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GEOCHEMISTRY OF SEDIMENTS
IN BACK BAY AND YELLOWKNIFE BAY
OF THE GREAT SLAVE LAKES

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NWRI Contribution No. 86-190

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EXECUTIVE SUMMARY

Large quantities of arsenic and zinc in gold mining wastes have been discharged into Yellowknife Bay of Great Slave Lake, Northwest Territories. This study was carried out to determine the extent of contamination of bottom sediments in two areas of Yellowknife Bay. The results of the study indicated historical trends of arsenic and zinc inputs into the bay. The historical record was in good agreement with implemented remedial actions and usage pattern of both elements. It was estimated that it will take about 20 years at the present sedimentation rate to cover contaminated sediment by a five centimeter layer of naturally deposited clean material at Yellowknife Bay. The investigation was carried out under study no. ECD-236 in conjunction with Environmental Protection Service, Yellowknife, Northwest Territories.

MANAGEMENT PERSPECTIVE

This report provides information on the effectiveness of implemented treatment to remove aresenic and zinc from gold mining wastes discharged into Yellowknife Bay of Great Slave Lake, Northwest Territories. It also provides information on the extent of contamination of sediments by arsenic and zinc in Yellowknife Bay. This information can be used for future planning of effective gold mine waste treatment and assessment of the period necessary for natural recovery of sediment quality in the bay.

RÉSUMÉ

L'exploitation des mines d'or a produit des déchets renfermant des concentrations élevées d'arsenic et de zinc dans la région de Yellowknife (Territoires du Nord-Ouest), au Canada. Des déchets ont été déversés dans la baie Yellowknife du Grand lac des Esclaves. On a déterminé les concentrations d'arsenic et de zinc dans des carottes de sédiments prélevées dans les zones d'accumulation de la baie Yellowknife. Les taux de sédimentation ont été calculés à l'aide de deux méthodes radiométriques différentes : le profil de concentration en fonction de la profondeur du Cs-137 et celui du Pb-210. La composition géochimique des carottes de sédiments indique que les mêmes matières se sont déposées depuis 50 ans dans la zone où on a fait les prélèvements. L'âge des sédiments obtenu d'après les mesures des radionucléides a permis de déterminer les tendances chronologiques de l'accumulation d'arsenic et de zinc dans la baie Yellowknife. Les données chronologiques concordent bien avec les mesures appliquées pour corriger la situation et les modes d'utilisation des deux éléments.

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PERSPECTIVES DE GESTION

Le présent rapport procure des données sur l'efficacité du traitement appliqué pour éliminer l'arsenic et le zinc des déchets de mines d'or déversés dans la baie Yellowknife du Grand lac des Esclaves (Territoires du Nord-Ouest). Il procure également des données sur le degré de contamination des sédiments par l'arsenic et le zinc dans la baie Yellowknife. Ces données pourront être utilisées pour mettre au point un traitement efficace des déchets de mines d'or et pour évaluer le temps qu'il faudra pour que les sédiments de la baie retrouvent naturellement leur qualité.

ABSTRACT

Gold mining activities generated wastes with high concentrations of arsenic and zinc in the vicinity of Yellowknife, Northwest Territories, Canada. Some of the waste material has been discharged into Yellowknife Bay of Great Slave Lake. Concentrations of arsenic and zinc were determined in sediment cores collected at the depositional areas of Yellowknife Bay. Sedimentation rates were estimated using two different radiometric approaches: the depth profiles of Cs-137 and Pb-210. Geochemical composition of the sediment cores indicated input of similar material into sampling areas over the past 50 years. Age profiles of the sediment constructed from the radionuclides measurements were used to determine historical trends of arsenic and zinc inputs into Yellowknife Bay. The historical record was in good agreement with implemented remedial actions and usage patterns of both elements.

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RÉSUMÉ A L'INTENTION DE LA DIRECTION

De grandes quantités d'arsenic et de zinc dans des déchets de
mines d'or ont été déversées dans la baie Yellowknife du Grand lac
des Esclaves, dans les Territoires du Nord-Ouest. Cette étude a été
effectuée pour déterminer jusqu'à quel point les sédiments de fonds
ont été contaminés dans deux zones de la baie Yellowknife. Les
résultats de cette étude ont montré que l'arsenic et le zinc avaient
tendance à se déposer dans la baie avec le temps. Les données
chronologiques concordent bien avec les mesures qui ont été prises
pour corriger la situation et le mode d'utilisation des deux
éléments. On a estimé qu'il faudra environ vingt ans au taux
actuel de sédimentation pour recouvrir les sédiments contaminés
d'une couche de cinq centimètres de matières naturelles non
contaminées dans la baie Yellowknife. Ces recherches ont été
effectuées dans le cadre de l'étude numéro ECD-236 en collaboration
avec le Service de protection de l'environnement de Yellowknife
(Territoires du Nord-Ouest).

INTRODUCTION

Gold mining has been an important industry in Canada since the middle of the nineteenth century. Much of the gold is produced as a by-product of nickel, copper, lead and zinc mines. Major gold mines are located in northern Ontario, Quebec and Northwest Territories. Like every industry, gold mining has generated typical waste products which contain some naturally occurring toxic elements in gold deposits, and toxic elements and compounds, which are introduced during the processing of the gold ores. Arsenic is almost always naturally associated with gold deposits. Other elements which usually accompany gold in the ore are copper, zinc, lead and nickel. In the past, mercury was used for amalgamation in the refining process. Later, gold has been extracted from milled ore by alkali cyanide solution and then precipitated by metallic zinc. Results of several studies of gold mining waste discharges into the aquatic environment indicated negative effects such as accumulation of arsenic and mercury in bottom sediments and their uptake by biota (Metcalfe and Mudroch, 1985; Mudroch and Clair, 1986).

There are two major gold mines in the Northwest Territories located on the shore of the Great Slave Lake. One of the mines, Giant Yellowknife Mines, Ltd., about 5 km north of the city of Yellowknife, discharges its effluent into a creek flowing into Yellowknife Bay of Great Slave Lake. Tailings from the second mine, Con-Rycon-Vol, located south of Yellowknife, are being discharged through a chain of

small lakes directly into the North Arm of Great Slave Lake, outside of Yellowknife Bay (Allan, 1979). Giant Yellowknife Mines, Ltd., has been in operation since 1949. Between 1949 and the middle of the 1960's, gold was extracted from the ore using a combination of mercury amalgamation and cyanidation. However, subsequent extraction depended entirely on the cyanidation process (Moore and others, 1978). Chemical analyses of wastes from the gold mine showed a significant input of arsenic, cyanides and several metals into Yellowknife Bay (Wallace and Hardin, 1974; Moore and others, 1978). Chemical analyses of wastes from the gold mine showed a significant input of arsenic, cyanides and several metals into Yellowknife Bay (Wallace and Hardin, 1974; Moore and others, 1978). In the early 1980's the gold mine introduced a treatment of the effluent in order to reduce concentrations of arsenic and cyanide.

At present, the city of Yellowknife obtains its drinking water from the Yellowknife River which enters the Yellowknife Bay upstream of the gold mine. However, the maintenance of the about 9 km long intake pipe was a subject of recent reconsideration of a drinking water supply from Yellowknife Bay.

This study is a part of a comprehensive investigation of the effect of mine wastes on aquatic ecosystems in Canada. The objectives of this study were to identify the extent of the contamination originating from the gold mine waste in Yellowknife Bay, and to assess the effectiveness of the mine effluent treatment implemented in the early 1980's.

MATERIALS AND METHODS

Study Area and Sediment Sampling

Great Slave Lake with an area of 28,000 km^2 is one of the world's four sub-Arctic great lakes (Fig. 1). Limnology and geological setting of the lake were described by Rawson (1950) and Allan (1979). Yellowknife Bay is about 11.3 km long, 2.8 km wide and is situated at an elevation of 165 m and receives the discharge from Yellowknife River to the north and communicates directly with Great Slave Lake to the south. The city of Yellowknife with a population of 11,000, is located on the western shore of the bay (Fig. 2). Giant Yellowknife Mines, Ltd., lies about 5 km north of the City of Yellowknife on the western shore. Tailings from the mine are currently piped to a series of ponds which decant directly into Baker Creek, although in the early 1960's some tailings were deposited directly into Yellowknife Bay just north of Baker Creek. Baker Creek discharges into Back Bay of the Yellowknife Bay (Fig. 2).

Sediment cores were collected at a 12 m depth in Back Bay and at a 14 m depth in Yellowknife Bay, downstream of the city of Yellowknife. The sampling stations were chosen to obtain information on the transport of contaminants from Baker Creek into the area in Yellowknife Bay which may be considered for the city's drinking water intake. Four cores were collected at each sampling locality on a square sampling grid shown in Fig. 2. All cores were immediately

subdivided in 1 cm sections to a 30 cm depth. All samples were kept refrigerated during the transport to the laboratory at the Canada Centre for Inland Waters in Burlington, Ontario.

CHEMICAL ANALYSES

All sediment samples were freeze dried and homogenized by grinding to 189 um particle size. One core from each sampling locality was used for sediment dating. The determination of concentrations of major elements (Si, Al, Fe, Ca, K, Mg, Na, Ti, Mn and P), as well as As and Zn was carried out on all samples by X-ray fluorescence spectrometry. The precision of the analysis was determined by analysing five pellets made from a homogenized sediment sample. Relative deviations for major elements can be expected at the following levels: SiO_2 2%, K_2O and Al_2O_3 4%, Fe_2O_3 and CaO 2%, MgO and Na_2O 10%. Absolute deviations of 0.01% to 0.02% were found for MnO, TiO_2 and P_2O_5. For Zn and As absolute deviations are to be expected in the range of 5 to 15 ug/g at the determined levels. The accuracy of the analysis was verified by running Canadian Reference Standards Syenite SY-2 and soils SO-2 and SO-4, and comparing the analytical 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.

SEDIMENT DATING

Recent sedimentation rates can be estimated using two different radiometric approaches. In the first, the depth of profiles of an artificially produced radionuclide such as Cs-137 (half life 30 years) is measured (Krishnaswamy and others, 1971). Very small amounts of this radionuclide were introduced into the environment in 1945 when the first atmospheric nuclear detonations took place. Testing of large-scale nuclear weapons in the northern hemisphere started in 1954, increased significantly around 1958-59, and peaked during 1961-63. Since then the fallout debris has decreased markedly. In the conventional application of this technique, the average rate of sedimentation is inferred by reference to either the 1963 fallout peak activity maximum or the 1958-59 horizon corresponding to the onset of increase in atmospheric testing. Consequently, this technique is satisfactorily applied only in cases where higher sedimentation rates would provide sampling resolution adequate enough for locating either of the two events. Moreover, the known tendency of this radionuclide to migrate in the sediment core further limits its direct application for dating purposes (Durham and others, 1980; Joshi, 1985a).

In the second approach, the depth distribution of a naturally occurring radionuclide such as Pb-210 (half life 22.26 years) is measured with the assumption that constant amounts of the radionuclide have reached the sediment/water interface over the study period (Krishnaswamy and others, 1971). This assumption is generally

considered valid over long periods of time, although short-term variations in the levels of atmospheric Pb-210 are known to occur. Sedimentation rate is inferred from the decay characteristics of Pb-210 deposited with the sediment.

Our earlier success in applying this technique in similar National Water Research Institute investigations prompted us to use only Pb-210-derived dates in the present study although the Cs-137 profiles were also computed.

The total Pb-210, Ra-226 and Cs-137 concentrations in dried, ground samples were measured with Aptec hyperpure germanium detectors. The 662-keV γ-ray (Cs-137) was measured in a large volume, closed and coaxial detector, while the 46.5 (Pb-210), 186 and 352 keV (Ra-226) γ-rays were measured with a detector in planar configuration. The detector calibration and data accumulation procedures are similar to those given earlier (Joshi, 1985b). The self-absorption of low-energy γ-rays in these samples is considered to be negligible since both the detector efficiency calibration material and study samples have similar densities.

Precise sample thickness and porosities were determined as described earlier (Joshi, 1985a; Durham and Joshi, 1980).

STATISTICAL ANALYSES

Statistical analyses were carried out on data obtained by geochemical analyses to compare the trends in concentrations of As and Zn between Back and Yellowknife Bays, and to examine the heterogeneity

of the sediment. The Statistical Programs for Social Sciences (SPSS) was used to perform regression analysis. For statistically significant regression lines the similarity of trends was tested by a T-test for parallelism (Kleinbaum and Kupper, 1978).

RESULTS AND DISCUSSION

The measured concentration fo excess Pb-210 (i.e. total Pb-210 less that supported by Ra-226 in the sediment) and Cs-137 are plotted as a function of depth in Fig. 3 and 4. The dashed line in each excess Pb-210 profile is the best fit to the data points obtained using formulations described earlier (Joshi, 1985a; Durham and Joshi, 1980), which take into account the compression of the sediment layers upon burial. Major parameters derived from the regression line, particularly surface porosity, sedimentation rate and flux of excess Pb-210, are summarized in Table 1. The calendar ages assigned to various depth intervals are based on the equation derived earlier (Joshi, 1985a).

Both the excess Pb-210 profiles show the expected general exponential decrease with sediment depth. The noticeable deviation, at 9-11 cm in the profile of Back Bay may represent additional, but brief, input of Pb-210. The excess Pb-210 profiles for both cores do not show any flattening in the top few sections thus ruling out any recent episodes of physical as well as biological mixing. The fluxes of excess Pb-210 at the sediment/water interface in both cores are

within the range measured for other Canadian freshwater ecosystems and suggest that a significant amount, if not all, amount of atmospheric Pb-210 reaching the bay water surface is scavenged to the bottom sediments.

The Cs-137 profiles in both cores clearly rule out any downward migration of this radionuclide as a result of molecular diffusion or physical/biological mixing since no Cs-137 was detected at the pre-1945 levels. The peak corresponding to maximum Cs-137 fallout activity is better preserved in the Back Bay core than in the Yellowknife Bay core. This is probably due to the better sampling resolution obtainable in the former core due to a higher sedimentation rate. The onset of Cs-137 activity peak is better recorded in the Yellowknife Bay core than in the Back Bay core where it occurred nearly two years after the 1963 peak in the Cs-137 fallout activity. We believe that this shift in Cs-137 peak activity is probably accounted for by the total sampling and analytical uncertainty associated with our Pb-210-derived ages which have an error of 11% due to radionuclide counting statistics alone.

In view of above mentioned radiometric data, it is reasonable to conclude that both cores faithfully reflect the depositional history of arsenic and zinc in the area of Back Bay and Yellowknife Bay.

Mineralogical analyses of sediments from Back and Yellowknife Bays showed the presence of quartz, feldspar, amphibole (cummingtonite) and clay minerals, particularly illite and chlorite. Relative amounts of these minerals were similar in all samples.

Except for enrichment of the top 3 cm sections by Mn, P and Fe, concentrations of major elements were similar in sediment core from Yellowknife Bay (Table 2). The increase of Mn in the surface sediment was ascribed to subsurface migration of this element in the sediment column (Marshall, 1979). A greater concentration of P at the sediment surface may reflect an increased input of nutrients into the bay in the past 10 to 15 years. An elevated concentration of Fe may have originated from the waste treatment process implemented at the gold mine. Similar trends in concentrations of major elements were observed in the sediment from Back Bay. However, no enrichment by Mn was observed in the surface sediment at this area. A lower redox potential at the sediment-water interface at Back Bay may impede the precipitation of Mn at the sediment surface.

Mining activities as well as construction associated with the growth of the city of Yellowknife had little effect on the geochemistry of material deposited at the sampling stations in Back and Yellowknife Bays.

Boyle (1960) found As present in small quantities in all rocks of the Yellowknife District, for example, 2 ug/g in grandiorites, granites and pegmatites, 10 to 20 ug/g in slates, greywackes and schists, and up to 100 ug/g in tuffs. However, he found up to 3 percent of As in the gold bearing ores around Yellowknife. Rocks of the Yellowknife District contain Zn, up to 40 ug/g in grandiorites, granites and pegmatites, and up to 100 ug/g in amphibolites, greywackes and diabase dykes. Sphalerite is the dominant zinc mineral

(Boyle, 1960). Consequently, expected background concentrations of As and Zn originating from the regional geology which affects the geochemistry of the sediment in Yellowknife Bay will be about 2 to 100 ug/g, and 40 to 100 ug/g, respectively. An increased concentration of As in the surficial sediment at the centre of the Western Basin of Great Slave Lake observed by Allan (1979) most likely originated from the mining activities at Yellowknife Bay. Concentration profiles of As and Zn in the sediment investigated in this study indicated an input of significant quantities of these elements into Yellowknife Bay.

Concentrations of As and Zn in sections of radio-dated sediment cores from both bays are shown in Figs. 5 and 6. Giant Yellowknife Mines, Ltd. extracts gold from an ore containing about 2 to 3 percent of arsenopyrite. Four major steps in the mine's operation are crushing and grinding, flotation, roasting and cyanidation. These roasting processes generate wastes containing arsenic, cyanides and some metals, particularly zinc, which is used for gold precipitation. In 1976-77, a technical and economical feasibility of the treatment of effluents from gold mines was investigated in Canada. This investigation was carried out on a pilot scale by the implementation of an alkaline chlorination and arsenic oxidation process at Giant Yellowknife Mines (Wiskel and others, 1978). In addition to this experimental effluent treatment, a lower grade gold ore was processed at Giant Yellowknife Mines, Ltd. in 1976=1980. Further significant reductions in arsenic and zinc in the mine effluent were achieved from

1981 to 1985 with a larger scale implementation of an arsenic oxidation and precipitation process. Changes of concentrations of As and Zn in sediment cores from Back Bay and Yellowknife Bay indicated the history of the discharge and waste treatment process implemented at the gold mining plant. A sharp increase in concentrations of As and Zn in the sediment occurred after moving tailing effluent discharge to Baker Creek in 1968. After implementation of mine waste treatment by alkaline chlorination and arsenic oxidation process a significant decrease of As and Zn concentrations was observed in sediment cores from both bays. Concentration profiles of As and Zn in the other three cores from each sampling location are shown in Table 3. The greatest concentration of As and Zn in the sediment from Back Bay was 2,800 ug/g and 940 ug/g, respectively, and that in Yellowknife Bay 890 ug/g and 200 ug/g, respectively. The concentration of As and Zn at the 25 to 28 cm sediment depth ranged from 15 to 25 ug/g and 98 to 123 ug/g, respectively. These can be considered the background concentrations.

Important conclusions were drawn from the statistical analyses of Back Bay and Yellowknife Bay sediment data: As and Zn concentrations in both bays showed similar pattern of increase and decrease. The rate of increase of both elements was greater in Yellowknife Bay sediment, but the increase began approximately four years later than in Back Bay sediment. The difference in the rate of increase can be explained by lower sedimentation rate in Yellowknife Bay. The distribution of As and Zn was more uniform in the sediment from Yellowknife Bay than in that from Back Bay.

The decrease of the concentration of Zn towards the surface of all sediment cores from Back Bay indicated that the combination of the use of low grade ore and implemented treatment of the gold mine effluent effectively reduced the quantities of discharged Zn. However, the combination of these processes did not remove As to such an extent as Zn in the effluent. Although a decreased concentration of As was observed in three of four cores from Back Bay (Table 3 and Fig. 5), remaining great concentrations at the sediment surface suggest a continuous input of large amounts of As into the bay. In Yellowknife Bay, concentrations of both elements in all four cores (Table 3 and Fig. 6) showed similar trends to those observed in Back Bay. However, even if the input of As into Yellowknife Bay became completely eliminated, it would take about 20 years to cover the arsenic-contaminated sediment by an uncontaminated sediment layer approximately 5 cm thick. The low sedimentation rate will slow the natural rehabilitation process of covering contaminated sediments by a layer of clean material in an oligotrophic lake. In Great Slave Lake, in addition to the oligotrophic nature of the lake with a low sedimentation rate, the uniqueness and value of an arctic lake should be considered in planning proper management of industrial waste disposal in the lake's drainage basin.

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FIGURE CAPTIONS

Figure 1   Great Slave Lake, Northwest Territories, Canada.

Figure 2   Sampling locations in Yellowknife Bay.

Figure 3   Concentration profiles of radionuclides in sediment from Back Bay

Figure 4   Concentration profiles of radionuclides in sediment from Yellowknife Bay

Figure 5   Concentration of arsenic and zinc versus radionuclide dating (bottom axis) and depth (top axis) in sediment core from Back Bay

Figure 6   Concentration of arsenic and zinc versus radionuclide dating (bottom axis) and depth (top axis) in sediment core from Back Bay

Table 1   Parameters derived from excess ^{210}Pb measurements

	Surface Porosity	Flux of Excess ^{210}Pb at Sediment/ Water Interface ($mBq\ cm^{-2}\ y^{-1}$)	Surface Sedimentation Rate	
			Linear $cm\ yr^{-1}$	Mass $mg\ cm^{-2}\ y^{-1}$
Yellowknife Bay	0.91	9.4	0.24±0.03	54.1±6.8
Back Bay	0.88	18.3	0.37±0.04	112.4±12.2

Table 2 Concentrations of major elements in Back Bay and Yellowknife Bay
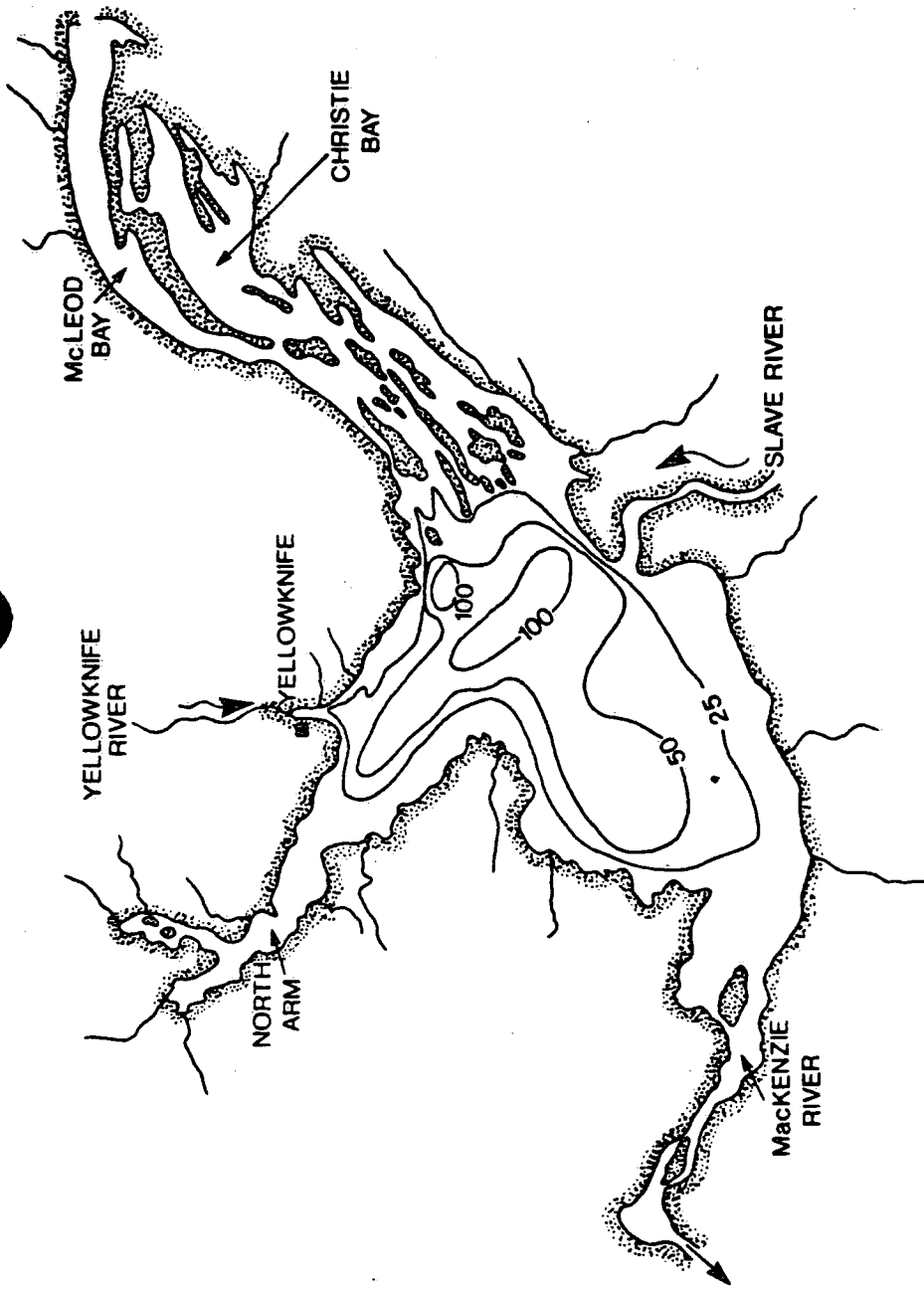sediments (in percent dry weight)

Back Bay

Depth (cm)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5
0-1	68.1	13.2	8.81	2.17	1.54	1.54	3.42	0.61	0.08	0.38
1-2	69.0	14.0	7.58	2.09	1.47	1.29	3.48	0.66	0.06	0.24
2-3	67.8	14.5	8.15	2.23	1.32	1.30	3.59	0.73	0.07	0.27
3-4	68.4	14.5	7.49	2.34	1.19	1.26	3.68	0.67	0.08	0.27
4-5	68.1	14.6	7.35	2.36	1.47	1.37	3.72	0.69	0.07	0.16
5-6	69.0	14.0	7.32	2.02	1.46	1.52	3.65	0.62	0.08	0.22
6-7	69.1	14.4	7.03	2.13	1.39	1.41	3.51	0.63	0.07	0.21
7-8	69.3	14.1	7.01	1.98	1.45	1.50	3.64	0.63	0.07	0.18
8-9	69.9	13.9	6.74	1.88	1.51	1.53	3.55	0.64	0.07	0.17
9-10	69.6	14.2	6.63	2.09	1.49	1.51	3.55	0.62	0.07	0.17
10-11	69.0	14.1	6.88	2.12	1.85	1.42	3.58	0.62	0.08	0.20
11-12	68.9	14.6	6.99	2.02	1.45	1.41	3.65	0.66	0.08	0.19
12-13	69.3	14.4	6.68	2.17	1.45	1.48	3.57	0.63	0.08	0.17
13-14	69.0	14.8	6.67	2.11	1.39	1.41	3.67	0.65	0.07	0.16
14-15	68.9	14.8	6.82	2.03	1.37	1.44	3.64	0.66	0.08	0.16
25-26	68.8	14.9	6.79	2.22	1.30	1.30	3.70	0.64	0.08	0.16

Yellowknife Bay

Depth (cm)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5
0-1	68.1	14.9	6.92	2.43	1.54	1.31	3.64	0.65	0.24	0.22
1-2	66.8	14.5	8.33	2.52	1.54	1.43	3.56	0.65	0.33	0.30
2-3	66.6	14.5	8.59	2.42	1.50	1.52	3.59	0.65	0.12	0.33
3-4	68.0	15.0	7.07	2.44	1.54	1.36	3.49	0.68	0.07	0.20
4-5	67.7	15.5	6.96	2.41	1.53	1.29	3.52	0.72	0.06	0.18
5-6	68.2	15.1	6.96	2.27	1.52	1.31	3.59	0.73	0.06	0.17
6-7	68.6	14.8	6.78	2.25	1.47	1.40	3.68	0.68	0.07	0.19
7-8	67.9	15.1	7.23	2.32	1.45	1.27	3.69	0.70	0.07	0.21
8-9	67.8	15.4	7.03	2.35	1.43	1.17	3.74	0.72	0.07	0.19
9-10	67.8	15.6	6.81	2.48	1.42	1.20	3.60	0.68	0.06	0.17
20-21	67.7	15.6	6.90	2.41	1.58	1.27	3.51	0.67	0.07	0.18
27-28	67.6	15.6	7.30	2.33	1.41	1.17	3.60	0.70	0.07	0.18

Table 3 Concentrations of As and Zn in three cores from Back Bay and Yellowknife Bay (μg/g dry weight)

Back Bay

Depth (cm)	Core #1		Core #2		Core #3	
	As	Zn	As	Zn	As	Zn
0-1	1,010	170	630	168	2,800	168
1-2	720	202	790	222	1,160	222
2-3	890	274	1,130	450	990	560
3-4	1,230	560	960	830	670	940
4-5	790	890	550	178	640	252
5-6	595	245	145	107	176	108
6-7	180	110	68	100	169	110
7-8	172	100	54	96	182	108
8-9	160	98	59	98	160	100
9-10	140	105	65	109	145	98
25-26	20	110	25	98	23	115

Yellowknife Bay

Depth (cm)	Core #1		Core #2		Core #3	
	As	Zn	As	Zn	As	Zn
0-1	550	187	490	173	280	157
1-2	890	200	590	195	543	183
2-3	95	168	700	184	433	195
3-4	53	116	108	181	72	131
4-5	12	102	54	113	23	113
5-6	15	105	26	110	26	109
6-7	19	110	23	112	17	112
7-8	21	108	19	98	11	116
8-9	25	110	21	109	19	118
9-10	22	107	18	105	36	113
20-21	12	105	15	110	11	110
27-28	16	102	18	108	15	123

GREAT SLAVE LAKE

McLEOD BAY

CHRISTIE BAY

SLAVE RIVER

YELLOWKNIFE RIVER

YELLOWKNIFE

NORTH ARM

MacKENZIE RIVER

100
100
25
50

0   50   100 km

114°W
102°W
62°N
60°N
0   400   800 km

Fig. 1

YELLOWKNIFE RIVER

TAILINGS PONDS

DISCHARGE POINT PRIOR TO 1968

BAKER CREEK

GIANT MINES LTD.

PRESENT TAILINGS EFFLUENT DISCHARGE

LATHAM ISLAND

BACK BAY

CITY OF YELLOWKNIFE

N

2 km

YELLOWKNIFE BAY

DETAH
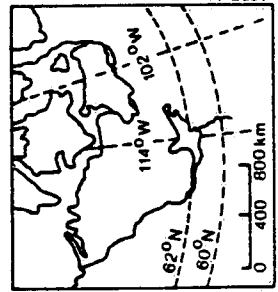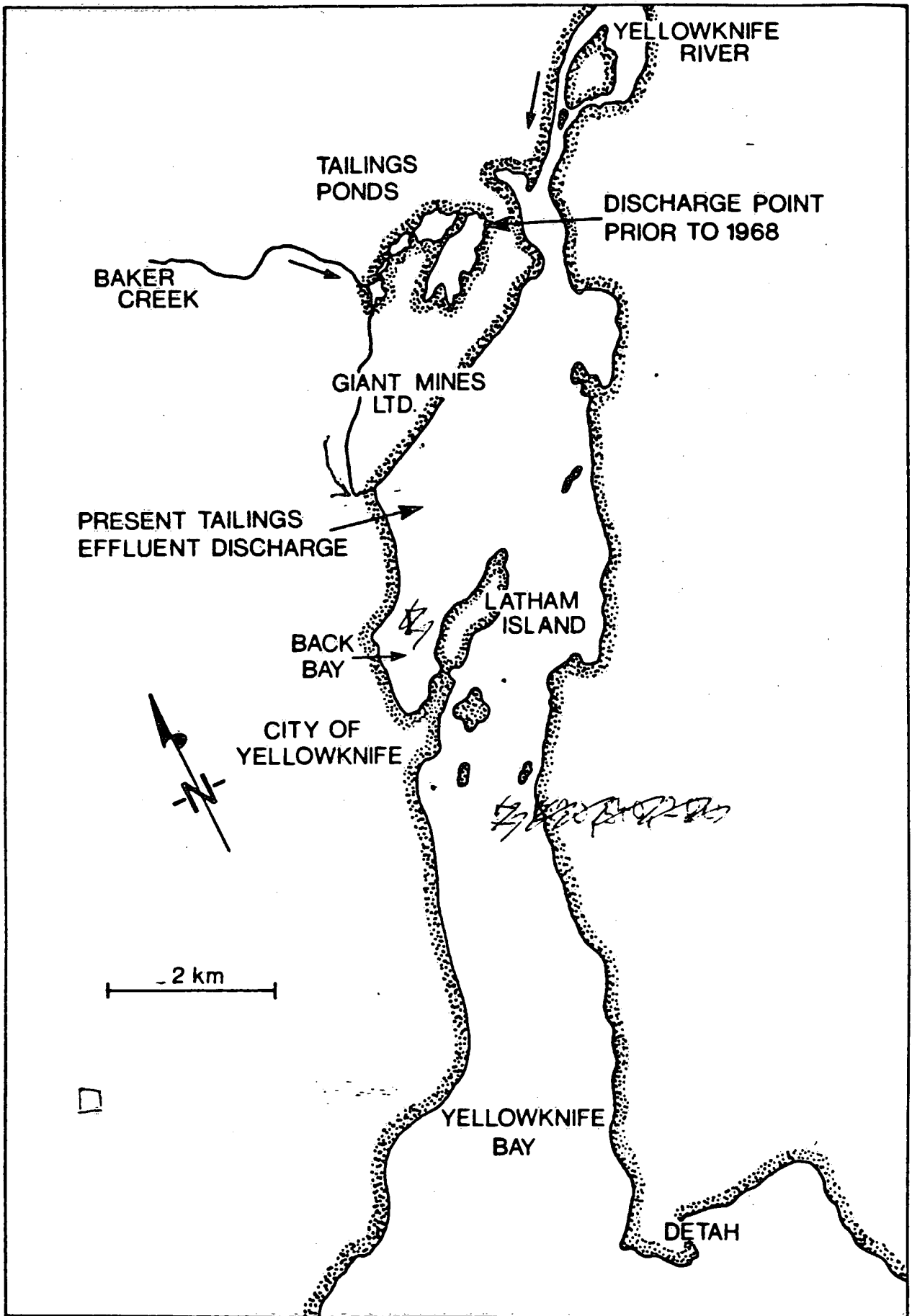
Figure 2.

BACK BAY
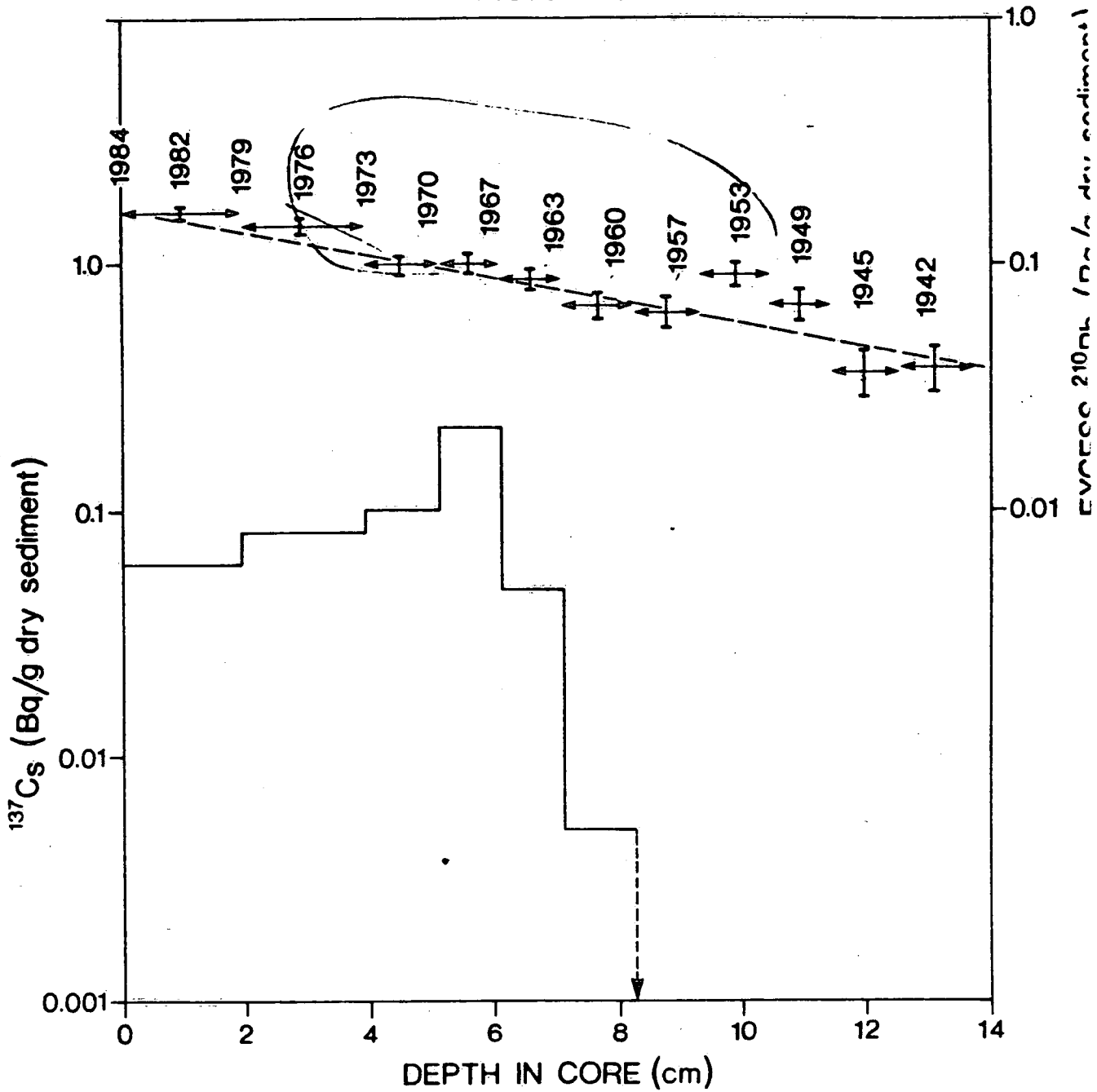
Figure 3 4.

YELLOWKNIFE BAY

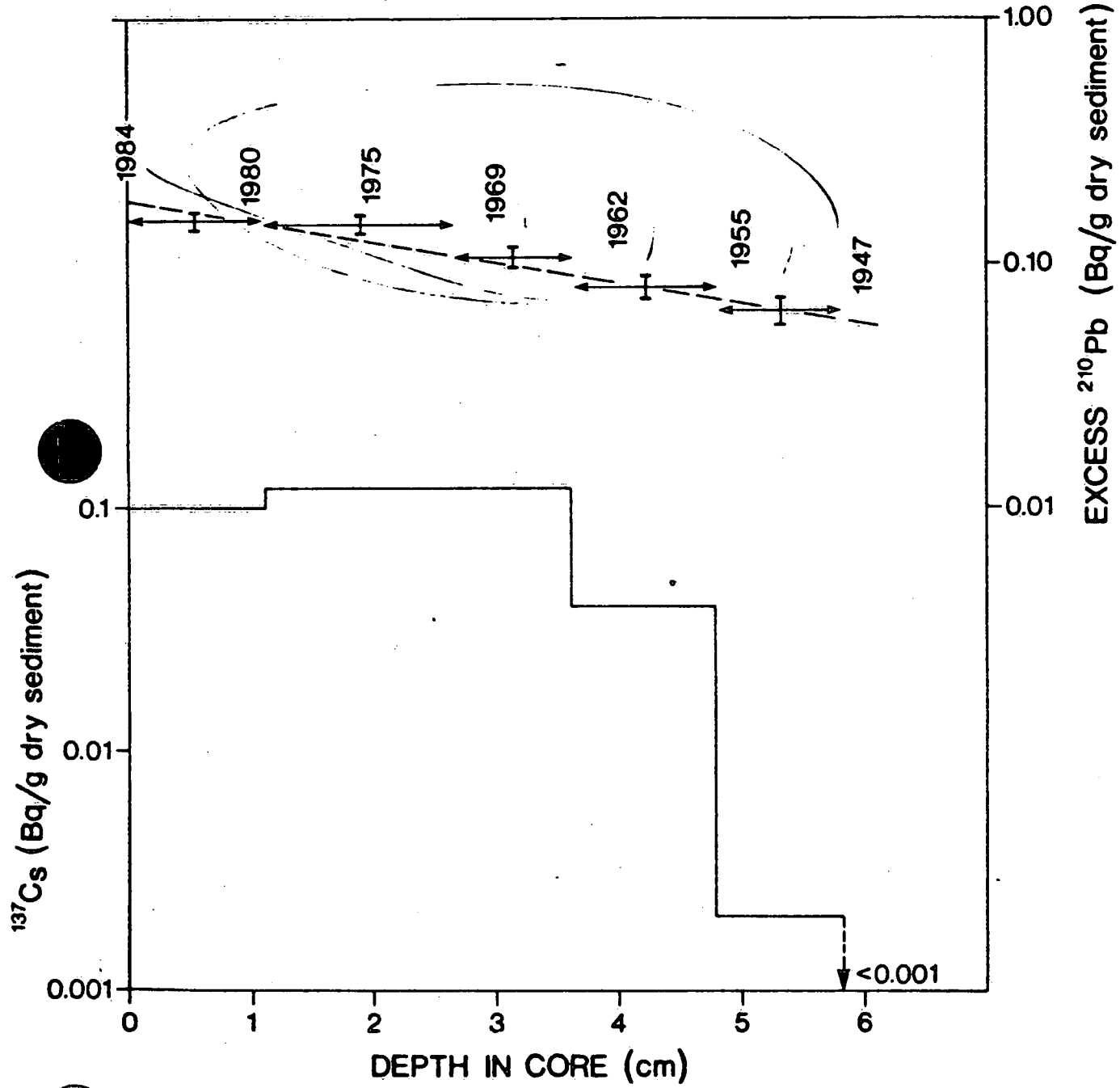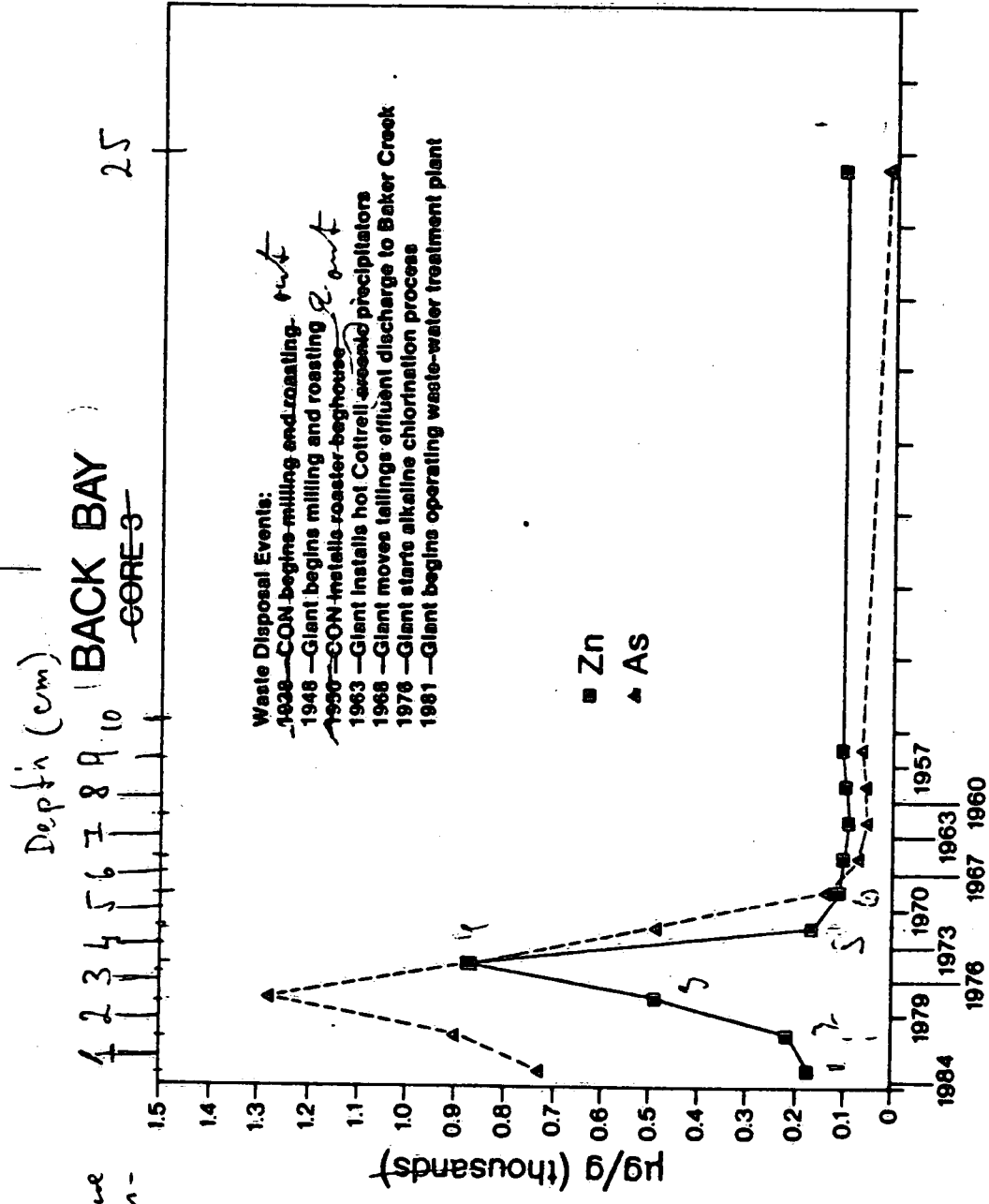Figure 4.

BACK BAY
CORE 3

Depth (cm)

Re-label μg/g
(thousands)

& Events - leave
out the con-
date

μg/g (thousands)

Waste Disposal Events:
1938 —CON begins milling and roasting out
1948 —Giant begins milling and roasting & out
1950 —CON installs roaster baghouse & out
1963 —Giant installs hot Cottrell arsenic precipitators
1968 —Giant moves tailings effluent discharge to Baker Creek
1978 —Giant starts alkaline chlorination process
1981 —Giant begins operating waste-water treatment plant

■ Zn
▲ As

↓ time

Figure 6.5

YELLOWKNIFE BAY
CORE 4

Waste Disposal Events:
1938 — CON begins milling and roasting
1948 — Giant begins milling and roasting
1950 — CON installs roaster baghouse
1963 — Giant installs hot Cottrell arsenic precipitators
1968 — Giant moves tailings effluent discharge to Baker Creek
1976 — Giant starts alkaline chlorination process
1981 — Giant begins operating waste-water treatment plant

■ Zn
▲ As

$\mu g/g$

900 800 700 600 500 400 300 200 100 0

1981 1980 1975 1969 1962 1955 1947

Figure 6