

BASELINE LEVELS OF TRANSITION AND HEAVY METALS IN THE BOTTOM SEDIMENTS OF THE BAY OF FUNDY

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Total concentrations of Zn, Cu, Pb, Co, Ni, Cr, V, Hg, Cd, Be, As, Ba, and Se vary regionally and with sediment texture in the Bay of Fundy. Relatively high concentrations occur in fine grained sediments from the "Quoddy region" of the Bay and near a dredge disposal site off St. John Harbour. Low concentrations of the metals occur in the sandy sediments from the central and eastern part of the Bay. Average levels of the elements are at or near natural levels when compared with levels found elsewhere in unpolluted sediments.

Introduction

The Marine Ecology Laboratory and others have begun an evaluation of the Bay of Fundy ecosystem and the potential environmental impact of tidal barrages on this system. As part of these studies, a series of environmental geochemical studies have been made to determine the levels, behavior and dynamics of potential biologically toxic metals in the sediments of the Bay. This paper reports on the abundance and distribution of Hg, Cd, Zn, Cu, Pb, Co, Ba, Ni, Cr, Be, V, As, and Se, in the Fundy sediments and compares them with levels found in comparable sediments elsewhere in the region and the world.

Field and Laboratory Methods

Sediment samples at 84 locations were obtained with a Van Veen (0.1m²) grab. The samples were placed in plastic bags or vials and refrigerated or frozen on board ship until it returned to the laboratory. Representative portions of the samples were air-dried and stored in air-tight bottles until used for sedimentological and chemical analyses.

After removal of material > 2mm, the sand (particles 2-0.05 mm diam) and pelite or mud (particles < 0.05 mm diam) were separated by wet sieving. These data were used to determine the partition of those components in the sediments and to classify the sediments in the Bay according to the nomenclature of Loring and Nota (1973).

Hg, Zn, Cu, Pb, Co, Ba, Ni, Cr, Be, and V were analysed by atomic absorption spectrometry using the techniques described by Loring and Rantala (1977). Using these methods, the coefficient of variation in the USGS standard mud MAG-1 was: Co 10%, Ni 7%, Cr 2%, V 3%, Zn 2%, Pb 19%, Cu 14%, Ba 6% (Rantala & Loring 1978). Arsenic was determined by Bondar-Clegg Ltd. using a colorimetric method in which 0.2 g sample was digested in a HNO₃-HClO₄ mixture for 3 h. Mercury was determined in this laboratory by the cold vapor atomic absorption method comparable to that described by Hatch and Ott (1968). Total cadmium and selenium were determined by Dr. C. Elson, St. Mary's University, Halifax, N.S., using a standard flameless atomic absorption technique.

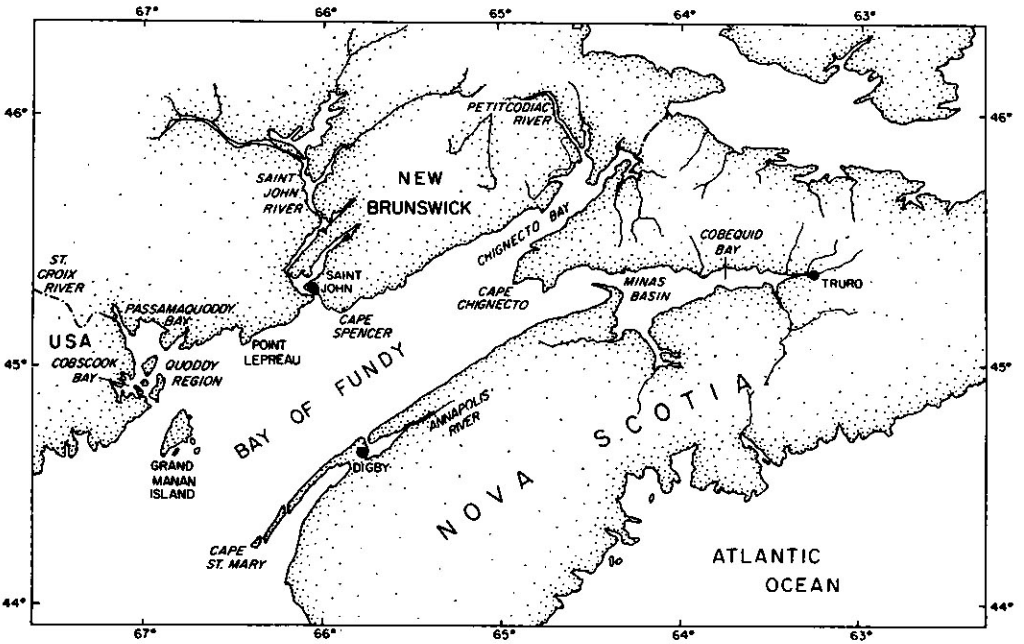


Fig 1 Place names in the Bay of Fundy

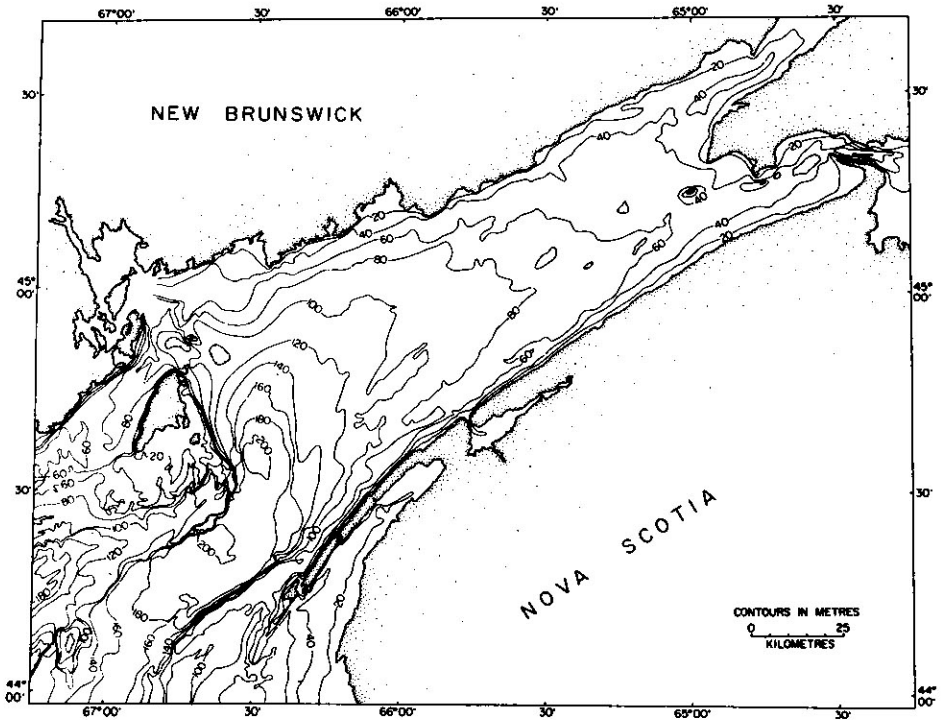


Fig 2 Bathymetry of the Bay of Fundy

Environmental Setting

The Bay of Fundy is a funnel shaped body of water lying between Nova Scotia and New Brunswick that is famous for its enormous (6-13 m) tidal range (Fig 1). The Bay proper is about 168 km long and about 75 km wide before it splits at its head into Chignecto Bay and Minas Basin. Water depths in the Bay proper range from 20 m at its head to over 100 m at its mouth (Fig 2).

The geology, physiography, sedimentology, and physical oceanography have been described in some detail by Swift and Lyall (1968), Swift et al. (1973), and Fader et al. (1977). The Bay is a glaciated preglacial drainage basin incised into Triassic sandstones, mudstones, and basalts. A Pleistocene glacial drift cover has been reworked to form extensive thin deposits of gravel, sand, and mud in hydraulically suitable locations. The high energy tidal regime of the Bay maintains varying amounts (0.2 mg/l - 65.4 mg/l) of material in suspension (Swift et al. 1973; Kranck 1978 in verb.) that is deposited and eroded from time to time to form and maintain the present sedimentation pattern.

The Bay receives freshwater from 8 major drainage basins. The St. John River is the major contributor (70%) to the Bay and drains the urban and industrial areas of New Brunswick (Fig 1). Second is the St. Croix River that drains the agriculture and lumbering areas of northern New Brunswick and Maine and discharges into Passamaquoddy Bay. On the Nova Scotian side, the Annapolis River and those entering Minas Basin drain the agricultural lands of western Nova Scotia. In addition, dredge spoils from St. John Harbour are dumped 5 km off Cape Spencer. Construction of a nuclear generating station at Point Lepreau adds a potential contamination hazard to the Bay to those already existing along the New Brunswick coast such as pulp mill effluents, municipal sewage, fish processing plants, and cottages.

The potential dispersal pattern of material in the Bay may be inferred from the counterclockwise surface residual circulation pattern of the water shown by Swift et al. (1973) whereas natural and anthropogenic material from Passamaquoddy Bay may follow the clockwise circulation pattern in the Quoddy region that has been determined by a series of drift bottle studies (Chevrier & Trites 1960).

Results and Discussion

Sediment Distribution

Classification of the sediments on the basis of their sand and mud contents provides the sediment distribution pattern that is shown in Figure 3 for material < 2 mm in diameter. Figure 3 shows that sands (> 95% material > 0.05 mm in diameter and < 5% material < 0.05 mm) occur in a belt along the Nova Scotian coast, and along the New Brunswick coast, northeast of St. John. Westwards, the mud component in the sediments increases with the result that muddy sands (5-30% mud) occupy the central and offshore western part of the Bay, and very sandy muds (30-70% sand) are found southwest of St. John and in a basin at the mouth of Chignecto Bay. The finest grained sediments sandy mud (5-30% sand) and mud occur off the mouth of Passamaquoddy Bay. They occupy a triangular shaped area that has its base along the New Brunswick coast from a point near the mouth of Passamaquoddy Bay to Point Lepreau and its apex extending to the southeast and lying just (about 10-15 km) off the east side of Grand Manan Island. Within this area referred to as the "Quoddy region" (Forgeron 1959; Chevrier & Trites 1960), the percentage of mud or pelite decreases seaward from the base to the apex.

Table I Bay of Fundy Sediments - Textural Variation of Trace Elements in Total Sample(ppm)

S. Type	No. Samples	Hg (ppb)											
		Zn	Cu	Pb	Co	Ni	Cr	V	Ba	Cd	As	Se	Be
Sand	17	35	12	15	10	14	49	58	300	30	9(1)*	.14(5)*	1.2
	Range	18-65	5-26	8-23	4-20	3-39	15-214	27-127	150-540	20-50	.03-.44	.12-16	8-2.0
Muddy Sand	32	44	13	19	10	12	48	61	290	30	7(8)	.14(20)	1.4
	Range	26-64	8-21	8-30	5-18	4-24	19-220	34-132	230-370	20-50	.07-.52	.11-.19	1.1-2.2
Very Sandy Mud	21	58	16	20	13	15	68	77	310	30	8(6)	.19(13)	1.7
	Range	42-100	10-32	14-31	7-27	7-46	38-352	51-167	240-390	20-50	.05-.52	.11-.36	1.3-2.1
Sandy Mud	11	75	19	28	15	22	71	91	350	60	9(9)	.21(9)	2.3
	Range	52-98	15-23	19-35	11-20	14-37	51-91	72-108	220-430	30-90	.19-.35	.13-.34	1.6-2.9
Mud	2	93	22	40	17	26	82	118	400	70	9	.33(1)	2.5
	Range	81-104	21-23	38-42	13-20	24-27	72-91	99-136	370-430	50-90	.13-.17	-	2.2-2.8
Average Fundy Sediment	83	51	15	20	12	15	57	70	310	30	8(26)	.17	1.6
	Range	18-104	5-32	8-42	4-27	3-46	15-352	27-136	150-540	20-90	.03-.52	.11-.36	8-2.9

* Numbers in brackets refer to number of samples averaged

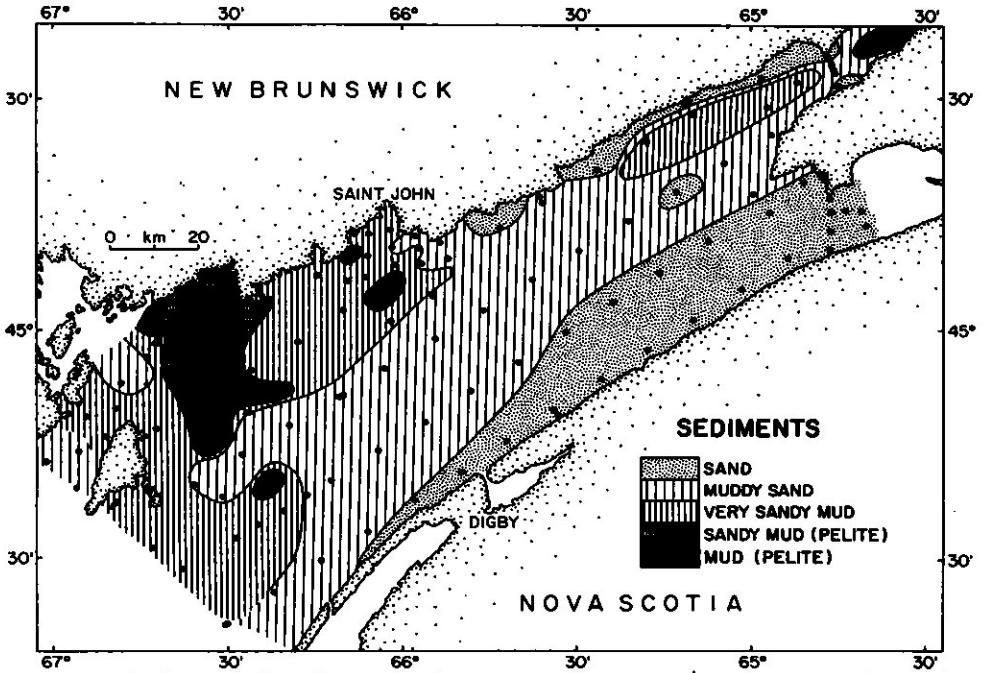


Fig 3 Sediment distribution of material < 2mm in the Bay of Fundy, nomenclature of Loring and Nota, 1973.

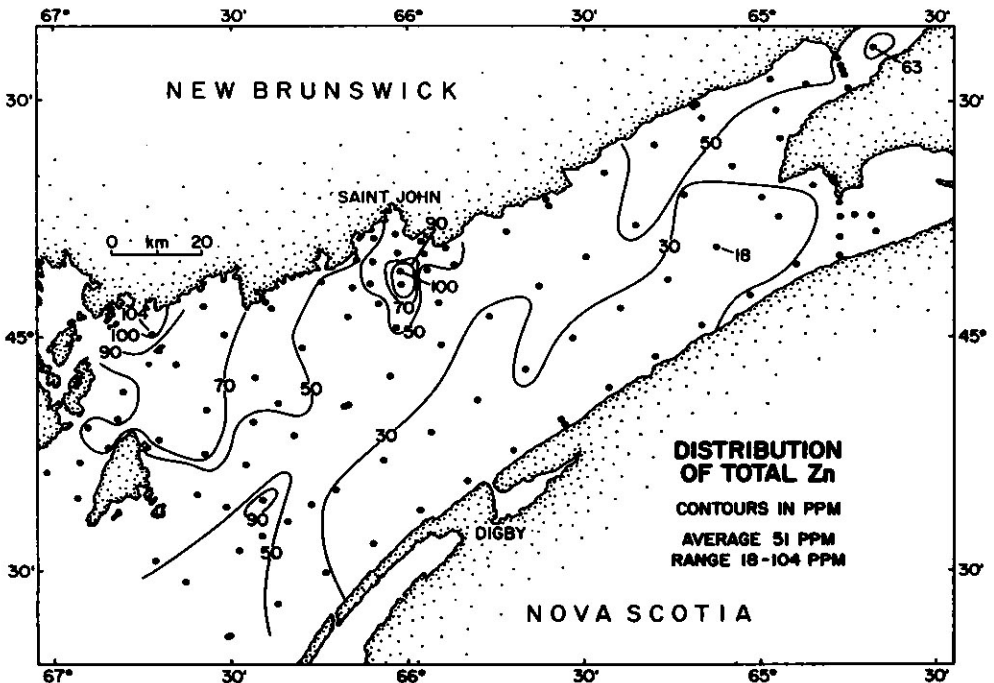


Fig 4 Distribution of total Zn in the surface sediments (< 2mm). Dots show sample locations.

Metal Abundances and Their Relation to Texture

Total metal concentrations measured in the sediments (Table I) show that the average concentrations of Zn, Cu, Se, Pb, Co, Ni, Cr, Be, Hg, and V are low in the sands and increase with decreasing grain size of the sediments so that the highest concentrations occur in the muds. However, the concentrations of As, Cd, and Ba show only slight changes with grain size. Statistical analyses of the data except Pb, Be, and Hg, indicate that the concentrations of Zn, Cu, Co, Ni, Cr, and V increase directly ($r = 0.47-0.83$, $P < 0.01$) with increasing mud content of the sediments. Particle size, therefore, appears to be a controlling factor for the total concentrations of these elements in the sediments and their regional distribution pattern.

Regional Dispersal - Patterns

Because of space restrictions, some but not all of the regional dispersal patterns are shown in Figures 4 to 8. Although they differ in some detail, inspection reveals common dispersal patterns closely related to geographic distribution and the particle size of the sediments. Figure 8 summarizes the geographic distribution of the elements and shows the sedimentary areas containing the relatively high, medium, and low element concentrations. The highest concentrations of Zn (> 70 ppm); Pb (> 30 ppm); Cu (> 20 ppm); Co (> 20 ppm); Ni (> 20 ppm); Cr (> 70 ppm); V (> 90 ppm); Ba (> 400 ppm); Se (> 200 ppb); Hg (> 70 ppb); and As (> 10 ppm) occur in the muddy sands and sandy muds of the Quoddy region. Within this area, most of the elemental concentrations decrease seaward towards the southeast. This pattern suggests a declining source dispersal pattern that follows the surface circulation from Passamaquoddy Bay. Locally, high concentrations of Cr (Fig 5), V, and Ni occur at sites off the west and north coasts of Grand Manan Island. Mercury is an exception to the overall patterns in that it is concentrated in the sediments adjacent to the coast between Passamaquoddy Bay and Point Lepreau (Fig 7).

High concentrations of Zn (94 ppm); Cu (24 ppm); Se (340 ppb); Co (15 ppm); Ni (37 ppm); Cr(80 ppm) and V (103 ppm) also occur at a single site in fine sediments at the mouth of the Bay (Fig 8). Of more importance, however, are the high metal anomalies found near the dredge disposal site off St. John Harbour (Figs 4-8). These anomalies, particularly that of Cd (Fig 6), are a clear reflection of anthropogenic inputs on the local environment and their far-reaching potential influence on other parts of the marine environment of the Bay as evidenced by the dispersal patterns of the elements away from the dumpsite. To the northeast, medium element concentrations occur in the very sandy ($> 30\%$ sand) muds from the basin at the mouth of Chignecto Bay. Medium concentrations of Pb (20-25 ppm) also occur in the center of the Bay (Fig 8). Eastwards the elemental concentrations decline in the sands adjacent to the Nova Scotian coast.

Low concentrations of Zn (< 30 ppm), BA (< 300 ppm), and Se (< 100 ppb) occur in the belt of sands along the Nova Scotian coast, whereas the lowest concentrations of Cr (< 30 ppm), V (< 40 ppm), Ni (< 10 ppm), and Cu (< 10 ppm) occur in the muddy sands from the center of the Bay. It is of importance and interest to note that the concentrations of Cr, V, Ni, and Cu are relatively higher than those found offshore at a number of sites in the sands adjacent to the shoreline of Nova Scotia northeast of Digby. This is believed to result from detrital bedrock material derived from underlying and coastal basalts. Together, the dispersal patterns show the influence of anthropogenic metal inputs to the environment as well as the natural control of particle size on the trace element concentration and distribution.

Comparisons With Other Sediments

Although the abundance and regional dispersal pattern of the trace metals show

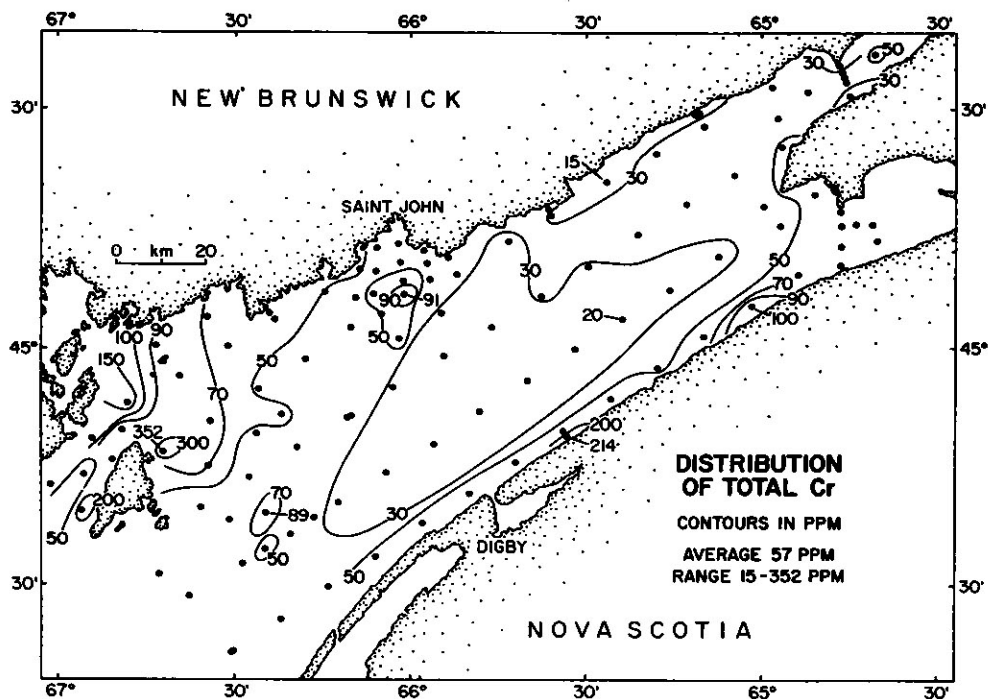


Fig 5 Distribution of total Cr in the surface sediments (< 2mm).

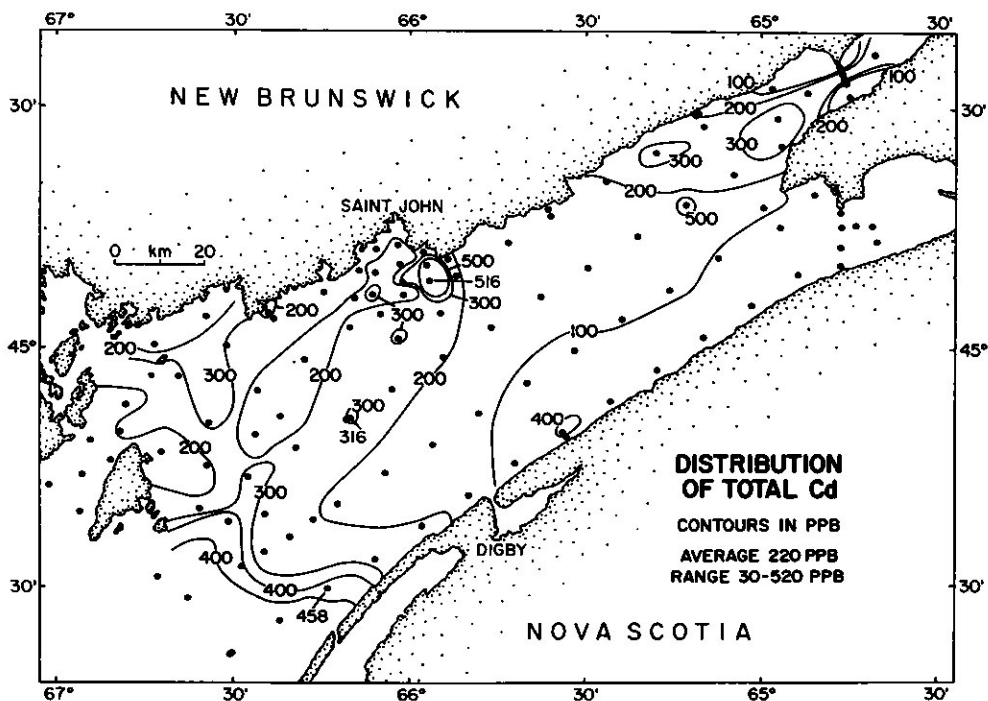


Fig 6 Distribution of total Cd in the surface sediments (< 2mm).

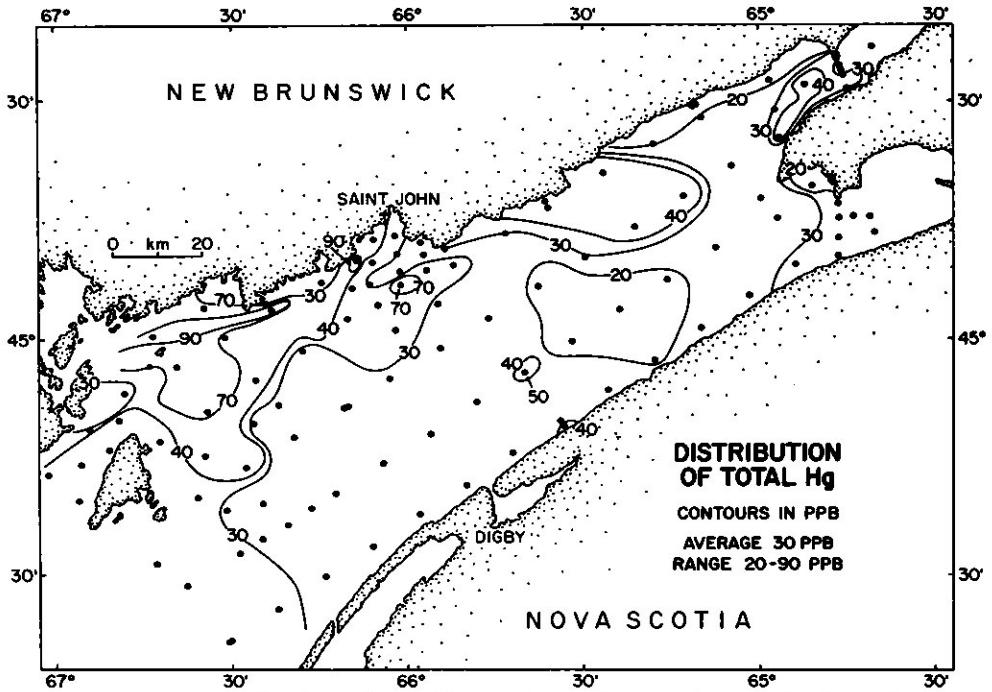


Fig 7 Distribution of total Hg in the surface sediments (< 2 mm).

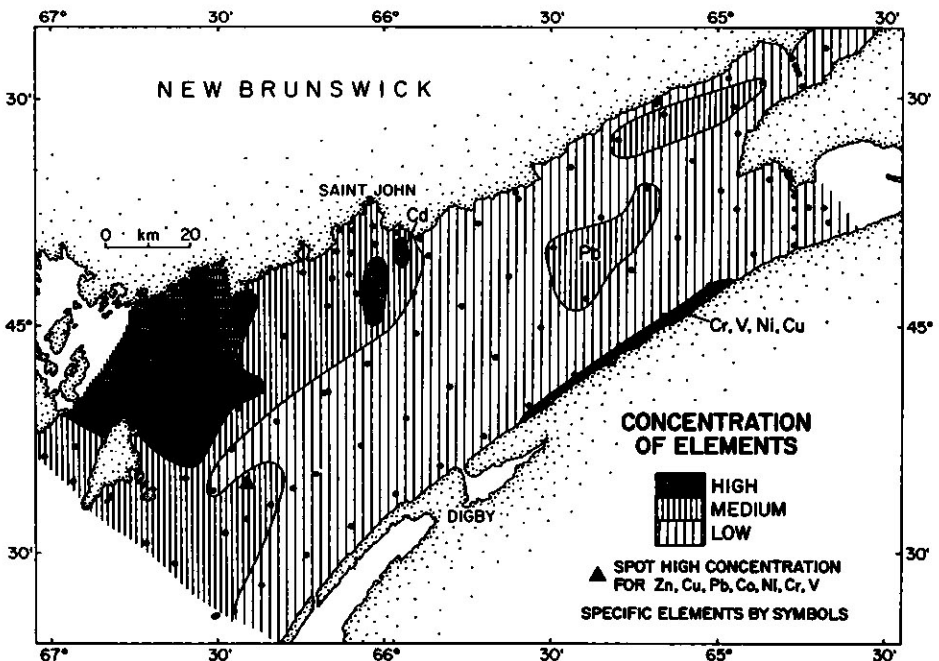


Fig 8 Distribution of the relatively high, medium, and low concentrations of Zn, Cu, Pb, Co, Ni, Cr, V, Be, Ba, Se, Hg, and Cd in the surface sediments (< 2mm).

small, but significant anthropogenic influences, it is of utmost importance to assess them in relation to the levels found elsewhere. Since the elemental concentrations vary with particle size, it is essential that comparisons be made with texturally equivalent sediments when possible. Table II compares the elemental concentrations of the fine-grained Fundy sediments with those found in various parts of the Gulf of St. Lawrence, and polluted and unpolluted sediments from the United Kingdom and the Netherlands.

The Fundy muds contain lower concentrations of Zn, Cu, Ni, Cr, and Hg, than those of the St. Lawrence Estuary (upper and lower) and the Saguenay Fjord. The Zn concentrations of the Fundy muds are comparable with, and the concentrations of Cu and Ni are lower than, those of the open Gulf and Placentia Bay sediments. Fundy Pb concentrations are, however, higher than those from the open Gulf and comparable to those values found in the St. Lawrence estuary. Co concentrations are comparable to all parts of the St. Lawrence region. V concentrations are comparable to those found in the upper St. Lawrence estuary, but lower than those from other parts of the St. Lawrence system. Arsenic concentrations of the Fundy muds are also much lower than those of the Saguenay Fjord sediments, but are comparable to the other parts of the St. Lawrence region.

Thus, there is no indication that the fine-grained sediments are particularly high in the metals; rather most are lower when compared with texturally equivalent sediments from the St. Lawrence system. A possible exception is Pb, which is concentrated in the fine-grained Fundy sediments and is comparable in concentration to polluted sediments of the St. Lawrence estuary (Loring 1978).

When compared with unpolluted sediments from other outside areas, Table II indicates that Fundy pelites contain comparable or slightly higher Zn, Cu, Co, Cr, and Pb concentrations than the unpolluted sediments of Solway Firth, and V and Cr concentrations comparable to those reported for sediments of the Severn estuary. In contrast the Fundy elemental concentrations are much lower than those reported for the very polluted sediments from the Firth of Clyde, Clyde estuary, and Severn estuary (except Co, Vi, Cr). Thus, Fundy sediments contain trace metal levels comparable to those found in unpolluted sediments from other parts of the world. This is not to say that the natural levels of trace metals have not been altered, but rather than the anthropogenic inputs of heavy metals have not yet reached significant levels, although they may do so in the future.

Conclusions

Particle size is the main factor controlling the abundance and distribution of the total trace metal concentrations in the Bay of Fundy. This is because detrital host minerals are mostly fine grained except those of Cr, V, and Ni and the absorption of the metals onto particles increases with their surface area. The finer offshore sediments of the Quoddy region are a sink and an enrichment area for total trace metals. These are supplied in particulate and perhaps dissolved form from natural and industrial sources. The most likely anthropogenic sources are the St. Croix drainage basin, the coastal industries, municipalities between Passamaquoddy Bay and Point Lepreau, and the offshore dredge disposal site. Any material discharged from the proposed nuclear generating station at Point Lepreau may also end up in this sink depending of course on the depositional conditions at the time of discharge.

At present, the average levels of trace metals in the Fundy sediments, perhaps with the exception of Pb, are at or near natural levels found in unpolluted fine-grained sediments. This is not to say that this will not change as the data clearly

Table II Average Total Elemental Concentrations in the Fine Sediments of the Bay of Fundy Compared to Those Found Elsewhere

Location	No. of Samples	Zn	Cu	Pb	Co	Ni	Cr	V	Hg (ppb)	As	Cd	Se
Bay of Fundy	13	77	19	30	15	22	73	95	60	9(11)*	.24	.22(10)
Upper St. L. Est. a,b	3	185	36	34	15	27	92	97	380	6(2)	.26	.56
Lower St. L. Est. a,b	29	115	24	30	17	33	99	110	449	7(27)	.22	
Open Gulf of St. L. a,b	71	84	25	21	14	36	87	105	221	6(62)	.26	
Saguenay Fjord c,d	13	130	27	48	16	28	83	121	3660	21(11)	.25	.51
Placentia Bay Nfld. e	28	80	34	32	16	41	53	-	-	-	-	-
Severn Est. f	-	280	38	119	7	36	71	86	-	-	1.9	1
Firth of Clyde g	-	165	37	86	34	50	64	-	-	-	3.4	-
Clyde Est. g	-	1680	225	528	60	69	624	-	-	-	-	-
Solway Firth h	-	63	10	37	16	38	35	-	-	-	2.9	-
Gulf of Paria i	-	-	17	22	8	31	93	130	-	-	7	-
Rhine River j	-	2400	300	530	-	48	640	-	10000	200	13	-

aLoring 1978; bLoring 1979; cLoring 1976a; dLoring 1976b; eWilley 1976; fChester and Stoner 1975; gMackay et al. 1972; hPerkins et al. 1973; iHirst 1962; jDeGroot et al. 1974.

* Numbers in brackets refer to number of samples averaged.

show that small, but significant anthropogenic inputs are having an effect on the natural levels of the metals in the sediments.

ACKNOWLEDGMENTS

The sediment samples were collected by Dr. Kate Kranck during the DAWSON Cruise 77-032 in August 1977. Sedimentological and chemical analysis were very capably performed by R.T.T. Rantala.

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