *et al.*, 1987; Wagemann and Muir, 1984; Wagemann *et al.*, 1983) and humans (Charlebois, 1978; Eaton, 1982) has also received considerable attention. However, with one notable exception (Bourgoin and Risk, 1987), there are no published studies on leachates containing trace metals from municipal waste disposal sites in the eastern Canadian Arctic.

Although the amounts of liquid and solid waste produced in the communities of the eastern Canadian Arctic are small, the potential impact is considerable. Lack of adequate disposal facilities, manpower and funds, coupled with climatic restrictions, permafrost and inadequate cover material, forces many communities to dispose of their waste on open sites — often in direct contact with the marine environment. Fishing and gathering of seafood occasionally occur in close proximity to these sites. In order to evaluate the potential health hazards for the population, knowledge about concentrations of natural background levels and anthropogenic contamination by specific trace metals (and other toxic substances) is necessary.

SITE DESCRIPTION

The Hamlet of Pangnirtung is located on the southeastern shore of Pangnirtung Fiord, Baffin Island, about 40 km south of the Arctic Circle (Fig. 1). Pangnirtung is situated on bedrock and deltaic sediments, with broad intertidal flats stretching to the northeast. The physical and biological setting of the study area has been described by Aitken and

Gilbert (1986) and Gilbert *et al.* (1987). In 1985, the settlement had a population of 1120 people, mostly Inuit, and a yearly consumption of about 10 000 m³ of freshwater (Hamlet of Pangnirtung, unpubl. data). More than 27 000 garbage drums (45 gallons capacity), 18 700 honeybags and 7600 m³ of liquid sewage and domestic waste water were collected by a trucked system and discharged at the communal waste disposal site in 1985 (Hamlet of Pangnirtung, unpubl. data).

The dump is situated on glaciomarine sands and gravels about 2 km northeast of the settlement (Fig. 1). The surface waters from the talus slope of Mt. Duval drain toward the site and are collected in drainage ditches above and at the southwestern side of the dump, before being discharged to the fiord. The movement of water through the waste disposal site itself is restricted by the road and by a berm constructed for this purpose. The northeastern part of the dump is mostly used for the disposal of honeybags, which provide a considerable input of liquid sewage. Potential sources of lead (batteries, boat fuel, paints, etc.) and iron (construction material) were observed on the dump.

MATERIALS AND METHODS

Surface water samples were obtained by hand or with a small hand pump into 500 ml polyethylene bottles that had been precleaned according to standard methods (American Public Health Association, 1985; Environment Canada, 1979). The samples were collected daily from 18 to 24 August 1986 and on 24 August 1987; they were acidified to pH 1.5-2 and kept at 4°C until processing (American Public Health Association, 1985). Temperature, pH, electrical conductivity (EC) and dissolved oxygen (DO) were measured *in situ* using a Hydrolab Model TC-2 Conductivity/Temperature Meter, a Fisher Model 54ARC Dissolved Oxygen Meter and

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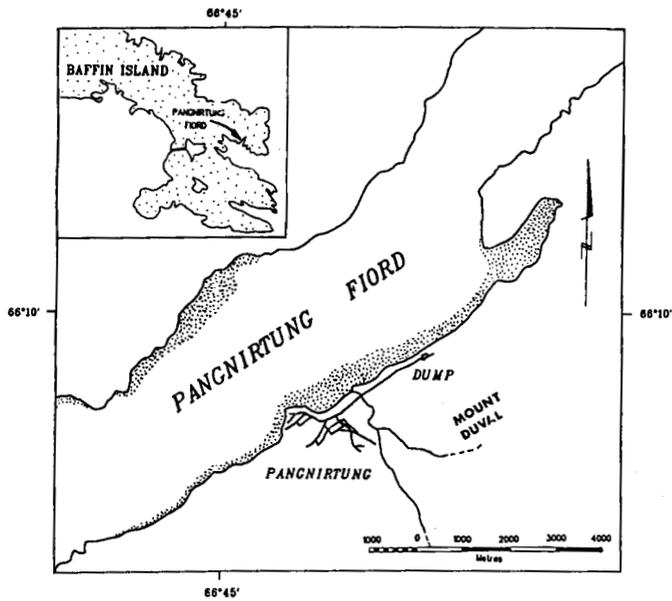


FIG. 1. Location of the study area.

a Fisher Accumet Mini pH Meter Model 640. During 24 August 1986, three short (20 cm) sediment cores were taken at the high tide line, sealed and stored at 4°C until analyzed. The locations of the water sampling stations and of the cores are shown in Figures 2 and 3.

After filtration at 0.45 μm , the water samples were analyzed for dissolved Cd, Cu, Fe, Pb and Zn by dual atomic absorption spectroscopy (AAS) (Varian SpectrAA-10 and Perkin-Elmer). The aqueous solutions were aspirated directly into an air-acetylene flame.

The sediment cores were split, photographed for later analysis of sedimentary structures, dried and sieved at 2 mm. The readily exchangeable trace metals were extracted by 1 N NH_4OAc at pH 7 (Förstner and Wittmann, 1983; Thomas, 1982). This phase represents very loosely bound metals that may regulate the composition of the surface waters and may readily go into solution under changing pH-Eh conditions and salt concentrations (Förstner and Wittmann, 1983). Ten grams of < 2 mm air-dried sediment were placed in a 50 ml centrifuge tube, 25 ml of extractant were added, and the sample was shaken for 2 h. The samples were then centrifuged at 2000 rpm for 600 s and filtered through Whatman No. 5 filter paper. This was repeated with an additional 25 ml

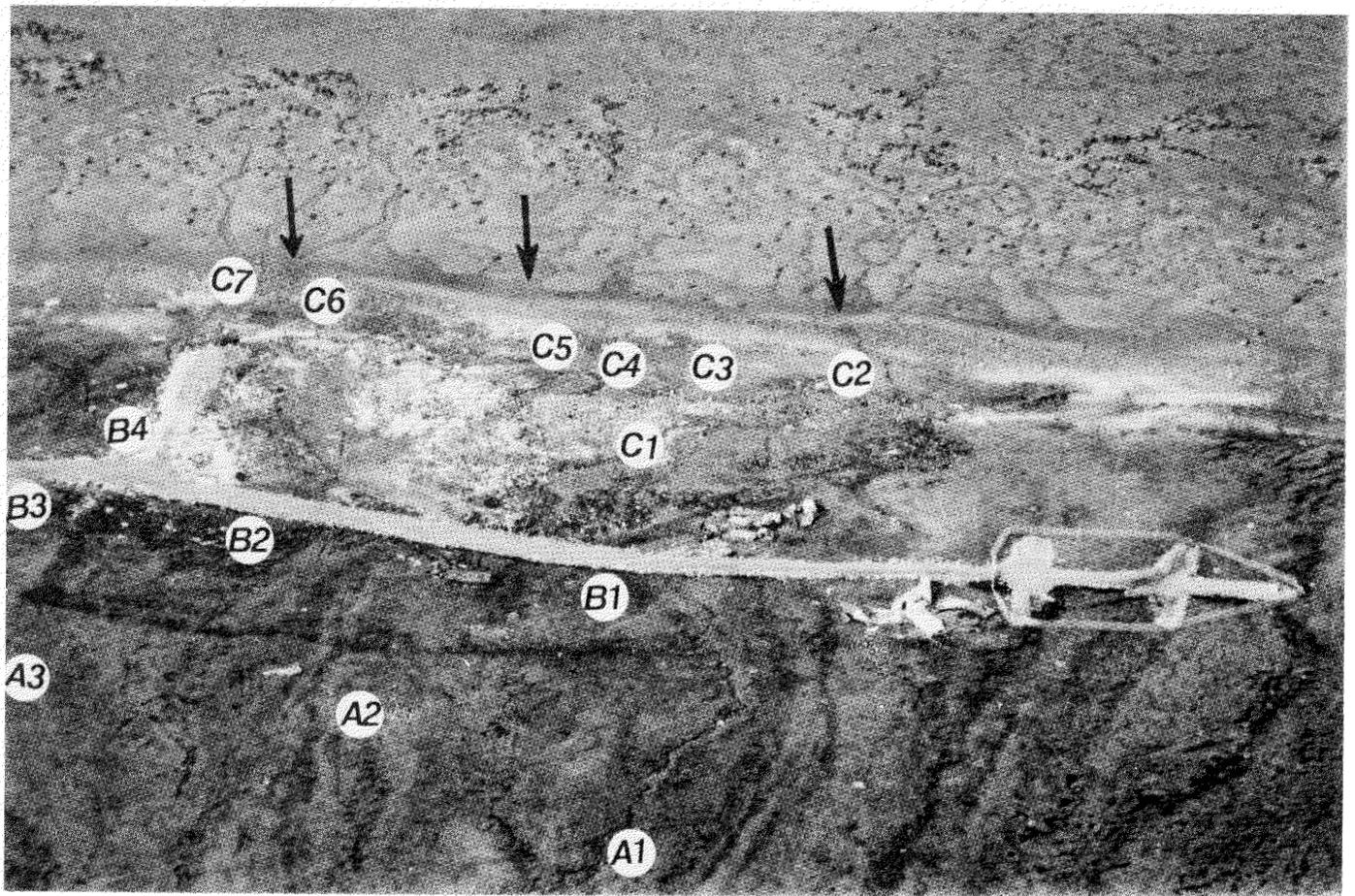


FIG. 2. Location of the water (A1 to C7) and sediment sampling sites during low tide. Arrows indicate the high tide line.

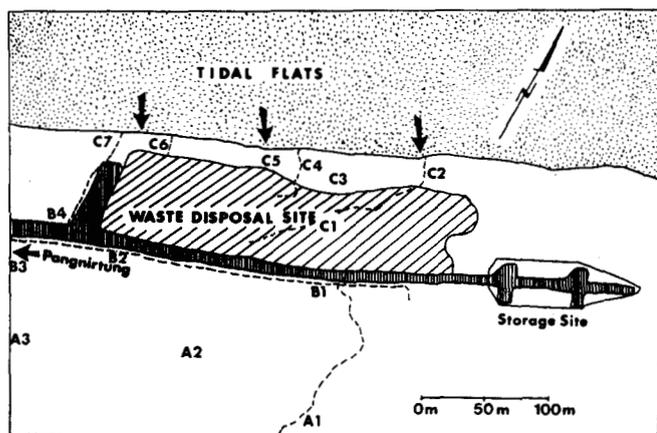


FIG. 3. Location of the water (A1 to C7) and sediment sampling sites (arrows) during low tide (dashed lines indicate channel flow).

of ammonium acetate solution and with a shorter shaking time (1 h). Finally, the volume was brought up to 50 ml by adding 1 N NH_4OAc . Total metals were extracted by boiling aqua regia (Förstner and Wittmann, 1983; Salomons and Förstner, 1980; Tessier *et al.*, 1979).

The metal concentrations were determined by AAS (taking the solid-solution ratios into account) and Instrumental Neutron Activation Analysis (INAA). Total carbon (TC) was determined using a Leco Carbon Analyzer, pH (in 0.01 M CaCl_2) with a Fisher Accumet pH Meter Model 210 (McKeague, 1978), and organic matter (OM) by combustion using the gravimetric difference between 105° and 650°C (Konrad *et al.*, 1970). Cation exchange capacity (CEC) was estimated by the sum of the ammonium acetate extracted cations Ca, Mg, K and Na (in meq·100 g^{-1} sediment).

Quality control was insured by field and laboratory blanks (distilled water, 1 N NH_4OAc , aqua regia), standard references (BCC Soil Pulp Standard 86, NBS 1643, synthetic standards for AAS), duplicates and replicate measurement on the two AAS instruments and by INAA. Measurement of liquid samples (AAS) showed errors of $\pm 10\%$ (Na) to $\pm 25\%$

(Pb) based on two standard deviations. Recovery rates for the solid samples extracted by NH_4OAc were from 92.9% (Fe) to 122% (Na). Comparison of total Fe in solid samples measured by AAS and INAA showed large errors ($> 50\%$ with 2σ). All data shown in Tables 1 to 3 were obtained by AAS. Notice that significant numbers changed with the dilution ratios.

Due to the prolonged storage, losses of metals to the walls of the sampling containers occurred. Losses of 20-40% Pb were recorded in replicate measurements of the 1986 water samples after one year of storage at 4°C. According to Bartlett and James (1980), the drying procedure increased the solubility of the metals and the solubility and oxidizability of OM in the sediment samples, due to increased surface acidity and the breaking of hydrogen bonds within the organic structures.

RESULTS AND DISCUSSION

Tables 1 and 2 show the concentrations of Cd, Cu, Fe, Pb and Zn in the water samples collected in 1986 and 1987 respectively. The samples were divided in group α (A1 to B1) and group β (C) for easier comparison. During both years, there is a general increase of dissolved metals from the "uncontaminated" group α (above the dump) to the "contaminated" group β (below the dump). In 1986, the average Cu values rose from 0.045 $\text{mg}\cdot\text{L}^{-1}$ to 0.13 $\text{mg}\cdot\text{L}^{-1}$, Pb from 0.055 $\text{mg}\cdot\text{L}^{-1}$ to 0.19 $\text{mg}\cdot\text{L}^{-1}$, Zn from 0.020 $\text{mg}\cdot\text{L}^{-1}$ to 0.24 $\text{mg}\cdot\text{L}^{-1}$, and Fe from 0.36 $\text{mg}\cdot\text{L}^{-1}$ to 12.2 $\text{mg}\cdot\text{L}^{-1}$. The Cd levels were below the detection limit (0.02 $\text{mg}\cdot\text{L}^{-1}$) for this method. The total concentrations and the ratios of the means of group α and β were slightly lower in 1987, but the general trend was confirmed.

The trace metal concentrations in the water samples provide a direct comparison between natural background and contaminated levels. Although the analysis was restricted to discrete grab samples, the results show a distinct potential for environmental contamination of the biota in the fiord. The Pb contents of samples B4 to C7 from 1986 exceeded

TABLE 1. pH (units), conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$) and dissolved oxygen, cation and trace metal concentrations ($\text{mg}\cdot\text{L}^{-1}$) in the water samples from the waste disposal site at Pangnirtung (24 August 1986)*

| No. | pH | EC | DO | Ca | Mg | Na | K | Fe | Cu | Pb | Zn |
|-----------------|-----|------|------|------|-------|-------|------|-------|------|------|------|
| A1 | 5.6 | 41 | 8.9 | 0.39 | 0.59 | 8.02 | DL | 0.40 | 0.06 | 0.05 | 0.02 |
| A2 | 5.6 | 49 | 9.0 | 0.32 | 0.57 | 6.27 | DL | 0.50 | 0.04 | 0.07 | 0.02 |
| A3 | 5.9 | 51 | 8.9 | 0.44 | 0.68 | 5.34 | DL | 0.23 | 0.05 | 0.05 | 0.02 |
| B1 | 5.9 | 42 | 9.5 | 0.34 | 0.49 | 5.83 | DL | 0.31 | 0.03 | 0.05 | 0.02 |
| B2 | 5.7 | 50 | 8.8 | 0.39 | 0.57 | 6.65 | DL | 0.65 | 0.05 | 0.06 | 0.03 |
| B3 | 5.7 | 48 | 8.9 | 0.48 | 0.93 | 10.90 | 1.34 | 0.65 | 0.05 | 0.05 | 0.03 |
| B4 | 6.0 | 78 | 9.7 | 0.42 | 0.68 | 7.98 | DL | 1.85 | 0.06 | 6.10 | 0.03 |
| C1 | 6.8 | 1400 | ND | 7.48 | 9.24 | 41.9 | 12.0 | 15.85 | 0.10 | 0.08 | 0.21 |
| C2 | 6.2 | 1270 | ND | 4.51 | 2.84 | 77.0 | 3.41 | 6.10 | 0.12 | 0.35 | 0.33 |
| C3 | 7.4 | 220 | ND | 3.51 | 4.76 | 46.2 | 8.50 | 14.96 | 0.10 | 0.22 | 0.13 |
| C4 | 7.8 | 1900 | ND | 13.9 | 15.12 | 66.9 | 58.0 | 6.09 | 0.28 | 0.27 | 0.31 |
| C5 | 6.6 | 1400 | ND | 19.9 | 14.34 | 233 | 20.5 | 11.19 | 0.09 | 0.09 | 0.35 |
| C6 | 6.5 | 230 | 9.9 | 20.1 | 20.06 | 91.8 | 9.50 | 30.02 | 0.12 | 0.09 | 0.29 |
| C7 | 6.5 | 115 | 9.7 | 1.15 | 1.02 | 8.25 | 1.42 | 1.13 | 0.08 | 0.22 | 0.07 |
| Detection limit | | 0.1 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.02 | 0.03 | 0.05 | 0.02 |

*Significant numbers change with dilution ratios.

DL = Value below the detection limit.

ND = No data.

TABLE 2. T (degrees), dissolved oxygen ($\text{mg}\cdot\text{L}^{-1}$) and trace metals ($\text{mg}\cdot\text{L}^{-1}$) in the water samples from the waste disposal site at Pangnirtung (24 August 1987)

| No. | T | DO | Fe | Cu | Pb | Zn |
|-----------------|-----|------|------|------|------|------|
| A1 | 4.2 | 12.3 | 0.72 | 0.02 | 0.08 | 0.03 |
| A2 | 4.1 | 12.1 | 0.69 | DL | 0.07 | 0.02 |
| A3 | 3.2 | 11.1 | 1.20 | DL | 0.08 | 0.02 |
| B1 | 4.3 | 10.7 | 1.42 | DL | 0.07 | 0.02 |
| B2 | 5.1 | 9.9 | 2.13 | DL | 0.09 | 0.02 |
| B3 | 3.8 | 11.2 | 3.64 | 0.08 | 0.10 | 0.02 |
| C1 | 4.2 | 8.8 | 31.1 | 0.08 | 0.08 | 0.32 |
| C2 | 6.5 | 11.7 | 1.85 | 0.02 | 0.13 | 0.04 |
| C4 | 3.8 | 0.6 | 9.63 | 0.02 | 0.12 | 0.07 |
| C5 | 2.7 | 4.9 | 53.3 | 0.02 | 0.09 | 0.57 |
| C7 | 3.9 | 10.0 | 1.66 | DL | 0.13 | 0.05 |
| Detection limit | 0.1 | 0.1 | 0.05 | 0.02 | 0.05 | 0.02 |

DL = Value below the detection limit.

the drinking water guidelines (Canada, Department of National Health and Welfare, 1987) — one extreme sample (B4) by more than 100 times ($6.1 \text{ mg}\cdot\text{L}^{-1}$). Iron levels are also high (up to $53.5 \text{ mg}\cdot\text{L}^{-1}$). The guidelines recommend $0.05 \text{ mg}\cdot\text{L}^{-1}$ for lead and $0.3 \text{ mg}\cdot\text{L}^{-1}$ for iron as maximum acceptable concentrations in drinking water (Canada, Department of National Health and Welfare, 1987). Cd, Cu and Zn were below the recommended guidelines ($5 \mu\text{g}\cdot\text{L}^{-1}$, $1 \text{ mg}\cdot\text{L}^{-1}$ and $5 \text{ mg}\cdot\text{L}^{-1}$ respectively).

The sediments of all cores were well-sorted sands and silts. The size fraction $> 2 \text{ mm}$ was erratic in content and shape. Of the size fraction $< 2 \text{ mm}$, sands predominate (80-90%) over silts (5-15%) and clay ($< 3\%$). X-radiography showed strong bioturbation in the upper 10 cm of the cores. The colour of the surface sediments (C1A, C2A, C4A) ranged from yellowish brown to light reddish brown, indicating free circulation of water and oxygen. At 10-12 cm the colour of the sediments in core C4 changed abruptly to dark grey to black (without any change in grain size or OM), probably indicating a change to reducing conditions. Below 15-17 cm the colour returns to a light greyish brown. This reduced layer was observed at many locations on the tidal flats.

Table 3 shows the pH, TC, OM and trace metal concentrations in the three cores. The values for TC ($0.25\% \leq x$

$\leq 0.32\%$), OM ($0.3\% \leq x \leq 0.4\%$) and the readily soluble metals are low and show only slight variations. The sediments are slightly acidic ($\text{pH } 6.1 \leq x \leq \text{pH } 6.7$) and their CEC is below $3 \text{ meq}\cdot 100 \text{ g}^{-1}$. The hierarchy observed for the ratio of exchangeable to total metal concentration was $\text{Cu} > \text{Zn} > \text{Pb} > \text{Fe}$, indicating that the exchange sites were preferentially occupied by the more mobile copper and zinc ions.

Both the readily exchangeable and the total trace metals showed relatively low concentrations. In their analysis of a sediment surface sample located 250 m downslope from the same dump, Bourgoin and Risk (1987) found slightly higher Cu ($24 \mu\text{g}\cdot\text{g}^{-1}$) and Zn ($29 \mu\text{g}\cdot\text{g}^{-1}$) levels and considerably higher lead concentrations ($22 \mu\text{g}\cdot\text{g}^{-1}$) than in this study. A grab sample collected from the bottom of the fiord downslope of the waste disposal site (Gilbert and Chomyn, pers. comm. 1987) also exhibited higher levels of Cu ($22 \mu\text{g}\cdot\text{g}^{-1}$), Cd ($0.8 \mu\text{g}\cdot\text{g}^{-1}$), Pb ($33 \mu\text{g}\cdot\text{g}^{-1}$) and Fe (2.7%).

Low concentrations of mud and OM in the intertidal sediments were also observed by Aitken and Gilbert (1986). Due to the low numbers of exchange sites and the constant vertical and horizontal flow of water through the sediments, most metals discharged from the dump are rapidly transported to the fiord. There they are scavenged by dynamic, physiochemical and biological processes (probably primarily by complexation and flocculation with OM, coprecipitation with hydrous Fe/Mn oxides and uptake by organisms) before accumulating in the bottom sediments.

CONCLUSIONS

This study demonstrates the occurrence of lead contamination and high iron levels in surface water downhill of the municipal water disposal site at Pangnirtung, N.W.T. The environmentally important readily exchangeable metals and the total concentrations of Cd, Cu, Fe, Pb and Zn in sediments directly downslope of the dump were low in comparison to fiord bottom sediment concentrations, indicating a rapid removal of trace metals from the very active tidal zone. However, high concentrations of Cu, Fe, Pb and Zn in surface waters downhill of the waste disposal site indicated the potential for metal contamination of the biota in the fiord. In a survey of metal bioaccumulation in fish in the Eastern

TABLE 3. Averaged CEC ($\text{meq}\cdot 100 \text{ g}^{-1}$ sediment), pH (units), OM (%) and readily exchangeable and total trace metals ($\mu\text{g}\cdot\text{g}^{-1}$) in three sediment cores collected below the waste disposal site at Pangnirtung (24 August 1986) (results are based on sediment dry weight)

| Core* | pH | CEC | OM | Fe | Cd | Cu | Pb | Zn |
|------------------|-----|-----|-----|----------------------|-----|--------|-------|--------|
| C1 (0-10cm) | 6.7 | 1.1 | 0.3 | (a) 5.5 | DL | 1.1 | 0.2 | 0.9 |
| | | | | (0.04)** | | (12.0) | (2.5) | (4.6) |
| C2 (0-10cm) | 6.6 | 2.0 | 0.3 | (b) $14.4\cdot 10^3$ | 0.1 | 9.2 | 8.0 | 19.6 |
| | | | | (a) 18.5 | DL | 1.5 | 0.1 | 1.6 |
| C4A (0-10cm) | 6.3 | 2.2 | 0.3 | (0.22) | | (13.2) | (4.6) | (8.0) |
| | | | | (b) $8.5\cdot 10^3$ | 0.2 | 11.4 | 2.2 | 20.0 |
| C4B (10-20cm) | 6.1 | 1.7 | 0.4 | (a) 1.4 | DL | 1.0 | 0.3 | 1.9 |
| | | | | (0.02) | | (5.6) | (7.9) | (10.8) |
| C4B (10-20cm) | 6.1 | 1.7 | 0.4 | (b) $7.8\cdot 10^3$ | 0.2 | 18.1 | 3.8 | 17.6 |
| | | | | (a) 4.1 | DL | 1.2 | DL | 1.3 |
| C4B (10-20cm) | 6.1 | 1.7 | 0.4 | (0.04) | | (18.7) | (<5) | (14.1) |
| | | | | (b) $10.3\cdot 10^3$ | 0.1 | 6.4 | 1.8 | 9.2 |

*(a) NH_4OAc extraction; (b) Aqua regia extraction.

**Values in parentheses are (exchangeable metal/total metal) $\cdot 100$.

Arctic, Muir *et al.* (1987) found high levels of Zn in Arctic cod from Pangnirtung. It is recommended that direct monitoring of leachates from waste disposal sites or biomonitoring be used in high energy environments, such as intertidal flats, with a very recent history of anthropogenic contamination.

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