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THE RELATIONSHIP BETWEEN MERCURY OCCURRENCE AND MINING ACTIVITY IN THE NOTTAWAY AND RUPERT RIVER BASINS OF NORTHWESTERN QUEBEC

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ABSTRACT

Composite samples of ore heads, concentrates and tailings were collected from some base metal (Cu, Zn, Pb) mines in northwestern Quebec. Daily, weekly and monthly composites were analyzed for mercury. It was shown that monthly composites provided the most representative and reproducible values for mercury in a given ore deposit. Fluctuations due to local variations in ore grade tend to be smoothed out in the longer term composites. The mines in question are near Chibougamau, Chapais, Matagami, Val d'Or and Noranda and lie within the drainage basins of the Bell and Rupert river systems. The mines near Chibougamau produce only copper, those near Matagami yield considerably more zinc, whilst those near Noranda-Val d'Or produce copper, zinc and lead in major quantities. Mercury contents of these base metal ores were observed to increase with increasing zinc content of the ore, indicating that most of the mercury is present as a constituent of sphalerite (ZnS). Mercury contents of zinc concentrates ranged from 2 ppm (Matagami area) through 20 ppm (Noranda area) up to 150 ppm (Val d'Or area). Mercury in copper concentrates was found to be much less abundant, usually 1 to 10 per cent of that found for a zinc concentrate from any given mine.

In all areas, relatively little mercury was found to carry through into tailings which consist of waste silicates and iron sulphides. In the mines of primary interest, namely those near Chibougamau and Matagami, less than 0.20 ppm mercury was found in most tailings composites. Values reached about 1 ppm in the Val d'Or area mines tailings and slightly higher in waste materials from the adjacent Noranda area.

In general, tailings were observed to be well confined in ponds and the little mercury that is potentially available is considered unlikely to influence mercury levels reported for the local drainage systems. Other possible sources of mercury, such as Precambrian shales (slates) which are widespread throughout the Bell-Nottaway and Rupert River basins, are proposed and discussed. Data for ores and tailings from other regions of Canada are presented for comparative purposes.

RÉSUMÉ

Des échantillons composés provenant d'éboulis, de concentrés et de résidus de minerais ont été recueillis dans quelques mines de métaux non précieux (Cu, Zn, Pb), dans le nord-ouest québécois. On a analysé à intervalles quotidiens, hebdomadaires et mensuels des composés pour y déceler du mercure. Il a été prouvé que ce sont les composés examinés mensuellement qui, dans un gisement dépôt de minerai donné, contenaient les valeurs les plus représentatives et reproductibles de mercure. Les fluctuations produites par les variations locales de la teneur du minerai tendent à s'atténuer dans les composés à plus long terme. Les mines dont il est question sont situées près de Chibougamau, Chapais, Matagami, Val d'Or et Noranda et retrouvent dans les bassins de drainage des systèmes des rivières Bell et Rupert. Les mines situées près de Chibougamau ne produisent que du cuivre, celles qui sont avoisinantes de Matagami, surtout du zinc alors que les gisements de la région de Val d'Or et Noranda sont riches en cuivre, en zinc et en plomb. On a observé que dans ces minerais de métaux non précieux, la proportion de mercure augmente en même temps que celle du zinc, ce qui indique que la plus grande partie du mercure se présente sous forme de sphalérite (ZnS). La teneur en mercure dans les concentrés de zinc varie de 2ppm (région de Matagami) à 20 ppm (région de Noranda) et peut atteindre 150 ppm dans la région de Val d'Or. Le mercure est toutefois beaucoup moins abondant dans les concentrés de cuivre, habituellement de l à 10 p. 100 de la quantité trouvée dans les concentrés de zinc de n'importe quelle autre mine.

Dans toutes les régions, on a trouvé relativement peu de mercure dans les résidus constitués de silicates et de sulfures de fer. Dans les mines d'intérêt particulier, notamment celles avoisinant Chibougamau et Matagami, on a relevé moins de 0.20 ppm de mercure dans la plupart des composés de résidus. La teneur s'est élevée à environ une ppm dans les résidus des mines situées près de Val d'Or et à un peu plus dans les résidus des mines de Noranda.

En général, on observe que les résidus ne se retrouvent que dans des étangs et on considère que la petite quantité de mercure qui peut s'y trouver n'influence probablement pas la teneur de mercure dans les bassins de drainage avoisinants. On a proposé et commenté d'autres sources possibles de mercure, notamment les schists (ardoises) du Précambrien qui se retrouvent en abondance dans les bassins Bell-Nottaway et de la rivière Rupert. Pour fins de comparaison on présente également des données sur des minerais et résidus d'autres régions du Canada.

THE RELATIONSHIP BETWEEN MERCURY OCCURRENCE AND MINING ACTIVITY IN THE NOTTAWAY AND RUPERT RIVER BASINS OF NORTHWESTERN QUEBEC

INTRODUCTION

Samples of the biota, waters and sediments from the drainage basins of the Nottaway and Rupert rivers in northwestern Quebec have recently been subjected to close investigation following the discovery of unusually high mercury levels in the blood of some Indians in the Waswanipi Lake region (Berkes et al., 1971).

The work described herein was an attempt to evaluate whether base metal ore occurrences currently being mined in northwestern Quebec contribute significant quantities of mercury to nearby streams and water courses which drain into the Rupert and Nottaway systems. To this end, samples of ore heads, concentrates and tailings were collected from the various mining operations and analyzed for mercury. Samples were also obtained from other similar base metal mines in the Val d'Or-Noranda area. On the basis of these analyses and with the input of other relevant geological information, it should be possible to indicate in general terms whether the mining activities markedly influence the mercury levels reported in fish from certain lakes within the study area.

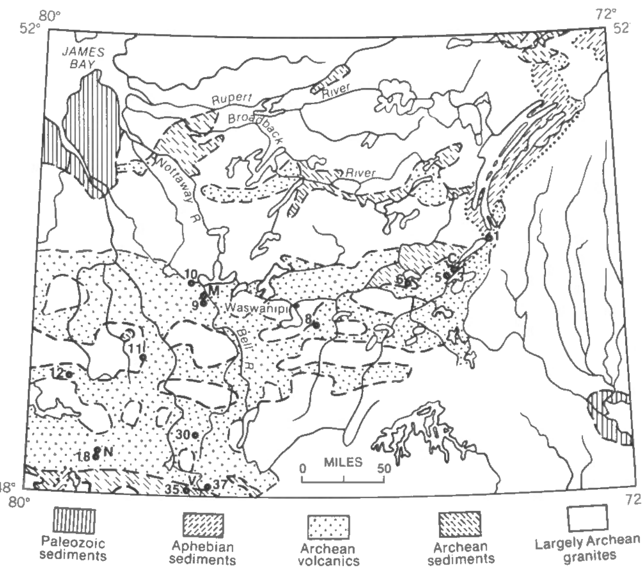
Mining is perhaps the most widespread industrial activity in northwestern Quebec, although other industries, including a paper-pulp complex and a chlor-alkali plant, are also important to the economy of the region. More recently, the area has received considerable public attention because of the development of the James Bay hydroelectric project in the immediate region.

THE STUDY AREA

The location of the study area is shown on Figure 1. Mines which were sampled are marked along with their relationship to the Nottaway-Rupert drainage system. The major mining activities are centred around Chibougamau, Chapais and Matagami. In addition to existing mines, there are a number of abandoned or inactive mines in the area. A few small gold mines have been worked in this region but they were of little economic significance when compared with the larger base metal mining operations. The whole region is considered to be one of good mineral potential and so, geochemical and geophysical exploration for new deposits remains a continuing process.

The Val d'Or and Noranda mining camps lie southwest of the study area. Mines of this region from which samples were also collected are similarly marked on Figure 1.

Table I lists the principal existing, abandoned and inactive base metal mines of northwestern Quebec. The current activity status of each mine and its principal metal products are described.



Mines of the study area are assigned numbers the same as given on Geological Survey of Canada Map 1252A, "Mineral Deposits of Canada".

(1) Icon,
(3) Patino Copper Rand,
(5) Campbell-Chibougamau,
(6) Opemiska,
(8) Coniagas,
(9) Matagami Lake and Orchan,
(10) New Hosco,
(11) Poirier and Joutel,
(12) Normetal,
(18) Horne and Lac Dufault,
(30) Barvue,
(35) Manitou,
(37) Bevcon.

C = Chibougamau, M = Matagami,
V = Val d'Or N = Noranda

Geology is essentially as shown, undesignated areas are primarily Precambrian granitoids except near James Bay where rocks consist of Paleozoic sediments.

Figure 1. Geology of the study area and mine sample site locations.

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Author's affiliation: J.E. MacLatchy: Environmental Protection Service, Department of the Environment, Ottawa, Canada.
I.R. Jonasson: Geological Survey of Canada, Ottawa, Canada.

Table I. Principal mines within the study area

Name of Mine	Status	Main Products	Location
Matagami Lake	active	Cu, Zn	Mattagami, west of Bell River
Orchan	active	Cu, Zn	Mattagami, west of Bell River
New Hosco	abandoned	Cu, Zn	Mattagami, Allard River
Coniagas	abandoned	Pb, Zn, Ag	Desmaraisville, 10 miles east of Lake Waswanipi
Barvue	abandoned	Zn, Ag	Barraute, Laflamme to Bell River
Opemiska Copper Mines	active	Cu	Chapais
Patino Copper Rand	active	Cu	Chibougamau, at Lac Chibougamau
Campbell Chibougamau	active	Cu	Chibougamau, at Lac Doré
Icon-Sullivan (Merrill Island Mill)	active	Cu	Lac Mistassini
Chesbar Iron Powder	inactive	Fe	Miquelon, at Lac Waswanipi
Norbeau (Quebec)	inactive	Au	Chibougamau
Bevcon	abandoned	Au	17 miles east of Val d'Or, Tiblemont to Bell River

Most of the ore bodies of note lie in Archean or Aphebian volcanics and sediments (Fig. 1). The deposits from which samples were collected may be broadly categorized as occurrences of massive chalcopyrite with a little zinc (Patino Copper Rand, Opemiska, Merrill Island, Campbell-Chibougamau and Icon Sullivan), or as occurrences of sulphides rich in both copper and zinc, and in some instances, in lead and silver (Joutel, Mattagami Lake, Poirier, Normetal, Lac Dufault, Coniagas, Manitou-Barvue, Orchan and Horne).

It is important to note that no smelting activities are associated with the mining operations within the study area. Copper concentrates are smelted at Noranda, southwest of the study area, and zinc concentrates are shipped elsewhere. Roasting and smelting activities can release mercury from metal sulphides in vapour form.

SAMPLING PROCEDURES

In the ores of the mines under study copper, lead and zinc occur primarily as the sulphides, chalcopyrite ($CuFeS_2$), galena (PbS) and sphalerite (ZnS), respectively. Also occurring with these marketable sulphides are varying, but generally much larger, amounts of pyrite (FeS_2) and pyrrhotite ($Fe_{1-x}S$) which are not of commercial value and usually contain significantly less mercury than the economic minerals (Table II). In the milling of these ores, copper, lead and zinc sulphides are separated from the pulverized rock and sulphide mixture (heads) by froth flotation. This process yields a metal sulphide concentrate and also tailings consisting of waste silicates, and iron sulphides and other minerals. The tailings are pumped in slurry form to a suitable pond, swamp or dammed-off lake where the solids settle out and where the water, now substantially free from solids, overflows the tailings pond into the local natural drainage system.

Chesbar Iron Powder, the only iron mine in northwestern Quebec, was located at Miquelon where magnetite (Fe_3O_4) was recovered from the ore by magnetic separation rather than by a flotation process.

It is conventional practice in the mining industry to prepare daily and monthly composite samples of ore heads, tailings and metal sulphide concentrates. The advantage of using such composites for a study of mercury occurrence lies in the fact that analysis of them yields an average figure for mercury representative of thousands of tons of ore, tailings and concentrates. In preparation for the conventional assay purposes of mining companies, the samples are oven dried (110°C - 200°C) or dried over a laboratory hot plate. This treatment, calculated to rid the sample of excess moisture, would possibly be expected to promote a loss of mercury which may have existed in the crushed sample in a thermally unstable form or as elemental mercury. However, it is probable that these losses would represent only a small percentage of the total mercury content of the sulphide samples. Temperatures considerably in excess of 250°C are required in order to decompose appreciable amounts of mercury-rich sulphides (Koksoy et al., 1967; Watling et al., 1972). Therefore, upon taking all of these factors into account it was considered that the averaged mercury contents of four or more different monthly composites collected from each mine would be sufficient to characterize the mercury output of a given mining operation.

A number of grab samples gathered from each mine were not subjected to forced drying treatments. Rather, they were slowly air-dried to avoid potential loss of volatile mercury components. Values for grab samples are not particularly comparable with composites because they tend to reflect local ore variations which the composites largely smooth out. However, comparisons between grab and composite samples suggest that small amounts of mercury which may be lost during forced drying will not significantly influence the mean values found for a given mine composite.

Composite samples were obtained from all of the active mines in the study area and from several similar operations farther to the west. Grab samples of old composite materials were obtained from the defunct Coniagas mine.

Table II. Mercury content of some common sulphide minerals
(*after* Jonasson and Boyle, 1972)

Sulphide Mineral	Empirical Composition	Normal Range Limits (ppm)	Highest Reported Content (%)
tetrahedrite	$Cu_{12}Sb_4S_{13}$	10 - 1,000	21
grey copper ores	$(Cu, As, Sb)_xS_y$	5.0 - 500	14
sphalerite	ZnS	0.1 - 200	1
wurtzite	ZnS	0.1 - 200	0.03
stibnite	Sb_2S_3	0.1 - 150	1.3
realgar	AsS	0.2 - 150	2.2
pyrite	FeS_2	0.1 - 100	2.
galena	PbS	0.04- 70	0.02
chalcopyrite	$CuFeS_2$	0.1 - 40	-
bornite	Cu_3FeS_4	0.1 - 30	-
bournonite	$PbCuSbS_3$	0.1 - 25	-
chalcocite	Cu_2S	0.1 - 25	-
marcasite	FeS_2	0.1 - 20	0.07
pyrrhotite	$Fe_{1-x}S$	0.1 - 5	-
molybdenite	MoS_2	0.1 - 5	-
arsenopyrite	FeAsS	0.1 - 3	-
orpiment	As_2S_3	0.1 - 3	-

Mercury occurs most abundantly in sphalerite, and in arsenic- or antimony-rich sulphides (sulphosalts) such as tetrahedrite. In general, the ores of the study area are comprised entirely of any or all of sphalerite, chalcopyrite and pyrite. Elevated levels found elsewhere in Canada can often be attributed to the presence of small amounts of sulphosalts. The highest reported contents are found only in the presence of mercury minerals.

ANALYTICAL METHODS

All samples were sieved to allow collection of the sub-100 mesh (ASTM) fraction. In general, 80 per cent of any composite passed through a 100 mesh sieve. Mercury was determined on all samples according to the cold vapour atomic absorption method developed by Jonasson et al. (1973).

All other metal values quoted here were either determined in our laboratories by atomic absorption methods or were taken from the assay records provided by the mining companies concerned.

RESULTS OF THE STUDY

Comparisons of sample types

The results of the investigation are summarized in Table III. Average figures for mercury contents of heads, tailings and concentrates are subdivided into three groups: monthly composites, daily composites and grab samples. The individual mines of the study area are grouped under drainage basins of either the Rupert River or the Bell-Nottaway system. Mines outside but adjacent to the study area are displayed separately for comparative purposes which will be discussed later.

Some observations may be made immediately regarding the value of sampling both daily and monthly composites. Mines which contain essentially massive chalcopyrite with very little sphalerite, i.e., the first five listed in Table III, show very little differences in mercury contents for similar sample types whether collected on a monthly or daily basis. A greater scatter of values exists between composites and grab samples, but in all cases the order of magnitude for mercury content remains the same.

The two copper-zinc ore bodies in the study area (Nos. 9a and b) show less consistency of values between daily and monthly composites for all samples; this is especially striking for the copper and zinc concentrates. Values quoted for the grab samples reflect this inconsistency even more clearly. It would appear that these ore bodies are not as homogeneous with respect to mercury as the copper deposits of the Chibougamau region or those located outside the study area (Nos. 11a and b). It is likely that measured carry-over of up to 5% zinc as sphalerite in typical copper concentrates influences the data. Zinc concentrates are obtained relatively pure, usually with less than 1% Cu impurity according to our analyses.

The data for the lead-zinc-copper concentrates at Manitou-Barvue show few differences between monthly or daily composites and grab samples. The values presented for lead concentrates reflect a significant carry-over of zinc of up to 5% in these samples. These aspects are further discussed later.

The two copper-zinc mines in the Noranda area show different characteristics with respect to mean levels found in the different composites. The data for Normetal (No. 12) show a spread of values similar to those noted for Mattagami Lake and Orchan. Local ore

Table III
Average mercury levels in ore heads, tailings and concentrates (ppm)

Watershed		Rupert	Bell-Nottaway-Waswanipi (Chibougamau area)								Harricanaw (Val d'Or and Noranda areas)					
Location No.		1	5	5	3	6	8		9	9	11	11	35		18	12
Name of mine or mill		Icon-Sullivan	Merrill Island	Campbell-Chibougamau	Patino Copper Rand	Opemiska	Coniagas	Chesbar	Mattagami Lake	Orchan	Joutel	Poirier	Manitou-Barvue (two ores)		Lac Dufault	Normetal
Milling Capacity: tons per day		Ships 600	600	3500	3000	3000	(350)	(850)	3850	1900	Ships 700	2500	1600		1300	1000
Principal Products		Cu	Cu	Cu	Cu	Cu	Zn,Pb	Fe	Zn,Cu	Zn,Cu	Cu	Cu	Zn,Pb	Cu	Cu,Zn	Cu,Zn
Mercury in Monthly Composites	Ore Heads	-	0.410*	0.025	0.065	0.075	-	-	0.430	0.540	0.245	0.245	4.65	0.215	13.1	3.21
	Tails	-	0.095	0.015	0.020	0.070	-	-	0.120	0.290	0.340	0.210	1.27	0.380	10.1	0.575
	Conc.	-	2.42	0.170	0.240	0.290	-	-	0.440Cu 2.56 Zn	0.920Cu 3.25 Zn	0.520	0.325	154 Zn 64.4Pb	1.40	32.2Cu 7.44Zn	3.71Cu 21.8Zn
Mercury in Daily Composites	Ore Heads	0.415	-	0.020	0.055	0.040	-	0.095	0.450	0.325	0.305	0.210	5.00	0.320	8.00	2.50
	Tails	0.115 float	-	0.010	0.015	0.015	-	0.105	0.100	0.075	0.210	0.150	1.08	0.550	6.20	0.32
	Conc.	0.420* sink	-	0.200	0.225	0.330	-	0.035	0.385Cu 2.78 Zn	0.615Cu 2.06 Zn	0.565	0.395	155 Zn 57.7Pb	1.12	8.19Cu 10.6Zn	3.31Cu 21.5Zn
Mercury in Grab Samples	Ore Heads	-	0.755*	0.025	0.020	0.020	1.76	-	0.405	0.230	-	-	3.33	0.205	5.81	2.83
	Tails	-	0.170	0.015	0.015	0.015	0.280	-	0.285	0.825	-	-	-	0.035	6.67	0.455
	Conc.	-	3.58	0.140	0.445	0.295	2.71	-	0.450Cu 2.76 Zn	0.570Cu 3.76 Zn	-	-	166 Zn 60.2Pb	1.23	6.10Cu 8.01Zn	4.79Cu 31.4Zn

NOTE:

1. **Icon-Sullivan sink concentrate becomes Merrill Island Heads. Merrill also mills its own ores separately.*
2. *Where there are two concentrates or where tailings are sampled separately; each concentrate or tailing is appropriately identified by the symbols Cu, Zn, Pb.*
3. *Location numbers correspond to those given on Geol. Surv. Can. Map 1252A, "Mineral Deposits of Canada".*

Table IV. Mercury contents of some copper and zinc sulphides from various mineral-rich areas of Canada

Name of Mine	Area Location	Zn sulphides ppm Hg	Cu sulphides ppm Hg	Type of Sulphides
Merrill Island[1]	N.W. Quebec	-	2.42	cpy
Campbell-Chibougamau	N.W. Quebec	-	0.17	cpy
Patino Copper Rand	N.W. Quebec	-	0.29	cpy
Opemiska	N.W. Quebec	-	0.33	cpy
Orchan	N.W. Quebec	3.25	0.92	cpy, sph
Mattagami Lake	N.W. Quebec	2.56	0.44	cpy, sph
Joutel	Val d'Or, Quebec	-	0.52	cpy
Mines de Poirier	Val d'Or, Quebec	0.80	0.33	cpy, sph
Coniagas[2]	N.W. Quebec	2.71	-	cpy, gal
Lac Dufault	Noranda, Quebec	10.6	8.19	cpy, sph
Normetal	Noranda, Quebec	21.5	3.31	cpy, sph
Horne	Noranda, Quebec	-	0.16	cpy
Manitou-Barvue	Val d'Or, Quebec	153.5	1.40	cpy, sph
Balmat	New York	1200	-	sph, gal
New Calumet[2]	W. Quebec	34.9	-	sph, gal
Eustis	S. Quebec	-	0.25	cpy
Long Lac	Kingston, Ontario	405	-	sph, gal
Errington[2]	Sudbury, Ontario	170	-	sph
Mattabi Mines	N.W. Ontario	100	3.35	cpy, sph
Kidd Creek	Timmins, Ontario	6.3	1.42	cpy, sph
Hudson Bay Mining and Smelting Co.	N. Manitoba	89	17.1	cpy, sph
Fox Lake	N. Manitoba	238	35.4	sph, cpy
Hackett River[3]	N.W.T.	21.2	-	sph, gal
Coppermine River[3]	N.W.T.	-	0.82	bor, chl
Keno Hill	Yukon	12.0	28.0	sph, tet
Walton	N.B.	0.55	0.35	cpy, sph, gal, tet
Dorchester	N.B.	7.30	-	sph, gal, chl
Hudson Bay Mt.	Smithers, B.C.	11.3	1400	sph, gal, tet
Coast Copper Mines	B.C.	-	10.5	cpy

cpy = chalcopyrite, sph = sphalerite, gal = galena, tet = tetrahedrite, chl = chalcocite, bor = bornite

1 = Icon-Sullivan mine *2 = defunct* *3 = no existing mine*

variations are most strongly indicated by the values noted for grab samples. However, Lac Dufault mine (No. 18) shows the greatest variation between all groups of samples, e.g., mercury in the copper concentrates range from 6.10 ppm in grab samples to 32.2 ppm in monthly composites.

In view of such variations it is clear that the most representative samples, in terms of trace element composition, are obtained from the longest time span composites, which in this case are the monthly composites.

Mercury levels in ores from the Chibougamau region

The chalcopyrite ores of the Chibougamau region, which occur mainly in altered anorthosites, are notable for their low mercury contents. It follows that any tailings derived from the ores will probably contain even less mercury.

In fact, none of the mines of the study area can be said to contain more than low trace quantities of the element. The tailings of the two largest milling operations at Chibougamau, viz., Campbell-Chibougamau and Patino Copper Rand, had particularly low mercury values. The same was true for Opemiska tailings except for one set of monthly composites which, for reasons unknown, were several factors richer in mercury than typical tailings from that operation; however, they were still not considered to be unusually high. The mercury levels encountered in the Merrill Island tailings are typical of copper ore tailings. The same assessment applies to the coarse reject material at Icon-Sullivan which trucks its up-graded ore to Merrill Island for final milling.

The mercury levels found in samples collected from Chesbar Iron Powder near Miquelon are considered typical of those expected for magnetite ore bodies. This operation was of small scale and produced a little tailings which hold only small amounts of pyrite. The tailings have been shown here to contain very little mercury.

The abandoned Coniagas Cu-Pb-Zn mine is located at Desmaraisville. Eight grab samples of old tailings were collected around a pond. Except for one sample which contained 0.958 ppm mercury, all samples

Table V. Average mercury contents (ppm) of ore heads and tailings from some Canadian mines

Mine	Heads	Tailings, type
New Calumet, Quebec	7.50	0.56, Zn
Coast Copper Mines, B.C.	3.50	0.07, Cu
Eustis, Quebec	0.20	0.01, Cu
Fox Lake, Man.	8.70	3.60, Zn
Hudson Bay Mining and Smelting Co., Ltd., Man.	24.90	1.20, Zn
Bethlehem Copper, B.C.	0.03	0.01, Cu
Manitou-Barvue, Quebec (zinc ore)	4.65	1.27, Zn
Manitou-Barvue, Quebec (copper ore)	0.21	0.38, Cu
Normetal, Quebec	3.21	0.57, Cu, Zn

1. *Data are based on the average of grab samples except for Manitou-Barvue and Normetal which are averaged monthly composites.*
2. *Data in Table IV are based on the mercury content of copper and zinc sulphide minerals alone; data in Table V are based on the mercury content of the ore processed in the milling operation which would include either copper or zinc sulphides or both, iron sulphides and waste minerals.*

yielded less than 0.3 ppm mercury, which is quite a small quantity. There are of the order of 500,000 tons of well-confined tailings in a pond adjacent to the mill.

Mercury levels in ores from the Matagami region

The Mattagami Lake and Orchan mining operations are located in what is essentially the same copper-zinc ore zone within andesite-rhyolite sequences. The mercury levels in the composite tailings from each were found to be low and of similar magnitude, although slightly more variation was noted in the Orchan tailings.

Mercury levels in ores from elsewhere in Canada

It is of general interest to compare the mercury contents of the copper and zinc ores of the study area with some of those for the same sulphides obtained from other diverse parts of Canada where similarly intensive mining activity also prevails.

Table IV presents a selection of data from other typical massive sulphide deposits. For ease of comparison, some data for copper and zinc sulphides from northwestern Quebec are also included.

Table V lists a selection of data for ore heads and tailings from some of the high and low mercury areas described in Table IV. In most cases, zinc tailings contain less than 0.5% zinc with which fraction most of the mercury is generally associated. Tailings derived from copper ores are generally low in mercury.

It is immediately obvious that by comparison with mining operations in the Val d'Or area, in northwestern Ontario, New Brunswick, northern Manitoba and British Columbia, the Chibougamau area emerges with one of the lowest average mercury contents with respect to the commercially viable ore bodies. Ores from the Matagami area are also low in mercury when compared with some other zinc-bearing ores (Table IV).

Some of the ore zones listed, notably those in northwestern Ontario and northern Manitoba, are particularly enriched in mercury. In general, however, the tailings derived from these mining operations are low in mercury and are confined to tailings ponds.

Other mines in the study area

A few abandoned mines in the study area were not investigated. The Barvue mine near Barraute produced zinc and silver from 5,600,000 tons of ore between 1952 and 1957.

New Hosco Mines Limited operation, located beside the Allard River, near Mattagami, was a copper-zinc producer. Some 932,000 tons of ore were milled at Orchan, 12 miles west. Thus, its tailings are mixed with Orchan tailings in a shallow dammed-off lake. The ore (3.5% Zn, 1.1% Cu) has been shown to contain between 0.010 and 0.140 ppm Hg (Sears, 1970).

Norbeau Mines (Quebec) Limited operated a mine near Chibougamau which produced gold from 1964 to 1969. Only 419,000 tons of ore were milled.

The Bevcon mine was a gold producer from 1950 to 1965 and was located about 17 miles east of Val d'Or. It milled over 3,200,000 tons of ore during this period, almost all of which became tailings. These are confined to an area adjacent the mill site from where drainage discharges into the Bell River via the Tiblemont River. Sears (1970) reported that gold ores from the nearby Sigma and Lamaque mines contain very little mercury (0.001 to 0.140 ppm). It is likely that Bevcon ore contained similarly low amounts of mercury.

DISCUSSION

Availability of mercury in tailings

It is important to ncte that base metal mining and milling operations do not use mercury in the processing of the ore, nor do they treat the ore in a manner that would release mercury from a solid matrix. This is in contrast with mercury chlor-alkali plants which use liquid mercury, or, with smelting operations which may vaporize mercury. The mercury present in ore, concentrates, or tailings exists naturally in the minerals and generally occurs interstitially or in isomorphous replacement of metal ions in the mineral lattice structure. The presence of mercury in the tailings does not necessarily mean that there is mercury available which can be readily transported into the aquatic environment. If a mining operation is to discharge mercury to the environment, a chemical mechanism for releasing the mercury from the tailings must exist.

Acid mine waters

In some mining operations acid mine waters are generated by the natural oxidation of iron sulphide minerals. An acid water condition may arise either underground in the ore zone itself or on the surface in the tailings or waste rock where pyrite or pyrrhotite are present. Acid conditions caused by oxidizing pyrite or pyrrhotite are less common in active tailings ponds because of the basic reagents added in the milling process. In some cases a tailings pond may become acid when it is abandoned and no longer receives additions of basic reagents.

The presence of iron sulphides does not necessarily result in acid mine water conditions. The presence of basic minerals in the ore or tailings can prevent the natural generation of acid. Moreover, some forms of iron sulphides are more stable than others and do not readily oxidize to form acid.

Development of such an acid condition would be expected to promote disintegration of mercury-bearing minerals and to provide a mechanism for transporting mercury into the waterways. In the absence of such oxidizing acid conditions, the rate of movement of mercury from the pond would be exceedingly slow.

Analogous leaching conditions do exist naturally, but the degree of dispersion is often very limited and may take thousands of years to develop a detectable metal dispersion halo. These haloes surround all naturally oxidizing ore bodies to a varying extent and are important sources of information to exploration geochemists in their search for such ore bodies.

In the study area, no serious acid mine water conditions were encountered, although a number of problems are known elsewhere in northern Quebec.

It was noted previously that the most striking levels of mercury in ores, concentrates and tailings were found outside the study area at Manitou-Barvue Mines Limited (Goldon Manitou), Falconbridge Copper Limited (Lac Dufault Division) and Normetal Mines Limited. Manitou-Barvue has the highest mercury levels in its zinc concentrates wherein the mercury is closely associated with sphalerite and sulphosalts in which silver and antimony values are found. The mercury content of sphalerite (about 150 ppm) is one of the highest so far reported from any such sulphide in Canada (Table IV).

The composite samples of Manitou-Barvue tailings average just over 1 ppm mercury which is relatively low in view of the high levels in the concentrate. The mine also has acid water underground which is discharged at the surface. The mine water contains significant quantities of copper, zinc, lead, arsenic and other metals which are discharged into a ditch which flows into the Bourlamaque River. This particular mining operation provides an excellent study site to observe the aqueous dispersion of mercury and other metals.

Confinement of tailings

Adequate confinement of tailings can prevent aquatic life of rivers and lakes from being exposed to mineral material that may have a higher mercury content than natural river and lake sediments. It is not known whether aquatic organisms living on top of tailings with above background levels of mercury would acquire higher levels of mercury. However, if the tailings are adequately confined, this possible problem would become insignificant, particularly where there are no acid conditions in the tailings and where the tailings contain the same order of background levels of mercury as other rock, sand, and sediments in the area.

The mines of the study area dispose of their tailings into arms of lakes, swamps, or shallow lakes which are dyked so that the dumps are confined to a limited area. Serious tailings disposal problems were not encountered at any of the mines visited. Some mines in the Chibougamau region did not originally have dams to confine tailings in this way. These practices may have been detrimental to aquatic life, but not because of mercury in view of the very small amounts of the metal in tailings from this region. Even inadequate confinement of tailings may not result in significant release of mercury to the environment if acid conditions do not exist.

Mattagami Lake Mines and Orchan Mines provided additional information on the disposal of their tailings into Watson Lake, which is quite shallow and is dammed off from the Allard River. The overflow from Watson Lake was analyzed for mercury by Mattagami Lake Mines four times in 1971. In all cases there was less than 0. 2 ppb (parts per billion) mercury, which was the detection limit of the analytical method used. A typical background level for mercury in natural waters is about 0. 1 to 0. 2 ppb or less depending on the area in question (Jonasson and Boyle, 1972). Higher natural background levels do occur and can be expected in view of the geological make-up of the study area. Because of the fact that mercury in the tailings effluent is near background levels, it is virtually impossible at this time to ascertain what proportion of mercury found in the effluent might have been derived from weathering of tailings and what proportion is due to natural background sources.

Natural sources of mercury in the study area

The study area is largely composed of Aphebian and Archean rocks of both volcanic and sedimentary

Table VI. Average mercury contents of common rock types*

Rock Type		Range	Mean
(a) Igneous		ppm	ppm
Ultrabasic (dunite, kimberlite, etc.)		.007 - .250	.168
Basic intrusives (gabbro, diabase, etc.)		.005 - .084	.028
Basic extrusives (basalt, etc.)		.005 - .040	.020
Intermediate intrusives (diorite, etc.)		.013 - .064	.038
Intermediate extrusives (andesite, etc.)		.020 - .200	.066
Acidic intrusives (granite, granodiorite, syenite)		.007 - .200	.062
Acidic extrusives (rhyolite, trachyte, etc.)		.002 - .200	.062
Alkali-rich rocks (nepheline syenite, phonolite, etc.)		.040 - 1.400	.450
(b) Metamorphic			
Quartzites		.010 - .100	.053
Amphibolites		.030 - .090	.050
Hornfels		.035 - .400	.225
Schists		.010 - 1.000	.100
Gneisses		.025 - .100	.050
Marbles, crystalline dolomites		.010 - .100	.050
(c) Sedimentary			
Recent Sediments:	stream and river	.010 - .700	.073
	lake	.010 - .700	.073
	ocean and sea	<.010 - 2.000	.100
Sandstones, arkoses, conglomerates		<.010 - .300	.055
Shales, argillites, mudstones		.005 - .300	.067
Carbonaceous shales, bituminous shales		.100 - 3.250	.437
Limestones, dolomites		<.010 - .220	.040
Evaporites:	gypsum, anhydrite	<.010 - .060	.025
	halite, sylvite, etc.	.020 - .200	.030
Rock phosphates (composite samples)		....	.120

* *after Jonasson and Boyle, 1972*

origin. It has been noted that many of the ore bodies occur in volcanic sequences consisting mainly of metamorphosed andesites and rhyolites. These volcanic flows were laid down on ancient sea-beds and were in places later surrounded or overlain by sediments now metamorphosed to shales, carbonaceous shales, slates, carbonaceous schists and crystalline dolomites.

Table VI presents world averages for most of the common rock types, many of which are represented in the study area. Of particular note are the andesites and rhyolites (0.002-0.200 ppm) which are low in comparison with carbonaceous metasediments (0.100-3.250 ppm). It is emphasized that these data are typical of normal background levels, i.e., data where sulphide mineralization causes an elevation of the values well above normal, are not included in the averages. As a rule of thumb, values exceeding 3 or 4 times these figures would typify rocks containing sulphide mineralization which may consist of pyrite only.

The metal content of metasediments (formerly shales) of the study area have been intensively studied (Cameron and Jonasson, 1972) along with other similar materials from elsewhere in the Canadian Shield and from the Maritimes. Mercury was determined in 406 samples of Archean shale from 153 localities in the Superior Geological Province of the Shield and on 396 samples of the younger Aphebian shale (1.7 to 2.5×10^9 yr) from 54 localities. One of the latter formations studied was the Albanal Formation in which the drainage basin of Mistassini Lake and the lake itself partly lies. Thirty-eight samples from this formation yielded an arithmetic mean mercury content of 0.400 ppm, compared with the mean for all 396 samples of Aphebian shales of the Shield which was 0.513 ppm. The overlying Temiscamie Formation contains shales with a mean mercury content of 0.672 ppm. Twenty-nine samples of Archean shale from the Chapais area had a mean mercury content of 0.080 ppm, the mean for all 406 Archean samples of the Shield was 0.124 ppm. These Precambrian shales, which are several thousand feet thick in places, are distributed widely throughout the study area. By contrast, Paleozoic shales from the Maritime provinces contained 0.042 ppm mercury.

Mercury is probably bound up in carbonaceous matter consisting largely of graphite. Pyrite, which forms during diagenesis of sulphur-rich muds into shales, has also been shown to contain a high proportion of the mercury. Thus, in the study area there is a potentially large source of mercury which is very widely distributed--a fact of some importance because it means that mercury can be locally derived within the confines of any given river system.

The presence of oxidizing pyrite in the rocks promotes the release and sustains the migration of mercury in meteoric waters. This is the same chemical process which produces acid mine water, but in undisturbed rock formations the process occurs much more slowly.

CONCLUSIONS

On the basis of the data presented for the mines of the Chibougamau and Matagami areas of northwestern Quebec and by taking into consideration relevant geological information of the study area, it is possible to draw the following conclusions regarding the sources, availability and migration characteristics of mercury.

1) Mercury levels in the copper ores of the Chibougamau region are low. In fact, they are probably less than average for typical chalcopyrite ores gathered from all parts of Canada. The tailings are virtually devoid of mercury for all of the mining operations; a fact which probably reflects the effectiveness of ore separation processes.

2) Mercury levels in the copper-zinc ores of the Matagami region are similarly low, but due to the increasing amounts of sphalerite mined, are somewhat higher than around Chibougamau. Nevertheless, the milling operations are efficient and the mercury contents of the tailings reflect this. The zinc sulphides of Mattagami Lake and Orchan mines are low in mercury when compared with average values for zinc sulphide ores.

3) In the study area tailings disposal practices were found by the authors to be adequate; no evidence of acid tailings conditions which might be expected to promote the release of mercury to the environment was found.

4) The presence of large masses of Precambrian pyritic carbonaceous metasediments, particularly of those of Aphebian age, may be a significant factor with regard to the establishment of elevated background levels for mercury in sediments, waters and subsequently, in lake and river biota. The metamorphosed shales of the Albanal and Temiscamie formations contain more mercury in available form than do most of the tailings of the mines studied. The presence of iron sulphides in the rocks would enhance release of mercury into ground and stream waters. The mass of such rocks is very large in comparison with the small quantities of confined tailings dumped by the mining operations. Similar rocks occur in other areas of the Shield.

5) Some mining operations in other parts of Canada mine ores containing more mercury than any of those in the study area. In particular, the adjacent Val d'Or and Noranda mining camps contain zinc ores which are relatively enriched in mercury compared with Canadian averages for those ore types. In some instances inadequate tailings disposal and acid mine water conditions do exist. Opportunities for further study are readily available.

6) On the basis of the available data, it is considered that higher levels of mercury observed in the lakes of the study area of northwestern Quebec are primarily of natural geochemical origin. However, further work is required to establish conclusively that the high mercury levels are related to shales of Aphebian age. More work is also required on the acid volcanic rocks of the region to check for mercury levels. It is unlikely that any of the existing or abandoned mining operations in the study area could release sufficient mercury rapidly enough to produce any significant elevation of mercury over measured naturally high background values. The same cannot be said for all other industrial activities in the region.

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