# The Occurrence of Arsenic and Heavy Metal Contamination from Natural and Anthropogenic Sources in the Cobalt Area of Ontario

Charles G. Dumaresq, B.Sc.

1993



**Electronic Version, November 2005** 

# The Occurrence of Arsenic and Heavy Metal Contamination from Natural and Anthropogenic Sources in the Cobalt Area of Ontario

by

Charles G. Dumaresq, B.Sc.

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science

Department of Earth Sciences

Carleton University Ottawa, Ontario May, 1993

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The undersigned recommend to the Faculty of Graduate Studies and Research acceptance of the thesis

### "The Occurrence of Arsenic and Heavy Metal Contamination from Natural and Anthropogenic Sources in the Cobalt Area of Ontario"

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> Dr. F.A. Michel Thesis supervisor

Dr. F.A. Michel Chair, Department of Earth Sciences

> Carleton University May 17, 1993

# **Blood on the Rocks**

The great stope stands stripped of his might Bearing Satin's blood - erythrite For eons he did live in pleasure Secure in possession of silver treasure.

The hunters came with weapons galore To rob him of his ancient ore They pounded it, grounded it and sent it away Back for more to this very day.

### But alas! It is the hunter being led to slaughter! The ultimate weapon - poison in his water.



Bryan Mason M.O.E. North Bay

**Erythrite on mine tailings in Cobalt** 

## Author's Note on the Electronic Version of This Report

This electronic version of my thesis was produced in 2005. I had wanted to produce this version of my thesis much earlier, but until relatively recently, the necessary technology to do this was not readily accessible. In particular, advances in scanning technology have allowed scanning of photos included in the original thesis, and many photos have been added in a new appendix at the end of the report. In addition, photos from a visit to Cobalt in the summer of 2005 have been added in an additional appendix, documenting some things which have changed, and some things which have not changed, since this research was conducted.

The text of the electronic version of the report is exactly as was written in 1993, with the exception of the correction of a few minor typographical errors. Text has however been reformatted. All graphs had been re-generated using the original data. Many of the original maps have been regenerated from original electronic files. However, electronic versions of some maps have been lost. In these cases maps have been scanned.

I decided to undertake this project so many years after it was originally completed because I believe that this material is still relevant. This remains a story that needs to be told, particularly to the people of Cobalt, who may not be aware of the extent of the contamination around them. I have not worked in the area since 1997, and I am aware of some efforts to carry out rehabilitation in the area, as well as recent monitoring conducted by the Ontario Ministry of the Environment. The data in this thesis can serve as a point of comparison for any monitoring work carried out to assess the effectiveness of these rehabilitation efforts.

Note that, in partnership with staff of Natural Resources Canada, some of the work initiated by my research continued. Further monitoring and research from 1993 to 1997 led to the publication, in 2004 of the following report:

Percival, J.B., Kwong, Y.T.J., Dumaresq, C.G. and Michel, F.A. (2004): *Transport and attenuation of arsenic, cobalt and nickel in an alkaline environment, Cobalt, Ontario.* Geological Survey of Canada, Natural Resources Canada, Ottawa, Open File 1680: 30 pp., on CD.

Note also that as a follow-up to my research in the Cobalt area, and number of other undergraduate and graduate students from Carleton University have conducted related research in the Cobalt area. Anyone wishing to find out more about this work should contact the Department of Earth Sciences at Carleton University.

Charles Dumaresq November, 2005

### Abstract

In the ore deposits of Cobalt, Ontario, silver is associated with arsenide and sulfarsenide minerals. These minerals occur in mine tailings, and oxidation of these minerals in tailings mobilizes As. Groundwater in tailings contains high As concentrations, and this groundwater discharges into surface waters. During the summer, water soluble As-rich crusts form on the tailings, and heavy rains dissolve these crusts, flushing As into surface waters. Erosion of tailings, and redeposition of tailings in downstream water bodies also contributes to surface water contamination. Thus, tailings are an import source of contamination for local surface waters. Surface waters around Cobalt contain high concentrations of As. Except for one lake, As concentrations in local water bodies range from 0.040 to 6.510 ppm, and the maximum acceptable concentration for freshwater aquatic life is 0.050 mg/L. Since As occurs naturally in the rock, some of the contamination is of natural origin. One lake unaffected by mining has a mean As concentration of 0.048 ppm. Some local groundwater also contains As, due to high As concentrations in various rock units. Most groundwaters used for consumption contain acceptable concentrations of As and heavy metals. Water from one well, in a campground, which is finished in a rock unit associated with high As concentrations in groundwater, has a mean As concentration of 6.970 ppm. Environmental contamination in the Cobalt area puts local ecosystems at risk, and there are a number of potential health threats to local residents, including: inhalation of dust from tailings, handling tailings and other solid materials, swimming in local lakes, and eating fish from these lakes.

# Acknowledgements

I wish to extend thanks to my thesis supervisor, Dr. Fred Michel, for his guidance, supervision and patience throughout this project. Thanks also to Dr. K. Subramanian of the Department of Health and Welfare Canada for his role in securing funding for this project, and for his editorial comments. Funding also came from NSERC operating grant A2646. A special thanks goes to Agnico-Eagle Mines, particularly John Young, for allowing access to their properties in the Cobalt area. Thanks to Matt Reinke, Jennifer Smith, the students of field camp 1991, and particularly David Lauzon, for field support.

There are several people in Cobalt who provided help in many ways, especially Pat Anderson, for her enthusiasm, and answers to a million questions. Thanks to the staff at the Cobalt Mining Museum, where I spent rainy days in search of old photographs. Many thanks to Elaine Baša of the Cobalt Resident Geologist's office for collecting precipitation samples, and to her and Jim Ireland for answered questions. Thanks also to Wayne Marshall of the MOE in North Bay, who provided copies of reports of previous research in the Cobalt area. Back at home, the Carleton University X-ray lab was invaluable, and Eric de Kemp was a patient teacher as I learned the art of computer cartography.

This thesis had a very long gestation period, and there are several people who provided direction in its earliest stages during my "sabbatical" in the Geography Department, particularly Ken Torrance from Geography, Ian Clark from the University of Ottawa, Mike Filion, formerly of CANMET, and Bill Blakeman of Environment Canada. The road they helped set me on led me to where I am today. I am very grateful to my colleagues at the Eco-Health Branch of Environment Canada for their support, particularly to my supervisor, Sheila Forsyth, and Divisional Chief, Murray Clamen, for their patience and understanding as I worked on my thesis day and night to meet the final deadline.

Loving thanks are extended to my wife, Gina, for her impatience at the right times, her patience and understanding at the right times, and her love at all times. A special thanks to my Father, who got me where I am today.

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# **1** Introduction

### 1.1 Introduction

Legend has it that one evening in the summer of 1903, Fred LaRose, a blacksmith working on the construction of the Temiskaming and Northern Ontario Railway, was in his tent near the Mile 103 post of the railway when he saw a fox outside the tent. LaRose grabbed his hammer and threw it at the fox. He missed, and the hammer clanged against a rock face. In the morning LaRose picked up his hammer, and discovered that when he had thrown it, it had chipped away some of the rock and exposed a silver vein. The Cobalt silver camp had been born.

The true stories of the discovery of silver around the Mile 103 section of the railway (distance measured from North Bay) are not as romantic as the legend, but by the time of the first snow in November of 1903 word of the discovery had spread. By 1905 there were sixteen mines in the area, and by 1911 production exceeded 30,000,000 oz./yr. Cobalt was the biggest silver mining camp in the world and was known by everyone in North America who ever picked up a newspaper. Mining continued until the 1930's, then slowed to a trickle. Activity renewed in the 1950's then slowly dropped off; there are currently no operating mines in the area.

One of the legacies of silver mining in Cobalt is an environmental legacy. Millions of tons of mine waste rock and mill tailings were dumped on the land and in local lakes. These wastes are more than just an eyesore: they threaten the local flora and fauna, and the health of the people of Cobalt and surrounding towns. In Cobalt ores, silver was associated with arsenic (As) minerals. Little of this As was ever recovered; most of it ended up in the tailings as well as the waste rock. Today this As contaminates surface water in the area, and As is present in groundwater supplies. In addition to As, Hg and cyanide, both used in the milling of the ores, are also present in the mine wastes and may also pose environmental and health threats.

### **1.2 Geographic Setting of Research Area**

Cobalt is a town with a population of about 1500 people, located on Highway 11B, about 140 km north of North Bay, Ontario, within the District of Temiskaming (NTS 31 M/5)(see Figure 1.1). Cobalt is one of three towns comprising an area called the Tri-Town; the other towns are Haileybury, about 8 km north of Cobalt, and New Liskeard, about 18 km north of Cobalt. The total population of the Tri-Town is about 10,000. The area is easily reached by the TransCanada Highway.

### **1.3 Objectives of the Current Study**

This study was funded by the Environmental Health Directorate of the Department of Health and Welfare Canada, and NSERC operating grant A2646. Research was conducted under the supervision of Dr. F.A. Michel of the Carleton University Department of Earth Sciences. Field work was conducted between April, 1991 and May, 1992.



# The location of Cobalt

Figure 1.1

The Department of Earth Sciences at Carleton University has held an introductory field camp in Cobalt for over 20 years. On the basis of this experience it was known that there was As contamination in the Cobalt area, and previous research in the area by the Ontario Ministry of the Environment and the Geological Survey of Canada confirmed this.

The primary objectives of this research are:

- 1. To conduct a thorough review of previous research on environmental contamination in the Cobalt area, including a review of literature on the extent of tailings deposits.
- 2. To establish research sites for the detailed study of mine tailings, including tailings geochemistry and mineralogy and the geochemistry of groundwater in the tailings.
- 3. To sample surface waters in the Cobalt area to determine the extent of contamination of surface waters, and to identify possible natural and anthropogenic sources of contamination.
- 4. To collect water samples from private wells and public water supplies, in order to assess the quality of drinking water in the Cobalt area.
- 5. To identify the possible health risks to the residents of the Cobalt area as a result of As and heavy metal contamination, including those who live adjacent to tailings deposits and those who use the tailings deposits for recreation.

### **1.4** Geographic Scope of the Study

The mines in the Cobalt area are spread over a large area. To focus the scope of this research, the area of study includes only the Farr Creek drainage basin (see Figure 1.2). This area includes Sasaginaga Lake, Sasaginaga Creek, Short Lake, Cobalt Lake, Mill Creek, Cart Lake, Peterson Lake, Peterson Creek, Crosswise Lake and Farr Creek. Many of the major mines in Cobalt are in this area, including the Tretheway, Coniagas, Buffalo, Hudson Bay, Chambers-Ferland, McKinley-Darragh, Nipissing, Right-of-Way, LaRose, O'Brien, Nova Scotia, Colonial, King Edward and the Deer Horn Mine (see Figure 1.3).

The study area was restricted for two reasons:

- 1. This area is large enough to be representative of the area as a whole, and
- 2. The greatest environmental and health threats in the Cobalt area are in this basin. Crosswise Lake, Peterson Lake and Cobalt Lake are used for swimming, and all three contain tailings. Some of the most contaminated tailings in the area, including the tailings of the Nipissing Mine, are within the Farr Creek drainage basin. All of this area drains into Farr Creek and north through North Cobalt where shallow drinking water wells have been contaminated with As.





# 2 The Geology of the Cobalt Area, and a Summary of Previous Environmental Research

#### 2.1 Geologic Setting of Cobalt

#### 2.1.1 General Geology

The oldest rocks in the Cobalt area are Archean volcanics and interflow sediments containing pyrite, pyrrhotite, chalcopyrite, sphalerite and galena. Unconformably overlying the volcanics are Archean sedimentary rocks, referred to as the Temiskaming Formation. Unconformably overlying the Archean rocks is the Proterozoic Cobalt Group. The oldest unit of this group is the Coleman Member of the Gowganda Formation, a sequence of conglomerate, greywacke, quartzite and arkose. Overlying the Coleman is argillite of the Firstbrook Member. The youngest unit of the Cobalt Group is the Lorrain Formation, a unit of arkose and quartzite. In the late Proterozoic the region was intruded by the Nipissing diabase. All of the deposits occur within the diabase, or within about 200 m of it (Jambor 1971)(see Table 2.1 and Figure 2.1).

#### 2.1.2 Occurrence, Mineralogy and Geochemistry of the Silver Deposits

Silver deposits occur in fractures, faults and joints within the Archean rocks, the Cobalt Group and the Nipissing diabase. The ore occurs in veins which vary in width from a few millimetres to as much as 1.2 m, but average less than 5 cm (Petruk 1971a). Some of the richest veins in the area were on the west and east sides of Cobalt Lake.

The mineralogy of the veins is complex. The gangue minerals are calcite, dolomite, quartz and chlorite. Ore minerals include native Ag, Au, As and Bi, as well as arsenides, sulfarsenides and sulfides such as nickeline, cobaltite, safflorite, loellingite, rammelsbergite, gersdorfite, skutterudite, arsenopyrite, tetrahedrite, chalcopyrite, bornite, galena, pyrite and marcasite (Petruk 1971b)(see Appendix 1 for chemical formulae of these minerals).

Petruk (1971b) analysed four ore samples (see Table 2.2a), and presented data from ore analyses by previous workers (see Table 2.2b). These data show that ore compositions are variable, but all of the ore analysed contained high levels of As, in the range of 31.86 to 64.79 wt. %. The As:metal ratios in the ore range from 1.57 to 2.95 (Petruk 1971b). The wall rocks adjacent to the veins are enriched in As, with As halos detected up to 30 m from the veins (Boyle *et al.* 1967). The four samples analysed by Petruk (1971b) also contained 0.01 to 0.87 wt. % Hg, 9.18 to 14.35 wt. % Co and 0.54 to 12.19 wt. % Ni.

Boyle, *et al.* (1967) analysed samples from local rock units in areas away from mineralization, to determine background compositions (see Table 2.3). Arsenic occurs in several units, including the Archean volcanics (up to 200 ppm) and the Cobalt Group (up to 10 ppm). Mercury was detected in the 0.02 to 0.10 ppm range in all samples analysed.

Eon	Time	Rock Units						
Р	Recent	Soils, lakes and stream deposits						
Н								
А	Pleistocene	Glacial sand, gravel and bedded clay						
Ν								
E	Unconf	formity						
R		-						
0	Silurian	Dolomite, limestone, sandstone						
Z								
O	Ordovician	Limestone, shale and sandstone						
I ~								
С								
	Unconformity							
Р	Olivine and quartz diabase dikes							
R	Intrusive contact							
О		Nipissing Diabase						
Т		Intrusive contact						
E		Lorrain Formation sandstone						
R		Gowganda Formation						
0		Firstbrook Member argillite						
Z		Coleman Member conglomerate						
0		greywacke						
Ι		and sandstone						
С								
	Kenora	n Orogeny						
А		Dikes, sills and batholith intrusives of late to						
R	middle Archean age							
С		Intrusive contact						
Н		Temiskaming Group sediments						
Е		Unconformity						
А		Volcanics and interflow sediments						
N								

**Table 2.1:**Geological column for the Cobalt area (after Jambor 1971)



**Table 2.2a & b:**Composition of ore from veins in the Cobalt area (after Petruk 1971b)

CaO	MgO	MnO	Fe	Co	Ni	Cu	Zn	Pb	As	Sb	Ag	Hg
5.82	4.41	0.25	1.61	10.56	12.19	tr	0.04	0.04	44.53	2.00	7.85	0.37
11.20	3.50	0.39	4.04	10.00	4.41	0.07	0.13	0.05	41.11	0.82	10.78	0.87
7.98	0.36	0.05	8.55	14.35	1.82	0.10	0.01	0.03	57.00	0.09	0.01	0.01
21.06	2.02	0.06	11.60	9.18	0.54	0.01	0.01	nd	35.57	0.10	0.04	0.03

(a) Data in weight percent

#### (b) Data in weight percent

CaO	MgO	Fe	Со	Ni	Cu	As	Sb	S	Ag	SiO <sub>2</sub>
27.48	tr	7.19	5.04	0.74	nd	31.86	na	0.66	2.68	1.50
na	na	4.28	21.10	tr	0.19	64.45	tr	4.77	na	na
na	na	6.69	13.97	0.53	0.40	50.70	1.05	1.71	0.17	na
na	na	7.43	12.10	2.24	tr	62.56	tr	0.67	0.12	na
na	na	12.42	9.27	tr	nd	52.93	na	1.32	0.03	na
18.30	tr	10.40	6.25	0.47	nd	47.65	na	tr	2.81	0.13
na	na	4.81	16.02	1.10	tr	64.79	tr	1.26	9.48	na
na	na	6.05	9.56	0.78	0.26	38.90	0.27	0.72	0.39	na

tr: trace concentrations, nd: not detected, na: not analysed

<b>Rock</b> Type	Pb	Zn	Cu	As	Sb	Mo	Ag	Ni	Со	Bi	Mn	Hg
Archean Volcanics	5	135	100	10	<2	1	0.25	122	56	< 0.05	2500	0.03
Archean Interflow Sediments	500	500	400	80	5	3	3.0	130	80	0.83	500	0.05
Granite	15	25	6	<1	<2	1	< 0.5	2	<10	< 0.05	70	0.03
Coleman Conglomerate	12	105	57	4	<2	<1	<0.5	150	30	< 0.05	1500	0.02
Coleman Conglomerate	5	25	22	<5	<2	<1	<0.1	60	25	< 0.05	500	0.10
Coleman Greywacke	12	75	45	5	<2	<1	<0.5	125	25	< 0.05	1000	0.02
Coleman Greywacke	<5	20	20	<5	<2	<1	<0.1	60	25	< 0.05	500	0.10
Lorrain Sandstone	<2.5	5	2	<1	<2	<1	< 0.5	20	<10	< 0.05	20	0.03
Nipissing Diabase	<2.5	65	90	<2	<2	1	0.11	128	40	< 0.05	2000	0.03

**Table 2.3:**Average metal concentrations in rocks from the Cobalt area (after Boyle *et al.*<br/>1967)(data in parts per million)

tr: trace concentrations, nd: not detected

#### 2.1.3 Supergene Alteration of Ore Veins

Supergene alteration processes which occur in veins in the Cobalt area were discussed by Boyle and Dass (1971). Little or no research has been done on this subject since that time (Jambor, Energy Mines and Resources, pers.comm. 1992, Kissin, Lakehead University, pers.comm. 1993, Susack, University of New Brunswick, pers.comm. 1993). This section is a summary of their discussion. Further details are found in Appendix 1.

Supergene processes are mineral alteration processes that occur as a result of the interactions between minerals and water of surface origin. As a result of the complex mineralogy of the Cobalt ores, phase relationships during alteration processes are complex, and solution compositions are constantly changing as new reactions occur. Thus, the alteration solutions are multicomponent systems which are not easily interpreted. Boyle and Dass (1971) based their discussion on the analyses of water samples and observed mineral products.

#### 2.1.3.1 Iron, Manganese, Calcium and Magnesium

In the veins, dolomite, calcite, Fe-arsenides, arsenopyrite and pyrite are abundant, and influence reactions in oxidation zones. In zones of oxidation, Fe occurs in limonite and scorodite, Mn in wad, and Ca and Mg in secondary carbonates.

When dolomite and calcite react with water containing dissolved CO<sub>2</sub>, soluble secondary bicarbonate minerals are produced. When arsenopyrite or pyrite are oxidized, sulfuric acid is

produced. This acid reacts with carbonates, raising the pH and producing soluble Fe, Mn, Ca and Mg sulfates such as melanterite. These minerals are water soluble and will redissolve during an influx of water. Where water is available, most Fe is fixed in the ferric oxide mineral limonite.

The chemistry of Mn in oxidized zones is similar to that of Fe. Once Mn is released as manganous sulfate or manganous hydrogen sulfate, much of the Mn is bound in wad (MnO<sub>2</sub>). Wad may coprecipitate with limonite, depending on the pH of the solution.

If arsenides are abundant, some Fe may be bound in scorodite, (Fe,Al)(AsO<sub>4</sub>)<sup>2</sup>H<sub>2</sub>O. If prolonged leaching occurs, the arsenate component may be removed, leaving the Fe bound as limonite.

In oxidized zones, the Ca and Mg released from calcite and dolomite may be reprecipitated as secondary carbonates.

#### 2.1.3.2 Alkalies, Silica and Alumina

In the Cobalt area, alkalies, silica and alumina occur mainly in the wall rock, but they also occur in small amounts in quartz, chlorite and carbonates within the veins. Sulfuric acid released during the oxidation of sulfide minerals attacks silicates and quartz. The alkalies are released as carbonates, bicarbonates, sulfates and arsenates. Once in solution, some of the Na and K are precipitated in secondary clay minerals. Similarly, much of the Al is bound in clay minerals and chlorite.

### 2.1.3.3 Arsenic

Most As occurs as Ni, Co and Fe arsenides and sulfarsenides. The main secondary As minerals are scorodite, annabergite and erythrite. The reactions involved in the oxidation of arsenide minerals are complex, and not completely understood. Starting with arsenopyrite, the first step in oxidation yields ferrous sulfate and arsenic acid. The oxidation of cobaltite and gersdorffite is similar. In acid environments the Fe, Co, Ni and As are mobile and may be completely removed. When carbonates are present and neutralization occurs, dissolved Fe may precipitate as limonite, or it may react with arsenic acid and precipitate as scorodite. Dissolved Co and Ni react with arsenates and yield erythrite and annabergite.

Under intense weathering, scorodite, erythrite and annabergite will be altered. Scorodite alters to limonite, freeing the As as arsenic acid and/or soluble arsenates which may be removed from the oxidation zone. Similar reactions will remove Ni and Co.

### 2.1.4 Structural Geology of the Cobalt Area

There are three sets of faults in the Cobalt area (see Figure 2.2). The largest set is a group of southeast trending faults of regional extent, which includes the Lake Temiskaming West Shore Fault, the McKenzie Fault east of Cobalt, and the Cross Lake Fault (Wilson 1986). Two sets of

faults occur locally, one trending northeast and one trending east-southeast. Brief Lake, Short Lake, Cobalt Lake and Mill Creek occur in a valley defined by the Cobalt Lake Fault, a northeast trending fault which dips 50° to 70° to the southeast. Sasaginaga Creek is in a valley defined by the Valley Fault, which dips 45° to 65° to the southeast (Wilson 1986). The east-southeast trending faults are smaller, vertically dipping faults (Wilson 1986). Faulting occurred prior to mineralization, and several of the faults are intersected by veins, although most are not mineralized (Knight 1922).

There are at least two references to structurally controlled groundwater flow in the historical literature. Whitehead (1920) stated that groundwater flow is "sluggish on the veins and joints and more swift upon the faults". When the Cross Lake Fault was intersected by mine workings, a "considerable amount of water" was encountered (Knight 1922).

#### 2.1.5 Surficial Geology of the Cobalt Area

Glacial deposits in the Cobalt area vary in thickness from a few centimetres to more than 90 m (Boyle *et al.* 1967). North of Cobalt there are glaciolacustrine deposits of bedded clays which extend as far south as Mileage 104. There are extensive glaciofluvial deposits of silt, sand and gravel in the Montreal River valley west of Cobalt (Roed 1979).

Boyle *et al.* (1967) determined the average compositions of 10 different soils, clays and glacial tills from non-mineralized areas around Cobalt (see Table 2.4). Samples were also collected within mineralized areas, including samples taken from material overlying veins. In the material from non-mineralized areas, low concentrations of As (2 to 5 ppm) were reported in 5 of the samples (no As was detected in the other 5), while 0.10 to 0.50 ppm Hg, 11 to 54 ppm Ni and 3 to 19 ppm Co were reported in all samples. Glacial clays have the highest metal concentrations, and in soils the metals are most highly concentrated in the A horizon. In mineralized areas the degree of enrichment of elements is always greater than 2, mostly greater than 10, and for some elements it is greater than 100 (Boyle and Dass 1971). The concentration ranges of As, Ni and Co in mineralized and non-mineralized areas are generalized as follows (Boyle *et al.* 1967):

- As: mineralized: in soils on till, A horizons are enriched, and can contain over 400 ppm As. Soils on glacial clay are less enriched, except in areas downslope from veins, where downslope drainage occurs. non-mineralized: soils and glacial material contain small amounts of As. A horizons are generally enriched in As compared to the B and C horizons.
- Ni: mineralized: soils on till are enriched in Ni. Generally more enriched in the A horizon, but concentrations up to 500 ppm have been reported in the B horizon. non-mineralized: soils and glacial material contain relatively small amounts of Ni.
- **Co:** mineralized: in soils on till, A horizons can contain up to 500 ppm, and the B and C horizons are less enriched. Soils on glacial clay, and the clay are not enriched. Generally, Co is more enriched than Ni. non-mineralized: soils and glacial material contain relatively small amounts of Co.


Soil Type	Pb	Zn	Cu	As	Sb	Mo	Ag	Ni	Co	Bi	Mn	Hg
soil on till, A horizon	10	33	16	2	3	<1	0.5	30	11	<0.5	572	0.20
soil on till, B horizon	12	30	15	<2	<2	<1	<0.5	35	13	<0.5	505	0.11
till	10	30	16	2	<2	<1	< 0.5	35	10	< 0.5	500	0.20
soil on sand & gravel, A horizon	5	7	4	<2	<2	<1	<0.5	11	3	<0.5	400	0.20
soil on sand & gravel, A horizon	25	60	7	<5	2	1	<0.5	25	10	<0.5	500	0.50
soil on sand & gravel, B horizon	5	27	5	<2	<2	<1	<0.5	20	10	<0.5	600	0.30
sand & gravel	5	18	9	<2	<2	<1	< 0.5	27	15	0.5	500	0.10
soil on clay, A horizon	14	131	41	5	2	<1	<0.5	46	15	<0.5	490	0.20
soil on clay, B horizon	12	106	33	2	1	<1	<0.5	46	17	<0.5	590	0.14
clay	13	90	34	2	1	<1	< 0.5	54	19	< 0.5	880	0.11

Table 2.4:Metal concentrations in tills and soils (after Boyle *et al.* 1967). All<br/>concentrations in parts per million

# 2.2 The History and Extent of Tailings Deposits in the Cobalt Area

#### 2.2.1 Ore Milling and Refining Processes

An understanding of the milling and refining processes used in Cobalt is important to understanding the nature of the tailings and other mine wastes in the area. Milling techniques are summarized here, and the history of the discovery and development of the deposits, as well as details of the milling techniques are described in Appendix 2.

From 1904 to 1906 ore from Cobalt was hand sorted and high grade ore was shipped elsewhere for processing. The only mine waste was waste rock (Baldwin and Dunn 1988). Gravity concentration mills were introduced in 1907 (Murphy 1977). In these mills, an ore concentrate was produced by the mechanical sorting of crushed ore. The concentrates were shipped elsewhere for refining (Reid *et al.* 1922). The waste product of this milling was powdered rock, called tailings, which often contained several ounces per ton Ag, as well as As, Co, Ni, Hg and other metals occurring in the ore (Barnes 1986).

In 1909 the first cyanide mill was put into operation. In the cyanide process ground ore was

mixed with a solution of KCN which dissolved the Ag. Powdered Al was then added, causing the Ag to precipitate. The precipitate was melted down, yielding a Ag bullion (Reid *et al.* 1922). The tailings from the cyanide treatment, which included cyanide complexed with Ni and Co, were discarded.

During World War I, many mills switched to flotation separation. In this process ore was ground in a mixture of creosote, pine oil and coal tar. The emulsified ore was agitated in flotation cells, causing the concentrate to float, and the waste to sink. The concentrates were shipped to smelters elsewhere for refining. The waste products included waste water and the tailings, which consisted of oil coated mineral grains (Reid *et al.* 1922).

The highest grade ores from Cobalt presented unique problems for milling. In 1911 the Nipissing high grade mill (NHGM) was brought into operation. In this mill high grade ore was ground in Hg and KCN (Reid *et al.* 1922). After grinding, 98% of the Ag was amalgamated with Hg. The amalgam was refined in furnaces to produce a final Ag bullion (Reid *et al.* 1922).

During the operation of the NHGM attempts were made to reduce the Hg losses in gas from the furnaces. Initially, the gases were passed through water cooled pipes, causing some of the Hg vapour to condense. Later, a bag house was added, in which the gases were passed through cloth bags, trapping particulates which consisted of As, Sb, Ni, Co, Bi, Hg and Ag. The proportion of particulates collected by the bag house is not known (Reid *et al.* 1922). That material which was collected was resmelted.

By the early 1930s, there was little mining activity left in Cobalt. However, during and after World War II, activity resumed. Most post-war mills were flotation mills, while those reprocessing tailings were cyanide mills.

### 2.2.2 An Overview of Tailings Deposits in the Cobalt Area

There are a large number of tailings deposits in the Farr Creek drainage basin, on land and in lakes and streams (see Figure 2.3). This section briefly describes deposits relevant to the current study. Detailed descriptions of all tailings deposits in the Cobalt area are given in Appendix 3. This section, and Appendix 3, draws on the work of Pat Anderson, who worked for the Ontario Ministry of Northern Development and Mines at the Cobalt Resident Geologist's Office in the mid 1980s. Her research was not published, but is still present in the Cobalt office.

### 2.2.2.1 Chambers-Ferland Tailings

The Chambers-Ferland property is near the confluence of Sasaginaga Creek and Mill Creek. Tailings from the Coniagas, Tretheway and Hudson Bay mines, as well as mines around Cobalt Lake and Mill Creek have migrated to this property.



Anderson (1985) estimated that more than 200,000 tons of tailings have accumulated on this property. Raw sewage from the town is discharged into Sasaginaga Creek and flows through this area (see Plate 2.1).

## 2.2.2.2 Nipissing Tailings

Tailings from the Nipissing low grade mill (NLGM), which used cyanide, were deposited in a depression about 400 m by 150 m in size ( $60,000 \text{ m}^2$ ), north of the mill (see Figure 2.4 and Plate 2.2). Three containment dams were built, but all have failed and a considerable quantity of the tailings have migrated into Mill Creek. It is not clear from previous work where the high grade mill (NHGM) tailings were deposited. In the summer of 1991, a small tailings deposit about 100 m by 25 m in size, downhill from the NHGM, was identified as the NHGM tailings. The tailings are contained by a concrete dam which has a culvert at the base of it, and a considerable amount of tailings have been removed by erosion.

## 2.2.2.3 Cobalt Lake Tailings

Between 1907 and 1969 tailings from mills using cyanide, Hg and flotation were deposited in Cobalt Lake (Anderson 1985). From 1914 to 1932, the lake was drained and tailings were removed and reprocessed. The south end of the lake was drained in 1951 to reprocess tailings, and new tailings were deposited in the north end of the lake. The south end was drained again in 1966 and tailings were removed for reprocessing. New tailings were deposited in the north end of the lake (Anderson 1985). Hawley (1977) estimated that there are more than 300,000 tons of tailings in the lake, with an average thickness of 10 to 11.5 m (see Plate 2.3).

### 2.2.2.4 Cart Lake Tailings

Between 1966 and 1983 the Silverfields mill deposited 1.2 million tons of tailings in Cart Lake, almost completely filling it (Anderson, 1985)(see Figure 2.5 and Plate 2.4). The tailings have migrated north into a marshy area between Cart Lake and Peterson Lake. There is a problem with wind-borne tailings, and tailings are encroaching into the adjacent forest.

# 2.2.2.5 Crosswise Lake Tailings

Tailings were deposited in the north end of Crosswise Lake from 1908 to 1970. A comparison of the current lake dimensions with those shown on Miller's 1903 map suggest that the lake is 200 to 300 m shorter than it was prior to mining. The northern portion of the tailings are marshy. Miller's 1903 map shows that the area currently covered by tailings was marshy prior to mining. At the north end of this marsh is a small water level control dam (see Plate 2.4)



**Note:** Taken in May 1992. Sasaginaga Creek is seen on the left side of the photograph, and the sewage outfall into the creek is about 750 m upstream of point 1. The confluence of Sasaginaga Creek and Mill Creek is downstream from a large open area (2). Mill Creek (3) can be seen on the right side of the photo.

Photo by the author

Chambers-Ferland tailings, looking north

Plate 2.1





**Note:** Taken in May 1992. In the foreground, the remains of a mine headframe can be seen (1). At this location, tailings now fill the trench worked from this headframe, and the depth of tailings is not known. It is not known when this headframe ceased operations. Three dams were built to contain the tailings. Dam #1 can be seen (2). Dam #2 and dam #3 are difficult to see in this photograph, but they are at locations 3 and 4. Note the water on the surface of the tailings at location 5, and the stream flowing along the eastern edge of the tailings (6). A stream also flows along the western edge of the tailings (7). The streams discharge from the tailings at location 3.

Nipissing Low Grade Mill tailings, looking northwest

Photo by the author

Plate 2.2



Plate 2.3a: Cobalt Lake in 1967. The south end of the lake was drained to remove tailings for reprocessing. New tailings from reprocessing were deposited in the north end of the lake. Some of these tailings were used to build a park which now bisects the lake. Photo after OWRC (1967).



Plate 2.3b: Cobalt Lake, taken looking north from the south shore of the lake in May 1992. The park is difficult to see in the photograph, but it is just north of location 1. Photo by the author.

Cobalt Lake looking north in 1967 and 1992

Plate 2.3





Cart Lake tailings, looking south, taken in June 1991. It is about 900m from the point where this photo was taken, to the south end of the tailings. The headframe on the left side of the photo (1) marks the location of the Silverfields mill, which produced these tailings. Photo by the author.

Cart Lake tailings

Plate 2.4a



The Crosswise Lake tailings, looking north, taken in May, 1991. Peterson Creek can be seen flowing across the tailings (1) and Mill Creek can also be seen (2). The northern limit of tailings migration is at 3, about 2.4 km from the location where the photo was taken. Photo by the author.

Crosswise Lake tailings

Plate 2.4b

# 2.3 Summary of Previous Environmental Research in the Cobalt Area

A number of previous workers have conducted environmental research in the Cobalt area. Details of their results are given in Appendix 4, and a summary of the results is presented in this section.

### 2.3.1 Tailings Composition

In 1980 the Ontario Ministry of the Environment published a report on the chemical characteristics of tailings in Ontario, which included data for samples from a number of tailings deposits in the Cobalt area (see Table 2.5). The actual locations on the tailings from which these samples were collected are not known. There is a wide range in composition for tailings in the area. Large amounts of As, Hg, Co, Ni, and Sb occur in the tailings.

### 2.3.2 Surface Water Contamination

A report on surface water contamination in the Cobalt area was written by the Ontario Water Resources Commission (OWRC) in 1967. This report presented data on pH, suspended and dissolved solids, total dissolved As, and Co, and Ni concentrations. The locations of sampling sites are given in Figure 2.6, and analytical data are presented in Table 2.6.

Sasaginaga Lake, west of Cobalt, is the town's drinking water reservoir. The lake had no mines on it, and the only tailings in it are near the outlet to Sasaginaga Creek. The lake was not sampled by the OWRC, but 5 samples collected by the Ontario Ministry of the Environment (MOE 1977) had mean As and Hg concentrations of 0.003 ppm and 0.18 ppb, respectively. Sasaginaga Creek, which drains Sasaginaga Lake, was not sampled by the OWRC.

Samples were collected from Cobalt Lake by the OWRC, and the MOE collected monthly samples from the lake between January 1988 and March 1990, and all of these samples contain high As concentrations (unpublished data, obtained from the MOE office in North Bay, see Table 2.6).

Cobalt Lake is drained by Mill Creek, which flows north from Cobalt Lake to the Chambers-Ferland tailings, where it joins Sasaginaga Creek. The stream is contaminated by tailings from Cobalt Lake and the NLGM (OWRC 1967). From the confluence with Sasaginaga Creek, Mill Creek flows to the east and joins Farr Creek on the Crosswise Lake tailings. A water sample from Mill Creek contained 0.96 ppm dissolved As (OWRC 1967).

Southeast of Cobalt Lake is Cart Lake. Water from Cart Lake was not analysed by the OWRC, but discharge from the Silverfields Mill into the lake was sampled. Cart Lake drains north to Peterson Lake via a short stream. Samples from this stream contained a mean dissolved As concentration of 0.63 ppm (OWRC 1967), and the As concentration in a sample from Peterson Lake was lower (OWRC 1967). The MOE (1991) states that there are restrictions on the consumption fish from the lake due to Hg contamination.

Element (ppm)	Buffalo	Coniagas	Tretheway	Hudson Bay	NLGM	Cobalt Lake Mine*	Cobalt Lake Baseball**
As	6800	594	652	952	11700	11700	41
Al	60400	47200	50000	46000	40400	39300	47400
Sb	468	99	93	148	445	531	229
Fe	56700	43500	40900	41100	51200	60400	47700
Mn	680	400	360	401	624	516	455
Cl	<10	<10	<10	<10	<10	10	10
Mg	13200	8670	14400	15000	7730	6350	6340
Ca	9900	4670	4190	3310	4260	2880	5940
Hg	3.31	0.72	0.29	0.34	16.6	2.54	0.58
Na	23600	38900	31200	33100	25400	17500	63600
CO <sub>3</sub>	9000	<1000	<1000	<1000	7200	5400	2000
$SO_4$	11100	40300	6010	11500	9700	6170	7790
Cu	699	419	175	650	813	1390	40
Pb	961	19	33	107	91	75	11
Zn	913	107	282	361	545	347	99
Мо	<0.6	<0.6	<0.6	<0.6	<0.6	2.2	<0.6
Co	490	95	142	265	2100	4060	80
Ni	278	76	63	52	10000	2070	64
Cd	2.9	1.1	1.9	1.9	2.4	0.9	0.6
Cr	155	263	360	110	89	119	119
Bi	<10	12	15	20	90	<10	<10
Ba	42	27	42	50	14	30	35
Sr	82	77	93	36	67	27	61
V	971	195	156	160	159	142	142

**Table 2.5:**Trace element concentrations in tailings in the Cobalt area (after Hawley 1980)

Author's notes on sampling locations:

\* It is not clear where this sample was collected since there are no on land tailings in this area. The sample may have been collected from tailings in the lake.

\*\* Sample was likely collected from the playing surface of the baseball diamond at the Cobalt Lion's Club Park

## Table 2.5 (continued):

Element (ppm)	Right of Way Mine***	LaRose	Sasaginaga Creek****	Nova Scotia	Crosswise Lake, S.W.	Crosswise Lake, S.E.
As	4700	1040	718	8330	5120	7110
Al	36200	50400	53800	46000	42700	30900
Sb	234	19	143	1590	10	176
Fe	46900	49100	41900	46400	42700	56500
Mn	566	450	369	509	490	592
Cl	10	<10	<10	<10	17	17
Mg	6740	106000	5720	9700	7680	7370
Ca	2832	3260	2420	10400	4030	3200
Hg	8.36	0.61	0.42	0.77	2.54	2.37
Na	23900	23700	68900	2500	24400	21000
CO <sub>3</sub>	2000	3600	2500	9150	9000	9000
$SO_4$	15700	13600	10000	2980	12600	20100
Cu	693	159	262	210	192	281
Pb	66	1130	370	267	69	314
Zn	342	801	194	200	346	233
Мо	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Со	1490	173	84	8	286	566
Ni	862	103	88	182	100	88
Cd	1.2	3.2	1.4	1.6	1.2	1.2
Cr	107	99	116	130	106	38
Bi	<10	<10	<10	<10	<10	53
Ba	25	63	20	57	38	29
Sr	57	46	61	58	49	55
V	167	198	116	120	192	222

Trace element concentrations in tailings in the Cobalt area (after Hawley 1980)

Author's notes on sampling locations:

\*\*\* Sample of tailings which have migrated to this site, probably from the NLGM tailings. The Right of Way Mine did not produce any tailings

\*\*\*\* Sampling location is not known. Possibly collected within the tailings on the Chamber-Ferland property, or upstream of these tailings



Sample Location	Total As (ppm)	Dissolved As (ppm)	Co (ppm)	Ni (ppm)	Reference
Sasaginaga Lake	0.004	na	na	na	MOE 1977
	0.003	na	na	< 0.01	
	0.002	na	na	0.05	
	0.004	na	na	0.01	
Flow from Short Lake to Cobalt Lake	0.00	0.00	0.0	0.00	OWRC 1967
Agnico tailings mill discharge	98.50	2.48	na	na	OWRC 1967
Cobalt Lake, 1988 to 1990	mean	na	na	mean	MOE, unpublished data
	0.937			0.038	
	st.dev.			st.dev.	
	0.302			0.029	
Flow from Cobalt Lake to Mill	2.4	0.59	0.2	0.19	OWRC 1967
Creek	1.38	1.38	na	na	
	4.55	2.02	na	na	
	0.00	0.00	na	na	
Mill Creek at Highway 11B	3.42	0.96	na	na	OWRC 1967
Silverfields Mine discharge	1.92	0.32	na	na	OWRC 1967
Flow from Cart Lake to Peterson	1.23	0.31	0.1	0.06	OWRC 1967
Lake	0.96	0.96	na	na	
Peterson Lake, N.E. corner	0.47	0.32	na	na	OWRC 1967
	0.53	na	0.002	0.018	Boyle et al. 1967
Peterson Creek	0.47	na	na	0.017	Boyle et al. 1967
Peterson Creek at confluence with Farr Creek	1.81	0.25	0.2	0.11	OWRC 1967
Crosswise Lake at Deer Horn Mine	0.80	0.06	na	na	OWRC 1967
Tailings from Deer Horn Mill to	27.25	0.15	1.0	0.87	OWRC 1967
Crosswise Lake	13.50	0.13			
Flow from Crosswise Lake to Farr Creek	2.38	0.14	0.15	0.14	OWRC 1967
Farr Creek at bridge	11.8	0.59	na	na	OWRC 1967
Farr Creek S. of North Cobalt	0.48	0.48	0.2	0.07	OWRC 1967
Farr Creek downstream from	mean	na	na	mean	MOE, unpublished data
Crosswise Lake, 1988 to 1990	0.633			0.024	
	st.dev.			st.dev.	
	0.731			0.007	
Farr Creek in North Cobalt	2.68	0.80	na	na	OWRC 1967
Farr Creek at Lake Temiskaming	0.53	0.53	0.1	0.06	OWRC 1967

**Table 2.6:** Arsenic, nickel and cobalt concentrations in surface water in the Farr Creek Basin

Peterson Lake drains to Farr Creek via Peterson Creek, which was sampled by the OWRC, and also by Boyle *et al.* 1967.

East of Peterson Lake is Crosswise Lake, which contains a lower As concentration (OWRC 1967). The MOE (1991) states that the consumption of fish from the lake is restricted because of Hg contamination. Crosswise Lake is drained by Farr Creek, which flows north for 2 km across tailings. Peterson Creek joins Farr Creek and further downstream, Mill Creek joins Farr Creek. The creek flows across tailings until it reaches a point just south of North Cobalt. From that point to the mouth of the creek at Lake Temiskaming the creek flows across bedrock (OWRC 1967). At the north end of the tailings there is a small water control dam, and the average annual discharge at this dam is 21,100,000 m<sup>3</sup> (Environment Canada 1992).

The OWRC collected samples at 5 points along Farr Creek. The As concentrations increase as Farr Creek flows across the tailings and is joined by Peterson Creek and Mill Creek, and the concentration increases further in North Cobalt, downstream from the tailings. Hawley (1977) estimated that Farr Creek discharges 30,850 kg of As into Lake Temiskaming each year.

From 1988 to 1990, the MOE collected monthly samples from Farr Creek downstream from Crosswise Lake (unpublished data obtained from the MOE office in North Bay). The mean As concentration in these samples was 0.633 ppm (see Table 2.6). In Figure 2.7, As concentrations for this two year period are plotted against average monthly water discharges. There is a correlation between low water flows in July through September, and high As concentrations during the same period.

### 2.3.3 Groundwater Contamination

Two reports have been published which document the occurrence of contaminated groundwaters in the Cobalt area. The first was the Geological Survey of Canada Paper 67-35, written by R.W. Boyle and others in 1967, and the second report was produced by the MOE in 1977.

Boyle *et al.* (1967) sampled water from 244 locations, 38 of which were within the current study area (see Figure 2.8). Locations included wells, springs, diamond drill holes, underground mines and surface water. The results of analyses are included in Appendix 4. Arsenic was found in a large number of the samples analysed. The most notable As occurrences are (numbers correspond to sample numbers in Boyle, *et al.* (1967)):

- **#1)** Spring water from the Coleman conglomerate. Spring is near the confluence of the west and south branches of Sasaginaga Creek. Sample contained 1.16 ppm As and 96 ppb Co.
- **#84)** Water from a diamond drill hole in the Coleman conglomerate. The hole is beside Lake Temiskaming, within the Bucke Park campground, owned by Bucke Township, and at the time of sampling the water was used for consumption. The water contains 9.10 ppm As, 360 ppb Ni and 700 ppb Co.

**S-9)** Collected underground at the Silverfields Mine. Water was taken from a fault zone in the Coleman greywacke and contains 8.04 ppm As.

The MOE sampled 375 private and 5 communal water supplies in several townships, including Coleman Township and Bucke Township (see Figure 2.9). Arsenic was detected in 100 wells, of which 14 had As concentrations in excess of 0.01 ppm and 3 had an As concentration in excess of 0.05 ppm, the maximum allowable As concentration for drinking water (CCREM 1987).

One of the areas of concern identified in this study was the community of Mileage 104, about 3 km northeast of Cobalt. Of 17 wells sampled in this area, 13 had detectable As, with levels ranging from 0.001 ppm to 0.010 ppm. Also of concern was West Cobalt, about 2 km southwest of Cobalt. Six wells were tested in this area, 5 of which had measurable As, ranging from 0.001 ppm to 0.93 ppm. A third area of concern is the area east of North Cobalt, along Highway 567. Of 14 samples collected, 8 contained As, with concentrations ranging from 0.001 ppm to 0.08 ppm.

The authors of this report concluded that there is a link between contaminated wells and the Coleman Formation.

**Figure 2.7:** Mean monthly water flow versus arsenic concentration in Farr Creek at the water level control dam



• Water Flow + As Concentration





# 2.4 Summary

Silver occurs in the Cobalt area in veins composed primarily of calcite, dolomite, quartz and chlorite. Numerous As, Ni and Co bearing minerals occur in the veins and in the rocks in which the veins occur. When exposed to oxidizing conditions, the As, Ni and Co bearing minerals alter to secondary minerals, particularly erythrite, annabergite, scorodite, limonite and wad. Secondary sulfates and clay minerals are also produced. These secondary minerals are unstable, and under further oxidation they break down, releasing their components.

There are numerous faults in the area, and several of the faults are intersected by veins. At least two references suggest that groundwater flow rates are higher in the faults than in the veins and fractures. Soils in mineralized areas are enriched in As and heavy metals, compared to soils in non-mineralized areas, and soils are most enriched in the immediate vicinity of mineralized veins.

As a result of the high As content of the vein material, mine tailings in the area contain high levels of As. During the milling of ore, many mills used Hg or cyanide to separate and purify the Ag, and as a result Hg occurs in tailings, and cyanide may occur. Some of the most important tailings deposits in the area are the Chambers-Ferland tailings, the Nipissing low grade mill tailings, the Nipissing high grade mill tailings, and the Cart Lake tailings. Tailings were also deposited in Cobalt Lake and Crosswise Lake.

Many of the water bodies in the area are contaminated with As and metals, particularly those which contain tailings or are adjacent to tailings deposits, such as Cobalt Lake and Mill Creek. All of the water bodies within the study area drain into Farr Creek, which has elevated levels of As. Farr Creek drains to Lake Temiskaming, carrying about 30,000 kg of As to that lake each year.

The groundwaters of the area also contain As and metals, particularly Ni and Co. Groundwater sampled at several different locations around Cobalt contains in excess of 0.010 ppm As. High As concentrations occur most frequently in groundwaters coming from the Coleman Member rocks. Arsenic occurs in some well water in the area, particularly in West Cobalt, Mileage 104 and North Cobalt, but in all but a few cases the As concentration is lower than the maximum allowable concentration of 0.05 ppm. The most serious incidence of contaminated well water was the water supply used at Bucke Park in North Cobalt. This water, which was coming from a diamond drill hole in the Cobalt Group, had an As concentration of 9.10 ppm in 1967.

# **3** Geochemistry and Mineralogy of Tailings and other Solid Materials from the Cobalt Area

# 3.1 Introduction

The sampling of tailings and other solid materials was one of the key aspects of the current study. This sampling program had several goals:

- 1. To examine in greater detail the Nipissing low grade mill tailings. In particular, to determine the thickness of the tailings, and to examine the mineralogy and geochemistry of the tailings and surface crusts.
- 2. To examine the mineralogy and geochemistry of the Cart Lake tailings, since these tailings are representative of most tailings deposited in the area after 1950.
- 3. To sample the Nipissing high grade mill tailings, which had not been sampled prior to this study.
- 4. To sample concrete from mill foundations in the area, particularly the Nipissing low grade and high grade mill foundations. This sampling was conducted because of concern about possible Hg contamination.
- 5. To sample other solid materials, such as smelter slag, which may also contain elevated levels of As and metals, and thus may also pose a health risk as well as being a potential source of environmental contamination.
- 6. To identify possible health risks for people who use the tailings for recreational purposes, and who live adjacent to tailings deposits.
- 7. To conduct leaching experiments with tailings, to determine which elements are leached from the tailings, and approximate the rates of mobilization for those elements.

# 3.2 Nipissing Low Grade Mill Tailings Thickness Survey

Two methods were used to determine the thickness of the Nipissing low grade mill (NLGM) tailings; hand augering and drilling. The hand auger used was about 4 cm in diameter, and could penetrate up to 1 m of tailings. The drill used was a gas powered 10 cm diameter auger which could penetrate up to 3.6 m of tailings. The hand auger was used to determine the thickness of thin tailings at a number of locations. The drill was used during the installation of piezometers (see Chapter 4), and logs were kept for each of 56 holes drilled. The logs included the depth of each hole, and the depth to underlying material if any was encountered.

A surveyors level was used to determine the former height of dam #1 on the NLGM tailings, in

order to estimate the amount of material removed by erosion.

# 3.3 Solid Materials Sampling Program

Tailings samples, 1 to 2 kg in size, were collected using a steel garden trowel (see Figures 3.1, 3.2 and 3.3 for sampling locations). All samples were stored at room temperature in plastic bags. Core samples were collected by driving ABS tubing into the tailings using a sledge hammer. After removal from the tailings, the tubes were sealed with rubber stoppers and stored at room temperature.

Several types of surface crusts occur on the NLGM tailings, and samples of each of these crust types were collected, along with samples of the tailings from below the crust layer. In addition, samples were collected from three different depths in a small trench, to sample material from deeper in the tailings (see Figure 3.2). At the Cart Lake tailings, surface crusts are homogenous in appearance, and only limited sampling of these crusts was conducted (see Figure 3.3). The crusts observed on the NLGM tailings and the Cart Lake tailings are similar in colour and texture to those occurring on other tailings deposits, so the samples collected are considered to be mineralogically representative of crust types throughout the area.

At Cart Lake, in 1979, top soil was added to a  $1520 \text{ m}^2$  area of tailings, and vegetation was planted (see Figure 3.3)(Anderson, 1985). This vegetation is still growing, and considerable soil development has occurred, as there is now a strong soil profile. A sample from each of the soil horizons was collected.

Concrete samples, 1 to 2 kg in size, were collected from the foundations of the NLGM, NHGM, and the McKinley-Darragh mill, to determine As and heavy metal content, particularly Hg (see Figure 3.1). These mills were selected because different milling processes were used at each: the NHGM used Hg amalgamation and cyanide, the NLGM used cyanide, and the McKinley-Darragh mill used flotation separation (Anderson, 1985). Since these were the main milling methods used in Cobalt prior to 1950, these foundations may be representative of mill foundations for that period.

Slag is a waste product from the final stage in the refining of silver and other metals. Slag samples 1 to 2 kg in size were collected from the NLGM and NHGM (see Figure 3.1). A sample identified as NHGM "stuff" was collected. A small pile of this sandy, reddish brown material ( $\approx 9 \text{ m}^3$ ) is at the NHGM. The exterior of the pile is covered with erythrite. It is not clear what stage of the milling this material came from, hence it is called "stuff" (see Figure 3.1).

Five large samples were collected from the following locations: NLGM tailings, NHGM tailings, Cart Lake tailings, Peterson Lake Road soil - A horizon, and Peterson Lake Road glacial till (see Figure 3.1). These samples were collected using a clean metal shovel, and stored in pails lined with plastic bags.







See Appendix 6 for descriptions of all solid phase samples collected. Sample preparation procedures are described in Appendix 11.

# 3.4 Laboratory Leaching Studies on Tailings, Glacial Till and Soil

To learn more about the rates of mobilization of contaminants from tailings, leaching studies were conducted on samples of tailings, glacial till and soil. Samples were leached with solutions at two different pHs, one to simulate natural rainwater (pH = 5.6), and the other to simulate acid rain (pH = 4.7).

## 3.4.1 Precipitation Monitoring Program

It is possible that Cobalt may receive acid rain, which may affect the rates of mobilization of metals from tailings and other materials. Acid precipitation is defined as precipitation with a pH lower than 5.6. To monitor the pH of precipitation received in Cobalt, precipitation samples were collected using a brass rain gauge with a plastic liner. Upon return to Ottawa, the pH of each sample was measured using a Corning 106 pH meter.

# 3.4.2 Leaching Experiment Design

To conduct leaching experiments, large samples from the NLGM and NHGM tailings and the Cart Lake tailings were used, as well as glacial till and soil A horizon samples from the Peterson Lake Road, to compare tailings with natural materials (see Figure 3.1). In the laboratory, two sets of samples were leached, one with distilled water, assumed to have the same pH as natural rain, and the other with a laboratory prepared solution of "acid rain" with a pH of 4.7. Leachate water was analysed to compare the As and metal contents of the samples leached with "natural rain" and with "acid rain".

Leaching experiments were performed using the following procedure:

- 1. Ten leaching vessels were prepared by lining 11 cm diameter, ceramic Buchner funnels with Whatman #1 qualitative filter paper, and adding 300 g of oven dried sample. The funnels were placed on top of pyrex Erlenmeyer flasks to collect the leachate.
- 2. An "acid rain" solution was prepared by adding H<sub>2</sub>SO<sub>4</sub> to clean, fresh snow collected on the Carleton University campus. The pH after acidification was 4.7. Some NaOH was added to compensate for an excess addition of H<sub>2</sub>SO<sub>4</sub>.
- 3. Leaching experiments were performed by adding approximately 200 ml of water to the leaching vessels each day for 5 days, using a spray bottle to apply the water evenly and prevent channelling of water flow. Between additions of water, the tops of the funnels were sealed with plastic wrap to limit evaporation and prevent contamination. The total volume of water added was about 1 L, an amount required to complete all analyses.

Based on a comparison with precipitation data obtained from the Earlton Airport, about 40 km north of Cobalt, this volume is equivalent to about 0.65 years worth of precipitation.

- 4. After leaching, two 250 ml leachate samples were collected from each flask, filtered with 45 μm millipore filter paper, and sent to Bondar-Clegg & Company Ltd. in Ottawa for analysis. The pH, Eh, conductivity and alkalinity of each water sample were measured in the laboratory on the remaining leachate.
- 5. The experiment was then repeated with the same samples. During the second run, distilled water acidified to a pH of 4.7 was used instead of acidified snow.

# 3.5 Results

### 3.5.1 Thickness of the Nipissing Low Grade Mill Tailings

South of dam #1, the NLGM tailings are very thin, except in an old mine working at the southeast corner. A series of holes was drilled along an east west line across the tailings in this area, and several holes were drilled using a hand auger. The tailings range in thickness from about 15 to 85 cm (see Figure 3.4).

In the area between dam #1 and dam #2 the tailings are much thicker. At piezometer number P26 the tailings are greater than 3.6 m in thickness, and tailings thicker than 2.9 m were encountered at several locations in the central portion of the tailings. Tailings are thinner near the edges of the deposit. At P30, near the western edge, the tailings are 1.7 m thick. In the stream bed along the eastern edge of the deposit, tailings range in thickness from 2.6 m at P10 to 0.6 m at P15, closest to the edge of the tailings. The tailings are also thin (0.5 m) at P35, immediately south of dam #2.

In the area north of dam #2, tailings are more than 2.7 m thick. In the northeastern portion of the tailings, the tailings thickness ranges from 1.5 to 1.8 m.

A photograph taken looking south towards the NLGM in the summer of 1934 shows the tailings. In Plate 3.1, this photograph is compared with a photograph taken from nearly the same location in May, 1992. From a comparison of these two photographs it is clear that dam #1 has deteriorated considerably, and a significant amount of tailings has been removed from the area south of dam #1. Features between dam #1 and dam #2 are not as clear, but in this area, too, it is evident that tailings have been removed.

In June 1991, a levelling survey was conducted along dam #1. The highest point on the existing dam is 314.21 m.a.s.l.. Remnants of wood from the dam can be found moving up the hill east of the tailings, so the level to which the dam previously extended can be estimated. The highest remnants of the dam were found at an elevation of 316.31 m.a.s.l.. Thus, at least 2.1 m of the dam has been removed. From the old photograph in Plate 3.1, it is evident that the tailings





The Nipissing low grade mill tailings, looking south towards the mill foundation (1). Plate 3.1a was taken in the early summer of 1933 or 1934 (photo courtesy of the Cobalt Mining Museum). Plate 3.1b was taken from nearly the same location in May, 1992 (photo by the author). Dam #1 is seen in both photographs, and a comparison of the two photos shows how much the condition of the dam has deteriorated. In Plate 3.1a, tailings can be seen at the edge of the dam (2) which in Plate 3.1b much of the dam at the same location is gone. A comparison of the level of the tailings with a ridge along the eastern edge of the tailings (3) provides further evidence of tailings erosion. Just north of dam #1m a boulder on a rock outcrop (4) provides a reference point to show that tailings erosion has occurred

north of dam #1. Comparisons of the level of tailings with a ridge along the west side of the deposit (5), and an outcrop at the base of dam #1 (6), provide further evidence of tailings erosion north of dam #1. North of dam #2 (7, difficult to see in Plate 3.1b) there is no evidence of extensive tailings erosion.

Nipissing Low Grade Mill tailings, looking south, May 1992

Plate 3.1b



reached the top of the dam. Near the highest remnants of the dam, small amounts of residual tailings occur in bedrock depressions. These observations, and the fact that tailings were deposited as a slurry, provide evidence that the tailings south of dam #1 were formerly level with the top of the dam.

Using Anderson's (1985) map of the NLGM tailings, and a topographic map, it is possible to estimate the amount of tailings remaining south of dam #1, and the amount of tailings that have been removed. The current surface area of the tailings south of dam #1 is about 18,300 m<sup>2</sup>. Assuming an average thickness of 0.75 m, the volume of tailings present is 13,750 m<sup>3</sup>. Assuming a tailings density of 2.7 g/cm<sup>3</sup>, it is estimated that there are 37,140 tonnes of tailings south of dam #1. Assuming the original dam reached a height of 316.5 m.a.s.l. and the tailings were level with the top of the dam, the surface area covered by the tailings would have been 21,200 m<sup>2</sup>. Assuming a maximum tailings thickness of 3 m, the volume of tailings in this area is estimated to have been 59,200 m<sup>3</sup>, with a mass of 160,000 tonnes. Thus, according to this estimate, about 123,000 tonnes, or about 75% of the tailings deposited south of dam #1, have been removed by erosion.

In the old photograph in Plate 3.1, the area between dam #1 and dam #2 appears much flatter than it is currently. It is estimated that the tailings were level with the current location of P28, the highest piezometer north of dam #1, with an elevation of 310.21 m.a.s.l.. Piezometer P26, 20 m east of P28, has an elevation of 309.16 m.a.s.l., and the lowest piezometer in the area between dam #1 and dam #2 is P14, with an elevation of 307.74 m.a.s.l.. In an area just north of dam #1, residual tailings occur on the slopes east of the tailings. Thus, erosion has removed a considerable amount of tailings in the area between dam #1 and dam #2. Using an assumed mean tailings thickness of 2.5 m through most of this area, and an assumed mean thickness of 1 m in the area along the western edge of the deposit, it is estimated that there are currently about 123,000 tonnes of tailings in the area between dam #1 and dam #2. Assuming that 1.5 m of tailings have been removed by erosion, it is estimated that 110,000 tonnes of tailings have been removed.

On the basis of a comparison of the photographs in Plate 3.1, and field observations, it is apparent that little material has been removed from the area north of dam #2. It is estimated that there are 106,000 tonnes of tailings in this area.

Overall, there are estimated to be about 266,000 tonnes of tailings present in the NLGM tailings deposit, and it is estimated that 270,000 tonnes have been removed by erosion.

### 3.5.2 Tailings Stratigraphy

### 3.5.2.1 Nipissing Low Grade Mill Tailings

In the spring, the surface of the NLGM tailings is very wet, and the moisture content of the tailings is very high so that liquefaction will occur if the tailings are vibrated.

In the summer, the tailings surface becomes very hard and desiccated, and surface crusts form on

the tailings (see Plate 3.2). These crusts are water soluble, and are redissolved in heavy rains. South of dam #1, and in the area between dam #1 and dam #2, the crusts are white to light grey, hard and brittle. Different textures occur: some crusts are very thin (< 1 mm), and occur around desiccation cracks in the tailings surface; some crusts are thicker ( $\approx$  1 to 1.5 mm), and occur as flaky layers over large areas of tailings; and other crusts occur as scale like patches up to a few centimetres in diameter. North of dam #2, and just south of dam #2, in areas where the tailings surface is flatter, thicker (up to 1 cm) crusts occur which range in colour from light grey to orange to reddish brown. These crusts tend to have a powdery or blister like appearance, and they crumble when touched.

Three cores were collected from the NLGM tailings, and one trench was dug, in order to examine the stratigraphy of the top 1 m of the tailings (core logs are included in Appendix 6). In addition, the drill logs from the piezometer installations include some information on the tailings stratigraphy, as well as the nature of the underlying material, where holes were deep enough to penetrate this material.

The tailings are generally very fine grained, but some coarser grained tailings are present, and fragments of waste rock and slag are present near the surface of the tailings. The tailings are well laminated with only minor soft sediment deformation features. Much of the tailings are a brownish grey to greyish brown colour, but some zones of altered tailings are present, particularly in the upper 50 cm of the tailings. Alteration zones are present in all three cores and the trench, and the altered tailings were frequently observed in the cuttings from drill holes.

In the alteration zones the tailings are pale rusty to greenish in colour. The uppermost 10 cm of the tailings are generally unaltered, and below this unaltered zone the intensity of alteration is variable, with unaltered tailings grading into progressively more altered tailings with increasing depth within the alteration zone. Altered tailings may alternate with unaltered tailings within the uppermost 50 cm of the tailings. In the trench, the alteration zones in the top 25 cm were continuous across the face, a width of about 1.5 m (see Plate 3.3).

Below 25 cm alteration is discontinuous. In the trench, vug like structures occur down to the bottom of the trench, a depth of about 1 m (see Plate 3.4). These vugs are lined with rusty alteration material, likely limonite. Such vugs were not observed in any of the cores, but discontinuous streaks and patches of alteration were observed to a depth of 57 cm.

In one core, taken at the northeast end of the tailings deposit, at the edge of an area which is wet throughout the year, an extremely intense alteration zone occurs at a depth of 32 to 42 cm (see Plate 3.4). The top 1 cm of this zone is dark brown to black, and distinct, black grains or aggregates of grains are present. The next 9 cm of the alteration zone is an intense rust colour, with some scattered black grains, especially near the top and bottom of the zone. When the core was opened, this rusty material was gel like. The rusty material is limonite, while the black material is likely wad. In this core, only one small area of alteration was observed above this zone, and alteration below this zone was limited.



The Nipissing low grade mill tailings, looking north from the mill foundation. The light coloured areas on the tailings are surface crusts. Photo by the author.

NLGM tailings from mill foundation

Plate 3.2a



Altered tailings in a core collected near piezometer P26 in the Nipissing low grade mill tailings. The top of the core is to the left, and the rule is for scale only and does not indicate distance from the top of the core. Two areas of alteration are evident, in the mide section of the core (1) and at the bottom of the core (2). The small pebble in the core (3) is coated with a thin layer of erythrite. Photo by the author.

# Altered tailings in core from Nipissing low grade mill

Plate 3.2b




(b) Intensely altered tailings in a core taken near piezometer P51 at the Nipissing low grade mill tailings. The top of the core is to the left, and the ruler is for scale only. When the core was opened this material was gel-like. The colour suggests that the alteration material is composed primarily of limonite. At the top of the zone (1) the material is darker in colour. And small black blebs, likely composed of wad, occur in the limonite. Also note the less intense area of alteration further up in the core (2). Photo by the author.

Tailings alteration and tailings core, NLGM tailings

Plate 3.4

One core was collected just south of dam #2. The bottom 12 cm of this 76 cm core is predominantly dark grey to black organic-looking material, with some small rusty patches (see Plate 3.5). At 68 to 72 cm there is a piece of wood whose exterior surfaces are coated with a thin, bright orange layer of limonite. In one hole, drilled for the installation of a piezometer about 1.5 m south of dam #2 (P35), very close to the point where this core was collected, only about 45 cm of tailings were encountered. Below these tailings was 150 cm of dark brown, wet, cohesive organic muck. The organic material is strongly decomposed, but some small roots and seed cases are present. Similar material was found in the cuttings from the bottom 30 cm of holes drilled for the installation of a 2.8 m deep piezometer about 20 m north of dam #2 (P48) and for a 2 m piezometer about 70 m north of dam #2 (P37).

Ten holes were drilled to install piezometers along the eastern edge of the deposit, between dam #1 and dam #2 (P8 to P17). In 8 of these holes sand and gravel was encountered at the bottom of the holes. The hills immediately adjacent to the tailings were hydraulically stripped by crews from the Nipissing Mining Company, prior to the deposition of tailings in this area. It is possible that this sand and gravel was deposited from a stream created by this stripping. South of dam #1, sand and gravel were encountered in three holes, and in one of these holes (P20), the sand and gravel layer is underlain by organic soil. This occurrence of soil under the sand and gravel supports the hypothesis that the sand and gravel is of anthropogenic origin.

## 3.5.2.2 Nipissing High Grade Mill Tailings

One trench was dug in the NHGM tailings, and one core was collected. Like the NLGM tailings, these tailings are very fine grained. The tailings surface is dark grey in colour, with no surface crusts evident. The tailings are lighter in colour below the surface. The tailings are underlain by a layer of coarse sand to fine gravel.

After the opened cores had dried, some erythrite was observed on the core surfaces.

# 3.5.2.3 Cart Lake Tailings

The Cart Lake tailings are coarser grained than the NLGM tailings, and so the infiltration rate is high and the tailings surface is dry throughout the year, except very close to the lake. Crusts form on the tailings during the summer (see Plate 3.6). These crusts are white to light grey in colour, but they are much thicker than those occurring on the NLGM tailings (up to 5 cm). The crusts occur in patches up to several square metres in area.

Two trenches were dug in the Cart Lake tailings; one along the bank of the stream along the western edge of the deposit (see Plate 3.6), and the other in the vegetated area in the southeast portion of the deposit. In the trench along the stream bank, the top 30 cm of tailings are well laminated, with clay layers alternating with sandy layers. There is little evidence of alteration. Below this upper portion, the tailings are laminated, but are more uniform in grain size and colour.



Tailings core from the NLGM tailings



The Cart Lake tailings, looking northwest. The light coloured areas are surface crusts. Note the dust blowing across the tailings (1). The vegetated area in the foreground (2) is the area in which a trench was dug to examine the soil horizons (see Plate 3.7). Photo by the author.



A trench dug in the Cart Lake tailings, near the western edge of the deposit. Note the well developed layering. The lighter coloured areas are finer grained. Photo by the author

Cart Lake tailings and trench detail

Plate 3.6

Alteration material similar to that occurring in the NLGM tailings was observed in the cuttings for several of the piezometers installed nearest the lake. Very close to the lake, in an area where cattails are growing, some altered tailings occur about 6 to 7 cm below the surface.

In the vegetated area in the southeast portion of the deposit, a trench was dug to examine the soil horizons developed in the vegetated area. This area was originally tailings with a layer of topsoil added as a cover. There are now three distinct soil horizons above the tailings (see Plate 3.7). The A horizon ( $\approx$  7 cm thick) is high in organic content, but also contains a high proportion of tailings because of wind transport. Below the A horizon is a light grey, silty to clayey horizon ( $\approx$  7 cm thick) with a well developed microstructure consisting of fine laminations, less than 1 mm thick, with more porous intervals in between. On the basis of colour, this horizon was identified in the field as an E horizon, or zone of metal leaching, but as will be discussed in Section 3.6.5, this horizon is actually a zone of metal enrichment. Below the "E" horizon is a sandy, reddish brown B horizon ( $\approx$  10 cm thick). Tailings (the C horizon) underlie the B horizon.

## **3.5.3** Trace Element Concentrations in Tailings

The trace element concentrations in tailings samples are given in Table 3.1 and Table 3.2. Analyses were completed at Bondar-Clegg & Company, Ltd., in Ottawa. Details of analytical procedures are given in Appendix 11. The trace element concentrations in tailings from each of the deposits are discussed in detail below.

There is a wide range in trace element concentrations for the tailings from the three deposits examined. Figure 3.5 shows mean concentrations of As, Hg, Cu, Pb, Co, Ni, Ag, Sb, V and Bi for samples from the NLGM and NHGM tailings, and the Cart Lake tailings. For all elements except Pb and V, concentrations are highest in the NHGM tailings.



Soil horizons in a trench in the vegetated plot at the Cart Lake tailings. The top layer is the A horizon, which contains roots and organic matter, as well as tailings. The light grey layer below the A horizon resembles a zone from which metals have been leached, called an E horizon. In this soil, metals are actually concentrated in this horizon, but the field designation of "E" horizon has been retained. Below this horizon is the reddish brown B horizon, which is underlain by tailings, designed the C horizon. Photo by the author

Soil profile at Cart Lake tailings

Plate 3.7

Element	NHGM #1	NHGM #2	NLGM #2	NLGM Crust #4	NLGM Subcrust #4a	NLGM Subcrust #4b	NLGM Subcrust #5
Al (%)	2.61	3.74	2.13	1.76	2.34	2.45	2.36
Fe (%)	5.01	5.99	4.28	3.30	4.61	4.54	4.64
Mg (%)	5.76	6.61	4.47	4.20	4.97	4.97	5.15
Ca (%)	4.26	1.89	2.60	8.63	1.95	1.79	2.45
Na (%)	0.03	0.03	0.04	0.12	0.08	0.11	0.06
K (%)	0.03	0.03	0.03	0.03	0.04	0.04	0.03
As (ppm)	100500.0	15050.0	7630.0	19060.0	2200.0	3250.0	3160.0
Sb (ppm)	1870.0	133.0	272.0	410.0	51.0	132.0	117.0
Mn (ppm)	859	617	838	623	799	829	906
Cl (ppm)	10.10	3.30	0.80	24.00	14.30	2.40	68.00
SO <sub>4</sub> (ppm)	2080.0	754.0	508.0	2880.0	525.0	304.0	294.0
Hg (ppm)	846.0	128.0	69.0	23.0	26.0	47.0	41.0
Cu (ppm)	1064	224	430	304	297	215	362
Pb (ppm)	406	63	351	199	251	415	470
Zn (ppm)	816	226	319	194	223	237	440
Mo (ppm)	537	214	11	47	15	3	10
Co (ppm)	28170	5459	2045	644	702	711	1116
Ni (ppm)	17645	2407	1854	559	599	620	941
Cd (ppm)	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Cr (ppm)	96	121	95	75	116	94	95
Bi (ppm)	752	122	83	36	43	57	67
Ba (ppm)	20	7	5	5	5	7	5
V (ppm)	82	119	89	72	98	102	101
Sr (ppm)	23	8	15	87	13	15	14
Y (ppm)	11	6	8	5	7	6	8
Sc (ppm)	9	11	9	7	10	11	11
Ag (ppm)	Ag (ppm) 241.6		208.0	69.7	74.7	99.4	155.6

**Table 3.1:** Trace element concentrations in tailings samples

Element	NLGM Crust #10	NLGM Subcrust #10	Cart Lake Soil - A	Cart Lake Soil - "E"	Cart Lake Soil - B	Cart Lake Soil - C	Cart Lake Crust #2
Al (%)	1.86	2.36	2.14	3.66	1.19	1.83	3.14
Fe (%)	3.83	4.87	4.57	7.51	1.78	3.84	6.25
Mg (%)	4.19	4.97	4.30	5.91	1.42	3.92	5.73
Ca (%)	1.96	2.06	0.80	1.25	0.30	1.20	1.67
Na (%)	4.80	0.09	0.02	0.04	0.02	0.04	0.04
K (%)	0.76	0.06	0.09	0.20	0.04	0.06	0.10
As (ppm)	17990.0	4600.0	518.0	1150.0	305.0	660.0	696.0
Sb (ppm)	272.0	120.0	9.6	14.8	3.1	9.2	169.0
Mn (ppm)	696	893	675	1048	275	661	978
Cl (ppm)	3632.0	24.0	2.08	6.36	4.17	0.16	0.48
SO <sub>4</sub> (ppm)	56000.0	286.0	6.1	40.0	10.7	24.0	44.0
Hg (ppm)	35.0	33.0	8.0	17.0	4.0	5.0	15.0
Cu (ppm)	467	582	57	174	12	82	221
Pb (ppm)	764	373	163	178	15	184	281
Zn (ppm)	385	328	175	188	37	180	298
Mo (ppm)	138	6	3	2	3	3	4
Co (ppm)	1100	1283	253	489	19	146	534
Ni (ppm)	652	1080	125	289	37	82	397
Cd (ppm)	< 0.2	< 0.2	< 0.2	< 0.2	0.2	< 0.2	< 0.2
Cr (ppm)	86	105	113	158	42	97	160
Bi (ppm)	60	61	21	55	6	15	31
Ba (ppm)	4	5	11	25	24	8	20
V (ppm)	87 111 11		111	180	36	96	159
Sr (ppm)	13 12 7		7	9	12	6	21
Y (ppm)	6 7 6		6	12	2	4	10
Sc (ppm)	8	10	10	17	<5	8	15
Ag (ppm)	m) 111.6 95.9		16.6	32.2	2.2	12.5	71.0

 Table 3.1 (continued):
 Trace element concentrations in tailings samples

Element	NLGM Tailings	NHGM Tailings	Cart Lake Tailings	Glacial Till, Peterson Lake Road	Soil A Horizon, Peterson Lake Road
As (ppm)	4200.0	17000.0	3.2	0.50	1.00
CN (ppm)	<2.0	<2.0	N/A	N/A	N/A
Hg (ppb)	31620.0	4794.0	266.0	97.0	250.0
SiO <sub>2</sub> (%)	58.65	48.29	63.15	67.92	63.64
TiO <sub>2</sub> (%)	0.75	0.88	0.83	0.50	0.50
$Al_2O_3$ (%)	14.23	17.67	14.19	13.21	11.23
$Fe_2O_3$ (%)	7.92	11.30	6.75	5.11	4.07
MnO (%)	0.12	0.10	0.10	0.08	0.09
MgO (%)	4.53	7.91	3.65	2.78	2.31
CaO (%)	3.09	1.74	1.92	2.38	3.15
Na <sub>2</sub> O (%)	4.90	4.53	5.26	2.86	2.70
K <sub>2</sub> O (%)	0.73	0.55	0.95	2.16	1.79
$P_2O_5$ (%)	0.12	0.07	0.08	0.11	0.08

**Table 3.2:** Composition of large samples of tailings and other materials

**Figure 3.5:** Mean As and metal concentrations in samples from the NHGM, NLGM and Cart Lake tailings





## **3.5.3.1** Nipissing High Grade Mill Tailings (3 samples)

The NHGM processed small tonnages of very rich ore. Residues from the mill contained 30 to 40 wt. % As, 8 to 10 wt. % Co and 4 to 8 wt. % Ni (Nipissing Mining Company Annual Report, 1913). The tailings may be unsold residue, although the Nipissing Mining Company Annual Reports for 1912 to 1918 suggest that all of the residue was sold. The data in Tables 3.1 and 3.2 show that these tailings contain from 15050.0 to 100500.0 ppm As. High Hg concentrations are also expected, since high grade ore contained 0.75 to 1.00 wt. % Hg (7500 to 10000 ppm), and losses of Hg occurred during processing (Reid *et al.* 1922). In the three samples, Hg concentrations range from 4.8 to 846.0 ppm. Cyanide was used at the NHGM, but the only sample of these tailings submitted for cyanide analysis contained less than 2 ppm cyanide.

From Figure 3.5, it is apparent that the mean concentrations of As, Hg, Co and Ni in samples from the NHGM tailings are at least an order of magnitude higher than the mean concentrations of these metals in samples from the NLGM and Cart Lake tailings. The mean Sb and Bi concentrations are almost an order of magnitude higher in the NHGM tailings. Within the NHGM tailings, all metals except Cr, V and Sc are significantly more concentrated in sample NHGM #1, from the uppermost tailings, than they are in sample NHGM #2, from the bottom of the deposit (about 1 m deep), and the concentrations of As, Sb, Co and Ag are an order of magnitude higher in NHGM #1 (see Figure 3.6)

## **3.5.3.2** Nipissing Low Grade Mill Tailings (6 samples)

The NLGM was typical of mills in the Cobalt area in the period 1910 to 1920. This mill processed large tonnages of low grade ore. The mean As concentration for six samples of tailings from this mill, excluding two crust samples, is  $4173 \pm 1727$  ppm (range: 2200 to 7630 ppm). The NLGM did not use Hg, but Hg from the ore does occur in the tailings, at concentrations much lower than those occurring in the NHGM tailings. The mean Hg concentration in the six samples is  $42 \pm 14$  ppm (range: 26.0 to 69.0 ppm). Cyanide was used at this mill from 1912 until 1932, but for the one sample analysed, no cyanide was detected (Anderson, 1985).

The concentrations of Co, Ni, Ag and  $SO_4$  were determined in five of the six samples, and the mean concentrations, standard deviations and concentration ranges for these are given in Table 3.3.



Figure 3.6: Concentrations of As, SO<sub>4</sub>, and metals in samples from the NHGM tailings

■NHGM #1 (top) ■NHGM #2 (bottom)

Table 3.3:	Cobalt, nickel, silver and sulf	ate concentration ranges in the NLC	GM tailings
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Element	Mean Concentration (ppm)	Standard Deviation (ppm)	Minimum (ppm)	Maximum (ppm)
Со	1171	492	702	2045
Ni	1017	453	599	1854
Ag	126	48	74.7	208.0
$SO_4$	383	109	286	525

### 3.5.3.3 Cart Lake Tailings (2 samples)

The Silverfields Mill which produced the Cart Lake tailings between 1967 and 1983 processed very large tonnages of low grade ore, using flotation separation. Tailings analysed in 1972 contained 0.21 wt. % As (2100 ppm)(Hawley 1977). The two samples collected for this study contained 3.2 and 665 ppm As. Low concentrations of Hg (0.27 and 5.0 ppm) were detected. Neither sample was submitted for cyanide analysis, since no cyanide was used in the mill.

#### **3.5.4** Trace Element Concentrations in Surface Crusts (3 samples)

Two crust samples from the NLGM tailings and one from the Cart Lake tailings were submitted for analysis. The trace element concentrations in these three samples are compared in Table 3.4 There are significant variations in the concentrations of major constituents in these crusts, particularly SO<sub>4</sub>, Cl, Na, and Ca. The crusts from the NLGM tailings contain very high As concentrations.

There are significant variations in trace element concentrations between crusts and the underlying tailings. Figures 3.7 and 3.8 are comparisons of the trace element concentrations in crusts from the NLGM tailings with tailings just below the surface. Figure 3.7a shows that Ca, As, SO<sub>4</sub>, Sb, Sr, Mo and Cl are more concentrated in NLGM Crust #4 than in samples from depths of 3 cm or 5 to 8 cm (see Figure 3.2). Figure 3.7b shows that, in the same samples, Mn, Co, Ni, Pb, Zn, V, Ag, Bi and Hg are more concentrated at depth than they are at the surface. Similar trends are illustrated in Figure 3.8, for NLGM Crust #10. For NLGM crust #10, samples were taken from only two depths. As a result, it is more difficult to define trends, so only metals for which concentrations in the crust are more than 100% greater than the concentrations in the subcrust are plotted. It is clear that As, SO<sub>4</sub>, Cl, Mo and Sr are enriched in both of these crusts, while Ca is enriched in NLGM Crust #4 and Na is enriched in NLGM Crust #10.

Element	NLGM	I Crusts	Cart Lake Crust
	NLGM Crust #4 (ppm)	NLGM Crust #10 (ppm)	(ppm)
As	19060.0	17999.0	696.0
$SO_4$	2880.0	56000.0	44.0
Cl	24.0	3632.0	0.48
Na	0.12%	4.80%	0.04%
Ca	8.63%	1.96%	1.67%
Со	644	1100	534
Ni	559	652	397
Hg	23.0	35.0	15.0

**Table 3.4:**Comparison of the As, SO4, Cl, Na, Ca, Co, Ni and Hg concentrations in crust<br/>samples from the NLGM tailings and the Cart Lake tilings



Figure 3.7a: Enrichment of Ca, As, SO<sub>4</sub>, Sb, Sr, Mo and Cl in NLGM Crust #4

Figure 3.7b: Depletion of metals in NLGM Crust #4





**Figure 3.8:** Enrichment of Na, SO<sub>4</sub>, As, Cl, Sb and Mo in NLGM Crust #10

### 3.5.5 Trace Element Concentrations in Soil on the Cart Lake Tailings

There are significant differences in the trace element concentrations in the A, "E" and B soil horizons, which occur in the revegetated area of the Cart Lake tailings. Trends are illustrated in Figure 3.9, which shows that As, Mn, Co, Ni, V, SO<sub>4</sub>, Ag and Cl are most concentrated in the horizon identified in the field as an E horizon. Since an E horizon is a soil horizon from which metals have been leached, this field designation was incorrect. It is not clear what the correct name for this horizon is, since enrichment normally occurs in the B horizon, but this soil has a characteristic B horizon below the "E" horizon. However, the B horizon contains the lowest concentrations of all of the elements in Figure 3.9, except SO<sub>4</sub> and Cl.

### 3.5.6 Mineralogy of the Tailings

The X-ray analyses of tailings samples indicate that the tailings are composed primarily of quartz, albite, calcite or dolomite, and chlorite. Metallic minerals are present, but none of them occur in sufficient amounts to be identified by X-ray analysis.

Crust samples from the NLGM tailings are composed primarily of sulfates, either gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O) or thenardite (Na<sub>2</sub>SO<sub>4</sub>). In the field, the white to light grey, thin brittle crusts are composed primarily of gypsum, while the white to reddish brown, thicker, powdery crusts are composed primarily of thenardite.



Figure 3.9: Concentrations of As, SO<sub>4</sub>, Cl and metals in soil horizons at Cart Lake

Subsamples from three samples of thenardite crust, NLGM Crust #8, NLGM Crust #9, and a crust collected near piezometer P34, were dissolved in distilled water and reprecipitated. The resultant precipitates were X-rayed. Only thenardite was positively identified in these samples.

No arsenate minerals were identified in the crusts. However, little if any substitution for  $SO_4$  occurs in gypsum or thenardite (Berry, *et al.* 1983). Therefore, given the high concentrations of As in the crusts, some arsenate minerals must be present in the crusts.

Two samples from the NHGM tailings were X-rayed. Both samples, one from the top of the tailings (NHGM #1), and the other from the base of the tailings (NHGM #2), are composed primarily of quartz, feldspar, and chlorite.

A sample of the "E" horizon of the soil from Cart Lake was X-rayed, and chlorite, quartz and albite were identified as the main minerals in this horizon.

## **3.5.7** Trace Element Concentrations in Other Solid Materials (5 samples)

The trace element concentrations in concrete from mill foundations, and other solid material collected in the Cobalt area, are given in Table 3.5. Of the three concrete samples, the sample from the NHGM contains the highest concentrations of As, Sb, Cl, SO<sub>4</sub>, Hg, Co, Ni, Bi and Ag (see Figure 3.10).

Element	NLGM Concrete	NHGM Concrete	McKinley Darragh Concrete	NLGM Slag	NHGM "Stuff"
Al (%)	2.94	1.89	2.06	5.79	1.52
Fe (%)	4.86	2.62	3.02	6.54	3.51
Mg (%)	4.17	1.23	1.46	5.35	1.52
Ca (%)	8.28	9.77	15.30	11.83	2.56
Na (%)	0.13	0.14	0.17	1.22	0.12
K (%)	0.11	0.14	0.18	0.49	0.09
As (ppm)	1320.0	10400.0	880.0	14500.0	218000.0
Sb (ppm)	36.0	770.0	17.9	208.0	6200.0
Mn (ppm)	804	547	583	1742	1127
Cl (ppm)	4.22	390.0	122.0	57.0	175.0
SO <sub>4</sub> (ppm)	194	3440	1498	415	1050
Hg (ppm)	18.0	56.06	0.90	6.62	526.88
Cu (ppm)	1039	364	700	459	1241
Pb (ppm)	342	199	222	221	1448
Zn (ppm)	579	239	843	752	3342
Mo (ppm)	7	10	8	213	82
Co (ppm)	250	5530	174	9288	53660
Ni (ppm)	287	3947	91	2513	38990
Cd (ppm)	<0.2	<0.2	<0.2	< 0.2	<0.2
Cr (ppm)	141	118	137	159	73
Bi (ppm)	47	349	<5	237	711
Ba (ppm)	68	112	129	246	84
V (ppm)	136	71	65	104	49
Sr (ppm)	67	236	649	206	36
Y (ppm)	7	5	6	45	9
Sc (ppm)	13	7	7	17	5
Ag (ppm)	201.5	346.7	68.1	435.5	356.0

**Table 3.5:** Trace element concentrations in concrete and other solid materials

**Figure 3.10:** Concentrations of As and metals in concrete from the NHGM, NLGM and McKinley-Darragh foundations



Concrete samples were collected because of concerns about Hg contamination. The Hg concentrations in these samples range from 0.90 ppm in concrete from the McKinley-Darragh mill foundation, to 56.06 ppm in concrete from the NHGM foundation. The Hg concentration in the NHGM foundation is slightly higher than the mean Hg concentration in samples from the NLGM tailings, but much lower than the mean Hg concentration in samples from the NHGM tailings.

The sample identified as NHGM "stuff" contains the highest concentrations of As, Sb, Co, Ni, Cu, Pb and Zn of any sample collected in this study, and it also has a very high Hg concentration. The origin of this material is not known, but one possibility is that it is particulate matter collected in the bag house of the refinery. Normally, such material would have been resmelted, but some would have been left when the refinery shut down in 1932.

## **3.5.8** Leaching Experiments

## **3.5.8.1** Results of Precipitation Monitoring Program

Water was collected from 18 precipitation events between April and October, 1991. Table 3.6 gives the pH of the precipitation received during each of these events. An error is not given for these measurements, but it is important to note that it is difficult to measure the pH of rain water due to its very low conductivity. These pH measurements range from 6.0 to 5.3, with a mean of  $5.6 \pm 0.2$ .

Date	pН	Date	pН	Date	pН
04/08/91	5.6	07/22/91	5.9	09/03/91	5.6
06/12/91	5.9	08/08/91	5.3	09/06/91	5.6
07/04/91	5.6	08/10/91	5.5	09/14/91	5.6
07/05/91	5.9	08/16/91	5.4	09/16/91	5.6
07/09/91	5.8	08/26/91	5.6	09/30/91	5.5
07/20/91	5.8	08/30/91	6.0	10/20/91	5.3

**Table 3.6:**The pH of precipitation received in Cobalt during the period April 8, 1991 to<br/>October 20, 1991.

Only the precipitation received on August 8 and October 20 (pH of 5.3) can be considered "acid rain", but this rain was only slightly more acidic than natural rain. The pH of acid rain can be much lower; rainfall collected in 1983 in southwestern Pennsylvania had an average pH of 3.5 (Pierson, *et al.* 1987).

## **3.5.8.2** Results of Leaching Experiments

The results of the leaching experiments are given in Table 3.7. The high conductivities,  $SO_4$  and Na concentrations in the acid leached samples are due to the addition of  $H_2SO_4$  and NaOH to create the "acid rain".

There are some anomalous data in Table 3.7. The leachate sample from the soil leached with "acid rain" in the first run of the experiment contains very low levels of As and Sb, compared to the soil sample leached with "natural rain", and neither Cl nor  $SO_4$  were detected in this sample, despite being present in the other "acid rain" leached samples. The source of these low values is not known. The leachate sample from the soil leached with "acid rain" in the second run of the experiment contains elevated levels of Zn, Co, Ba and Sr, and extremely high levels of Cd. The source of these anomalous data is not known.

Sample and	pН	Cond	Eh	Alk	As	Sb	Fe	Cl	Mg	Ca	Na	SO4	Hg	Zn	Мо	Co	Ni	Cd	Cr	Ba	Sr
Leaching Solution		μS/cm	mV	mg/L as CaCO3				ppm									ppb				
First Run of Experiment																					
"Natural Rain" Solution	5.6	10	+259	0	< 0.001	< 0.001	<5	<0.10	<5	<5	<5	1.20	< 0.10	<20	<50	<20	<50	<2	<50	<50	<10
"Acid Rain" Solution	4.7	2660	+251	5	0.002	< 0.001	<5	4.80	<5	<5	731	1417.0	<0.10	<20	<50	<20	<50	7	<50	<50	<10
NHGM Natural Rain	7.8	520	+266	165	139.00	6.40	<5	1.49	<5	268	<5	394.0	0.40	<20	5403	303	856	<2	<50	<50	112
NHGM Acid Rain	7.8	3470	+272	75	149.00	6.50	<5	5.79	<5	358	708	1863.0	0.40	<20	5548	390	1160	<2	<50	<50	177
NLGM Natural Rain	7.7	970	+261	100	64.00	6.50	<5	1.71	<5	56	26	79.0	0.17	<20	186	121	73	<2	<50	<50	104
NLGM Acid Rain	7.9	3030	+275	110	52.20	5.80	<5	5.92	<5	105	717	1863.0	0.23	<20	127	116	93	<2	<50	<50	238
Cart Lake Natural Rain	7.7	90	+260	45	3.71	0.122	<5	1.15	<5	15	<5	8.5	< 0.10	<20	<50	12	<50	<2	<50	<50	11
Cart Lake Acid Rain	7.8	2850	+271	45	4.64	0.176	<5	5.33	<5	39	765	1442.0	< 0.10	<20	<50	<10	<50	<2	<50	<50	39
A-Horizon Natural Rain	7.3	320	+264	110	0.441	0.048	<5	3.92	<5	15	<5	12.0	0.17	<20	<50	<10	<50	<2	<50	<50	43
A-Horizon Acid Rain	6.9	2730	+297	340	0.080	0.004	<5	< 0.10	<5	152	549	< 0.01	< 0.10	<20	<50	<10	<50	<2	<50	100	150
	-	-	_		-		-		-	-	-	-	-	-	-	-			-	-	
Glacial Till Natural Rain	7.5	90	+251	15	0.027	< 0.001	<5	0.85	<5	9	<5	2.7	< 0.10	<20	<50	<10	<50	<2	<50	<50	19
Glacial Till Acid Rain	7.2	2600	+279	25	0.041	0.002	<5	5.55	<5	166	515	1435.0	< 0.10	<20	<50	<10	<50	<2	<50	186	402

# **Table 3.7:** Trace element concentrations in leachate samples

Sample and	рН	Cond	Eh	Alk	As	Sb	Fe	Cl	Mg	Ca	Na	SO <sub>4</sub>	Hg	Zn	Мо	Co	Ni	Cd	Cr	Ba	Sr
Leaching Solution		µS/cm	mV	mg/L as CaCO3				ppm									ppb				
Second Run of Experiment	-																				
"Acid Rain" Solution	4.7	450	+243	5	0.007	< 0.001	<5	<0.10	<5	<5	6	16.34	0.12	<20	<50	<20	<50	<2	<50	<50	<10
NHGM Natural Rain	7.7	260	+268	65	48.90	3.490	<5	0.10	<5	52	<5	9.1	0.15	<20	555	73	165	<2	<50	<50	23
NHGM Acid Rain	7.5	890	+281	405	68.60	6.050	<5	0.42	<5	31	155	228.0	0.29	<20	981	40	110	<2	<50	<50	14
NLGM Natural Rain	7.5	190	+275	60	23.30	2.33	<5	0.10	<5	22	<5	1.82	< 0.10	<20	<50	31	<50	<2	<50	<50	23
NLGM Acid Rain	8.1	550	+256	105	36.10	3.76	<5	0.75	<5	10	130	176.00	< 0.10	<20	<50	51	<50	<2	<50	<50	21
Cart Lake Natural Rain	7.5	60	+265	35	1.74	0.064	<5	0.10	<5	10	<5	0.40	< 0.10	<20	<50	<10	<50	<2	<50	<50	<10
Cart Lake Acid Rain	8.0	530	+260	65	2.91	0.076	<5	0.76	<5	6	107	185.00	< 0.10	<20	<50	<10	<50	<2	<50	<50	<10
	-						-				-						-				
A-Horizon Natural Rain	7.8	170	+263	60	0.349	0.001	<5	0.21	<5	20	<5	0.40	< 0.10	<20	<50	<10	<50	<2	<50	<50	19
A-Horizon Acid Rain	8.0	720	+260	135	0.465	0.003	<5	1.50	<5	24	134	272.00	< 0.10	210	<50	228	<50	191	<50	225	230

 Table 3.7 (continued):
 Trace element concentrations in leachate samples

Note: samples of leachate from glacial till were not analysed during the second run of the experiment

In the first run of the experiment, Ca concentrations were higher in the samples leached with "acid than" in samples leached with "natural rain", due to the dissolution of calcite and dolomite. The Ca concentrations are lower for samples from the second run (see Figure 3.11).

As a result of the dissolution of carbonates, all leachate samples are alkaline (except the soil leached with "acid rain" in the first run of the experiment, which is slightly acidic due to the mobilization of humic and fulvic acids in the soil, which gave the leachate a yellow colour). There are no apparent trends in pH data.

Figure 3.12 compares As concentrations in samples leached with "natural rain" and with "acid rain" for each run of the experiment. For all samples except the leachate from the NLGM tailings from the first run of the experiment, As concentrations are higher in the samples leached with "acid rain". Arsenic concentrations are lower in all leachate samples from the second run.



Figure 3.11: Calcium concentrations in leachate







# **4** Groundwater and Surface Water Monitoring Program for the Cobalt Area, 1991-1992

# 4.1 Tailings Groundwater Site Selection

The NLGM tailings and the Cart Lake tailings were selected for the monitoring of groundwater in tailings.

The NLGM tailings were selected for a number of reasons, including:

- 1. they were known from previous work to contain among the highest As, Hg, and heavy metal concentrations of all tailings in the area, and they may contain cyanide.
- 2. they were deposited by a single mill, and the milling process did not change significantly during the time the tailings were deposited.
- 3. the tailings were never reworked.
- 4. the tailings are adjacent to a number of homes and are a playground for local children.

The Cart Lake tailings were selected for the following reasons:

- 1. Hg and cyanide were not used in the processing of these tailings.
- 2. they are recent tailings, and they may be representative of other tailings in the area deposited after 1960, including those outside the Farr Creek drainage basin, such as the Glen Lake tailings about 1 km to the east.
- 3. revegetation experiments were conducted on the Cart Lake tailings in 1979, and the vegetation is still alive.
- 4. the deposit is one of the largest in the area, except for the Crosswise Lake tailings.
- 5. the Cart Lake tailings are coarser grained than older tailings such as the Nipissing low grade mill tailings, thus, different hydrologic properties were anticipated.

# 4.2 Tailings Groundwater Monitoring Procedures

The level of the piezometric surface in the piezometers was monitored using electrical water level tapes. Between measurements the piezometers were sealed with duct tape to prevent contamination.

Piezometers which contained a column of water more than 1 m deep were used to obtain samples for chemical analysis. Water samples were collected using a bailer made of rigid PVC. Details of the sampling procedure are given in Appendix 11. Samples were collected in glass apple juice bottles which had been cleaned with soapy water, tap water, methanol, dilute hydrochloric acid, and finally distilled water. These bottles served as temporary containers; within 12 hours the water was filtered and transferred to polyethylene bottles.

# 4.3 Surface Water Site Selection and Sampling Procedure

Surface water samples were collected from 36 locations in the study area (locations are shown on Figure 4.6). A number of factors were considered when selecting sampling sites:

- could the site be representative of background contaminant levels;
- is the site close to a possible source of contamination;
- is the site far enough downstream from possible sources of contamination that contaminant levels may be decreasing;
- is the site used by local residents for recreation;
- is the water used for consumption; and
- is the surface water a possible source of groundwater contamination?

Throughout the period of study, the number of sample sites was increased as new questions arose. In particular, more attention was given to wetland areas, such as the tailings on the Chambers-Ferland property, to assess whether the wetlands might be having some effect on contaminant loads.

Lake water samples were collected from the shoreline in 15 cm to 20 cm of water. When possible, stream water samples were collected at sites where the water was flowing swiftly, but in mid to late summer, 1991, as water levels fell, this was not always possible. Stream water samples were taken from depths of 10 cm to 25 cm depending on the depth of the water. Surface water samples were collected in glass sample bottles triple rinsed with the sample water. Within 12 hours the water was filtered and transferred to polyethylene bottles.

# 4.4 Groundwater Site Selection and Sampling Procedure

Groundwater was collected from 32 sites within the study area; 26 well water sites, 4 old mine workings, and 2 diamond drill holes (sampling locations are shown in Figure 4.11). The 1977 Ontario Ministry of the Environment report on the occurrence of As contamination in local water supplies was used as a guide to site selection. However, this was not a reliable guide, because the report listed sites by the owner's name, and in some cases ownership had changed. In addition, the location map for the report was unreliable when used to locate specific homes. Sampling for the current study focused on West Cobalt, Mileage 104, and North Cobalt; three areas of concern identified by the 1977 report. Houses which were sampled were determined partly by the 1977 report, partly by random choice and partly on the advice of neighbours who mentioned known or possible problems.

Well water samples were collected from the tap within each home, with the exception of the Bucke Park well, which was sampled at an overflow port in the concrete well casing, and two wells which have hand pumps. Prior to sampling of tap water, the water was allowed to run for about 1 minute. When collecting such samples, it is usually recommended that the water be allowed to run for 5 minutes to flush the system of any contaminants which may be coming from the pipes. In this study samples were collected sooner in order to assess the quality of water that the people are drinking on a daily basis, including any contaminants which come from the pipes. In two wells where elevated levels of Cd were found in the tap water, subsequent samples were collected after 1 minute and 5 minutes of flushing to determine whether or not the Cd was coming from the pipes. For the samples were collected from hand pumps, the wells were pumped for at least 5 minutes before the samples were collected, because in both cases, the wells had not been used for some time, and the initial water produced contained very high levels of suspended solids.

Groundwater samples were collected in glass bottles which were triple rinsed with the sample water prior to collection. Within 4 hours the water was transferred to polyethylene sample bottles. With the exception of the Bucke Park samples and the samples from hand pumps, well water samples were not filtered.

# 4.5 Results of the Tailings Groundwater Monitoring Program

Samples were collected from 10 piezometers in the NLGM tailings and 16 piezometers in the Cart Lake tailings. Analytical techniques and detection limits are given in Appendix 11.

# 4.5.1 Nipissing Low Grade Mill Tailings Groundwater

## 4.5.1.1 Groundwater and Surface Water Flow

Groundwater flow in the NLGM tailings is complex, with several small flow systems existing. There are several seasonal streams which flow across the surface of the tailings (see Figure 4.1 for surface streams and groundwater flow directions). A significant amount of surface water flow occurs at the NLGM tailings because infiltration rates are very low due to the fine grained nature of the tailings (infiltration rates were not measured). After a heavy rain, the tailings surface is covered with a film of water, and the water can be seen flowing downslope along the tailings surface. Seasonal streams on the tailings quickly swell with water, and the flow rate in the stream draining the deposit increases.

South of dam #1 it is not possible to determine the direction of groundwater flow, since most of the piezometers in that area were dry every time water level measurements were taken. When groundwater is present, the dominant directions of flow are likely towards the tailings filled mine working to the east, and a small stream along the western edge of the tailings. Surface water from a small, seasonal stream flows across dam #1 at the eastern edge of the deposit, and groundwater may discharge at the same point. A smaller amount of surface flow across dam #1 occurs at the western edge of the deposit, and groundwater may also discharge at this point. This



stream originates as groundwater discharging from the base of a slag heap south west of the tailings.

Groundwater flow directions north of dam #1 were determined from water level data obtained on June 9, June 26, and October 17, 1991, and groundwater flow directions are consistent for data collected on these three dates. Water level measurements were also taken in July and August, 1991, but many of the piezometers were dry, so flow directions were not determined.

Along the eastern edge of the deposit, between dam #1 and dam #2, water level data from 10 piezometers indicate that the direction of groundwater flow is to the north. A surface water stream also flows northward through this area, and unlike other streams on the tailings, this stream is wet through much of the year.

In the central portion of the tailings, there is a gulley between dam #1 and dam #2, and after heavy rains and during the spring runoff, surface water flows northward along the gulley, towards the central portion of the area north of dam #2. The water level data from 11 piezometers in and adjacent to this gulley indicate that the general direction of groundwater flow is downslope into this gulley, and northward towards dam #2.

At the western edge of the deposit, between dam #1 and dam #2, there is a small seasonal stream. Groundwater flows into this area from upslope areas to the east, but there are not enough piezometers in this area to determine the direction of groundwater flow in the tailings underlying the stream.

North of dam #2 there are 10 piezometers, the direction of groundwater flow, based on water level data from these piezometers, is to the northeast, towards dam #3. Throughout the summer, groundwater was observed discharging from the base of dam #3, even during dry periods when there is no surface water flow. A small seasonal stream also discharges at dam #3. Upon discharge, the surface water and groundwater enter a small stream which flows into Mill Creek.

By examining water level data from paired piezometers, the direction of vertical groundwater flow can be determined in several areas of the deposit. In the tailings filled mine shaft at the south east corner of the deposit, groundwater flow is downward, so that area is a zone of groundwater recharge. In the gulley along the central portion of the tailings between dam #1 and dam #2, groundwater was determined to be flowing upwards (discharge zone) at piezometer pairs P26/P44, P27/P45 and P32/P46. North of dam #2, there is little vertical groundwater flow.

Three piezometer pairs occur in the small embayment of tailings at the northeast corner of the deposit, in an area thought to be hydraulically isolated from the rest of the tailings. As previously mentioned, the area is wet throughout the year, and it supports vegetation. The opening to this area from the rest of the deposit is quite narrow, with bedrock on both sides, and the thickness of tailings in this opening is less than 1 m. In piezometer pair P51/P52 and P53/P54 there was no vertical groundwater flow during the two times when measurements were taken. In piezometer pair P55/P56, groundwater discharge occurs.

### 4.5.1.2 Nipissing Low Grade Mill Tailings Groundwater Geochemistry

Twenty groundwater samples were collected from the NLGM tailings, during sampling conducted in June, July and October of 1991. The locations of the piezometers are shown in Figure 4.2, and the results of the analyses are given in Table 4.1.

All samples have neutral to alkaline pH, and high conductivities. Samples from P48 and P50, north of dam #2, have particularly high alkalinities and conductivities. The results of these field geochemical measurements are summarized in Table 4.2.

	рН	Eh mV	Alkalinity mg/L as CaCO3	Conductivity µS/cm	Temperature °C
number of samples	20	9	20	17	10
mean	7.6	264	480	630	12.5
standard deviation	0.4	18	400	377	3
minimum	7.0 (P50)	213 (P56)	35 (P26)	240 (P1)	7.0
maximum	9.0 (P26)	277 (P10)	1690 (P48)	1810 (P48)	17.0

 Table 4.2:
 Results of field geochemical measurements for NLGM tailings groundwater samples

In the NLGM tailings, the highest As concentrations occur in samples from piezometers P1, P6 and P7, located south of dam #1. These three piezometers are located in an old mine working which has been infilled with tailings. The total depth of tailings at this point is not known. High Hg, Co and Ni concentrations also occur in the six samples from these piezometers. These As, Hg, Co and Ni concentration data are summarized in Table 4.3. One sample from piezometer P1 was analysed for cyanide and the concentration was 0.019 ppm.



Sample	Date	Т	pН	Cond	Eh	Alk	As	Sb	Al	Mn	Fe	CI	Mg	CN	Ca	Na	SO <sub>4</sub>	Hg	Cu	Pb	Zn	Мо	Co	Ni	Cd	Cr	Ba	Sr
Number	m/d/y	°C		µS/cm	mV	mg/L as CaCO3						ppm											ppb					
P1	06/26/91	N/A	7.7	460	N/A	245	26.200	1.660	<5	<5	<5	3.00	21	0.019	47	79	45	0.2	<50	<200	<20	132	653	191	<2	<50	<50	71
P1	07/24/91	N/A	7.5	240	N/A	225	23.200	1.500	<5	<5	<5	2.40	19	N/A	45	80	35.9	0.1	<50	<200	<20	128	728	182	<2	<50	<50	72
P1	10/17/91	7.0	7.5	400	+268	290	46.400	0.766	<5	<5	<5	27.00	18	N/A	44	39	3.0	0.12	<50	<200	<20	115	675	151	<2	<50	<50	87
																	-											
P6	06/26/91	N/A	7.7	450	N/A	165	19.200	1.990	<5	<5	<5	7.00	19	N/A	51	50	50	0.3	<50	<200	<20	52	430	145	<2	<50	<50	65
																	-											
P7	06/26/91	11.9	7.7	510	N/A	245	34.900	1.620	<5	<5	<5	2.00	20	N/A	58	66	47	0.6	<50	<200	<20	<50	255	186	<2	<50	<50	87
P7	10/17/91	9.0	7.6	390	+274	370	48.700	0.478	<5	<5	<5	16.00	20	N/A	61	30	56.0	0.12	<50	<200	27	58	289	155	<2	<50	<50	122
																	-											
P10	06/26/91	N/A	7.9	710	N/A	505	1.390	0.125	<5	<5	<5	4.00	22	N/A	109	160	18	< 0.1	<50	<200	<20	<50	168	<50	<2	<50	60	152
P10	10/17/91	12.0	7.5	490	+277	515	0.348	< 0.001	<5	<5	<5	3.66	21	N/A	90	74	4.6	< 0.1	<50	<200	<20	<50	200	<50	<2	<50	<50	148
P13	06/26/91	N/A	7.8	260	N/A	215	0.465	0.086	<5	<5	<5	4.00	15	N/A	61	47	6	< 0.1	54	<200	<20	<50	870	<50	<2	<50	68	96
P13	07/24/91	N/A	7.4	N/A	N/A	245	0.232	0.062	<5	<5	<5	N/A	7	N/A	27	24	N/A	N/A	<50	<200	<20	<50	414	<50	<2	<50	<50	47
P13	10/18/91	10.0	7.4	250	+274	105	0.290	0.023	<5	<5	<5	1.80	15	N/A	58	20	4.4	< 0.1	<50	<200	<20	<50	995	<50	<2	<50	<50	100
P26	10/17/91	13.0	9.0	1120	+270	35	4.640	0.638	<5	<5	<5	60.00	<5	N/A	343	43	1075	0.1	<50	<200	<20	1044	169	146	<2	<50	<50	278
P48	06/27/91	N/A	8.0	820	N/A	1690	2.670	0.450	<5	<5	<5	60.00	58	N/A	71	904	370	0.1	<50	<200	<20	62	806	544	<2	<50	85	240
P48	10/17/91	14.0	7.5	1810	+269	1045	17.400	0.174	<5	<5	<5	48.00	34	N/A	46	339	108	0.29	<50	<200	<20	165	767	146	<2	<50	<50	144
P50	06/27/91	N/A	7.6	890	N/A	910	1.400	0.700	<5	<5	<5	28.00	51	N/A	91	531	61	< 0.1	<50	<200	<20	<50	267	389	4	<50	60	648
P50	10/17/91	16.0	7.0	680	+269	1105	0.696	0.116	<5	<5	<5	32.00	39	N/A	74	297	27	< 0.1	<50	<200	22	57	394	255	<2	<50	<50	482
P51	06/27/91	N/A	7.4	N/A	N/A	365	2.172	N/A	<5	<5	<5	N/A	12	N/A	87	68	N/A	N/A	<50	<200	37	<50	252	499	<2	<50	<50	324
P51	10/18/91	17.0	7.5	480	+270	265	0.986	0.023	<5	<5	<5	0.66	8	N/A	94	N/A	<1.0	0.19	<50	<200	<20	<50	242	442	<2	<50	<50	134
																•												
P56	06/27/91	N/A	7.3	N/A	N/A	510	0.617	N/A	<5	<5	<5	N/A	36	N/A	89	112	N/A	N/A	<50	<200	<20	<50	152	117	<2	<50	68	326
P56	10/18/91	15.0	7.2	760	+213	550	1.620	0.186	<5	<5	<5	2.04	38	N/A	79	37	< 0.1	< 0.1	<50	<200	<20	<50	221	85	<2	<50	<50	180

**Table 4.1:** Trace element concentrations in groundwater from the Nipissing low grade mill tailings

Statistics for the 6 samples collected	As (ppm)	Hg (ppb)	Co (ppb)	Ni (ppb)
mean	33.1	0.24	505	168
standard deviation	11.3	0.17	189	18
minimum	19.2 (P6)	0.1 (P1)	255 (P7)	145 (P6)
maximum	48.7 (P7)	0.6 (P7)	728 (P1)	191 (P1)

**Table 4.3:** Arsenic and heavy metal concentrations in piezometers P1, P6 and P7

The other tailings groundwater samples collected from the NLGM tailings were collected north of dam #1 (see Figure 4.2). With the exception of one sample (from P48), the 14 samples collected in this area contain lower levels of As. Concentrations of Hg and Ni are also lower, but some of the samples from these piezometers contain high Co concentrations. Arsenic and heavy metal concentrations from these piezometers are summarized in Table 4.4. No cyanide analyses were performed for these samples.

Table 4.4:	Arsenic, Hg, Co and Ni concentrations in p	piezometers north of Dam #1
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	As (ppm)	Hg (ppb)	Co (ppb)	Ni (ppb)
number of samples	14	11	14	14
number of samples in which concentration is below detection limit	0	7	0	5
mean for samples in which concentration is above the detection limit	2.49	0.17	422	291
standard deviation	4.29	0.08	289	168
minimum	0.232 (P13)	0.1 (P26, P48)	152 (P56)	85 (P56)
maximum	17.400 (P48)	0.29 (P48)	995 (P13)	544 (P48)

There are significant variations in major ion concentrations in the tailings groundwater. The concentrations of Na, Cl and Mg are higher in samples from piezometers P48 and P50 (north of dam #2), than in all other piezometers, and samples from these piezometers also contain high concentrations of  $SO_4$ . These variations are summarized in Table 4.5. The highest Ca and  $SO_4$  concentrations occur in the sample from P26.

	Na (ppm)		Cl (ppm)		Mg (ppm)		SO <sub>4</sub> (ppm)	
	P48 and P50	All Others	P48 and P50	All Others	P48 and P50	All Others	P48 and P50	All Others
number of samples	4	15	4	13	4	14	4	13
number of samples in which concentration is below detection limit	0	0	0	0	0	1	0	2
mean for samples in which concentration is above the detection limit	517	62	42.0	10.3	45	19	141	122 (27 without P26)
standard deviation	240	36	12.8	16.0	9	8	135	302
minimum	297	20 (P13)	28.0	0.66 (P51)	34	7 (P13)	27	3 (P1)
maximum	904	160 (P10)	60.0	60.0 (P26)	58	38 (P56)	370	1075 (P26)

**Table 4.5:**Comparison of major ion concentrations in P48 and P50 with all other<br/>piezometers at the NLGM tailings

### 4.5.2 Cart Lake Tailings Groundwater

### 4.5.2.1 Groundwater and Surface Water Flow

The direction of groundwater flow in the Cart Lake tailings, determined in August, 1991, is shown in Figure 4.3. The dominant direction of flow is to the north, towards the lake. The volume of groundwater discharge into the lake was not measured. No piezometers pairs were installed in the Cart Lake tailings, so the vertical direction of groundwater flow is not known.

The Cart Lake tailings are sandy, and the infiltration rate is quite high, and as a result there is limited surface water flow on these tailings, except in a stream along the western edge of the tailings. There is a small pond in the forested area to the south of tailings, and this pond is wet throughout the summer. Surface water flows north from this pond, along the western edge of the tailings deposit, to the lake. This stream is wet through much of the summer, and in the southern portion of the tailings groundwater is flowing towards the stream, and groundwater discharge into the stream may be occurring. In piezometer PC22, installed in the stream bed, water levels in the piezometer were very close to or at the level of the surface of the stream bed throughout the year. Lake levels fell throughout the summer of 1991, and because of the gentle slope of the tailings, these drops in lake level made a significant difference in the area of tailings exposed.



### 4.5.2.2 Cart Lake Tailings Groundwater Geochemistry

Thirty-five groundwater samples were collected from the Cart Lake tailings, during sampling conducted in June, July, August and October, 1991. The locations of piezometers are shown in Figure 4.4, and the results of analyses are given in Table 4.6.

Like the groundwater samples from the NLGM tailings, all groundwater samples from the Cart Lake tailings have neutral to alkaline pH and high conductivity. The results of field geochemical measurements of groundwater samples from the Cart Lake tailings are summarized in Table 4.7

	рН	Eh mV	Alkalinity mg/L as CaCO3	Conductivity µS/cm	Temperature °C
number of samples	33	12	31	32	13
mean	8.0	252	190	680	6
standard deviation	0.9	16	65	191	3
minimum	7.1 (PC1, PC2)	229 (PC3)	105 (PC20)	310 (PC24)	1.0
maximum	9.7 (PC32)	287 (PC33)	365 (PC32)	1030 (PC18)	13.0

 Table 4.7:
 Results of field geochemistry measurements for Cart Lake tailings groundwater samples

The mean As concentration in groundwater samples from the Cart Lake tailings is higher than that in samples from the NLGM tailings, except for the very high As levels in piezometers P1, P6 and P7. Large variations in As concentration occur in the water from some Cart Lake piezometers, particularly PC3 and PC5 (see Figure 4.4). Mercury was not detected in any groundwater samples from the Cart Lake tailings. Cobalt and Ni both occur in lower concentrations in the groundwater in the Cart Lake tailings than in the NLGM tailings. No cyanide analyses were performed for samples from Cart Lake. Arsenic and heavy metal concentrations in groundwater samples from the Cart Lake tailings are summarized in Table 4.8. The As and heavy metal concentrations in tailings groundwater from the NLGM tailings and the Cart Lake tailings are compared in Figure 4.5.


Sample	Date	Т	pН	Cond	Eh	Alk	As	Sb	Al	Mn	Fe	Cl	Mg	CN	Ca	Na	SO <sub>4</sub>	Hg	Cu	Pb	Zn	Mo	Co	Ni	Cd	Cr	Ba	Sr
Number	m/d/y	°C		µS/cm	mV	mg/L as CaCO3						ррт											ppb					
PC1	06/25/91	N/A	N/A	800	N/A	285	0.465	0.046	<5	<5	<5	6.00	10	N/A	194	23	359	< 0.1	<50	<200	<20	55	164	86	<2	<50	57	190
PC1	07/22/91	N/A	7.1	390	N/A	220	1.740	0.020	<5	<5	<5	4.90	9	N/A	198	25	328.4	< 0.1	<50	<200	25	<50	118	83	<2	<50	<50	205
PC1	10/18/91	6.0	9.3	510	+252	190	1.390	0.044	<5	<5	<5	6.60	7	N/A	129	7	227.0	N/A	<50	<200	<20	72	72	<50	<2	<50	<50	138
PC2	06/25/91	N/A	7.1	760	N/A	270	2.770	0.074	<5	<5	<5	5.00	13	N/A	156	24	332	< 0.1	<50	<200	<20	128	60	56	<2	<50	58	237
PC2	07/22/91	N/A	7.4	590	N/A	135	3.830	0.040	<5	<5	<5	2.90	13	N/A	165	23	336.4	< 0.1	<50	<200	<20	125	61	62	<2	<50	<50	250
				-	•			-					•															
PC3	06/25/91	N/A	7.4	790	N/A	235	10.800	0.245	<5	<5	<5	8.00	39	N/A	109	58	269	< 0.1	<50	<200	<20	86	298	166	<2	<50	76	389
PC3	07/22/91	N/A	7.3	N/A	N/A	215	8.470	0.085	<5	<5	<5	3.50	40	N/A	89	64	432.6	< 0.1	<50	<200	<20	96	165	76	<2	<50	<50	358
PC3	10/18/91	6.0	9.5	730	+229	200	0.001	0.052	<5	<5	<5	11.00	48	N/A	59	31	268.0	N/A	<50	<200	<20	62	80	<50	<2	<50	<50	297
	1							1																				
PC4	06/25/91	N/A	7.4	640	N/A	180	3.490	0.186	<5	<5	<5	3.00	12	N/A	117	19	214	< 0.1	<50	<200	<20	123	130	70	<2	<50	<50	169
	1							1																				
PC5	06/26/91	N/A	7.3	830	N/A	170	7.420	0.104	<5	<5	<5	6.00	24	N/A	147	40	359	< 0.1	<50	<200	<20	106	99	63	<2	<50	51	264
PC5	08/31/91	N/A	7.5	N/A	N/A	N/A	< 0.001	0.005	<5	<5	<5	6.00	23	N/A	147	17	364.0	< 0.1	<50	<200	29	94	103	70	<2	<50	<50	281
PC5	10/18/91	6.0	9.1	940	+249	185	11.600	0.099	<5	<5	<5	7.80	23	N/A	154	15	403.0	N/A	<50	<200	<20	78	113	<50	<2	<50	<50	317
	1				1								1															
PC8	06/26/91	N/A	7.4	890	N/A	195	4.650	0.061	<5	<5	<5	19.00	39	N/A	100	122	353	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	69	435
PC8	07/22/91	N/A	7.3	1010	N/A	175	4.520	0.018	<5	<5	<5	13.10	38	N/A	86	130	303.7	< 0.1	<50	<200	22	<50	13	<50	<2	<50	<50	450
PC8	10/18/91	8.0	9.4	770	+242	175	2.320	0.023	<5	<5	<5	24.00	35	N/A	70	53	259.0	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	407
	1							1																				
PC15	06/25/91	N/A	7.5	850	N/A	130	3.140	0.079	<5	<5	<5	16.00	30	N/A	58	184	340	< 0.1	<50	<200	<20	108	<10	<50	<2	<50	<50	305
PC15	07/23/91	N/A	7.2	860	N/A	110	4.410	0.040	<5	<5	<5	13.90	25	N/A	45	203	288.2	< 0.1	<50	<200	<20	87	<10	<50	<2	<50	<50	269
PC15	08/30/91	N/A	7.4	600	N/A	180	7.890	0.021	<5	<5	<5	19.00	22	N/A	36	86	274.0	< 0.1	<50	<200	<20	83	<10	<50	<2	<50	<50	246
				-								-																
PC17	07/23/91	N/A	7.2	370	N/A	160	16.200	0.050	<5	<5	<5	1.30	20	N/A	125	30	285.8	< 0.1	<50	<200	<20	243	<10	<50	<2	<50	<50	187
PC17	10/20/91	3.0	8.4	660	+276	140	4.640	0.162	<5	<5	<5	7.80	18	N/A	111	18	265.0	N/A	<50	<200	<20	214	19	<50	<2	<50	<50	167
	-			-	•			-					•															
PC18	07/23/91	N/A	7.2	1030	N/A	175	2.320	0.035	<5	<5	<5	3.70	30	N/A	130	50	319.2	< 0.1	<50	<200	<20	133	13	<50	<2	<50	<50	332
PC18	10/20/91	4.0	8.6	620	+270	165	6.030	0.046	<5	<5	<5	13.00	23	N/A	123	19	306.0	N/A	<50	<200	<20	142	11	52	<2	<50	<50	314

**Table 4.6:** Trace element concentrations in groundwater from the Cart Lake tailings

Sample	Date	Т	pН	Cond	Eh	Alk	As	Sb	Al	Mn	Fe	CI	Mg	CN	Ca	Na	SO <sub>4</sub>	Hg	Cu	Pb	Zn	Mo	Co	Ni	Cd	Cr	Ba	Sr
Number	m/d/y	°C		µS/cm	mV	mg/L as CaCO3						ppm											ppb					
PC20	06/25/91	N/A	7.4	960	N/A	105	17.400	0.203	<5	<5	<5	8.00	58	N/A	96	134	482	< 0.1	<50	<200	<20	68	17	<50	<2	50	65	516
PC20	09/01/91	N/A	7.2	660	N/A	N/A	5.920	0.058	<5	<5	<5	8.70	53	N/A	83	57	452.0	< 0.1	<50	<200	<20	59	11	<50	<2	<50	<50	479
PC20	10/18/91	6.0	9.0	750	+257	110	5.800	0.232	<5	<5	<5	20.00	51	N/A	77	56	452.0	N/A	<50	<200	<20	62	<10	<50	<2	<50	<50	481
PC24	06/25/91	12.9	7.4	570	N/A	175	7.560	0.198	<5	<5	<5	<1.00	12	N/A	119	16	218	< 0.1	<50	<200	<20	124	343	128	<2	<50	<50	154
PC24	07/22/91	N/A	7.3	310	N/A	135	8.120	0.054	<5	<5	<5	1.00	9	N/A	98	15	126.0	< 0.1	<50	<200	<20	102	248	112	<2	<50	<50	130
PC27	10/18/91	7.0	9.2	640	+241	105	9.850	0.070	<5	<5	<5	4.74	13	N/A	116	14	263.0	N/A	<50	<200	<20	147	26	<50	<2	<50	<50	212
PC30	09/04/91	N/A	7.5	340	N/A	N/A	5.220	0.070	<5	<5	<5	25.00	15	N/A	30	84	131.0	< 0.1	<50	<200	<20	53	<10	52	<2	<50	<50	124
PC30	10/18/91	6.0	9.6	380	+245	185	9.660	0.057	<5	<5	<5	31.00	7	N/A	18	79	34.0	N/A	<50	<200	<20	54	<10	<50	<2	<50	<50	71
PC32	10/18/91	8.0	9.7	730	+243	365	2.900	0.056	<5	<5	<5	27.00	10	N/A	21	148	80.0	N/A	<50	<200	<20	71	<10	<50	<2	<50	<50	116
PC33	10/20/91	1.0	8.7	630	+287	325	4.060	0.046	<5	<5	<5	29.00	17	N/A	47	82	63.0	N/A	<50	<200	24	<50	<10	<50	<2	<50	<50	199
PC34	09/05/91	N/A	7.5	520	N/A	N/A	0.151	0.012	<5	<5	<5	27.00	12	N/A	96	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PC34	10/20/91	2.0	8.1	640	+239	330	0.232	0.021	<5	<5	<5	39.00	14	N/A	76	39	42.0	N/A	<50	<200	23	<50	14	<50	<2	<50	109	165

 Table 4.6 (continued):
 Trace Element Concentrations in Groundwater from the Cart Lake Tailings

	As (ppm)	Hg (ppb)	Co (ppb)	Ni (ppb)
number of samples	34	21	34	34
number of samples in which concentration is below detection limit	1	21	11	20
mean for samples in which concentration is above the detection limit	5.53	-	99	82
standard deviation	4.16	-	93	32
minimum	0.151 (PC34)	-	11 (PC18)	52 (PC30)
maximum	17.40 (PC20)	-	343 (PC24)	166 (PC3)

**Table 4.8:**Arsenic, Hg, Co and Ni concentrations in groundwater samples from the Cart<br/>Lake tailings

Figure 4.5: Comparison of As, SO4, Ca, Co, Ni and Sr concentrations in tailings groundwater



There are geographical trends in Na, Cl and Ca concentrations. As shown in Table 4.9, the mean Na and Cl concentrations in samples from piezometers near Cart Lake are higher than in samples from piezometers further from the lake. An opposite trend occurs in Ca concentrations.

	Na	(ppm)	Cl(I	opm)	Ca	(ppm)
	Near Lake	All Others	Near Lake	All Others	Near Lake	All Others
number of samples	11	22	12	22	12	22
number of samples in which concentration is below detection limit	0	0	0	1	0	0
mean for samples in which concentration is above the detection limit	110	34	23.6	6.6	57	125
standard deviation	50	27	7.4	4.2	27	35
minimum	39 (PC34)	7 (PC1)	13.1 (PC8)	1.0 (PC24)	18 (PC30)	59 (PC3)
maximum	203 (PC15)	134 (PC20)	39.0 (PC34)	20.0 (PC20)	100 (PC8)	198 (PC1)

Table 4.9:	Geographical trends in Na, Cl and Ca concentrations of groundwater from the
	Cart Lake tailings

Note: Piezometers "Near Lake" are PC8, PC15, PC30, PC32, PC33 and PC34

## 4.6 Results of the Surface Water Monitoring Program

There is a wide range in trace element concentrations in surface waters of the Farr Creek basin. The locations of all sampling sites are shown in Figure 4.6, and the results of analyses are given in Table 4.10. Sampling sites are described in Appendix 9.

All surface waters in the Farr Creek basin have neutral to alkaline pHs, with the highest pHs occurring in the south end of Cobalt Lake (Site #7), the outlet from the NHGM tailings (Site #8) and the outlet from Cart Lake (Site #9). The data for pH and other field geochemical measurements are summarized in Table 4.11.



Site Number and	Date	Т	pН	Cond	Eh	Alk	Hardness	As	Sb	Al	Mn	Fe	CI	Mg	Ca	Na	SO <sub>4</sub>	CN	Hg	Cu	Pb	Zn	Mo	Co	Ni	Cd	Cr	Ba	Sr
Description	m/d/y	°C		µS/cm	mV	mg/L as	mg/L as						ppm											ppb					
						CaCO <sub>3</sub>	CaCO <sub>3</sub>																						
MILL CREEK SYSTEM	1	1	1		<del></del>	<del></del>	,										1			1	,	[	<del></del>	<del>.                                    </del>			<del>.                                    </del>	<del>.                                    </del>	,
#15 Short Lake	06/12/91	19.8	7.5	190	N/A	90	149	0.040	< 0.001	<5	<5	<5	0.60	15	35	<5	12.20	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	27
	07/23/91	N/A	7.4	130	N/A	90	98	0.046	0.005	<5	<5	<5	0.70	5	31	<5	14.5	N/A	<0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	27
	09/02/91	N/A	8.1	190	N/A	75	90	0.058	0.002	<5	<5	<5	0.40	6	29	<5	16.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	21
#7 Cobalt Lake	06/12/91	16.7	7.3	60	N/A	128	229	0.555	0.001	<5	<5	<5	27.60	26	49	21	18.70	N/A	N/A	<50	<200	<20	<50	27	<50	<2	<50	<50	61
south end	07/21/91	N/A	7.7	130	N/A	120	147	0.560	0.025	<5	<5	<5	8.60	9	44	40	18.7	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	57
	09/02/91	N/A	8.6	210	+285	N/A	153	0.603	0.022	<5	<5	<5	31.00	10	45	17	13.00	N/A	N/A	<50	<200	<20	<50	17	<50	<2	<50	<50	63
	10/17/91	11.0	9.6	300	+290	185	161	0.835	0.023	<5	<5	<5	41.00	10	48	22	23.00	N/A	< 0.1	<50	<200	<20	<50	15	<50	<2	<50	<50	69
					·												1						·						
#8 Outlet from NHGM	06/12/91	14.0	7.4	310	N/A	192	416	19.900	0.014	<5	<5	<5	18.40	51	83	12	48.50	< 0.010	1.7	<50	<200	<20	114	644	437	<2	<50	<50	88
tailings	06/28/91	N/A	7.5	N/A	N/A	N/A	250	18.000	1.240	<5	<5	<5	19.00	16	74	18	53	< 0.005	0.7	<50	<200	<20	87	353	275	<2	<50	<50	75
	09/02/91	N/A	9.5	500	+280	N/A	263	9.980	0.116	<5	<5	<5	18.00	19	74	9	63.00	N/A	< 0.1	<50	<200	<20	71	178	178	<2	<50	<50	75
	10/17/91	11.0	9.2	270	+302	180	245	22.000	1.800	<5	<5	<5	13.00	17	70	8	56.00	N/A	N/A	<50	<200	<20	86	282	282	<2	<50	<50	74
#18 Cobalt Lake	06/12/91	18.9	7.7	130	N/A	126	236	0.598	0.002	<5	<5	<5	34.40	27	50	25	19.60	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	66
north end	07/21/91	N/A	8.1	490	N/A	150	139	0.580	0.028	<5	<5	<5	32.20	9	41	50	18.6	N/A	<0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	60
	09/02/91	N/A	8.3	N/A	+273	N/A	129	0.696	0.021	<5	<5	<5	36.00	9	37	20	121.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	53
	10/19/91	10.5	8.3	110	+257	135	137	0.905	0.035	<5	<5	<5	39.00	9	40	21	16.00	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	63
								1.250	0.010				0.50					.0.010											
#1 Outlet from NLGM	06/11/91	N/A	7.6	80	N/A	93	161	4.350	0.018	<5	<5	<5	9.50	18	35	11	6.70	<0.010	0.5	<50	<200	<20	<50	193	152	<2	54	<50	48
tailings	06/28/91	N/A	6.9	80	N/A	N/A	125	6.510	0.755	<5	<5	<5	8.00	6	40	18	28	<0.005	0.3	<50	<200	<20	<50	240	150	<2	<50	<50	51
	07/21/91	N/A	7.5	220	N/A	90 N/A	90	3.020	0.053	<>	<>	<5	8.80 N/A	5	28	18	6.7	0.007	0.1 N/A	<50	<200	<20	<50	237	165	<2	75	<50	39
	10/19/91	9.0	8.0	300	+205	IN/A	95 147	3.200	0.052	<>> <5	<>>	< 3	IN/A	3	29	18	IN/A	IN/A	IN/A	<50	<200	-20	<50	100	101		/0	<50	57 57
	10/19/91	-	-	-	-	- 2(0	14/	4.000	0.013	<0.2	<->	< 3	1.50	<i>y</i>	44 5( 0	<>>	31.00	<0.005	0.20	<30	<200	<20	<30	198	140	<20	< 30	< 30	52 72
	03/13/92	IN/A	/.4	400	IN/A	300	157	10.900	0.934	<0.∠	0.05	0.2	3.90	3.0	50.9	1/./	48.00	IN/A	IN/A	24	<100	33	04	199	140	<20	<20	<40	15
#6 Mill Creek at	06/12/91	16.9	7.8	90	N/A	124	233	0.810	0.002	<5	<5	17	32.70	27	49	25	19.40	N/A	0.1	<50	<200	<20	<50	16	77	<2	67	<50	66
Right-of-Way	07/21/91	N/A	7.7	270	N/A	130	137	0.720	0.030	<5	<5	<5	17.70	9	40	50	17.4	N/A	< 0.1	<50	<200	<20	<50	21	<50	<2	<50	<50	62
Mine	09/03/91	N/A	8.7	320	+275	N/A	127	0.893	0.021	<5	<5	<5	34.00	9	36	20	10.00	N/A	N/A	<50	<200	<20	<50	22	<50	<2	<50	<50	56
	10/19/91	10.0	8.1	90	+266	N/A	139	0.708	0.036	<5	<5	<5	39.00	9	41	21	17.00	N/A	< 0.1	<50	<200	<20	<50	29	<50	<2	<50	<50	65
	05/13/92	N/A	7.6	440	N/A	130	182	1.040	0.070	0.2	0.04	0.4	32.50	4.4	65.7	24.1	18.00	N/A	N/A	<20	<100	344	<50	36	32	<20	<20	<40	75

**Table 4.10:** Trace element concentrations in surface waters in the Farr Creek drainage basin

Site Number and	Date	Т	pН	Cond	Eh	Alk	Hardness	As	Sb	Al	Mn	Fe	Cl	Mg	Ca	Na	SO <sub>4</sub>	CN	Hg	Cu	Pb	Zn	Mo	Co	Ni	Cd	Cr	Ba	Sr
Description	m/d/y	°C		µS/cm	mV	mg/L as CaCO3	mg/L as CaCO <sub>3</sub>						ppm											ppb					
#5 Mill Creek at the	06/12/91	16.0	7.0	150	N/A	130	240	1.400	0.012	<5	<5	<5	32.00	28	50	24	21.40	N/A	0.5	<50	<200	<20	<50	49	65	<2	<50	<50	69
LaRose Mine	05/13/92	13.0	7.9	380	N/A	535	157	1.160	0.070	<0.2	< 0.02	0.2	34.50	4.2	56.1	22.9	19.00	N/A	N/A	<20	<100	57	<50	33	<20	<20	<20	<40	71
#43 Swamp at LaRose	05/13/92	15.0	7.3	480	N/A	170	177	3.210	0.107	<0.2	<0.28	0.3	26.60	5.2	62.5	35.3	86.60	N/A	N/A	74	<100	272	<50	2028	643	<20	<20	<40	83
#42 Mill Cr. under Hwy 11B bridge	05/13/92	N/A	7.9	410	N/A	125	157	1.180	0.060	<0.2	0.04	0.2	33.80	4.4	55.7	24.4	26.80	N/A	N/A	<20	<100	45	<50	296	107	<20	<20	<40	72
#4 Mill Cr. at Ontario	06/28/91	18.9	7.7	130	N/A	126	236	0.598	0.002	<5	<5	<5	34.40	27	50	25	19.60	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	66
Northland Railway	07/21/91	N/A	8.1	490	N/A	150	139	0.580	0.028	<5	<5	<5	32.20	9	41	50	18.6	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	60
tracks	09/02/91	N/A	8.3	N/A	+273	N/A	129	0.696	0.021	<5	<5	<5	36.00	9	37	20	121.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	53
	10/19/91	10.5	8.3	110	+257	135	137	0.905	0.035	<5	<5	<5	39.00	9	40	21	16.00	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	63
	05/13/92	13.0	7.4	410	N/A	130	154	1.180	0.058	<0.2	0.04	0.2	33.80	4.3	54.5	24.3	26.30	N/A	N/A	<20	<100	30	<50	258	98	<20	<20	<40	70
#44 Mill Cr. 100 m downstream from confluence with Sasaginaga Cr.	05/13/92	N/A	7.6	270	N/A	60	94	0.515	0.020	<0.2	< 0.02	<0.2	18.80	2.6	33.3	14.0	14.40	N/A	N/A	<20	<100	<20	<50	69	<20	<20	<20	<40	44
#3 Mill Cr. at	06/12/91	16	7.1	320	N/A	146	249	1.950	0.002	<5	<5	<5	37.30	29	52	30	21.50	N/A	N/A	<50	<200	30	<50	213	134	<2	<50	<50	76
Hwy 11B	07/21/91	N/A	7.2	220	N/A	130	161	2.090	0.028	<5	<5	<5	35.80	10	48	67	15.5	N/A	0.2	<50	<200	20	<50	152	97	<2	<50	<50	76
	09/04/91	N/A	7.6	350	+265	N/A	161	1.510	< 0.001	<5	<5	<5	39.00	10	48	27	9.00	N/A	N/A	<50	<200	<20	<50	123	81	<2	<50	<50	65
	10/19/91	9.5	7.5	170	+272	303	174	0.812	0.046	<5	<5	<5	47.00	12	50	27	33.00	N/A	0.12	<50	<200	<20	<50	228	92	<2	<50	<50	108
	05/13/92	13	7.5	240	N/A	105	103	0.745	0.022	<0.2	0.02	< 0.2	19.80	3.0	36.1	15.4	15.10	N/A	N/A	<20	<100	<20	<50	79	<20	<20	<50	<40	48
SASAGINAGA CREEK SYSTEM																													
#16 Sasaginaga Lake	06/12/91	18.9	7.3	130	N/A	56	103	< 0.001	< 0.001	<5	<5	17	6.20	13	20	7	6.60	N/A	< 0.1	<50	<200	31	<50	<10	<50	<2	58	<50	28
	07/23/91	N/A	7.5	120	N/A	60	<68	0.002	< 0.001	<5	<5	<5	6.40	<5	19	10	4.1	N/A	< 0.1	<50	<200	<20	<50	<10	<50	3	<50	<50	25
	09/02/91	N/A	8.6	70	+286	60	<68	0.012	< 0.001	<5	<5	<5	6.30	<5	19	<5	9.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	19
	10/19/91	15.0	7.7	100	+286	75	<70	0.003	< 0.001	<5	<5	<5	8.60	<5	20	<5	9.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	28

 Table 4.10 (continued):
 Trace element concentrations in surface waters in the Farr Creek drainage basin

Site Number and	Date	Т	pН	Cond	Eh	Alk	Hardness	As	Sb	Al	Mn	Fe	Cl	Mg	Ca	Na	SO <sub>4</sub>	CN	Hg	Cu	Pb	Zn	Мо	Co	Ni	Cd	Cr	Ba	Sr
Description	m/d/y	°C		μS/cm	mV	mg/L as CaCO <sub>3</sub>	mg/L as CaCO <sub>3</sub>						ppm											ppb					
#35 West arm of	10/21/91	6.0	6.0	70	+275	105	96	0.070	0.012	<5	<5	<5	7.10	7	27	<5	14.00	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	34
Sasaginaga Cr.	05/13/92	N/A	7.7	170	N/A	80	82	0.008	< 0.001	<0.2	< 0.02	<0.2	7.30	1.8	29.9	5.0	7.00	N/A	N/A	<20	<100	257	<50	<20	<20	<20	<20	<40	31
#40 S. arm of Sasaginaga Cr.	02/20/92	0.0	8.2	360	+145	130	<78	0.019	0.010	<5	<5	<5	36.00	<5	23	28	14.10	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	34
20 m above mine shaft	05/13/92	N/A	N/A	N/A	N/A	N/A	75	0.078	0.004	<0.2	< 0.02	<0.2	13.60	2.0	26.7	9.0	9.50	N/A	N/A	<20	<100	50	<50	<20	<20	<20	<20	<40	36
#41 S. arm of Sasaginaga Cr.	02/20/92	0.0	8.2	330	+155	270	<98	0.128	0.008	<5	<5	<5	43.00	<5	31	26	17.30	N/A	N/A	<50	<200	27	<50	22	<50	<2	<50	<50	44
50 m below mine shaft	05/13/92	N/A	N/A	N/A	N/A	N/A	173	0.615	0.026	<0.2	0.07	0.4	46.00	5.0	61.1	32.4	24.80	N/A	N/A	<20	<100	84	<50	82	43	<20	<20	<40	101
#36 S. arm of Sasaginaga Cr., 50 m from confluence with W. arm	10/21/91	7.0	7.4	290	+231	130	154	0.348	0.024	<5	<5	<5	53.00	9	47	34	30.00	N/A	<0.1	<50	<200	40	<50	62	<50	2	<50	<50	76
#38 Sasaginaga Cr., 75	10/21/91	9.0	7.5	370	+187	150	157	0.325	0.024	<5	<5	<5	52.00	9	48	33	31.00	N/A	< 0.1	<20	<200	40	<50	67	<50	<2	<50	<50	76
m downstream from confluence	05/13/92	N/A	N/A	N/A	N/A	N/A	143	0.480	0.022	<0.2	< 0.02	<0.2	56.80	4.1	50.5	34.5	26.80	N/A	N/A	<50	<100	84	<50	73	31	<20	<20	<40	83
#37 Sasaginaga Cr 500	10/21/91	8.0	76	180	+225	200	166	0 3 1 9	0.027	<5	<5	<5	50.00	10	50	32	33.00	N/A	<01	<50	<200	40	<50	83	<50	<2	<50	<50	78
m downstream from confluence	05/13/92	N/A	7.6	190	N/A	70	111	0.114	0.006	<0.2	0.03	0.3	14.5	2.3	40.6	9.5	9.80	N/A	N/A	<20	<100	469	<50	<20	<20	<20	<20	<40	44
PETERSON LAKE, PETERSON CREEK SYSTEM																													
#22 Pond S. of	07/22/91	N/A	7.3	150	N/A	195	177	0.093	0.004	<5	<5	<5	0.40	14	48	<5	2.3	N/A	< 0.1	<50	<200	<20	<50	<10	<50	3	<50	<50	51
Cart Lake	08/30/91	N/A	N/A	250	N/A	160	156	0.128	0.002	<5	<5	<5	0.21	13	41	<5	7.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	46
#9 Cart Lake	06/12/91	16.8	72	180	N/A	108	210	1 550	0.002	<5	<5	<5	0.80	28	38	9	26 50	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	53
Outlet	07/22/91	N/A	7.5	250	N/A	105	118	1.390	0.020	<5	<5	<5	0.80	11	29	18	29.5	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	55
	08/30/91	N/A	9.1	270	+265	80	120	1.160	0.023	<5	<5	<5	1.00	11	30	7	39.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	49
	10/19/91	10.0	8.1	230	+272	100	147	1.800	0.065	<5	<5	<5	5.10	12	39	9	70.00	N/A	N/A	< 50	<200	<20	<50	24	<50	<2	<50	<50	66

 Table 4.10 (continued):
 Trace element concentrations in surface waters in the Farr Creek drainage basin

Site Number and	Date	Т	pН	Cond	Eh	Alk	Hardness	As	Sb	Al	Mn	Fe	Cl	Mg	Ca	Na	SO <sub>4</sub>	CN	Hg	Cu	Pb	Zn	Мо	Co	Ni	Cd	Cr	Ba	Sr
Description	m/d/y	°C		μS/cm	mV	mg/L as CaCO3	mg/L as CaCO3						ррт											ppb					
#23 Drainage from Cart	07/22/91	N/A	7.4	160	N/A	190	196	0.244	0.010	<5	<5	<5	1.50	13	57	18	5.8	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	78
Lake to Peterson	08/30/91	N/A	7.2	240	+283	160	183	0.070	0.012	<5	<5	<5	0.10	13	52	6	8.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	67
Lake	10/19/91	13.0	7.4	350	+285	115	147	1.090	0.037	<5	<5	<5	5.60	11	41	8	61.00	N/A	N/A	<50	<200	<20	<50	12	<50	<2	<50	<50	56
#10 Peterson Lake	06/12/91	18.8	7.6	170	N/A	108	207	4.050	< 0.001	<5	<5	6	4.30	28	37	6	11.70	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	46
at the	07/22/91	N/A	7.4	170	N/A	125	121	0.464	0.010	<5	<5	<5	1.80	10	32	<5	9.8	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	43
Nova Scotia	09/06/91	N/A	8.5	200	+269	N/A	113	0.406	0.012	<5	<5	<5	3.40	10	29	<5	7.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	36
Mine	10/19/91	12.0	8.2	180	+270	110	109	0.441	0.012	<5	<5	<5	5.50	9	29	<5	13.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	43
			1			1			1																				
#24 Swamp below	07/22/91	N/A	7.3	320	N/A	N/A	156	0.487	0.010	<5	<5	<5	1.90	13	41	9	4.6	N/A	<0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	57
the O'Brien	09/04/91	N/A	8.6	120	+293	N/A	143	0.313	0.002	<5	<5	<5	2.60	13	36	<5	9.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	46
Mine	10/19/91	11.0	7.7	180	+262	150	144	0.116	< 0.001	<5	<5	<5	3.10	12	36	<5	14.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	48
#34 Peterson Creek downstream from	10/21/91	5.0	7.7	270	+289	180	182	0.905	0.023	<5	<5	<5	10.00	14	50	6	45.00	N/A	N/A	<50	<200	23	<50	48	<50	<2	<50	<50	76
Violet Mine																													
FARR CREEK SYSTEM																													
#12 Crosswise Lake	06/12/91	16.0	7.7	130	N/A	62	119	0.060	< 0.001	<5	<5	<5	0.60	15	23	<5	7.90	N/A	N/A	<50	<200	41	<50	<10	<50	2	<50	<50	32
north end	07/22/91	N/A	7.6	80	N/A	60	70	0.058	0.004	<5	<5	<5	0.40	5	20	<5	9.8	N/A	< 0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	30
	09/01/91	N/A	8.4	100	+283	N/A	77	0.058	0.002	<5	<5	<5	1.00	6	21	<5	3.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	25
	10/20/91	N/A	8.2	130	+279	85	73	0.070	0.014	<5	<5	<5	0.50	5	21	<5	11.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	33
#13 Farr Creek	06/12/91	18.1	74	150	N/A	84	477	0 398	0.001	<5	<5	6	4 20	59	94	11	25.14	N/A	N/A	<50	<200	43	<50	58	<50	</td <td>&lt;50</td> <td>57</td> <td>109</td>	<50	57	109
midway through	07/22/91	N/A	7.6	210	N/A	90	108	0.371	<0.001	<5	<5	<5	2.00	8	30	6	10.8	N/A	<0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	45
wetland	09/01/91	N/A	N/A	160	N/A	N/A	141	0 348	0.004	<5	<5	<5	4 10	10	40	<5	21.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	57
	10/19/91	12.5	7.7	90	+261	N/A	91	0.180	0.012	<5	<5	<5	4.60	7	25	<5	15.00	N/A	< 0.1	<50	<200	<20	<50	12	<50	<2	<50	<50	40

**Table 4.10 (continued):** Trace element concentrations in surface waters in the Farr Creek drainage basin

Site Number and	Date	Т	pН	Cond	Eh	Alk	Hardness	As	Sb	Al	Mn	Fe	Cl	Mg	Ca	Na	SO <sub>4</sub>	CN	Hg	Cu	Pb	Zn	Mo	Co	Ni	Cd	Cr	Ba	Sr
Description	m/d/y	°C		µS/cm	mV	mg/L as CaCO3	mg/L as CaCO3						ppm											ppb					
#33 Farr Cr. at dam, S.	09/05/91	N/A	N/A	270	N/A	N/A	148	0.162	0.015	<5	<5	<5	28.00	10	43	19	8.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	62
of North Cobalt	10/19/91	11.5	7.6	680	+272	140	153	0.464	0.030	<5	<5	<5	33.00	11	43	17	28.00	N/A	< 0.1	<50	<200	<20	<50	19	<50	<2	<50	<50	65
#28 Farr Cr. at	07/24/91	N/A	7.5	280	N/A	N/A	128	0.464	0.005	<5	<5	<5	22.70	10	35	41	3.1	N/A	<0.1	<50	<200	<20	<50	<10	<50	<2	<50	<50	65
Groom Rd.	09/02/91	N/A	8.1	120	+243	485	148	0.220	0.002	<5	<5	<5	10.50	10	43	20	10.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	67
North Cobalt	10/19/91	12.0	8.2	250	+260	105	141	0.534	0.032	<5	<5	<5	30.00	10	40	16	26.00	N/A	< 0.1	<50	<200	<20	<50	28	<50	2	<50	<50	68
#29 Farr Cr. 300m from	09/02/91	N/A	8.4	350	+261	N/A	150	0.487	0.006	<5	<5	<5	10.60	11	42	21	10.00	N/A	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<50	69
L. Temiskaming	10/17/91	9.0	8.5	230	+285	240	143	0.557	0.023	<5	<5	<5	29.00	10	41	17	28.00	N/A	N/A	<50	<200	<20	<50	18	<50	<2	<50	<50	68

Table 4.10 (continued): Trace element concentrations in surface waters in the Farr Creek drainage basin

Note: Hardness was calculated using the formula: Hardness = 2.5[Ca] + 4.1[Mg] (Freeze and Cherry 1979). Hardness was calculated because the toxicity of Ni is dependent on hardness (CCREM 1987).

	рН	Eh mV	Alkalinity mg/L as CaCO <sub>3</sub>	Conductivity µS/cm	Temperature °C
number of samples	81	38	61	83	37
mean	7.8	263	146	242	12.5
standard deviation	0.6	34	88	127	5.0
minimum	6.9	145	56	60	0.0
	(Site #1)	(Site #40)	(Site #16)	(Site #7)	(Site #40, 02/92)
maximum	9.6	302	535	680	19.8
	(Site #7)	(Site #8)	(Site #5)	(Site #33)	(Site #15, 06/91)

**Table 4.11:** Results of field geochemistry measurements for surface water samples from the<br/>Farr Creek basin

#### 4.6.1 Arsenic Contamination

Arsenic occurs in all surface waters in the basin, including those unaffected by mining. Mean As concentrations range from 0.004 ppm in Sasaginaga Lake near the Cobalt town water intake (Site #16), to 17.5 ppm for a small stream draining the NHGM tailings (Site #8). There are significant increases in As concentration from points upstream of the mining areas to points further downstream.

#### 4.6.1.1 Sasaginaga Creek System

Figure 4.7 is a plot of As concentrations in the Sasaginaga Creek system, and As concentration data are summarized in Table 4.12. In this system, the west arm of the creek drains the lake, while the south arm flows from the north end of town, carrying with it sewage effluent. The As concentrations in the west arm (Site #35) are quite low despite flowing across the tailings of the Hudson Bay property. The south arm of the creek (Site #40) contains relatively low concentrations of As until it passes a mine shaft from which As-rich groundwater is discharging (GW Site #31) (see Plate 4.1). Downstream (Site #41), the As concentrations are significantly higher.

About 75 m downstream from the confluence of the two branches of Sasaginaga Creek (Site #38), the As concentration is lower than that at Site #41, but much higher than that at Site #35. About 500 m further downstream, in the midst of a wetland area (Site #37), the As concentrations are lower.

Site #	number of samples	mean (ppm)	standard deviation (ppm)	minimum (ppm)	maximum (ppm)
#16	4	0.006	0.004	< 0.001	0.012
#35	2	0.039	-	0.008	0.070
#40	2	0.048	-	0.019	0.078
GW Site #31	2	0.880	-	0.780	0.980
#41	2	0.372	-	0.128	0.615
#38	2	0.402	-	0.325	0.480
#37	2	0.216	-	0.114	0.319

**Table 4.12:** Summary of As concentrations in the Sasaginaga Creek system

**Figure 4.7:** Trends in As concentrations in the Sasaginaga Creek system



South Arm — - - West Arm ··· \*··· Groundwater



Groundwater discharging from a mine shaft adjacent to the south arm of Sasaginaga Creek. The pipe is part of a structure which caps the shaft. The pipe is about 15 cm in diameter. The flow from the pipe was not measured, but from the photo it is evident that the volume of water discharging is significant. In addition to the water coming from the pipe, some groundwater also discharges around the base of the capping structure (see bottom photo). Photos by the author. Note: original thesis contained only one photo.

Groundwater discharging into Sasaginaga Creek

Plate 4.1

#### 4.6.1.2 Mill Creek System

In Figure 4.8, changes in As concentrations in the Mill Creek system are illustrated, and Table 4.13 summarizes the As concentrations. Short Lake (Site #15), south of Cobalt Lake, was sampled to determine background As concentrations. There has been little mining activity around this lake, and there are no tailings in it. The As concentration increases considerably in samples from Cobalt Lake (Site #7 and Site #18). There are tailings in the lake, and the lake receives drainage from the NHGM tailings (Site #8).

Between Cobalt Lake and the next sampling point in Mill Creek, drainage from the NLGM tailings (Site #1) enters Mill Creek. This drainage contains As from groundwater discharging at dam #3 of the NLGM tailings, and As in the surface water discharging at the same point. No samples were collected from this stream immediately after major precipitation events, but due to the dissolution of surface crusts during heavy rains, As concentrations in this drainage may be highest after heavy rains.

Despite the input from the NLGM tailings, the mean As concentration in Mill Creek at the Right-of-Way mine (Site #6) is not much higher than it is in Cobalt Lake. Downstream, the As concentration increases, due to input from tailings in the creek bed, and from the pond on the LaRose tailings (Site #43) (see Plate 4.2). Downstream from the LaRose tailings, higher As concentrations occur in samples from Mill Creek at the Ontario Northland tracks (Site #4). Beyond this point Mill Creek flows across the Chambers-Ferland tailings and joins Sasaginaga Creek. About 100 m downstream from its confluence with Sasaginaga Creek (Site #44), the As concentration is lower due to mixing with Sasaginaga Creek. The As concentration is higher at the final sampling point on Mill Creek, upstream of the point where Mill Creek again passes under Highway 11B (Site #3).

Site #	number of samples	mean (ppm)	standard deviation (ppm)	minimum (ppm)	maximum (ppm)
#15	3	0.048	0.003	0.040	0.058
#7	4	0.638	0.115	0.555	0.835
#8	4	17.460	4.560	9.950	22.000
#18	4	0.695	0.129	0.598	0.905
#1	6	5.768	2.806	3.020	10.900
#6	5	0.834	0.123	0.708	1.040
#5	2	1.280	-	1.160	1.400
#43	1	3.210	-	-	-
#42	1	1.180	-	-	-
#4	5	2.490	1.807	1.180	6.050
#44	1	0.515	-	-	-
#3	5	1.420	0.559	0.745	2.090

**Table 4.13:** Summary of As concentrations in the Mill Creek system

**Figure 4.8:** Trends in As concentrations in the Mill Creek system



#### 4.6.1.3 Peterson Lake, Peterson Creek System

The As concentrations also increase along the Cart Lake - Peterson Lake system (see Figure 4.9 and Table 4.14). Water from the outlet of Cart Lake (Site #9) has a relatively high concentration of As, but at the outlet from a small wetland between Cart Lake and Peterson Lake (Site #23), the As concentration is lower.

In the east lobe of Peterson Lake, where tailings from the Nova Scotia Mine are in the lake (Site #10), the As concentration is higher.

Downstream from Peterson Lake, Peterson Creek passes through three small wetlands before joining Farr Creek. At the inlet to the second wetland (Site #24), the As is lower, but the concentration is higher at the outlet from the third wetland, downstream from a waste rock pile at the Violet Mine.



Mill Creek looking south towards the Nipissing low grade mill tailings (1). The discharge from the tailings flows through a fracture in the rock at point 2. By this route, tailings are migrating from the NLGM tailings into Mill Creek. Most of the tailings in the foreground likely originated from the NLGM tailings. Photo by the author.



The tailings on the LaRose property, looking south from the Highway 11B bridge at Mill Creek and the railway tracks. Most of the LaRose tailings are submerged under a pond which remains wet throughout the year. This pond discharges into Mill Creek at point 1. Photo by the author

Tailings in Mill Creek and at the LaRose property

Plate 4.2

Site #	number of samples	mean (ppm)	standard deviation (ppm)	minimum (ppm)	maximum (ppm)
#22	2	0.111	-	0.093	0.128
#9	4	1.475	0.233	1.160	1.800
#23	3	0.468	0.445	0.070	1.090
#10	4	1.340	1.565	0.406	4.050
#24	3	0.305	0.151	0.116	0.487
#34	1	0.905	-	-	-

**Table 4.14:** Summary of As concentrations in the Peterson Creek system

**Figure 4.9:** Trends in As concentrations in the Peterson Creek system



#### 4.6.1.4 Farr Creek System

Arsenic concentrations increase along Farr Creek (see Figure 4.10 and Table 4.15). The As concentrations in Crosswise Lake (Site #12) are relatively low, but are much higher at the first sampling point in Farr Creek (Site #13), in the midst of the Crosswise Lake tailings, and downstream from the confluence of Peterson Creek and Farr Creek. About 300 m downstream from this site, Mill Creek joins Farr Creek, and the creek then flows for about 1 km through a wetland underlain by tailings, to sampling Site #33 where the As concentrations are slightly lower than those at Site #13. This sampling site is the same site at which Environment Canada monitored water flow from 1971 to 1983, and it is the same site at which the Ontario Ministry of the Environment collected monthly samples from 1988 to 1990.

This site is the northward limit of tailings migration, but As concentrations are higher at the next sampling site, in North Cobalt (Site #28), and at the final site, about 300 m upstream from Lake Temiskaming (Site #29).

Site #	number of samples	mean (ppm)	standard deviation (ppm)	minimum (ppm)	maximum (ppm)
#12	4	0.061	0.005	0.058	0.070
#13	5	0.324	0.085	0.180	0.398
#33	2	0.313	-	0.162	0.464
#28	3	0.406	0.134	0.220	0.534
#29	2	0.522	_	0.487	0.557

**Table 4.15:** Summary of As concentrations in the Farr Creek system

Figure 4.10: Trends in As concentrations in the Farr Creek system



Fair Creek ···· Peterson Creek ····\*··· Mill Creek

## 4.6.2 Cobalt, Nickel and Mercury Contamination in Surface Water

Cobalt and Ni occur in a number of surface water samples from the Farr Creek basin. The highest Co and Ni concentrations are in samples from the Mill Creek system, particularly the pond on the LaRose tailings (Site #43), the outlet of the NHGM tailings (Site #8), the outlet of the NLGM tailings (Site #1), Mill Creek at the Ontario Northland tracks (Site #4) and Mill Creek at Highway 11B (Site #3). Cobalt and Ni concentrations in samples collected outside the Mill Creek system are much lower, and in many samples, neither Co nor Ni were detected. Cobalt and Ni occurrences are summarized in Table 4.16.

Mercury was only detected in surface waters in the Mill Creek system. The highest Hg concentrations in the Farr Creek basin occur in samples from the outlet of the NHGM tailings (Site #8) and from the outlet of the NLGM tailings (Site #1). Mercury occurrences are also summarized in Table 4.16.

	Co (ppl	<b>b</b> )	Ni (ppb	)	Hg (pp	b)
	Mill Creek	All	Mill Creek	All	Mill Creek	All
	system	Others	system	Others	system	Others
number of samples	41	47	41	47	23	17
number of samples in	8	33	17*	45	11	17
which concentration is						
below detection limit						
mean for samples in	247	40	176	37*	0.4	-
which concentration is						
above the detection limit						
standard deviation	352	23	129	6	0.4	-
significant	Site #43:	Site #41:	Site #43:	Site #41:	Site #8:	does not
occurrences	2028	82, 22	643	43*	1.7, 0.7, <0.1	occur
	Site #8:		Site #8:		Site #1:	
	mean = 406 ± 147		$mean = 293 \pm 93$		$mean = 0.3 \pm 0.2$	
			Site #1:		Site #5:	
	Site #1:		$mean = 152 \pm 8$		0.5	
	mean = $217 \pm$					
	21		Site #4:		Site #4:	
			$mean = 162 \pm 59$		0.3, 0.3, <0.1	
	Site #4:					
	mean = $352 \pm$		Site #3:			
	128		$mean = 101 \pm 20$			
	Site #3:					
	$mean = 159 \pm 55$					

**Table 4.16:** Cobalt, nickel and mercury occurrences in surface waters of the Farr Creek basin

\* In the spring of 1991, Bondar-Clegg's detection limit for Ni was lowered, so Ni was detected in several samples collected in May, 1992 at concentrations lower than the previous detection limit of 50 ppb.

#### 4.6.3 Other Contaminants in Surface Water

Cyanide concentrations were measured in six surface water samples collected from the outlets of the NHGM and NLGM tailings (Site #8 and Site #1). Cyanide was only detected in one of these samples, at a concentration of 0.007 ppm. This water was collected from the outlet of the NLGM tailings (Site #1), tailings which were processed using cyanide. Samples from other locations were not analysed for cyanide because all other locations were further from possible sources of cyanide, and the dilution factors would be so great that cyanide concentrations would be below the detection limits for the analytical technique used.

Antimony occurs in most of the surface water samples collected. The only water body in which no Sb was found is Sasaginaga Lake (Site #16). The highest Sb concentrations occur in samples from the Mill Creek system. The mean Sb concentration for samples from the Mill Creek system

is  $0.188 \pm 0.388$ , while the mean Sb concentration for all other samples is  $0.019 \pm 0.017$  ppm.

Cadmium occurs at very low levels in the surface waters of the Farr Creek basin. This metal was only detected in 6 samples. The concentration did not exceed 3 ppb, and Cd was not detected more than once in any water body.

Chromium was detected in only 4 samples, including 2 samples from the outlet to the NLGM tailings (Site #1).

#### 4.6.3 Major Ion Concentrations in Surface Waters

Both Na and Cl occur in higher concentrations in samples from the Mill Creek and Sasaginaga Creek systems (excluding Sasaginaga Lake and Short Lake) than in other surface waters in the area. These data are summarized in Table 4.17.

		Na (ppm)		-	Cl (ppm)	
	Mill Creek	Sasaginaga Creek	All others	Mill Creek	Sasaginaga Creek	All Others
number of samples	41	15	32	40	15	32
number of samples in which concentration is below detection limit	4	3	13	0	0	0
mean for samples in which concentration is above the detection limit	26	24	14	27.15	34.48	7.20
standard deviation	14	11	8	11.75	18.88	9.70
minimum	8	5	6	1.50	7.10	0.10
maximum	70	34	41	47.00	56.80	33.00

<b>Table 4.17:</b>	Major ion	concentrations	in the	Farr	Creek	basin
	major ion	concentrations	in the	I ull	CICCIC	ousin

## 4.7 Results of the Groundwater Monitoring Program

Groundwater samples were collected from 23 private wells, 1 public well and 1 institutional well, as well as 2 diamond drill holes and 4 mine shafts. The locations of all groundwater sampling sites are shown in Figure 4.11, and the addresses and physical descriptions of each of the houses sampled are given in Appendix 10. The results of the analyses of groundwater are given in Table 4.18. The results of field geochemical measurements of the samples are summarized in Table 4.19.



Site Number and	Date	pН	Cond	Eh	Alk	As	Sb	Al	Mn	Fe	Cl	Mg	Ca	Na	SO <sub>4</sub>	Hg	Cu	Pb	Zn	Mo	Co	Ni	Cd	Cr	Bi	Ba	Sr
Description	m/d/y		μS/cm	mV	mg/L as						ppm											ppb					
//1 D 1 D 1 W 11	06/01	6.4	240	27/4		0.500	0.002	-15			0.5	101	0.4	10	20.0	27/4	-50	-200	-20	76	1000	550	-0	-50	-20	-50	012
#1 Bucke Park Well	06/91	6.4	240	N/A	348	8.500	0.002	<5	<5	<5	8.5	101	84	18	29.9	N/A	<50	<200	<20	/6	1998	550	<2	<50	<20	<50	812
	07/91	7.1	N/A	N/A	345	5.920	0.038	<5	<5	<5	7.9	34	76	35	31.0	<0.1	<50	<200	<20	61	1620	450	<2	<50	34	<50	/63
	09/91	1.3	/30	+153	330	4.180	0.035	<5	<5	<5	8.8	34	/5	14	34.0	<0.1	<50	<200	<20	80	1559	425	<2	<50	24	<50	/55
	10/91	9.0	640	-82	430	9.280	0.093	<5	<5	<5	8.9	32	71	14	33.0	N/A	<50	<200	<20	60	1514	407	<2	<50	40	<50	/4/
#2 Well, Mileage 104	07/91	7.0	N/A	N/A	335	0.004	< 0.001	<5	<5	<5	183	34	126	252	71	< 0.1	<50	<200	29	<50	<10	<50	2	<50	<20	98	181
		1	1	r				1	1																1		
#3 Well, Mileage 104	07/91	7.0	N/A	N/A	355	0.002	< 0.001	<5	<5	<5	43	27	94	95	27	<0.1	<50	<200	436	<50	<10	<50	4	<50	<20	<50	144
	10/91	7.1	440	+312	360	0.001	< 0.001	<5	<5	<5	65.0	26	92	38	27.0	N/A	79	<200	1312	<50	<10	<50	<2	<50	41	<50	149
#4 Well, Mileage 104	07/91	6.9	520	N/A	245	0.002	0.002	<5	<5	<5	68	15	135	81	90	< 0.1	122	<200	277	<50	<10	<50	5	<50	<20	<50	471
	10/91	6.8	830	+353	315	< 0.001	0.001	<5	<5	<5	77.0	15	128	31	115.0	N/A	90	<200	329	<50	<10	<50	<2	<50	<20	<50	445
#5 Well, West Cobalt	07/91	6.9	N/A	N/A	245	0.003	0.002	<5	<5	<5	108	15	131	117	89	< 0.1	295	<200	1270	<50	<10	<50	7	<50	<20	<50	338
	10/91	6.9	980	+343	250	0.005	< 0.001	<5	<5	<5	125.0	15	132	49	117.0	N/A	150	<200	1101	<50	<10	<50	7	<50	<20	<50	363
	02/92	6.6	950	+312	465	< 0.001	< 0.001	<5	<5	<5	116.0	7	143	44	143.5	N/A	94	<200	1349	69	<10	<50	4	<50	<20	<50	385
	02/92	-	_	-	-	N/A	N/A	<5	<5	<5	N/A	8	146	44	N/A	N/A	66	<200	1369	61	<10	<50	3	<50	<20	<50	393
	5 minutes											-											-				
			1	r																					1		T
#6 Well, North Cobalt	07/91	7.5	130	N/A	235	0.004	< 0.001	<5	<5	<5	17	24	50	40	20	<0.1	<50	<200	<20	<50	<10	<50	<2	<50	23	<50	2100
	10/91	7.5	400	+275	255	< 0.001	< 0.001	<5	<5	<5	60.0	26	65	27	25.0	N/A	<50	<200	76	<50	<10	<50	<2	<50	36	<50	1970
#7 Well, North Cobalt	07/91	7.4	1790	N/A	325	0.002	0.001	<5	<5	<5	216	<5	<5	705	33	< 0.1	114	<200	<20	<50	<10	<50	<2	<50	<20	<50	12
,																											
#8 Well, North Cobalt	07/91	7.0	N/A	N/A	295	< 0.001	0.001	<5	<5	<5	221	50	150	88	44	<0.1	294	<200	443	<50	<10	<50	7	<50	29	<50	357
	10/91	9.1	1040	+82	295	0.002	< 0.001	<5	<5	<5	333.0	54	163	43	39.0	N/A	<50	<200	1120	<50	<10	<50	<2	<50	60	<50	468
	1	1	r	r	1		1	1	1								1								1		1
#9 Well, North Cobalt	07/91	7.1	520	N/A	340	0.002	< 0.001	<5	<5	<5	231	53	146	114	38	<0.1	<50	<200	338	<50	<10	<50	<2	<50	55	<50	316
#10 Well, North Cobalt	07/91	7.2	600	N/A	370	0.002	< 0.001	<5	<5	<5	166	43	140	35	40	< 0.1	<50	<200	38	<50	<10	<50	<2	<50	25	<50	261
,	10/91	7.1	700	+304	315	0.001	< 0.001	<5	<5	<5	168.0	43	142	15	34.0	N/A	54	<200	76	<50	<10	<50	<2	<50	47	<50	302

 Table 4.18:
 Trace element concentrations in groundwaters in the Cobalt area

Site Number and	Date	pН	Cond	Eh	Alk	As	Sb	Al	Mn	Fe	Cl	Mg	Ca	Na	SO <sub>4</sub>	Hg	Cu	Pb	Zn	Мо	Co	Ni	Cd	Cr	Bi	Ba	Sr
Description	m/d/y		μS/cm	mV	mg/L as CaCO3						ppm											ppb					
#11 Well, North Cobalt	07/91	7.3	220	N/A	295	0.002	< 0.001	<5	<5	<5	37	32	93	21	24	< 0.1	<50	<200	165	<50	<10	<50	<2	<50	<20	<50	110
	10/91	7.4	380	+317	310	0.002	< 0.001	<5	<5	<5	54.0	29	88	9	21.0	N/A	68	<200	185	<50	<10	<50	<2	<50	49	<50	126
#12 Wall North Coholt	07/01	7.2	260	N/A	280	0.001	<0.001	-5	-5	-5	21	27	104	24	24	<0.1	<50	<200	256	~50	<10	<50	2	<50	25	<50	172
#12 wen, North Cobait	10/91	7.3 9.0	710	-6	345	0.001	<0.001	<5	<5	<5	36.0	27	104	16	53.0	<0.1 N/A	<50	<200	330	<50	<10	<50	<2	<50	23	<50	183
	10/51	7.0	,10	Ű	5.15	0.000	0.001		Ŭ	÷	50.0	2.	100	10	22.0	1011		200	550		10	50		00	20	00	105
#13 Well, North Cobalt	07/91	7.2	N/A	N/A	445	< 0.001	0.001	<5	<5	<5	38	48	110	103	62	<0.1	<50	<200	101	<50	<10	<50	5	<50	38	<50	415
	10/91	7.1	220	+300	395	0.003	< 0.001	<5	<5	<5	53.0	38	96	36	42.0	N/A	<50	<200	51	<50	<10	<50	<2	<50	48	<50	323
#14 Well, West Cobalt	10/91	7.6	300	+312	210	0.003	< 0.001	<5	<5	<5	13.0	14	68	8	29.0	N/A	<50	<200	61	<50	<10	<50	<2	<50	<20	<50	262
	1		1	1	1			1									1			1	1	1					
#15 Well, West Cobalt	10/91	7.0	1020	+276	265	0.002	< 0.001	<5	<5	<5	110.0	24	120	30	65.0	N/A	<50	<200	925	<50	<10	<50	4	<50	26	<50	206
	10/91	-	-	-	-	0.001	< 0.001	<5	<5	<5	114.0	25	121	30	67.0	N/A	<50	<200	931	<50	<10	<50	10	<50	30	<50	201
	02/92 1 minute	6.6	920	+291	265	<0.001	<0.001	<5	<5	<5	115.0	10	128	38	N/A	N/A	<50	<200	832	52	<10	<50	<2	<50	<20	<50	201
	02/92	-	-	-	-	N/A	N/A	<5	<5	<5	N/A	10	127	38	N/A	N/A	<50	<200	797	52	<10	<50	3	<50	<20	<50	199
	5 minutes																										
#16 Well, Mileage 104	10/91	7.1	710	+307	370	0.003	< 0.001	<5	<5	<5	25.0	23	115	5	39.0	N/A	233	<200	71	<50	<10	<50	<2	<50	30	<50	149
#17 Wall Milanza 104	10/01	74	570	+204	275	0.002	<0.001	-5	-5	~5	26.0	24	05	5	47.0	N/A	400	<200	54	<50	<10	<50	~	<50	26	<50	105
#17 wen, wheage 104	10/91	7.4	570	1304	215	0.002	<0.001	<5	5	5	20.0	24	85	5	47.0	IN/A	400	~200	54	<50	<10	~50	~2	~ <u>50</u>	20	~30	105
#18 Well, North Cobalt	10/91	7.1	440	+321	200	0.002	< 0.001	<5	<5	<5	24.0	18	60	7	29.0	N/A	360	<200	<20	<50	<10	<50	<2	<50	<20	<50	75
#19 Well_North Cobalt	10/91	73	580	+242	330	0.002	<0.001	<5	<5	<5	31.0	24	83	15	22.0	N/A	<50	<200	101	<50	<10	<50	<2	<50	33	<50	97
wij wen, woni coour	10/ ) 1	1.5	500	1212	550	0.002	-0.001	~5	-5	-0	51.0	21	05	15	22.0	10/21	-50	-200	101	-50	-10	-50	-2	-50	55	-50	71
#20 Well, North Cobalt	10/91	7.8	450	+275	225	0.008	0.001	<5	<5	<5	0.66	24	49	14	20.0	N/A	<50	<200	<20	<50	<10	<50	<2	<50	25	<50	1799
#21 Well North Cobalt	10/91	72	740	+314	380	0.003	<0.001	<5	<5	<5	26.0	41	84	16	17.0	N/A	60	<200	47	<50	<10	< 50	-2	<50	/0	<50	30/
#21 wen, Worth Cobart	10/71	1.2	/40	1314	500	0.005	~0.001	~5	~5	2	20.0	41	04	10	17.0	10/24	0)	~200	47	~50	-10	~50	~2	~50	77	~50	574
#22 Well, North Cobalt	10/91	7.4	560	+325	280	0.002	< 0.001	<5	<5	<5	66.0	15	82	8	26.0	N/A	296	<200	111	<50	<10	<50	3	<50	24	<50	164
	10/91	-	-	-	-	0.002	< 0.001	<5	<5	<5	65.0	15	80	8	24.0	N/A	289	<200	112	<50	<10	<50	<2	<50	27	<50	157
	10/91*	6.5	330	+318	75	0.002	< 0.001	<5	<5	<5	65.0	13	33	8	24.0	N/A	<50	<200	49	<50	<10	<50	<2	<50	<20	<50	66

 Table 4.18 (continued):
 Trace element concentrations in groundwaters in the Cobalt area

\*sample was filtered with a Brita water filter

Site Number and	Date	pН	Cond	Eh	Alk	As	Sb	Al	Mn	Fe	Cl	Mg	Ca	Na	SO <sub>4</sub>	Hg	Cu	Pb	Zn	Mo	Co	Ni	Cd	Cr	Bi	Ba	Sr
Description	m/d/y		μS/cm	mV	mg/L as CaCO3						ppm											ppb					
#23 Well, North Cobalt	10/91	8.9	600	+145	N/A	0.013	< 0.001	<5	<5	<5	3.18	22	88	<5	58.0	N/A	112	<200	56	<50	<10	<50	<2	<50	32	<50	132
#24 Well, North Cobalt	10/91	9.4	470	+103	N/A	0.003	0.001	<5	<5	<5	52.0	14	59	16	17.0	N/A	<50	<200	<20	<50	<10	<50	<2	<50	<20	<50	123
#25 Well, Camp Monde Ami at Gillies Lake	09/91	N/A	150	N/A	N/A	<0.001	0.012	<5	<5	<5	0.4	<5	22	<5	14.0	N/A	<50	<200	61	<50	<10	<50	<2	<50	<20	<50	36
#26 DDH, Sharp Lake	10/91	7.4	190	+294	95	0.004	< 0.001	<5	<5	<5	1.92	8	34	<5	14.0	N/A	<50	<200	45	<50	<10	<50	<2	<50	<20	<50	91
#27 DDH, Sharp Lake	10/91	7.2	280	+285	195	0.004	< 0.001	<5	<5	<5	1.62	13	44	<5	4.2	N/A	<50	<200	<20	<50	<10	<50	<2	<50	21	<50	132
#28 Mine water,	06/91	9.3	70	N/A	18	3.050	0.006	<5	<5	<5	0.60	<5	<5	<5	7.0	0.2	<50	<200	<20	<50	<10	<50	<2	<50	<20	<50	<10
Nipissing	07/91	7.6	120	N/A	75	2.440	0.400	<5	<5	<5	0.30	<5	20	<5	8.6	0.2	<50	<200	<20	<50	102	<50	<2	<50	<20	<50	22
property	10/91	7.7	160	+291	80	3.710	0.592	<5	<5	<5	0.40	6	28	<5	14.0	0.12	<50	<200	21	<50	282	94	<2	<50	<20	<50	32
			-				-		1					•								•					
#29 Mine water, Nipissing property	10/91	7.7	280	+282	165	2.090	0.064	<5	<5	<5	4.10	11	47	<5	25.0	<0.1	<50	<200	66	<50	235	100	<2	<50	<20	<50	44
#30 Mine water,	07/91	7.1	260	N/A	190	4.640	0.080	<5	<5	<5	1.40	16	82	13	N/A	< 0.1	<50	<200	64	<50	585	143	<2	<50	<20	<50	110
Cart Lake	09/91	N/A	130	N/A	N/A	2.320	0.004	<5	<5	<5	1.40	15	69	<5	58.0	N/A	<50	<200	39	<50	269	75	<2	<50	<20	<50	88
#31 Mine water,	02/92	7.4	400	+253	205	0.780	0.050	<5	<5	<5	13.50	<5	66	8	33.3	N/A	<50	<200	72	<50	129	85	7	<50	<20	97	90
Sasaginaga Creek	05/92	7.0	440	N/A	185	0.980	0.045	< 0.2	0.07	0.5	14.40	5.8	86.1	9.7	30.7	N/A	<20	<100	558	<50	159	81	<20	<20	<200	<40	106

Table 4.18 (continued): Trace Element Concentrations in Groundwaters in the Cobalt Area

	рН	Eh mV	Alkalinity mg/L as CaCO <sub>3</sub>	Conductivity µS/cm
number of samples	47	30	45	43
mean	7.4	253	276	512
standard deviation	0.7	103	100	331
minimum	6.4	-82	18	70
	(GW Site #1)	(GW Site #1)	(GW Site #28)	(GW Site #28)
maximum	9.4	353	465	1790
	(GW Site #24)	(GW Site #4)	(GW Site #5)	(GW Site #7)

**Table 4.19:** Results of field geochemical measurements for groundwater samples

## 4.7.1 Groundwater Used for Consumption

Arsenic was detected in 32 of the samples from private wells. The highest As concentration is 0.013 ppm, in a well in North Cobalt which was drilled into conglomerate of the Coleman Member (GW Site #23). All other samples have As concentrations less than 0.008 ppm, and the mean As concentration for all of the wells with detectable As is  $0.003 \pm 0.002$  ppm.

Cadmium was detected in 14 samples, a much higher proportion than occurs in surface water or groundwater from other sources in the area. Cadmium concentrations range from 2 to 10 ppb, and in two wells cadmium was detected in samples collected in both July and October (GW Sites #5 and #15).

Silver, Co, Ni, V and Pb were not detected in any of the samples, and Se was not detected in any of the 15 samples for which Se analysis was done. Mercury was not detected in any of the 13 samples for which Hg analysis was done. Antimony was detected in 8 samples, and the highest Sb concentration is 0.002 ppm.

There are 36 well water samples that contain detectable Zn, and 18 that contain detectable Cu. The Zn concentrations range from 21 to 1369 ppb, and Zn concentrations are greater than 1000 ppb in 6 samples. The Cu concentrations range from 54 to 400 ppb, and there are 7 samples in which the Cu concentration is greater than 200 ppb.

None of the well water samples were analysed for cyanide.

One sample was collected from the well at Camp Monde Ami, a summer camp on Gillies Lake, just west of the study area (GW Site #25). This is a shallow well in a glacial fluvial sand deposit. Arsenic and heavy metals were not detected in this sample.

Four samples were collected from the well at Bucke Park on Lake Temiskaming (GW Site #1). Prior to the installation of the current well, the water for the park came from a diamond drill hole in the conglomerate of the Coleman Member, and the As concentration in the water was 9.10

ppm (Boyle, *et al.* 1967, sample #84). The new well is also in the conglomerate. Samples from this well have very high As concentrations, and high Co and Ni concentrations. These data are summarized in Table 4.20. Mercury was not detected in the two samples collected from this well for which a Hg analysis was done, and all other metals of concern were not detected or occur at low concentrations.

Statistics for the four samples collected	As (ppm)	Co (ppb)	Ni (ppb)
mean	6.97	1672	458
standard deviation	2.03	191	55
minimum	4.18	1514	407
maximum	9.28	1998	550

<b>Table 4.20:</b>	Arsenic.	Co and N	Ni concentr	ations in	samples	from the	Bucke	Park well
1 abic 1.20.	<sup>1</sup> moenne,		vi concenti	utions m	Sumples	monn une	Ducke	

One of the two diamond drill holes from which samples were collected is located in a clearing along a trail from Sasaginaga Lake to Sharp Lake (GW Site #27). During the winter this trail is used by snowmobilers, and water from this drill hole is used for consumption. This water contains 0.004 ppm As; all other metals of concern were not detected.

#### 4.7.2 Other Groundwater Samples

Groundwater samples were collected from 4 other sites in the Cobalt area (see Figure 4.11). Four of these sampling sites are mine workings, and samples from these sites contain As, as well as Co and Ni. Composition of these samples is summarized in Table 4.21. Mercury occurs in samples from GW Site #30, but was not detected in samples from other mine workings.

**Table 4.21:** Arsenic, Co and Ni concentrations in groundwater samples from mine workings

	As	Со	Ni
	(ppm)	(ppb)	(ppb)
GW Site #28 (3 samples)	$3.067\pm0.519$	$192\pm90$	94
		(<10 in 1 sample)	(<50 in 2 samples)
GW Site #29 (1 sample)	2.090	235	100
GW Site #30 (2 samples)	4.640, 2.320	585, 269	143, 75
GW Site #31 (2 samples)	0.780, 0.980	72, 159	<50, 81

## 4.7.3 Major Ion Concentrations in Groundwater

Major ion concentrations in groundwater samples are summarized in Table 4.22. The sample from GW Site #7 was collected after the water had passed through water softener; consequently, the Na and Cl concentrations in this sample are high and the Ca and Mg concentrations are low.

	Na (ppm)	Cl (ppm)	Mg (ppm)	Ca (ppm)	SO <sub>4</sub> (ppm)
number of samples	54	52	54	54	50
number of samples in which concentration is below detection limit	9	0	5	2	0
mean for samples in which concentration is above the detection limit	53	63	26	91	40
standard deviation	107	73	17	37	29
minimum	5 (GW Site #16 & #17)	0.3 (GW Site #28)	6 (GW Site #28)	20 (GW Site #28)	4.2 (GW Site #27)
maximum	705* (GW Site #7)	333 (GW Site #8)	101 (GW Site #1)	163 (GW Site #8)	143 (GW Site #5)

<b>Table 4.22:</b>	Major ion	concentrations in	n groundwater	samples
	··· <b>j</b> - · · ·		0	

\* sample collected from a home using a water softener.

# **5** Discussion of the Results of the Tailings, Surface Water and Groundwater Monitoring Programs

## 5.1 Tailings Geochemistry

#### 5.1.1 Crust Formation and Supergene Alteration Processes

The surface crusts occurring on the tailings are being formed by translocation processes like those which result in the formation of salt pans in arid areas (Singer and Munns 1987). In these processes, soluble ions are drawn to the tailings surface as water evaporates, like wax drawn up the wick of a burning candle. The evaporation of water at the surface causes these ions to precipitate due to supersaturation conditions in the residual water, forming surface crusts. Similar processes have been observed in sulfide-bearing tailings, forming gypsum and iron sulfate crusts and hardpan layers (Blowes and Jambor 1987, Jambor and Blowes 1991).

The crusts on the NLGM tailings are composed of sulfate minerals, particularly gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O) and thenardite (NaSO<sub>4</sub>). Substitution of other ions in these minerals is very limited. Given the high As concentrations in the surface crusts, arsenate minerals must be present in the crusts, however, no arsenate minerals were positively identifed by X-ray diffraction analysis. The presence of sulfate and arsenate minerals in the crusts is evidence that the oxidation of sulfide, sulfarsenide and arsenide minerals is occurring within the tailings alteration zones. These reactions were described by Boyle and Dass (1971) and were summarized in Section 2.1.3 (see Appendix 1 for a more detailed discussion).

These oxidation reactions are typified by the reactions for the oxidation of loellingite (FeAs<sub>2</sub>), arsenopyrite (FeAsS) and pyrite (FeS<sub>2</sub>)(after Boyle and Dass 1971, BC AMD Task Force 1989):

<u>EQ. 5.1:</u>	$\text{FeAs}_2 + 3\text{O}_2 + 2\text{H}_2\text{O} \Rightarrow \text{Fe}^{+2} + 2\text{AsO}_4^{-3} + 4\text{H}^+$
EQ. 5.2:	$4\text{FeAsS} + 13\text{O}_2 + 6\text{H}_2\text{O} \implies 4\text{Fe}^{+2} + 4\text{SO}_4^{-2} + 4\text{AsO}_4^{-3} + 12\text{H}^+$
EQ. 5.3:	$2FeS_2 + 7O_2 + 2H_2O \implies 2Fe^{+2} + 4SO_4^{-2} + 4H^+$

As illustrated by these reactions, the oxidation of arsenide, sulfarsenide and sulfide minerals is acid generating. Under such acid conditions, the metal ions produced during these oxidation reactions (Fe<sup>+2</sup>, as well as Ni<sup>+2</sup> and Co<sup>+2</sup> from Ni and Co bearing arsenides and sulfarsenides) are mobile.

The acid produced during oxidation reacts with carbonate minerals present in the tailings, raising the pH (all tailings groundwater samples are alkaline) and the alkalinity, according to reactions such as:

EQ. 5.4: 
$$CaCO_3 + H^+ \Rightarrow Ca^{+2} + HCO_3^-$$

The dissolution of carbonate minerals in the tailings is an important source of  $Ca^{+2}$  for the gypsum crusts.

The presence of thenardite crusts on the NLGM tailings is evidence that the dissolution of albite  $((Na,Ca)(Al,Si)_4O_8)$ , derived from the host rock, is also occurring in the alteration zone. This dissolution occurs as a result of the reaction of albite with H<sup>+</sup>, a reaction which contributes to the rise in pH, and produces the Na<sup>+</sup> ions required for the formation of thenardite. During this dissolution reaction the clay minerals kaolinite (white, stained red, brown or grey) and/or montmorillonite (grey, greenish grey, white, yellow, yellow-green, pink or brown) are formed (Freeze and Cherry 1979, Berry *et al.* 1983). Boyle and Dass (1971) did state that unidentified greenish clay minerals are forming in the alteration zones. These clay minerals may be the source of the greenish colour in the alteration zone.

As the pH increases, as a result of these dissolution reactions, the solubility of the metal ions decreases. Boyle and Dass (1971) stated that the  $Fe^{+2}$  may be oxidized to  $Fe^{+3}$ , and precipitate as limonite, or it may react with  $AsO_4^{-3}$  to form the arsenate mineral scorodite,  $Fe(AsO_4)\cdot 2H_2O$ :

<u>EQ. 5.5:</u>  $Fe^{+3} + AsO_4^{-3} + 2H_2O \Rightarrow Fe(AsO_4)^2H_2O$ 

Similarly,  $Ni^{+2}$  and  $Co^{+2}$  react to form annabergite ( $Ni_3(AsO_4)_2 \ 8H_2O$ ) and erythrite ( $Co_3(AsO_4)_2 \ 8H_2O$ ). Further oxidation of these arsenate minerals results in the formation of limonite, and the release of  $AsO_4^{-3}$ :

EQ. 5.6: FeAsO<sub>4</sub> 
$$2H_2O + xH_2O \Rightarrow$$
 FeO(OH)  $xH_2O + AsO_4^{-3} + 3H^+$ 

Secondary arsenate minerals were not identified in the alteration zone in the tailings, but limonite is present. The presence of limonite in the alteration zones, and arsenate minerals in the surface crusts provide evidence that the formation of scorodite, annabergite and erythrite may be occurring in the alteration zones.

Below a depth of 1 m in the tailings, it is difficult to determine what, if any, alteration reactions are occurring. The only data from deeper in the tailings are the groundwater geochemistry data. The Eh values measured in tailings groundwater samples are positive, so oxidation reactions may be occurring. A groundwater geochemistry modelling program such as WATEC4F could be used to help identify what reactions may be occurring. Using temperature, pH, Eh and the concentrations of dissolved ions, this program calculates the concentrations of the chemical species in solution, the activities and activity coefficients of the dissolved species, and through a series of iterative calculations it determines the state of saturation of the solution with respect to various solid phases (Drever 1988). Unfortunately, little is known about the thermodynamics and solubility of arsenide and sulfarsenide minerals, so these minerals are not in the database of WATEC4F or other similar programs. Therefore, these programs cannot be used to examine alteration processes within the tailings, although they can be used to predict solution speciation and phases which may be precipitating from solution.

#### 5.1.2 The Release of Contaminants from Tailings to the Environment

Tailings are a major source of contamination in surface water in the Cobalt area. Contaminants are mobilized by oxidation reactions and can be remobilized as a result of the dissolution of soluble secondary minerals, such as crust minerals.

The results of the leaching experiments can be used to estimate the rate of mobilization of As. These experiments result in the release of As from the tailings as a result of dissolution of soluble secondary minerals, and as a result of the oxidation of primary minerals. The proportion of the total As mobilized by each of these processes is not known, but because the experiments were conducted at room temperature, the dominant mechanism for the release of As in these experiments is likely the dissolution of secondary minerals. To more accurately reproduce 1.3 years worth of oxidation, the experiments should be repeated at a higher temperature (Hollebone, pers. comm. 1993).

In the two rounds of these experiments, 300 g of material were leached with the equivalent of 1.3 years worth of precipitation. Using the As concentration in leachate samples from the two runs of the experiment, the amount of As mobilized from 1 kg of material in 1 year can be estimated. These calculations underestimate the total amount of As mobilized, since the experiments do not take oxidation reactions into full account. For the tailings, the deposit surface area, and an assumed depth of alteration can be used to estimate the total amount of reactive tailings present. Using this estimate, the amount of As mobilized from each tailings deposit in 1 year can be estimated. These mobilization estimates are given in Table 5.1. Given the total surface area of the Farr Creek basin (64 km<sup>2</sup>), estimates of area covered by soil and till, and estimated thicknesses of these materials, the rate of mobilization of As from soil and glacial till can also be estimated (see Table 5.1).

From these calculations, it is evident that the As mobilization rates are highest in the NHGM tailings, but the total As mobilized is greatest in the NLGM tailings. The amount of As mobilized in soils within the Farr Creek basin is estimated to be 4000 kg less than the amount mobilized from the NLGM tailings, while the amount of As estimated to be mobilized from till is similar to the amount estimated to be mobilized in the Cart Lake tailings. While based on several assumptions, these estimates indicate that the mobilization of As from natural material does occur, and could contribute significantly to the contaminant load in the Farr Creek basin.

In all cases, except the soil A-horizon, the amount of As mobilized is greater when leached with "acid rain". During the period of the precipitation monitoring program, none of the precipitation received in Cobalt had a pH as low as that of the "acid rain" solution used in the experiment. From these calculations, it is evident that if Cobalt did receive such acidic precipitation on a regular basis, the rates of As mobilization in the tailings would be higher.

The mean As concentration in the NLGM samples from the leaching experiment is higher than the mean As concentration in groundwater samples from the NLGM tailings. The lower As concentration in the groundwater may be due to the fixing of As in secondary minerals, limonite or wad after it is mobilized. In the leaching experiments, because of the intensity of the leaching, and the fact that the leaching vessels were sealed to prevent the evaporation of water, there is little if any opportunity for secondary minerals to reform in the material being leached.

	Leaching solution	Rate of As mobilization mg/kg/yr	Surface Area m <sup>2</sup>	Assumed depth of alteration m	Mass of reactive tailings kg	Total As mobilized kg/yr
NHGM tailings	"Natural Rain"	507	2500	0.5	337500	171
NLGM tailings	"Acid Rain" "Natural Rain" "Acid Rain"	236 238	60069	0.5	81091800	198 19150 19300
Cart Lake tailings	"Natural Rain" "Acid Rain"	15 20	164668	1	444603600	6669 8892
Soil, A-horizon	"Natural Rain" "Acid Rain"	2.1 1.5	4.8 x 10 <sup>7</sup> (75% of area)	0.10 (assumed average thickness)	7.2 x 10 <sup>9</sup> (assumed density of 1.5 g/cm <sup>3</sup> )	15120 10800
Glacial till	"Natural Rain" "Acid Rain"	0.15 0.22	3.2 x 10 <sup>7</sup> (50% of area)	0.5 (assumed thickness of reactive till)	$4.32 \times 10^{10}$ (assumed density of 2.7 g/cm <sup>3</sup> )	6480 9504

**Table 5.1:** Estimated rates of mobilization of arsenic from tailings, soil and glacial till

The mean As concentration in the Cart Lake samples from the leaching experiment is lower than the mean As concentration in groundwater samples from the Cart Lake tailings. This may be related to the higher infiltration rates in the Cart Lake tailings, compared to the NHGM and NLGM tailings. As a result of these higher infiltration rates, the amount of secondary minerals forming in the top 75 cm of the Cart Lake tailings (the sample used for leaching was from a depth of about 50 to 75 cm in the tailings) is likely less than the amount of secondary minerals forming in the top 75 cm of the NHGM and NLGM tailings. Thus, in the sample from the Cart Lake tailings, there are less secondary minerals available to be dissolved during the experiment.

The amount of As released from the NLGM and Cart Lake tailings can be estimated, using annual precipitation data, the surface area, and an assumed rate of evaporation. For the NLGM tailings, with an assumed moisture loss by evaporation of 20%, the estimated amount of dissolved As released in surface runoff in the outlet from the NLGM tailings (Site #1) is 550 kg As per year. The As comes from As dissolved in groundwater discharging at dam #3, at the northeast end of the tailings, and from As dissolved in surface runoff as a result of the dissolution of surface crusts. This estimate of As released is much lower than the amount of As estimated to be mobilized in the NLGM tailings. The difference between these estimates is attributable to the fixing of As in secondary minerals, and the magnitude of the difference indicates that the cycling is As in the tailings is very significant. The data collected to date are

insufficient to estimate the fluxes associated with this cycling.

In the Cart Lake tailings, precipitation infiltrating into the tailings, flowing north, and discharging into the lake, releases an estimated 365 kg of As into Cart Lake each year. As at the NLGM tailings, this estimate is much lower that the estimate of the amount of As mobilized, but the proportion of mobilized As which is released is much higher.

In one sample of groundwater from the NLGM tailings, and one surface water sample from the outlet of the NLGM tailings, cyanide was detected, but cyanide was not detected in the bulk sample of NLGM tailings. Much of the cyanide discharged to the tailings was fixed in metallocyanide complexes with "cyanicide" metals such as Ni (Reid *et al.* 1922). Such complexes are quite stable, and cyanide occurring in this form cannot be detected with the analytical method used, which measures free  $CN^-$  dissolved from the tailings by NaOH (Leduc *et al.* 1982, Subramanian, pers.comm. 1992). Alteration processes may be resulting in the slow breakdown of these complexes, releasing small amounts of cyanide to the environment, and resulting in CN<sup>-</sup> being detected in tailings groundwater and surface runoff.

## 5.2 Surface Water Contamination

## 5.2.1 Natural Contamination

The surface waters in the Farr Creek basin contain high levels of As and other contaminants. A substantial portion of the contaminant load in the drainage basin is related to mine wastes, but there may also be natural contamination inputs. With their high concentrations of heavy metals, mineral deposits can be regarded as naturally occurring hazardous waste sites. In many cases, these natural hazardous waste sites, particularly those close to the surface, are leaking, resulting in natural contamination. Such natural contamination has been documented in many areas, such as the MacMillan Pass area of the Yukon, where natural acid rock drainage and associated high metal loadings are occurring at an as yet unmined mineral deposit (Kwong and Whitley 1992).

In the early days of Cobalt, many rich ore veins were right at the surface. These veins were rich not just in Ag, but in As and other potential contaminants. Often, the surfaces of these veins were oxidized, with only Ag and secondary minerals left in place. As a result of this oxidation, the ore deposits of Cobalt, like those of MacMillan Pass, were leaking contaminants into the environment, prior to any mining activity. While much of the Ag has now been mined, the potential for such natural contamination still exists.

Determining natural contaminant levels in an area with such a strong input of contamination from anthropogenic sources is difficult, but important. Knowing the natural contaminant levels could have legal implications for Agnico-Eagle Mines, who hold most of the mining properties in the Cobalt area. There are also potential implications for the way future mining regulations are drafted and applied, since background levels are not considered in current regulations.

## 5.2.1.1 Historical Evidence of Natural Contamination

No one collected water samples in 1903, when the deposits in Cobalt were discovered, but the descriptions of the area by early geologists, particularly Miller, the Provincial Geologist for Ontario, and Park, of the Geological Survey of Canada, provide indirect evidence of natural contamination in the Cobalt area. Both Miller (1903) and Park (1904) described veins on the LaRose, Nipissing and McKinley-Darragh properties. Details of their descriptions are given in Appendix 2.

All four veins showed evidence of weathering and oxidation. The Little Silver Vein on the Nipissing property was so intensely oxidized that Miller was not able to get a fresh sample of ore. The specimens he collected contained Ag and erythrite, and chemical analyses were completed on four samples. Compared to the analyses of unoxidized high grade ore, these oxidized samples appear to have been depleted in As. At another vein on the Nipissing property, several tons of erythrite were removed during the early working of the deposit. Erythrite also occurred at the LaRose vein and the McKinley-Darragh vein. Park (1904) reported that erythrite occurred at many places in the Cobalt area, including several locations along the shore of Cobalt Lake. At the LaRose vein and the Little Silver Vein, weathering had left large blocks of Ag at the base of the hills in which the veins occurred. At the McKinley-Darragh property, so much Ag occurred in the gravel beach at the south end of Cobalt Lake that the gravel was bagged and shipped as high grade ore. Silver is more resistant to oxidation than arsenide and sulfarsenide minerals. These occurrences of weathered Ag represent the residue of vein material from which all of the arsenide and sulfarsenide minerals have been removed by oxidation.

As discussed in Section 2.1.3, erythrite, as well as annabergite and scorodite, are unstable under intense oxidizing conditions, and will undergo further alteration, releasing the As to the environment. With the widespread occurrence of erythrite in the Cobalt area, further oxidation of the erythrite was undoubtedly occurring, resulting in the release to the environment of soluble As species.

Another historical account providing evidence of high natural contaminant levels in the Cobalt area prior to mining is found in the description of several veins on the Nipissing property. These veins were marked by the occurrence of dead saplings which were described as being "mummified", and so brittle that "when stepped on they broke with a crack like a pistol shot" (Murphy 1977). Normally, in a temperate, boreal forest area such as Cobalt, such dead growth would become overgrown with moss and underbrush and within a relatively short time, the wood would rot. Such brittle, "mummified" saplings are peculiar. It is possible that As, mobilized from the weathering of the veins over which these saplings grew, had preserved the wood. Arsenic is used as a wood preservative, and the wood and sawdust used in the construction of the dams at the NLGM tailings are intact, and dry, despite almost 80 years of exposure to the elements.

## 5.2.1.2 Evidence of Natural Contamination Gathered During this Study

Mining activity has had little impact on Short Lake (Site #15), so the contaminant levels in the lake can be considered representative of natural levels in the lake. The mean As concentration in
samples from Short Lake is 0.048 ppm, and the maximum acceptable concentration of As for freshwater aquatic life is 0.050 mg/L (CCREM 1987). Thus, the natural concentration of As in Short Lake is almost at the recommended limit for aquatic ecosystems.

The basin of Short Lake is situated largely within conglomerate of the Coleman Formation, and the Cobalt Lake Fault runs along the east shore of the lake (see Figure 2.2). The Cobalt Lake Fault continues north from Short Lake, along the eastern edge of Cobalt Lake and north through the Mill Creek valley. It cuts Coleman Formation rocks, and passes through some of the most intensely mineralized rocks in the area. This fault intersects several smaller east-west trending faults, and this fault system intersects numerous ore-bearing veins.

The high natural As concentrations in Short Lake likely result from groundwater discharge, as well as leaching from the Coleman Formation rocks under and around the lake. Groundwaters from the Coleman Formation contain among the highest As concentrations of any groundwaters in the area (MOE 1977, Boyle *et al.* 1967). Prior to mining, groundwater flow rates were higher along faults than along veins or fractures, and in the Short Lake, Cobalt Lake area, the flow of these naturally contaminated groundwaters is expected to have been concentrated along the Cobalt Lake Fault, and along the east-west trending faults (Whitehead 1920). Any discharge from this groundwater flow system would have introduced naturally contaminated water into the surface environment.

Natural contaminant inputs into Cobalt Lake are difficult to identify, but one can speculate that prior to mining, the natural contaminant levels in Cobalt Lake must have been a least as high as those in Short Lake. This hypothesis is based on the fact that the rocks around and under Cobalt Lake are much more strongly mineralized than those around Short Lake. If this hypothesis is correct, then the As levels in Cobalt Lake were always close to, or in excess of, the maximum acceptable As concentration for freshwater aquatic life (CCREM 1987).

North of Cobalt Lake there is further evidence of natural contamination. On the LaRose property is a small tailings deposit adjacent to Mill Creek. There is limited surface water drainage into these tailings, yet throughout the year there is at least 60 cm of water covering the tailings. The sample collected from this pond (Site #43) has an As concentration of 3.210 ppm. The Cobalt Lake Fault passes under this tailings area, and it is possible that groundwater discharge from the fault is occurring, keeping the area wet throughout the year, and contributing the high As levels.

In the south arm of Sasaginaga Creek, groundwater is discharging from a mine shaft (GW Site #31) adjacent to the creek. Upstream from this point (Site #40), the mean As concentration is 0.048 ppm. Water from the shaft has a mean As concentration of 0.880 ppm, and downstream (Site #41), as a result of groundwater discharge from the shaft, the mean As concentration in the creek is 0.371 ppm. Legally, this is a source of anthropogenic contamination, since the water is discharging from a mine shaft (Metal Mining Liquid Effluent Regulations of the Fisheries Act, 1977). However, the water is naturally contaminated as a result of flowing through mineralized rocks.

Samples from Farr Creek in North Cobalt (Site #28) and near the mouth of the creek at Lake Temiskaming (Site #29) provide further evidence of natural contamination. At the northern limit

of tailings migration (Site #33), the mean As concentration is 0.313 ppm, but downstream from this point, As concentrations in the creek water increase. In North Cobalt, the mean As concentration is 0.406 ppm, and near the mouth of the creek, the mean As concentration is 0.522 ppm. Downstream from Site #33, there is only one mine shaft within about 200 m of Farr Creek, and there are no visible waste rock piles or tailings. Thus, there is little potential for As input from anthropogenic sources along this portion of the creek. A possible source of the As along this portion of the creek is groundwater discharge from two major faults which control the course of the stream in the North Cobalt area, the north-northeast trending Mill Creek Fault and the northwest trending McKenzie Fault. These two faults intersect in North Cobalt about 200 m north of site #28 (Ontario Department of Mines, Map 2050, 1963). Through this portion of the creek, the area is underlain by Coleman Formation rocks and Archean volcanics.

During the current study, and the studies by the MOE (1977) and Boyle *et al.* (1967), 51 groundwater samples were collected from wells in North Cobalt, and south along Highway 567 to the Bucke Park road. Twenty-two of these samples were from wells in the Coleman Formation, and in 13 of these samples the As concentrations are greater than 0.005 ppm. In the 29 other samples, collected from wells in other rock units, the As concentrations are less than 0.005 ppm, and in 12 of the samples, no As was detected. As concluded by the MOE (1977), groundwater from the Coleman Formation contains higher As concentrations than groundwater in other rock units.

Both the Mill Creek Fault and the McKenzie Fault intersect the Coleman Formation. The higher As levels in groundwater from the Coleman Formation, and the occurrence of this formation along both of the faults which control the course of Farr Creek in the North Cobalt area, suggests that discharge along the fault zones, of groundwater containing high As concentrations, is possible. Such discharge could result in the increased As concentrations along Farr Creek.

# 5.2.2 Contaminant Levels in Surface Waters of the Farr Creek Basin, and Sources of Contamination

All of the surface water samples collected in the Farr Creek basin, except samples from Sasaginaga Lake, contain As concentrations close to or in excess of 0.050 mg/L, the maximum acceptable As concentration for freshwater aquatic life (CCREM 1987). The highest As concentrations occur in samples from the Mill Creek system, and in some of these samples, the concentrations of Hg and Ni are also in excess of the maximum acceptable limits for freshwater aquatic life. Arsenic concentrations are lower in the rest of the basin, and only As occurs at concentrations above acceptable limits.

Trends in As concentrations in the Mill Creek system were described in Section 4.9.1.2, and illustrated in Figure 4.8. In samples from this system, As concentrations range from 0.040 ppm in Short Lake (Site #15), to 6.050 ppm in Mill Creek at the Ontario Northland tracks (Site #4), with even higher As concentrations (up to 22.000 ppm) occurring in the outlets from the NHGM and NLGM tailings (Site #8 and #1, respectively). In Cobalt Lake and Mill Creek, As concentrations are 10 to 100 times the maximum acceptable limit for freshwater aquatic life.

In four samples from Mill Creek at the Ontario Northland tracks (Site #4), and Mill Creek at Highway 11B (Site #3), Hg concentrations are in excess of 0.1  $\mu$ g/L, the maximum acceptable limit for freshwater aquatic life (CCREM 1987). Nickel concentrations in excess of the maximum acceptable limit for freshwater aquatic life occur in four samples from Site #4.

Important sources of anthropogenic contamination in the Mill Creek system include the outlets from the NHGM and NLGM tailings (Site #8 and Site #1), and drainage from the pond on the LaRose tailings (Site #43)(as previously discussed, the source of the As in the pond may be natural, but legally this would be considered an anthropogenic discharge). There may also be contaminant inputs from the tailings in Cobalt Lake and Mill Creek.

The only contaminant of concern which occurs at concentrations close to or in excess of the maximum acceptable concentrations in samples from the Sasaginaga Creek system is As, and trends in As concentrations were described in Section 4.9.1.1, and illustrated in Figure 4.7. Samples have As concentrations ranging from <0.001 ppm in Sasaginaga Lake (Site #16), to 0.615 ppm in the south arm of the creek, downstream from the mine shaft discharging groundwater into the creek (Site #41), and the maximum acceptable As concentration is exceeded in all samples except those from Sasaginaga Lake, and one sample from the west arm of the creek (Site #35). Important sources of anthropogenic contamination in the Sasaginaga Creek system are the groundwater discharging from the mine shaft, the Hudson Bay tailings along the west arm of the creek, and the Chambers-Ferland tailings.

In the Peterson Creek system, As occurs in all samples at concentrations above the maximum acceptable limit, with concentrations ranging from 0.070 ppm in a sample from the outlet of a small wetland between Cart Lake and Peterson Lake (Site #23) to 4.050 ppm in a sample from the east lobe of Peterson Lake (Site #10). Important sources of anthropogenic contamination include the Cart Lake tailings, and tailings from the Nova Scotia Mine, located in the east lobe of Peterson Lake and on land adjacent to the lake. A waste rock pile at the Violet Mine, adjacent to the creek upstream of the Crosswise Lake tailings, is also contributing to the As contamination.

As in the Peterson Creek system, the only contaminant which occurs at concentrations above acceptable limits in the Farr Creek system is As, and trends in As concentrations in this system were described in Section 4.9.1.4 and illustrated in Figure 4.10. All of the water samples collected in this drainage system contain As concentrations which are in excess of the maximum acceptable concentration for freshwater aquatic life, with concentrations ranging from 0.058 ppm in a sample from Crosswise Lake (Site #12) to 0.557 ppm in a sample collected about 300 m upstream from Lake Temiskaming (Site #29). Important anthropogenic sources of contamination in Farr Creek include the Crosswise Lake tailings, and inputs from Peterson Creek and Mill Creek. As previously discussed, natural inputs may be responsible for the increase in As contamination downstream from the limit of tailings migration.

Using the monthly average water flow data at Site #33, calculated by Environment Canada on the basis of daily flow measurements from 1971 to 1983, and the As concentrations in monthly samples collected by the Ontario Ministry of the Environment at this location between January 1988 and March 1990 (see Appendix 4, Section A.4.1.9), and data from samples collected in this study, it is possible to estimate the mean annual amount of As discharged past this point.

The mean annual discharge is estimated to be 18000 kg of As. Using the mean plus one standard deviation gives an estimated maximum annual As discharge of 28000 kg, and using the mean minus one standard deviation gives an estimated minimum annual As discharge of 9000 kg. Hawley (1977) estimated the discharge to be about 30000 kg of As per year, but he did not state what data this estimate was based on. To put these numbers in perspective, the estimated annual anthropogenic As discharge worldwide is  $9.98 \times 10^7$  kg (CCREM 1987). At a discharge of 28000 kg of As per year, the Farr Creek discharge would represent 0.03 % of the total world anthropogenic As discharge. Even at the minimum estimated annual discharge of 9000 kg, the Farr Creek discharge would represent 0.03 % of the total.

#### 5.2.3 Arsenic Speciation in Surface Waters

Given the pH and Eh of a water sample, it is possible to predict which As species is predominant in the water. The stability fields of various As species in the As-H<sub>2</sub>O system at 25  $^{\circ}$ C are illustrated in an Eh-pH diagram, Figure 5.1. As part of its solution characteristics calculations, the water geochemistry modelling program, WATEC4F, will predict which As species are present, and given a total As concentration, the concentration of each species present is calculated.

Analytical data for samples from the north and south ends of Cobalt Lake (Site #18 and #7), the outlet from the NHGM tailings (Site #8), and Mill Creek at the Ontario Northland tracks (Site #4), collected in October, 1991, were examined using WATEC4F. In each of these samples, the WATEC4F calculations predict that the dominant As species is the As(+V) species,  $HASO_4^{-2}$ . Much smaller amounts of  $AsO_4^{-3}$  and  $H_2AsO_4^{-3}$  are also predicted to be present. No As(+III) species are predicted to be present.

Analytical data for samples from Sasaginaga Creek, 75 m and 500 m downstream from the confluence of the two arms of the creek (Site #38 and Site #37, respectively), collected in October, 1991, were also examined using WATEC4F. In both samples,  $HAsO_4^{-2}$  is predicted to be the dominant As species, and no As(+III) species are predicted to be present. However, the use of WATEC4F to examine the speciation of samples from Sasaginaga Creek may not be valid, because WATEC4F does not take into account the presence of organic chemicals or biological activity, both of which may be quite significant in Sasaginaga Creek, since this is a wetland area, and it receives town sewage from Cobalt. The speciation of As in natural waters, such as those of Sasaginaga Creek, is complex due to the activity of bacteria and other organisms. Bacteria can reduce As(+V) to As(+III) forms even when the pH and Eh favour the existence of As(+V). Some bacteria, algae and fungi are capable of methylating As to produce volatile di- or trimethylarsine, or soluble di- or trimethylarsinic acids (Cullen and Reimer 1989).

**Figure 5.1**: Eh-pH diagram for the As-H<sub>2</sub>O system at 25 °C. Total dissolved As is 0.050 ppm. The area within the vertical bars represents the common Eh-pH domain for natural water (after Cullen and Reimer 1989)



### 5.2.4 Effects of Wetlands on Contaminant Levels in Surface Waters

Sasaginaga Creek flows through an extensive wetland which is underlain by the Chambers-Ferland tailings. Samples were collected at two points within this wetland, one about 75 m downstream of the confluence of the two arms of the creek (Site #38), and another about 500 m further downstream (Site #37). Despite the fact that the creek is flowing across tailings, the As concentrations at Site #37 are lower than they are at Site #38. Similarly, the As concentrations are lower in samples from the outlet of the small wetland between Cart Lake and Peterson Lake (Site #23) than they are in samples from Cart Lake (Site #9). A similar trend occurs in a wetland downstream from Peterson Lake. In Farr Creek, the As concentrations in samples collected at the northern limit of tailings migration (Site #33) are similar to those in samples collected further upstream (Site #13), despite input from Mill Creek, and from the tailings which underlie the wetland.

From these results it is evident that wetlands are having an effect on the As concentrations in the streams which pass through them. This may be related to three factors: the coprecipitation of As

with iron oxides and hydroxides; the adsorption of As onto iron oxides, hydroxides, and organic matter in sediments; and biotransformations of As (CCREM 1987, Cullen and Reimer 1989). (Note that in the Sasaginaga Creek wetland, and the wetland between Cart Lake and Peterson Lake, there is little if any surface water input between the sampling points.) Under most conditions, coprecipitation or sorption of As with iron oxides or hydroxides is the dominant process in the removal of As from water (CCREM 1987). Based on the data collected in this study, it is not possible to determine which of these processes are occurring in the wetlands of the Farr Creek basin, and which is responsible for most of the removal of As from the water column.

### 5.2.5 Effects of Contamination on Aquatic Ecosystems of the Farr Creek Basin

Despite the high levels of contamination in surface waters of the Farr Creek basin, there is life in these water bodies. Of particular interest are common loons (*Gavia immer*) resident on Cobalt Lake and the east lobe of Peterson Lake. Loons have been resident on Cobalt Lake since 1990, and they have successfully bred while on the lake. Prior to 1990, loons resident on Sasaginaga Lake regularly visited Cobalt Lake in search of food (Anderson, pers.comm. 1993). It is not known how long loons have been resident on Peterson Lake.

Little if any research has been conducted examining the effects of As on loons (A. Scheuhammer, Canadian Wildlife Service, pers.comm. 1993), but Cuthbert (1992) examined the effects on loons of consuming yellow perch contaminated with Hg. Mercury is a contaminant of significant concern in surface water because it is biomagnified in food chains (Lindqvist 1991). Loons, as consumers of carnivorous fish, are near the top of the food chain, and are thus at risk from Hg contamination, even in cases where the Hg concentration in surface water is relatively low. Arsenic has not been reported to be biomagnified in food chains (CCREM 1987).

Yellow perch is an important prey fish for loons, and Cuthbert (1992) reported that mercury concentrations greater than 0.3 to 0.4 ppm, in prey such as yellow perch, is associated with reduced egg laying and other negative effects. The consumption of white suckers over 45 cm in length, caught in Peterson Lake, is restricted because of Hg concentrations in the 0.5 to 1.0 ppm range (MOE 1991). Loons have been reported to consume fish up to 50 cm long, although most of their food consists of fish 10 to 15 cm long. There is a strong correlation between fish length and Hg concentration, and Hg concentrations in yellow perch tend to be higher than those in white suckers of similar size (Cuthbert 1991).

On the basis of this evidence, it is likely that some of the fish consumed by loons on Peterson Lake do contain Hg concentrations greater than 0.3 to 0.4 ppm. Fish from Cobalt Lake have not been tested. However, on the basis of the composition of water from Cobalt Lake and Peterson Lake, it is likely that the Hg concentrations in fish from Cobalt Lake are at least as high as those in Peterson Lake. Thus, the health and breeding success of these loons may be threatened by Hg contamination in these lakes.

Loons are also present on Sasaginaga Lake, and the consumption of fish from Sasaginaga Lake is also restricted. Loons were not observed on Crosswise Lake, but only the northern portion of this large lake was observed. The consumption of yellow perch from Crosswise Lake over 15 cm in length is restricted because of Hg concentrations between 0.5 and 1.0 ppm, and yellow perch over 20 cm in length have Hg concentrations of 1.0 to 1.5 ppm. Other fish species in this lake also contain high levels of Hg. Thus, any loons resident on Crosswise Lake would be affected by these high Hg concentrations in prey fish.

The Hg may also be having adverse effects further down the food chain. Rainbow trout exposed to Hg concentrations of 0.12 to 0.24  $\mu$ g/L for 5 and 18 months experienced "substantial mortality", and a freshwater community (primary producers, herbivores and carnivorous midges) exposed to 0.1  $\mu$ g/L Hg for 1 year experienced reduced algal standing stock and diversity (U.S. EPA 1984).

In addition to loons, beavers are also resident in several water bodies in the Farr Creek basin, including Cobalt Lake and the pond on the LaRose tailings. As herbivores, the effects of Hg biomagnification on beavers are not as significant as those in carnivores, and the effects of As on beavers are not known.

In May, 1992, a large number of ducks, likely mallards or black ducks, were observed in an open area of water in the wetland along Sasaginaga Creek, near its confluence with Mill Creek. These birds are resident in this wetland throughout the year (Anderson, pers.comm. 1993). The effects which As and Hg may be having on these birds are not known.

### 5.3 Quality of Drinking Water Supplies

### 5.3.1 Quality of the Cobalt Town Water Supply

Drinking water for Cobalt is taken from Sasaginaga Lake. The intake is about 150 m offshore from sampling site #16. Arsenic was detected in 3 of the 4 samples collected from the lake, and the average As concentration is  $0.006 \pm 0.004$  ppm (range: 0.002 to 0.012 ppm, <0.001 in 1 sample). Under the Canadian Water Quality Guidelines, the maximum acceptable As concentration is 0.050 ppm (CCREM 1987). Thus, water from the lake contains As concentrations below the maximum acceptable limit.

Mercury analyses were completed for two samples, and Hg was not detected in either sample. Cadmium was detected in one sample at a concentration of 3 ppb, which is an acceptable concentration under the Canadian Water Quality Guidelines (CCREM 1987). Other metals of concern were not detected in any of the samples analysed.

Thus, while As is present in the Cobalt water supply, the concentration is well within acceptable limits, and is not of concern. This water does not contain any other metals in sufficient concentrations to be of concern.

### 5.3.2 Quality of Groundwater Supplies

Of the 53 groundwater samples collected, 39 were collected from 23 private well water supplies in West Cobalt, Mileage 104 and North Cobalt, three of the areas of concern identified by the Ontario Ministry of the Environment (MOE) in 1977. In 31 of these samples, As is present. The mean As concentration in these samples is  $0.003 \pm 0.002$  ppm, with a range of 0.001 to 0.013. The highest As concentration is in a sample taken from a deep well in North Cobalt (GW Site #23), which is used for consumption.

The occurrence of As in the areas sampled is lower than that reported by the MOE in 1977. In particular, As concentrations in samples from wells in Mileage 104 are much lower. Most of the wells in this area are new, deep wells which were installed as part of two different well replacement programs during the mid 1980's. According to local residents, water from these wells is tested annually by the MOE.

Cadmium was detected in 14 of the 39 well water samples, and the mean Cd concentration is  $5 \pm 2$  ppb (range: 2 to 10 ppb). The maximum acceptable Cd concentration in drinking water is 5  $\mu g/L$  (CCREM 1987). This concentration is exceeded in 4 samples. This is a much higher incidence of Cd than was reported by Boyle, *et al.* (1967) or by the MOE (1977). Taps were only run for about 1 minute prior to sampling, which is not a sufficient amount of time to flush the water from the pipes in a home, so it is possible that the Cd in these samples may be coming from solder in the pipes, rather than from the groundwater. The two wells in which Cd was detected in both July and October, 1991, were resampled in February, 1992. In February, samples were collected after running the water for 1 minute, and again after 5 minutes. The results of this resampling are inconclusive. In one well (Well #4) the Cd concentration dropped after flushing the pipes, while in the other well (Well #15) the sample collected after 5 minutes had a higher Cd concentration than that collected after 1 minute.

In one sample from GW Site #8, the Cl concentration is above the maximum acceptable concentration of 250 mg/L, but this water does not pose a health threat to those who consume it. Water is considered to be a minor contributor of Cl, and the guideline is set for the prevention of undesirable taste in water (CCREM 1987).

The four samples collected from the Bucke Park well (GW Site #1) contain contaminant levels which are of significant concern. The mean As concentration in these samples is  $6.97 \pm 2.03$  ppm, with concentrations ranging from just under 100 to almost 200 times the maximum acceptable As concentration of 0.05 mg/L (CCREM 1987). Data for the sample collected from the well in October 1991 were analysed using WATEC4F. The program predicts that the dominant As species is the As(+V) species, HAsO<sub>4</sub><sup>-2</sup>, and H<sub>2</sub>AsO<sub>4</sub><sup>-</sup> and AsO<sub>4</sub><sup>-3</sup> are also predicted to be present. The As(+III) species, H<sub>3</sub>AsO<sub>3(aq)</sub>, is predicted to be present, but at a concentration several orders of magnitude less than the As(+V) species. The Canadian Water Quality Guidelines cover only total As, and do not consider As speciation, but this dominance of As(+V) may be significant, since the toxicity of As(+V) is generally lower than that of As(+III)(see Appendix 5).

Water samples collected from the Bucke Park well also contain high concentrations of Co and Ni, but these metals are not covered under the Canadian Water Quality Guidelines for drinking water. No other metals occur in these samples at concentrations which are of concern.

### 5.4 **Possible Health Threats**

### 5.4.1 Potential Health Threats from Tailings and Other Solid Materials

The Nipissing low grade tailings may present a significant health threat to local residents. On the west side of the NLGM mill tailings there are several residences, and teenage children from these residences ride trail bikes on the tailings, disaggregating the surface crusts and generating large clouds of dust. Inevitably, the children inhale this dust, which contains As from the tailings and surface crusts. There is also a lot of dust around these tailings on windy days. Severe dust clouds were observed at this site in early November, 1991, and less severe clouds were observed throughout the summer, particularly during dry periods. The prevailing wind is from the west, so tailings are not blown toward the homes on the west side of the tailings on a regular basis, but there is a home at the northeast corner of the tailings, and dust frequently blows toward that home.

The NLGM tailings are typical of many others in the area, particularly the Buffalo and Coniagas tailings, within the Town of Cobalt (see Appendix 3). Homes and the Cobalt Public School are built on these tailings, and there are young children living in that area. These tailings are covered with soil, but they may pose a potential threat to residents in that area. No sampling was conducted in this area as part of the current study, but samples collected by Hawley (1977) contained high As and heavy metal concentrations.

The Cart Lake tailings contain lower levels of As and metals than the NLGM and NHGM tailings. No one lives adjacent to these tailings, and they are not used as extensively for recreation as are the NLGM tailings. As a result, these tailings, and others like them, such as the Glen Lake tailings about 1 km to the east, pose a limited health threat. The primary health hazard around these tailings is wind blown dust.

In October 1991, a class of about thirty students from Cobalt Public School was observed playing on the NLGM foundation for about 30 minutes. The class then proceeded on to the NHGM foundation, and then to the McKinley-Darragh foundation where they ate lunch. Along that route there is no clean water in which the children could have washed their hands prior to eating. This example illustrates that the mill foundations of Cobalt do present a health threat to local children, most of whom have likely done what these children did. These three mills are of particular concern since they are part of a tour maintained by the town, which tourists can follow to learn about the history of Cobalt. The Buffalo and Coniagas mill foundations were not tested, but they are also of concern. Most parents recognize the physical dangers to children playing on these foundations, but many, including the teacher of that class, do not recognize the chemical dangers (Anderson, per.comm, 1991).

The NHGM "stuff" contains very high levels of As and metals, and is a concern because it is

very close to the road to the Nip Lookout, on the NLGM foundation, which is frequented by tourists and local teenagers.

### 5.4.2 Potential Health Threats from Surface Water Contamination

At all sampling sites in the Farr Creek basin, except Sasaginaga Lake, As concentrations are close to or in excess of the maximum acceptable concentrations for drinking water and for freshwater aquatic life (CCREM 1987). None of these waters are used for consumption, but Cobalt Lake, Peterson Lake and Crosswise Lake are used for swimming. There are no guidelines for As content in surface water used for recreation (CCREM 1987). The high As levels in Cobalt Lake may pose a health threat to children who swim in the lake because of the possibility of swallowing water while swimming. Children were frequently observed swimming in the lake, about 100 m from sampling site #7.

Mercury was not detected in samples from Sasaginaga, Peterson or Crosswise Lake, but the consumption of fish from these lakes does pose a health hazard due to high Hg concentrations in the flesh of fish from these lakes (MOE 1991).

### **6** Conclusions and Recommendations

### 6.1 Conclusions

### 6.1.1 Tailings Alteration and Contaminant Mobilization

Supergene alteration reactions are occurring in the top 1 m of the tailings. In these reactions, arsenide, sulfarsenide and sulfide minerals are oxidized, releasing sulfuric acid, arsenic acid and metal ions. These acids are reacting with carbonate minerals and albite in the tailings, raising the pH of the tailings groundwater, and releasing  $Ca^{+2}$  and  $Na^+$  ions, while producing secondary clay minerals. The rise in pH lowers the solubility of the metal ions, causing the precipition of secondary iron oxides and possibly arsenate minerals within the alteration zone. At the tailings surface the evaporation of water draws solute laden water in the vadose zone to the surface. As further evaportion occurs, supersaturation is reached, and sulfate and arsenate minerals are precipitated at the surface as water soluble crusts.

These oxidation reactions are responsible for the mobilization of contaminants in tailings, particularly As. Based on laboratory experiments, the estimated rates of mobilization of As as as result of oxidation and dissolution of secondary minerals in the NLGM, NHGM and Cart Lake tailings are 236, 507 and 15 mg As per kilogram of tailings each year, respectively. Much of the mobilized As is fixed in secondary minerals, and as a result, estimates of the amounts of As released to surface water are much lower than the estimated mobilization concentrations. For the NLGM tailings, it is estimated that the discharge of tailings groundwater, and surface waters which have dissolved surface crusts, results in the release of about 550 kg of As into Mill Creek each year. For the Cart Lake tailings, it is estimated that the discharge of tailings groundwater into the lake releases about 365 kg of As into Cart Lake each year. Leaching experiments, conducted on soil and glacial till, also indicated that As is mobilized from these natural materials.

The erosion of tailings also results in the release of contaminants to surface water. It is estimated that erosion of the Nipissing low grade mill tailings south of dam #1 has resulted in the removal of about 123,000 tonnes of tailings (75% of the total originally present), and a significant amount of erosion has also occurred north of dam #1. Most of these tailings are now in Mill Creek, further contributing to the contamination of that water body.

### 6.1.2 Surface Water Contamination in the Farr Creek Drainage Basin

All of the surface waters in the Farr Creek drainage basin, except Sasaginaga Lake, contain As concentrations close to or in excess of the maximum acceptable As concentration for freshwater aquatic life (0.050 mg/L). Arsenic concentrations are highest in the Mill Creek system, and some samples from Mill Creek also contain Hg and Ni concentrations in excess of the maximum acceptable concentrations for fresh water aquatic life for these metals. It is estimated the mean annual discharge of As in Farr Creek is 18000 kg.

Arsenic occurs naturally in the rocks of the Cobalt area, and some of the As contamination may be due to natural inputs. Short Lake has been relatively unaffected by mining activity, and it is south of the main zone of mineralization, yet the As concentrations in the lake are very close to the maximum acceptable concentration for freshwater aquatic life. Significant natural input may also be occurring due to groundwater discharge in the LaRose tailings, and in Farr Creek around North Cobalt.

Tailings deposits such as the NLGM and NHGM tailings, the tailings in Cobalt Lake, and the Cart Lake tailings, are an important source of anthropogenic contamination. Another source of anthropogenic contamination is a mine shaft adjacent to Sasaginaga Creek which is discharging naturally contaminated groundwater into the creek. Contamination attributable to waste rock was observed at one location, and waste rock piles may also be important sources of contamination.

Using the water chemistry modelling program WATEC4F, it is predicted that As in surface waters is in the As(+V) oxidation state. However, this program does not take into account biological activity. Biotransformations of As can occur in surface waters, so the actual As speciation may be different than that predicted by WATEC4F, particularly in wetlands.

Wetlands appear to be having a remedial effect upon contaminant levels in surface water. In the wetland on Sasaginaga Creek, there is a decrease in the As concentration over a distance of about 500 m, despite the fact that tailings underlie the wetland. Decreases in As concentrations were also reported in wetlands in the Peterson Lake, Peterson Creek system. In Farr Creek, As concentrations in samples taken upstream and downstream from a large wetland are similar, despite the fact that the wetland is underlain by tailings, and the confluence of Mill Creek and Farr Creek is between the two sampling points.

### 6.1.3 Quality of Drinking Water Supplies in the Cobalt Area

Drinking water for the Town of Cobalt is drawn from Sasaginaga Lake, and there are no inorganic contaminants in this water which may be of concern to the residents of Cobalt.

Well water samples were collected from 23 private wells, and all samples have As concentrations which are within acceptable limits. Cadmium levels above acceptable concentrations were recorded in four samples, but it is likely that the source of the Cd is the solder in the pipes from these homes, rather than the groundwater. No other contaminants of concern were identified in samples from private wells. Thus, the groundwater supplies currently used for consumption in the Cobalt area contain no inorganic contaminants at concentrations of concern to the local residents.

The water supply at Bucke Park is of serious concern. Samples from this supply have a mean As concentration of 6.970 ppm. The maximum acceptable concentration is 0.050 mg/L. High concentrations of Co and Ni were also recorded in these samples, but there are no limits for these metals in drinking water.

### 6.1.4 Potential Health Threats due to Mine Wastes in the Cobalt Area

Wind blown tailings from the NLGM tailings may present a significant health threat to local residents who inhale the dust. People who ride trail bikes on the tailings may be at particular risk. Most of the homes adjacent to the tailings are upwind of the prevailing wind direction, but one home is located downwind of the tailings.

Concrete from mill foundations such as the NLGM and the NHGM contains high levels of As and Hg. These foundations are a playground for local children, and are visited by tourists. There may be health hazards associated with handling material from these foundations.

Throughout the summer of 1991, young people were seen swimming in Cobalt Lake and Crosswise Lake. Swimming in these lakes, particularly Cobalt Lake, may present a health hazard, particularly if water is swallowed.

### 6.2 **Recommendations for Further Research**

The current study is the most in-depth examination of the occurrence of As and heavy metal contamination which has been completed in the Cobalt area to date, but it is preliminary and broad in scope. As a result, it has raised as many questions as it has answered. This study is seen as laying the groundwork for more detailed studies of specific problems, and the author has a number of recommendations for further research in the Cobalt area.

# 6.2.1 Recommendations Relating to the Health of the Residents of Cobalt, and Visitors to the Area

This study identified a number of potential health threats to the residents of Cobalt, and to tourists who visit the area. Research is required to quantify these threats. The research recommendations are:

- 1. The Cobalt Public School is built on tailings from the mill at Coniagas Mine. Soil testing should be conducted around the school, and the health risk posed by these tailings to the students of the school and nearby residents should be assessed.
- 2. Soil testing should be conducted in the vicinity of homes built on tailings from the mill at the Buffalo Mine, in the southwest end of the town of Cobalt. The health risks to local residents should be assessed. Produce grown in the gardens at these homes should also be tested.
- 3. Wind blown dust from tailings presents a health hazard due to its high As content. The severity of this hazard to those who use the tailings for recreation, and those who live adjacent to tailings should be assessed.

- 4. The potential health risks associated with the contamination of mill foundations should be assessed.
- 5. The health risks associated with swimming in surface waters in the Cobalt area, particularly Cobalt Lake, should be assessed.

### 6.2.2 Recommendations Relating to Environmental Effects Monitoring

Despite the contaminant levels in the Cobalt area, plant and animal communities do exist. Monitoring of contaminant loadings is important, but it tells little about the effects which the contaminants have on the environment, particularly aquatic ecosystems. Studies can be conducted in the area to determine the environmental effects which high contaminant loadings are having. The goal of the studies is to determine how healthy the local environment is. Possible environmental effects monitoring study areas include:

- 1. Loons on Cobalt Lake and Peterson Lake, and waterfowl populations in wetlands along Sasaginaga Creek and Farr Creek should be examined, and compared with birds from other local lakes and wetlands. Are the females laying the normal number of eggs? Are offspring surviving? Samples of feathers, egg shells and feces should be analysed to monitor contaminant loading in the birds.
- 2. Beavers are resident in Cobalt Lake, the pond on the LaRose tailings, and Peterson Lake. Are these populations healthy? Are they breeding? Are the offspring surviving? Fur and feces samples should be collected to monitor contaminant loading in the beavers.
- 3. Fish are present in the local lakes and streams. What fish species are present? What are the community structures like compared to those in lakes and streams of similar size? Are these fish breeding successfully, and are the offspring surviving? What amphibians, reptiles and invertebrates are present? What is the invertebrate population density, and what is the population structure like compared to similar lakes and streams? What are the contaminant loadings in these organisms? How healthy are these aquatic ecosystems?

### 6.2.3 Recommendations for Biogeochemical Studies

- 1. On the basis of this study, it appears that wetlands may be playing a role in contaminant remediation. A biogeochemical study should be undertaken to determine the nature of chemical and biological transformations of As and other contaminants which are occurring within wetlands.
- 2. The current study measured only total As concentrations. Arsenic speciation analyses should be completed to determine the forms of As present in surface waters, and to identify where any species transformations may be occurring.

- 3. The current study did not examine tailings deposited underwater. The extent of tailings in lakes and creeks should be assessed. Core samples should be collected from lakes and creeks, to determine whether or not oxidation is occurring in the tailings, and to determine the rates of mobilization of As and metals from the tailings.
- 4. Research is required to determine the thermodynamic properties of arsenide and sulfarsenide minerals. Until such properties are known, it will not be possible to model the oxidation reactions in the tailings, or to model the rates of mobilization of the As and metals from the tailings. More detailed studies should be conducted to better understand the oxidation reactions which occur in the tailings, and the secondary minerals which result from these reactions.
- 5. Further experimental oxidation/leaching studies should be conducted. Experiments can be conducted at higher temperatures, to more accurately model oxidation over an extended period of time. Experiments can be conducted with tailings samples from a variety of depths, including samples of altered and unaltered tailings. These studies should focus us on trying to establish rates of oxidation. Sulfur and oxygen stable isotope studies conducted on leachate from these experiments may be helpful in identify reaction pathways and mechanisms for sulfarsenide minerals, but this approach cannot be used for arsenide minerals, since there is only one isotope of arsenic.

### 6.2.4 Recommendations for Studies to Determine Natural Arsenic and Heavy Metal Concentrations in the Area

Determining the natural contaminant inputs and the historical contamination levels, prior to mining in Cobalt, is difficult, but a number of studies could be conducted which could help to better understand the natural contaminant inputs to the local environment.

1. Hydrogeologic studies should be conducted to identify groundwater discharge zones. Seepage meters and multilevel piezometers should be installed in the pond on the LaRose property to determine whether or not groundwater is discharging into the pond. Seepage meters and multilevel piezometers should also be installed in the wetland on the Chambers-Ferland property, along the trace of the Valley Fault.

In North Cobalt, the Mill Creek Fault and the McKenzie Fault should be examined to determine whether or not groundwater discharge is occurring along them. The goal of these studies is to quantify the inputs of contaminants to surface waters which result from the discharge of naturally contaminated groundwaters.

2. Several types of organisms can be used to estimate As and metal concentration in the Cobalt area prior to mining. Red cedar has been used to monitor long term changes in contaminant levels in areas downwind of smelters, and could be used in Cobalt to determine historical soil contaminant levels (Zayed and Loranger 1992). To determine historical contaminant loadings in surface water, core samples can be collected from area lakes. Cores will have to be deep enough to include pre-1900 material. Fossils of

invertebrates and planktonic organisms such as diatoms can be analysed for As and metal concentrations, and radiometric techniques can be used to determine the ages of the fossils. Comparisons of As and metal concentrations in these fossils with recent samples of the same organisms will allow the pre-mining contaminant loads to be estimated. This approach has been used to determine pre-mining contaminant levels in lakes in the Sudbury area (Dixit, *et al.* 1992).

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# **Appendix 1**

### **Mineralogy of Cobalt Ores**

# A.1.1 Minerals occurring in the ore bearing veins in Cobalt (after Petruk 1971b and Boyle and Dass 1971)

Arsenides:

Nickeline	NiAs
Langisite	(Co,Ni)As
Safflorite	(Co,Fe,Ni)As <sub>2</sub>
Loellingite	FeAs <sub>2</sub>
Rammelsbergite, pararammelsbergite	NiAs <sub>2</sub>
Skutterudite	(Co,Fe,Ni)As <sub>3-X</sub>

Sulfarsenides:

Cobaltite	(Co,Fe,Ni)AsS
Gersdorffite	NiAsS
Arsenopyrite	FeAsS
Alloclastite	(Fe,Co)AsS

Antimonides:

Breithauptite	NiSb
Ullmannite	NiSbS
Allargentum	$Ag_{1-X}Sb_X$

Arsenates:

Erythrite	Co <sub>3</sub> (AsO <sub>4</sub> ) <sub>2</sub> <sup>.</sup> 8H <sub>2</sub> O
Annabergite	$Ni_3(AsO_4)_2 BH_2O$
Scorodite	$(Fe,Al)AsO_4^2H_2O$

### Sulfides:

Pyrargyrite	Ag <sub>3</sub> SbS <sub>3</sub>
Tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$
Chalcopyrite	CuFeS <sub>2</sub>
Bornite	Cu <sub>5</sub> FeS <sub>4</sub>
Galena	PbS
Marcasite, pyrite	FeS <sub>2</sub>
Sphalerite	(Zn,Fe,Mn)S
Pyrrhotite	Fe <sub>1-X</sub> S
Molybdenite	MoS <sub>2</sub>

Oxides:

Rutile	TiO <sub>2</sub>
Hematite	Fe <sub>2</sub> O <sub>3</sub>
Magnetite	Fe <sub>3</sub> O <sub>4</sub>
Anatase	TiO <sub>2</sub>
Ilmenite	FeTiO <sub>3</sub>

Sulfates:

Melanterite	FeSO <sub>4</sub> ·7H <sub>2</sub> O
Gypsum	CaSO <sub>4</sub> ·2H <sub>2</sub> O

### Silicates:

Quartz	SiO <sub>2</sub>
Chlorite	$(Mg,Fe)_{10}Al_2(SiAl)_8O_{20}(OH,F)_{16}$
Albite	(Na,Ca)(Al,Si) <sub>4</sub> O <sub>8</sub>

### Carbonates:

Calcite	CaCO <sub>3</sub>
Dolomite	CaMg(CO <sub>3</sub> ) <sub>2</sub>
Malachite	$Cu_2(CO_3)(OH)_2$

### <u>Hydroxides:</u>

Limonite: limonite is not a mineral of definite composition, but rather a mixture of several different minerals, including hydrated iron oxides and iron hydroxides. Limonite can also include amorphous iron hydroxides. The colour of limonite ranges from yellow to orange to brown to black, depending on composition and texture. A wide range of metals can be coprecipitated with, or adsorbed onto, limonite, making it an important sink for many metals in oxidizing environments

Wad: like limonite, wad is a mixture of minerals rather than a distinct mineral. Wad consists primarily of hydrated manganese oxides, which give it a black colour. Wad can also contain iron oxides and cobalt.

### A.1.2 Supergene Alteration of Silver-Bearing Veins

Many of the veins discovered in Cobalt showed evidence of supergene alteration (see Appendix 2 for the history of Cobalt, including some of the early geological descriptions). Four samples of oxidized ore from the Little Silver Vein had an average composition of 23.5% Ag, 4.5% Co, 2.2% Ni and 17.7% As. Such weathered ore was frequently enriched in Ag, as the supergene processes removed most of the other material from the veins (Van Hise 1907). In most cases the weathered zones did not persist to more than a few metres in depth, and unoxidized veins were frequently found at surface (Reid 1917). The exception to this was the Wood's Vein, which was in South Lorrain, southeast of Cobalt. The Wood's Vein included an intensely oxidized zone down to the 560 foot level, which consisted largely of a limonite-clay mixture (Bell 1923).

The supergene alteration processes which occur in veins in the Cobalt area were discussed in detail by Boyle and Dass (1971). This section is a summary of their discussion.

Supergene processes are mineral alteration processes that occur as a result of the interactions between minerals and water of surface origin. The mobility of elements involved in such reactions is controlled by the solubility of their salts, and the pH and Eh. As a result of the complex mineralogy of the Cobalt ores, phase relationships during alteration processes are complex, and solution compositions are constantly changing as new reactions occur. Thus, the alteration solutions are multicomponent systems which are not easily interpreted. Boyle and Dass (1971) based their discussion on the analyses of water samples and observed mineral products. Various minerals and elements are discussed separately.

### A.1.2.1 Iron, Manganese, Calcium and Magnesium

In the veins, dolomite, calcite, Fe-arsenides, arsenopyrite and pyrite are abundant, and influence reactions in oxidation zones. In zones of oxidation Fe occurs in limonite and scorodite, Mn in wad and Ca and Mg in secondary carbonates.

When dolomite and calcite react with water containing dissolved CO<sub>2</sub>, soluble secondary bicarbonate and carbonate minerals are produced:

 $MgCO_3 (Mg \text{ component}) + H_2O + CO_2 \Rightarrow Mg(HCO_3)_2$  $CaCO_3 (Ca \text{ component}) + H_2O + CO_2 \Rightarrow Ca(HCO_3)_2$ 

When arsenopyrite is oxidized, ferric arsenate and sulfuric acid are produced:

 $2\text{FeAsS} + 7\text{O}_2 + 2\text{H}_2\text{O} \Rightarrow 2\text{FeAsO}_4 + 2\text{H}_2\text{SO}_4$ 

The oxidation of pyrite yields ferrous sulfate and sulfuric acid:

 $2FeS_2 + 7O_2 + 2H_2O \Longrightarrow 2FeSO_4 + 2H_2SO_4$ 

The sulfuric acid from these reactions immediately reacts with carbonates, raising the pH and producing soluble Fe, Mn, Ca and Mg sulfates, according to reactions such as the following:

$$FeCO_3 + H_2SO_4 \Longrightarrow FeSO_4 + H_2CO_3$$

If there is little available water, the oxidized Fe may be precipitated as melanterite or some other hydrated sulfate. These minerals are water soluble and will redissolve during an influx of water. Where water is available, most Fe is fixed in the ferric oxide mineral limonite. The formation of limonite from ferrous sulfate is described by the following reactions:

1) At a pH of about 2.5, ferrous sulfate is oxidized to ferric sulfate and hydrous ferric oxide:

$$12\text{FeSO}_4 + 6\text{O}_2 + x\text{H}_2\text{O} \Longrightarrow 4\text{Fe}(\text{SO}_4)_3 + 4\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$$

2) Hydrolysis of ferric sulfate occurs, forming hydrous ferric oxide and sulfuric acid:

$$Fe(SO_4)_3 + xH_2O \Longrightarrow Fe_2O_3 \cdot xH_2O + 3H_2SO_4$$

3) Splitting water from the hydrous ferric oxides yields limonite (FeOOH).

A similar series of reactions produces limonite from Fe(HCO<sub>3</sub>)<sub>2</sub>.

The chemistry of Mn in oxidized zones is similar to that of Fe. Once Mn is released as manganous sulfate or manganous hydrogen sulfate, much of the Mn is bound in wad  $(MnO_2)$ . Wad may coprecipitate with limonite, depending on the pH of the solution.

If arsenides are abundant, some Fe may be bound in scorodite, (Fe,Al)(AsO<sub>4</sub>)<sup>2</sup>H<sub>2</sub>O. If prolonged leaching occurs, the arsenate component may be removed, leaving the Fe bound as limonite.

In oxidized zones, the Ca and Mg released from calcite and dolomite may be reprecipitated, while much of the Mg may be precipitated as a greenish clay mineral, possibly chlorite.

### A.1.2.2 Alkalies, Silica and Alumina

Both Na and K are highly mobile under oxidizing and reducing conditions, and their mobility is not affected by pH. The mobility of silica is independent of pH in the range of 2 to 8, but above pH 8 the solubility of silica increases considerably. The mobility of Al is strongly pH dependant: below pH 4 and above pH 10, Al<sub>2</sub>O<sub>3</sub> is soluble, but from pH 6 to 8 it is relatively insoluble.

In the Cobalt area, alkalies, silica and alumina occur mainly in the wall rock, but they also occur in small amounts in the veins in the form of quartz, chlorite and carbonates. Sulfuric acid released during the oxidation of sulfide minerals attacks silicates and quartz. The alkalies are released as soluble carbonates, hydrogen carbonates, sulfates and arsenates. Silica is released in the form of alkali silicates or monosilicic acid. Aluminum is released as a soluble sulfate or as an alkali sulfate.

Once in solution, some of the Na and K are precipitated as secondary clay minerals. Similarly, much of the Al is bound as clay minerals and chlorite. Some of the Al is bound in limonite, wad and scorodite, as a result of coprecipitation with hydrous ferric oxide between pH 5 to 7.5. Much of the silica is bound as microcrystalline quartz in limonite and wad. Large amounts of silica are also bound in clay minerals which are often intimately mixed with limonite and other secondary minerals.

### A.1.2.3 Sulfur

In the veins of the Cobalt area, the primary S occurs in sulfides and sulfarsenides. During oxidation, most of the S is oxidized to  $SO_4$ . In dry environments, the sulfate is precipitated as melanterite and amorphous sulfates. Based on the large amounts of  $SO_4$  known to occur in limonite-clay precipitates, Boyle and Dass (1971) concluded that sulfates are also occurring in these precipitates, but the nature of these sulfates is unknown.

### A.1.2.4 Arsenic

Most As occurs as Ni, Co and Fe arsenides and sulfarsenides. The main secondary As minerals are scorodite, annabergite and erythrite. The reactions involved in the oxidation of arsenide minerals are complex, and not completely understood. Starting with arsenopyrite, the first step in oxidation yields ferrous sulfate and arsenious oxide, which is oxidized immediately to produce arsenic acid. The simplified equation is:

$$4FeAsS + 13O_2 + 6H_2O \Longrightarrow 4FeSO_4 + 4H_3AsO_4$$

Similar equations can be written for the oxidation of cobaltite and gersdorffite. Further reactions are controlled by pH and Eh. In acid environments the Fe, Co, Ni and As are mobile and may be completely removed. When carbonates are present and neutralization occurs, dissolved Fe may be oxidized and precipitate as limonite, or it may react with arsenic acid and precipitate as scorodite. Dissolved Co and Ni react with arsenates and yield erythrite and annabergite. The

equations for these reactions are:

 $\begin{aligned} &Fe_2(SO_4)_3 + 2H_3AsO_4 + 4H_2O \Rightarrow 2Fe(AsO_4) 2H_2O \text{ [scorodite]} + 3H_2SO_4 \\ &3CoSO_4 + 2H_3AsO_4 + 8H_2O \Rightarrow Co_3(AsO_4)_2 8H_2O \text{ [erythrite]} + 3H_2SO_4 \\ &3NiSO_4 + 2H_3AsO_4 + 8H_2O \Rightarrow Ni_3(AsO_4)_2 8H_2O \text{ [annabergite]} + 3H_2SO_4 \end{aligned}$ 

Scorodite, annabergite and erythrite may also coprecipitate in a mixture with limonite and wad, as a result of the aging of colloidal, gel-like precipitates. The simplified equations for the production of scorodite from a colloid are:

$$Fe(OH) + H_3AsO_4 \Rightarrow Fe(OH)_3 AsO_4 + 3H^+$$
$$Fe(OH)_3 AsO_4 + 3H^+ \Rightarrow FeAsO_4 2H_2O [scorodite] + H_2O$$

Boyle and Dass (1971) derived similar equations for the formation of erythrite and annabergite.

Other arseniferous minerals such as rammelsbergite and safflorite oxidize in a similar series of steps, yielding annabergite and erythrite.

Under intense weathering, scorodite, erythrite and annabergite will be leached. Scorodite alters to limonite, freeing the As as arsenic acid and/or soluble arsenates:

 $FeAsO_4 H_2O + xH_2O \Rightarrow FeO(OH) xH_2O [limonite] + H_3AsO_4$ 

This reaction will remove As from the oxidized zone, and similar reactions will remove Ni and Co.

### A.1.2.5 Nickel and Cobalt

Arsenides are the main Ni and Co bearing minerals. As discussed in the previous section, during oxidation at near neutral to alkaline conditions these minerals are altered to annabergite and erythrite. Under prolonged oxidation, these minerals become unstable and the Ni and Co components are remove in solution. Both metals have a high mobility in acid solutions, but are less mobile under neutral and alkaline solutions. Considerable amounts of Ni and Co are adsorbed and/or coprecipitated by limonite and wad.

### A.1.2.6 Copper, Lead, Zinc and Cadmium

These metals occur primarily in sulfide minerals, and they occur in small quantities in the Cobalt area. During oxidation some Cu is retained in the carbonates malachite and azurite, and some Pb is retained in anglesite, also a carbonate. Zinc and Cd do not occur in any secondary mineral. All four metals are adsorbed and/or coprecipitated by limonite and wad.

# **Appendix 2:**

# The Discovery of the Cobalt Silver Deposits, and the History of their Development

The first topographical and geological survey of the Nipissing District of Ontario, in which Cobalt lies, was commenced by A.E. Barlow of the Geological Survey of Canada in 1887 and 1888, and completed in the summers of 1892 through 1895. The results of this Survey are published in the 1897 annual report of the Geological Survey of Canada. At that time, the major waterways of the area were well known, having been used as fur trading routes for many years, and the villages of Haileybury and New Liskeard were being established. The only mine in the area was the Wright Silver Mine on the Quebec side of Lake Temiskaming, about 8 miles east of Cobalt. During Barlow's survey the major lakes and rivers as well as portage routes were mapped, major lithological units were mapped and described, accompanied by a description of the economic geology of the area, glacial deposits and soil. Notes on the climate were made, timber and fishing resources were noted, and animal populations were described. Even the local native populations were briefly described. These descriptions of the area are an important window to the past, giving contemporary researchers a picture of the area prior to development.

Included in the geological section is a description of the diabase units later called the Nipissing Diabase. Samples from this unit were collected from the cliffs around Devils Rock, just south of the current location of Bucke Park, in Bucke Township, and variations in the unit were noted in a small clearing on the lake shore south of the mouth of Farr Creek, likely the current location of Bucke Park. A traverse from Haileybury to Bay Lake, on the Montreal River, was also completed. On this traverse, a wagon road was taken from Haileybury to the north end of Sharp Lake, a route which skirted north of the mineralized area. Along this road there were no outcrops due to deep glacial deposits, but some of the finest cedar and poplar trees in all of the Nipissing District occurred along the road. Cobalt Group rocks and diabase along the shores of Sharp Lake were described, but no mineralization was observed. From Sharp Lake a portage was taken to Mud Lake and from there another portage was taken to Clear Lake and on to Sasaginaga Lake. The shores of Sasaginaga Lake were well wooded and surrounded by diabase, as well as some slate and volcanics. No mineralization was observed. A portage route from Sasaginaga Lake to Farr Creek existed, but was not followed (Barlow 1897). Thus, while Barlow came very close to the silver deposits, he never discovered them. It would be eight years after his final work in the region before the deposits were found.

The towns of New Liskeard and Haileybury on Lake Temiskaming were both established in the 1890's, but at that time the only way to reach the towns was by canoe, or by steamer up the lake in the summer. Only a few hundred people lived in the area, but there was a push to build a train line north from North Bay to New Liskeard. Initially there was commercial interest in the project, but this faded, and in the end, the Ontario Government decided to build the line. By the summer of 1903 the line, the Temiskaming and Northern Ontario, was getting close to Haileybury (Barnes 1986).

Numerous contractors were employed in the construction. (Because of the extensive use of contractors prior to 1906, there are no survey notes from this period in the archives of the Ontario Northland Railway. Such notes could provide further insight into conditions prior to mining.) Among the contractors were James McKinley and Ernest Darragh who were supplying ties for the line. In the summer of 1903 they were working north of the Montreal River, ahead of the rail line itself. They and others had seen mineral outcroppings but they had no idea what metals might be present. To relieve the tedium of searching for good trees for ties they had considered staking a claim, more as a lark than any attempt at serious prospecting (Barnes 1986).

About five miles south of Haileybury was a boot shaped lake called Long Lake. On a beach along the south shore of the lake McKinley and Darragh found some pebbles which contained some metal flakes. They did not know what the metal was, but on August 15, 1903 they staked a claim, and later sent a few samples to an assayer in Montreal. In the fall they got the results back, indicating that the samples graded 4,000 oz/ton silver (Murphy 1977).

In the meantime, Fred LaRose had a small cabin at the north end of the lake, near the Mile 103 post of the line. LaRose had noticed cobalt bloom on the rocks in the area. To quote LaRose "One evening I found a float, a piece as big as my hand, with little sharp points all over it. I say nothing but come back and the next night I take pick and look for the vein. The second evening I found it." Within a few weeks, what were to become the McKinley-Darragh and the LaRose mines had been discovered. In October, what was to become the Nipissing Mine was discovered (Barnes 1986). During the staking of this property, by the owner of a local hotel, four engineers from the railway, and a lumberman who had made the initial discovery, several more veins were discovered. These veins were marked by unusual obstacles: "These -- piled high in disarray on or near shallow earthen patches -- were clusters of sapling carcases, most of them toppled long since and mummified. All, however, were brittle; when stepped on they broke with a crack like a pistol shot" (Murphy 1977). Normally such fallen saplings would rot quickly, and be overgrown with moss or fungus.

In November, the Provincial Geologist of Ontario, Willet Miller, was sent to the area to find out more about the discoveries. The results of his work were published in the 1903 Annual Report of the Ontario Bureau of Mines. Miller returned in early 1904, and William Park of the Geological Survey of Canada went to the area in September 1904. The results of his work were published in the 1904 Annual Report of the Geological Survey of Canada. In 1903, Miller inspected four newly discovered veins, and assessed the potential for more veins being discovered. Some samples were collected for geochemistry. The same veins were visited by Park in 1904.

The first vein inspected was the vein discovered by LaRose, which lay just east of the rail line, at the edge of a swamp. The vein was exposed in three places, and "on weathered surfaces the vein matter is coated with the beautiful pink decomposition product, cobalt bloom" (Miller 1903). At that time it was difficult to determine the extent of the vein, but when Park saw the vein a year later, he concluded that the vein did not pinch out to the north east, but continued into the swamp. At the base of the slope, below the vein, were "lumps of weathered ore weighing from 10 to 50 lb. carrying a high percentage of silver" (Miller 1903).

The second vein inspected was a few hundred yards up the hill on the east side of the lake, later

known as Nip Hill. The vein contained little silver, but abundant nickel and cobalt. "Wherever the veinstuff is fractured, erythrite appears on the surface and is found also to occupy secondary cavities in the ore body. Several tons of cobalt bloom were taken from one such opening in the work of exploiting the deposit" (Park 1904). Cobalt bloom also occurred in the wall rock adjacent to the vein (Miller 1903).

In going from this vein to the next vein, both Miller and Park walked along the east shore of the lake, and Park (1904) reported that "at several points, along the water's edge and elsewhere on this location, cobalt bloom has been found in small quantities, all pointing to the remarkable dissemination of cobalt in this vicinity."

The third vein inspected was the Little Silver Vein, which was located on the side of a deep ravine south east of the lake. The ravine contained a small creek which drained to the lake (Park 1904). The vein extended up the ravine 64 feet, and was very rich in silver. However, Miller (1903) reported that "it was found impossible to get a fresh sample of the ore with the prospecting pick, the vein being so much decomposed. The weathered specimens, however, in addition to the native silver, contained cobalt bloom; and the unaltered ore will be found, in all probability." At the base of the hill were "pieces of native silver as big as stove lids and cannon balls...as well as cobalt bloom and niccolite" (Murphy 1977). The vein continued east from the top of the ravine for at least 50 feet, beyond which the overlying soil had not yet been removed. "Loose silver is common in immediate proximity to the vein; every depression in the rock on the top of the hill contains much free silver. The earth occupying these depressions is deemed by the owners of sufficient value to sack and ship for treatment" (at that time it was only profitable to ship high grade ore)(Park 1904). Four earthy, weathered ore samples collected by Miller (1903) had an average composition of 23.5% Ag, 4.5% Co, 2.2% Ni and 17.7% As. Compared with the results of 150 geochemical analyses of ore samples compiled by Petruk (1971b), in which all of the ore analysed contained high levels of As, in the range of 31.9 to 64.8 weight %, and compared with the results of the analyses of samples collected by Miller at other veins, these four samples of weathered ore from the Little Silver Vein were highly depleted in As.

The final vein inspected by Miller and Park was the vein at the south end of the lake, discovered by McKinley and Darragh. The vein was along the side of a small bluff, parallel to the lake shore and about 40 feet inland. It was similar to the others, and also coated with cobalt bloom. Early in the development of the McKinley Darragh Mine, a great deal of free silver was found in the gravel on the shore of the lake, which was bagged and shipped for processing (Ontario Bureau of Mines 1906).

From his visit in the fall of 1903, Miller concluded that, "The ore is undoubtedly very rich, containing values of nickel, cobalt, silver and arsenic, and a comparatively small vein could be worked at a handsome profit". Despite these discoveries, there was no great staking rush in the spring of 1904. Many were convinced that there were no precious metals east of the Rocky Mountains, and that this discovery would fizzle and fade like earlier ones, such as a silver discovery near Fort William in the 1880's in which many investors lost out (Murphy 1977). However, some prospectors did come to the area, and more ground was staked, including the ground for the Coniagas, Tretheway, Buffalo and O'Brien Mines. It was also in the spring of 1904 that Willet Miller named the new camp Cobalt and renamed Long Lake, Cobalt Lake

(Barnes 1986).

During the summer of 1904 a small shaft was sunk on the LaRose property with the backing of the Timmins brothers from North Bay (Baldwin and Dunn 1988). During his visit to the area in September 1904, Park reported that "cobalt bloom has been observed at many places throughout the region, and it is a reasonable assumption that other valuable properties will be located as the region is more thoroughly prospected." Thus, by the end of 1904, the future of the area looked bright, and the prospect of further silver discoveries was good.

Word began to spread that the discovery at Cobalt was no hoax, and prospectors and developers began to flood into the area. By late 1905 there were sixteen mines in the area employing 438 men and shipping \$1,366,000 worth of ore (Barnes 1986). Permanent though crude buildings replaced the tents of the previous year, and the town became more established, although growth was haphazard and anything but carefully planned (Baldwin and Dunn 1988).

The mines at that time were all very small and most were simple operations. Ore was mined with picks, hammers and drilling bars and hoisted to the surface by hand. Profits were huge; in 1906 \$2,000,000 worth of ore was shipped (Barnes 1986). As the richest surface veins were exhausted, the exploration for new veins intensified and existing mines started to go deeper. By 1909, the following depths were attained at some of the mines: Nipissing, 200 feet, LaRose, 325 feet, Central Cobalt, 400 feet, McKinley Darragh, 250 feet, and Nova Scotia, 350 feet. In 1908, Cobalt supplied nearly 9% of the world's total silver production (Higgins 1909).

Since most of the veins in Cobalt were surface veins or near surface veins, the best way to explore for new veins was to expose the rocks at the surface. The main way to do this was to denude the slopes of trees, and then dig trenches in grid like patterns. However, prospectors for the Nipissing Mine developed a more effective way of exposing the rock, to the detriment of Cobalt Lake and Peterson Lake. In 1906 they began using high pressure water, pumped from Peterson Lake at a rate of 1,800 gallons a minute, to wash the rocks clean and expose the veins (Ontario Bureau of Mines 1906). This caused a huge amount of sediment to run into both lakes, and it left the hill opposite the town, known as "Nip Hill", completely bare of trees. The following account of the effect of this operation on Cobalt Lake was written in 1913: "Formerly the water used to be tolerably clear; now it is tainted or yellow green, and is opaque, due largely or wholly to the powerful water hydrant of the Nipissing Mine clearing away the earth and clay from the surface of Nip Hill...Moreover, there is a portion of the south end of the Lake now being rapidly filled up by the slimes or tailings from the mills" (Baldwin and Dunn 1988).

Many of the veins which occurred on land were known to pass into the beds of the local lakes. Some mines extended workings under the lakes to remove this ore. In 1906, a mining company on Peterson Lake began cutting a 1,000 foot outlet from the north end of the lake, draining into Farr Creek. This would expose a great deal of Peterson Lake, which is quite shallow, and would have completely drained Cart Lake, which was only 8 feet deep (Ontario Bureau of Mines 1906). No further references to this channel are known, and it is not thought that the project was completed. A photograph of Peterson Lake near the Nova Scotia Mine in the 1910 Ontario Bureau of Mines Report shows the lake level to be very close to its 1991 level. In 1913 a decision was made to drain Cobalt Lake and work deposits under the lake bed. One company, the Cobalt Lake Mine, had bought the mineral rights to the lake and the McKinley-Darragh Mine also had interests in deposits under the lake. This decision was controversial because a number of local citizens felt that draining the lake would lead to the outbreak of disease, but a local doctor refuted this: "Were there not fish in the lake and did not gulls eat them without ill effect, he argued. He reminded [residents] that the waters were a gift of nature, but since they were now so polluted there was no real drawback to draining the lake" (Barnes 1986). It is unclear when the lake was filled again, although Barnes (1986) suggests that it was not until some time during World War II. Kerr Lake, to the east, was also drained, and "at one period when most of the clear water had been pumped away, some embarrassment was caused by the large number of fish which had been smothered by the mud and came to the surface. Great numbers ranging in size from small perch to eels and pike 30 inches long lay everywhere, and even clogged the suctions and entering valves" (Livermore 1913).

Mining in Cobalt reached its peak in 1911. By this time the town was thriving and had a population of between 10,000 and 15,000. There were few luxuries, and the town was cursed with fires, but life was much more comfortable, although there had been a severe typhoid fever outbreak in the summer of 1909, due to poor sanitation conditions following a major fire. In 1911 production reached 31,507,791 oz of silver, an all time high for the area (Barnes 1986). Profits were pushed even higher with the construction of a compressed air plant and two hydroelectric plants on the Montreal River. These plants supplied cheap power to the mines (Baldwin and Dunn 1988). Not only did this raise the profit margin, but it allowed the mines to recover lower grade ore.

The first two years of World War I were hard times in Cobalt. Many of the men were overseas in the war, leaving a smaller labour force to work the mines. In 1916 the price of silver went up, so all of the mines that could find men stayed open (Murphy 1977).

By the end of the war Cobalt had reached a milestone with the shipment of 10,000 tons of pure silver (Murphy 1977). However, the camp was entering its twilight. The postwar population was only about 7,000 thousand, and 1919 was marked by a long bitter strike. The highlight of 1919 was a Royal visit by Edward the Prince of Wales. He summed up the town aptly when he called it "A grey wee town" (Barnes 1986).

The 1920's were hard times, with few mines surviving the decade. The Beaver Mine closed in 1920, the railway ripped up several miles of spur track in 1924. The LaRose Mine closed in 1930, and by 1932 only the Nipissing Mine and a few minor producers were left on operation (Barnes 1986).

World War II and the period following saw a revitalization of mining in Cobalt. A few mines were reopened and old tailings were reprocessed for their silver and also for their cobalt content. Until then, there had been little use for the cobalt contained in the ores, and most of it ended up in the tailings, but during and after the war new medical uses were developed for cobalt for the treatment of cancer, and the metal also saw increasing use in metal alloys. Old properties which reopened during the war and on into the 1960's included the LaRose Mine (Silver Mines Limited), the Savage Mine (Silver Summit, Silverfields), the Cross Lake O'Brien Mine (Deer

Horn), and the Bailey property (Glen Lake Silver)(Barnes 1986). Most of these operations shut down in the 1970's, but Agnico Eagle continued to work in the area into the mid 1980's. The recent recession has closed down the last of the mines, but Cobalt has closed down before only to be revitalized later.

# **Appendix 3:**

### **Detailed Descriptions of Ore Milling and Refining Processes, and Tailings Deposits in the Cobalt area**

### A.3.1 Development of Ore Milling and Refining Processes

An understanding of the milling and refining processes used in Cobalt is important to understanding the nature of the tailings and other mine wastes in the area. A review of such processes also highlights other means by which contaminants could have entered the environment. An excellent review of milling and refining practices up to 1922 was written by F.D. Reid, J.J. Denny and R.H. Hutchinson, and published in the 1922 Annual Report of the Ontario Bureau of Mines.

Due to the complex mineralogy of the Cobalt ores, particularly the presence of Co and Niarsenides, milling and refining the rich ores was a formidable challenge, particularly in the earliest days of mining. From 1904 to 1906 the most economical way to process the ore from Cobalt was to hand sort and ship the high grade ore to the United States for processing. Thus, the only mine waste was waste rock, which included the low grade Ag which could not profitably be shipped (Baldwin and Dunn 1988). However, shipping the bagged ore was expensive, and soon the richest surface veins were exhausted. As the mines started to go deeper production costs rose, and it became imperative that further ore processing be done in Cobalt.

In 1907, the McKinley-Darragh Mine was the first mine to bring a gravity concentration mill into operation, and several other mines brought similar mills into operation soon after, so that by the end of the year there were nine mills in the area (Reid *et al.* 1922, Murphy 1977). In these mills, ore was first crushed into 2 to 4 cm pieces. High grade ore was then separated by hand picking or by bumping. The remaining material was sent to ball or roll crushers to be further broken down, and then sorted again. Finally, the material was crushed to a powder by 600 kg metal stamps. The powdered material was then mechanically sorted on jigging tables, which separated out the heavy Ag-rich concentrate (Baldwin and Dunn 1988). The high grade ore, carrying from 1,000 to 4,000 oz./ton Ag, and the concentrate were shipped elsewhere for refining (Reid *et al.* 1922). The waste product of this milling was powdered rock, called tailings, which often contained several ounces per ton of Ag, as well as As, Co, Ni and other metals occurring naturally in the ore (Barnes 1986).

These gravity concentration processes were a significant improvement over hand sorting, but losses of Ag still occurred. Some of the high grade ore tended to become too fine grained during the grinding, so this ore could not be effectively recovered. Also, the oxidized material from weathered veins was very difficult to separate by these methods, and much Ag was lost from these ores, which could contain as much as 12,000 oz./ton Ag. In addition, it was still necessary to ship all of the concentrates elsewhere for refining (Reid *et al.* 1922). Thus, the metallurgists from the mills, as well as metallurgists from all over the continent worked to find a way to

efficiently isolate the Ag. Most research focussed on using cyanide to extract the Ag.

The first successful cyanide mill was put into operation at the O'Brien Mine in 1909. In the cyanide process at the O'Brien mill, the ore was first separated by gravity concentration, and the concentrate produced was shipped to the O'Brien smelter in Deloro, Ontario. The tailings from this concentration were reground, and mixed in large tanks for 48 hours in a solution made up of 5 pounds of KCN per ton of ore. The KCN dissolved the Ag. The solution was then clarified, and the pregnant solution, containing the dissolved Ag, was sent to a precipitating tank where powdered Al was added, causing the Ag to precipitate. The precipitate was then melted down in a furnace, yielding a bullion about 960 fine (Reid *et al.* 1922). Similar mills, using a combination of gravity concentration and cyanide treatment, were brought into operation at the Buffalo and Nova Scotia mines and at the Cobalt Reduction Company, which was a custom mill.

These cyanide mills met with varying degrees of success. The main problem with the process was the presence of cyanicides, such as Ni and Fe, which form complexes with cyanide, lowering the effectiveness of the process, and increasing the amount of cyanide and treatment time required. Various solutions were developed to deal with the cyanicides (Reid *et al.* 1922).

At some mines, the composition of the ore was such that cyaniding was not the best way to concentrate the Ag. These mills continued using gravity separation until mid way through the First World War. The concentrate produced by these mills was sent elsewhere for refining.

In 1912, the Nipissing low grade mill was brought into operation. This was the only mill in the area which used an all cyanidation process, with no gravity separation. At that mill, the ore was first put through a rough, preliminary sorting which produced a very high grade concentrate which was sent to the Nipissing high grade mill for processing. The rejects were then crushed to a very fine grained material called a slime, to free the Ag as much as possible, and to maximize the surface area of the material. The slime was then treated with NaCN in mixing tanks, dissolving the Ag. Powdered Al was then added to the solution to precipitate the Ag (Reid *et al.* 1922). The two chemical reactions in this process were (Smith and Carson 1977, Reid *et al.* 1922):

 $\begin{array}{rl} 2Ag + 4NaCN + \frac{1}{2}O_2 \Rightarrow 2NaAg(CN)_2 + 2NaOH \\ 2NaAg(CN)_2 + 4NaOH + 2Al \Rightarrow 4NaCN + 2Ag + Na_2Al_2O_4 + 2H_2 \end{array}$ 

The precipitate was then sent to the refinery at the high grade mill. The precipitate contained mostly Ag (89.9%), but an analysis of precipitate from the Nipissing low grade mill shows that the precipitate contained 0.48% Hg, 0.48% As and 0.16% Ni. Precipitate from the Nova Scotia mill contained 88.04% Ag, 0.13% Co, 0.16% Ni, 2.41% As and 0.65% Pb (Reid *et al.* 1922). Much of the barren cyanide was recycled, but some would become complexed with cyanicide metals, and was lost, so as a result, the tailings generated by the cyanide mills contained complexed CN<sup>-</sup>, as well as As and heavy metals.

The advent of cyanide milling allowed mine owners to reprocess old mine tailings which still contained several ounces per ton of Ag. As milling techniques improved, the reprocessing of tailings was an ongoing endeavour in the area.

In response to changing economic conditions, as well as a decrease in the average ore grade with time, milling procedures continued to evolve. During World War I, the cost of Al rose so that the use of Al to precipitate the Ag became too expensive. Many mills switched to flotation separation, while others, such as the Nipissing low grade mill, began precipitating the Ag with NaS. Later, in 1921, the Nipissing low grade mill abandoned the all cyanide milling process, and began to use gravity concentration prior to cyanide treatment (Reid *et al.* 1922). The Nipissing mill continued to use cyanide until it closed in 1932 (Barnes 1986).

In 1915, the Buffalo mill built an experimental flotation circuit, which was so successful that a year later an operational mill was built. In this process, the ore was first treated by gravity concentration, to remove as much of the high grade Ag as possible. The tailings from the gravity circuit were reground in a tube mill, and at the end of the grinding, a mixture of 75% coal tar creosote, 15% pine oil and 10% coal tar was added to the mill, at a rate of about one pound per ton of ore, to completely coat the ore. The emulsified ore was agitated in flotation cells, causing the concentrate to float to the top, and the waste to sink to the bottom. The concentrates, which assayed about 300 to 600 oz./ton Ag, were shipped to smelters elsewhere for refining. The waste products were the overflow water, the water produced from the dewatering of the concentrate, and the tailings. The tailings consisted of a mixture of oil coated mineral grains (Reid *et al.* 1922). Numerous mills in this area continued to use flotation separation until mining in the area began to wind down in the 1920's and early 1930's.

The highest grade ores from Cobalt presented unique problems for milling, and the methods discussed above were not always effective at recovering the Ag. In 1911 the Nipissing high grade mill was brought into operation to treat high grade ores, and a similar mill operated at the Nova Scotia Mine. In this mill the ore was first crushed, then 6,500 pounds of ore, averaging 2,500 oz./ton Ag, were added to a tube mill, along with 8,500 pounds of Hg, 3,800 pounds of 5% KCN solution and six tons of pebbles as a grinding agent (Reid *et al.* 1922). After nine and a half hours of milling, 97 to 98% of the Ag was amalgamated with the Hg. The amalgam was drawn off into canvas bags and allowed to drain, while the pulp, containing 50 to 75 oz./ton Ag, was treated with cyanide. The remaining residue contained 35 oz/ton Ag, and 15 to 20 lbs./ton Hg, as well as Co and Ni. Much of this residue was sold (Reid *et al.* 1922).

After the amalgam was drained it was sent to the refinery where it was retorted for nine hours. The resulting amalgam sponge contained 80% Ag, as well as As, Co, Ni, Sb and Bi. The sponge was then fired in a reverbatory furnace. In the furnace, oxides of Co, Ni and other impurities rose to the surface of the molten liquid, and were skimmed off. The resulting bullion was 999 fine. The skimmings from this process, which contained about 15,000 oz./ton Ag, were mixed with precipitate from the cyanide plant, which contained 15,000 to 18,000 oz./ton Ag, and smelted in a blast furnace. The resulting bullion was remelted to produce a 999 fine bullion, and waste slag (Reid *et al.* 1922).

During the operation of the Nipissing high grade mill and refinery considerable research was done to reduce the Hg losses in flue gas from the retorts and the furnaces. Initially, the gases were passed through pipes which were cooled by spraying water, causing some of the Hg vapour to condense. Later, a bag house was added. After the gases had passed through the water cooled pipes they were passed through cloth bags which trapped much of the particulate material. The bulk of the material consisted of As, Sb, Ni, Co, and Bi, as well as Hg and Ag. Prior to the installation of the bag house all of these particulates were vented to the atmosphere and precipitated out downwind. However, the amount of material collected in the bag house was considered to be surprisingly small, considering the nature of the material being refined (Reid *et al.* 1922). That material which was collected in the bags was resmelted. In 1915 tests were conducted on a system which would have removed 90% of the particulates, but the value of the increased particulates collected was not considered high enough to warrant the installation of this system (Reid *et al.* 1922). The proportion of particulates collected by the bag house is not known. The type of particulate collection systems used at other mills which refined cyanide precipitates, such as the O'Brien mill and the Cobalt Reduction Company mill are not known, but these mills likely also operated bag houses.

Due to the increase in the cost of Hg during World War I, the amalgamation process was abandoned by Nipissing in 1918, and the high grade mill was closed, although the refinery remained operational until 1932 when the low grade mill closed. After 1918, a modified cyanide process was used to treat the high grade ores. The same process was used by the Cobalt Reduction Company. In this process the ground ore was treated with calcium hypochlorite prior to cyanidation. The calcium hypochlorite oxidized the base metal minerals, overcoming the problem of cyanicides. In 1921, Nipissing began using sulphuric acid instead of calcium hypochlorite, because it was more effective at dealing with cyanicides occurring in oxidized ore (Reid *et al.* 1922). It is not known if Nipissing continued to use this process until 1932, or if further changes were made after 1922.

By the time the Nipissing mill closed in 1932, there was little mining activity left in Cobalt. However, during and after the Second World War, mining activity resumed. Ores were worked for Ag, and also for Co. Prior to the war markets for Co had been limited, but new metallurgical and medical uses for Co resulted in an increase in the price of the metal. Most post war mills were flotation mills, while those reprocessing tailings were cyanide mills. Agnico-Eagle operated a refinery at the LaRose property, another refinery operated in Gillies Limit, southwest of Cobalt. It is not known if these refineries handled the concentrates and cyanide precipitates, or if some of this material was shipped elsewhere for refining.

### A.3.2 Tailings Deposits of the Cobalt Area

There are a large number of tailings disposal areas in the Cobalt area, and much is known about the history and extent of these tailings. Much of this work was done by John Hawley of the Ontario Ministry of the Environment in 1977, and by Pat Anderson of the Ontario Ministry of Northern Development and Mines (Cobalt Resident Geologist's Office) in 1984-85. None of Anderson's work was published, and little of the detailed work completed by John Hawley was published, but their work is on file at the Resident Geologist's Office in Cobalt.

This section is a compilation of available information about the tailings deposits of the Cobalt area. It draws heavily upon the work of Hawley and Anderson, as well as other sources. Where possible, information is brought up to date and gaps are filled in on the basis of the author's work in the area in the summer of 1991.
Tailings were deposited on land and in lakes. These two types of deposits are treated separately. A third section covers tailings outside the Farr Creek drainage basin. See Figure A.3.1 for the locations of tailings deposits in the Farr Creek basin.

# A.3.2.1 Tailings Deposited on Land

# A.3.2.1.1 Buffalo Tailings

The Buffalo Mine was located on the west side of Cobalt Lake, within the town of Cobalt. A low grade concentrator operated on this site from 1907 to 1923, and a cyanide plant operated from 1912 to 1916, 1920 to 1921 and for 3 years in the 1950's. Early tailings were deposited in a long, narrow valley extending northeasterly from the site. From 1916 to 1923 these tailings were reprocessed and redeposited at the same site. In addition, some were reprocessed at the Cobalt Reduction Mill and were deposited in Cobalt Lake. The mill was also used to reprocess slimes from the Coniagas Mine from 1920 to 1921 and in the 1950's, and the resultant tailings were added to the old pile (Anderson, 1985)(see Figure A.3.2).

After the mill shut down for the last time the tailings were levelled and covered with 15 cm of gravel and 15 cm of loam and used as a park and later a small housing development. After a major fire in Cobalt in 1977 the area was used for temporary housing in mobile homes, many of which are still present (Anderson 1985). Only a small area of tailings adjacent to the mill foundation remains exposed today, but these exposed tailings are just a few metres from the mobile homes.

# A.3.2.1.2 Coniagas Tailings

The Coniagas Mine was on the west side of Cobalt Lake, on the north edge of town. A mill was built on the property in 1907, and it operated until 1924 when the site was destroyed by fire. This mill was on a hill above the present site of the Cobalt-Coleman arena. Gravity concentration was used from 1907 to 1915. A small cyanide plant was added in 1915 to treat slimes. A flotation circuit was added in 1917 (Anderson 1985).

Early tailings were released and they migrated down the hill to the east. In 1915, coarse and slime fractions were separated, and the slimes were contained in a depression now occupied by the Cobalt Public School (see Figure A.3.2). With the construction of the flotation circuit in 1917, old coarse tailings were reprocessed. New tailings were sent north to Sasaginaga Creek by flume. After the 1924 fire, ore was sent to the Beaver mill, east of Giroux Lake, for processing.





As mentioned in the previous section, some of the Coniagas slimes were reprocessed at the Buffalo Mill in the 1950's. The quantity of slimes removed is not known. The remaining slimes were levelled and covered and they now underlie the Cobalt Public School. In 1977, 24,780 tons of coarse tailings were removed and reprocessed at the Canadaka Mill at Giroux Lake. Finer grained tailings which were underlying the coarse tails were left in place, and these tailings are still present in the area between the mill foundation and the arena (Anderson 1985).

# A.3.2.1.3 Tretheway Tailings

The Tretheway Mine was northwest of the Coniagas, near Sasaginaga Lake. A mill operated on the site from 1910 to 1920, using a gravity concentration process. Early tailings disposal was well planned, and tailings were contained in a valley with a dam at the mouth of it, preventing the tailings from entering Sasaginaga Lake. Some tailings did, however, enter the lake. Other dams were built at the north end of the containment area to prevent the tailings from spilling onto the Hudson Bay property, and to prevent them from draining into Sasaginaga Creek. One of these dams has been breached and some tailings have migrated north. For the most part however, the Tretheway tailings have been much better contained than others of similar age (Anderson 1985). An accounting of the tailings, however, shows that while 260,000 tons should have been produced, only 65,000 tons were reported to have been released to the containment area. The fate of the remaining 195,000 tons of tailings is not known, but it is probable that they were sluiced down Sasaginaga Creek towards the Chambers-Ferland property (Anderson 1985).

In 1918 and 1919, 29,416 tons of tailings were reprocessed, leaving 37,000 tons in place in the containment area when the mine closed in 1920. It is not clear where the new tailings from this reprocessing were disposed of. In 1977, 22,804 tons of tailings were removed and reprocessed at the Canadaka Mill. At the mouth of the valley there is now a 2 m high ridge of tailings, while the rest of the valley (300 m by 50 m) is lined with a veneer of tailings (Anderson 1985).

# A.3.2.1.4 Hudson Bay Tailings

The Hudson Bay Mine was north of the Tretheway Mine, adjacent to the north branch of Sasaginaga Creek. A mill operated on the site from 1910 to 1920, using a wet gravity process. All of the tailings from the mill were dumped into Sasaginaga Creek. From the mill, tailings migrated eastward along the stream valley to the Chambers-Ferland property. The original area covered by tailings was about 240 m by 110 m, but due to the migration the area is now much larger (Anderson 1985).

In the late 1940's and 1950's some tailings were removed and processed at the Silver Cliff mill. Little Ag was recovered and the operation was discontinued. The new tailings were deposited in Crosswise Lake. The remaining tailings have been partially naturally revegetated with wild grasses and small shrubs (Anderson 1985).

# A.3.2.1.5 Chambers-Ferland Tailings

The Chambers-Ferland property was east of the Hudson Bay Mine, near the confluence of Sasaginaga Creek and Mill Creek. The property did produce Ag, but ore was custom milled by the Cobalt Reduction Company on Cobalt Lake. Despite this, the property is one of the largest accumulations of tailings in the area. Tailings from the Coniagas Mine were deposited here, and tailings from the Tretheway and Hudson Bay mines migrated down Sasaginaga Creek and ended up on this property. Tailings have also migrated to here from Cobalt Lake, Nipissing Hill and the LaRose Mine, along Mill Creek. In addition, raw sewage from the town has been deposited in this area for many years. In total, more than 200,000 tons of tailings have accumulated here, reaching an average depth of 1 to 2 m (Anderson 1985).

These tailings were first assayed in the 1960's, and sampling in 1975 showed reserves of 250,000 tons grading 3.5 oz Ag/ton. In 1981, when Ag prices were high, an attempt was made to remove the tailings for reprocessing, but the recovery method used was not successful. In 1983 another attempt was made to recover the tailings. A total of 78,743 tons of tailings were removed before the operation was ended in 1984 when Ag prices fell (Anderson 1985).

# A.3.2.1.6 Nipissing Hill Tailings

The Nipissing Mine and Mill complex was one of the largest and longest operating sites in the camp. The complex was located on the hill on the east side of Cobalt Lake, opposite the town. The first mill built by Nipissing was completed in 1907 on the southeast shore of the lake, and it continued to operate until 1912. In 1911 the Nipissing high grade mill was built. This mill used Hg in an amalgamation process, in order to extract Ag from high grade ores (grade averaged 2,212 oz/ton in 1912) (Nipissing Mining Company Annual Report 1912). The amalgam sponge produced was then refined in a blast furnace, resulting in a pure Ag bullion. This mill produced residues which were rich in Hg, but the Nipissing Mining Company's Annual Report for 1913 states that residues also contained Ag, as well as 8-10% Co, 4-8% Ni and <u>30-40%</u> As. Many of these residues were sold to Co manufacturers, although Co sales fluctuated greatly from year to year. Presumably, the unsold residue portion became tailings.

In 1912, a second mill, known as the low grade mill, was built further north on the hill. This mill used a cyanide process to extract Ag from low grade ores, usually with grades of less than 100 oz/ton. The final precipitate was sent to the refinery at the high grade mill and melted down to pure Ag bullion (Nipissing Mining Company Annual Report 1912). This mill produced tailings which contained cyanide as well as As.

During the war, the price of Hg rose sharply, making the cost of the amalgamation process prohibitive. As a result, the amalgamation process was discontinued in 1918 and the high grade mill was closed. All milling then occurred at the low grade mill complex, to which a high grade circuit was added (Nipissing Mining Company, Annual Report 1918). The refinery, located at the site of the high grade mill, remained operational, producing bullion from precipitates of the low grade mill. The low grade mill and refinery operated until 1932, and the low grade mill burned down in a spectacular fire in 1934 (Anderson 1985).

All of the tailings from the low grade mill were deposited in a depression about 400 m by 150 m in size at the base of the northwest end of Nip Hill. At least three dams were built to contain this deposit, but all have partially or completely failed. The largest of these dams, a wood and earthen structure, failed decades ago, and the top of the dam is now about 2 m below the original top. On the basis of this, it is estimated that about half of the original volume of tailings produced remains in place. The remainder have migrated into Mill Creek.

This deposit is one of the few in the area which has not been reprocessed. This may be due in part to the very fine grained texture of these tailings which makes them very difficult to recover (Anderson 1985). This deposit is almost completely devoid of vegetation, and two attempts by Agnico Eagle to revegetate the pile, in the fall of 1990 and June 1991, have been unsuccessful.

It is not clear from previous work in the area if the tailings from the high grade mill were also deposited in this area or if they were dumped elsewhere. Work in the summer of 1991 has shown that the tailings from the high grade mill were deposited in a small depression about 100 m by 25 m, between the mill site and the lake. (Conversations in 1991 with Pat Anderson and long time Cobalt resident Bill McKnight have confirmed that this deposit is from the high grade mill.) This was a very small deposit, and was contained by a concrete wall. The wall is still in place, but it has a culvert at the base of it, and most of the tailings have been washed down to the lake through this culvert.

# A.3.2.1.7 LaRose Tailings

The LaRose mine was located north of Cobalt Lake, beside Mill Creek. A sorting mill was built at the site in 1911, but sorted high grade and low grade ore was sent elsewhere for processing. Not until 1952 was a processing mill built on the site. Initially, this mill was designed to recover Co. It was closed in 1956, then reopened in 1958 and modified to recover Cu as well as Co. The mill operated intermittently until 1971 (Anderson 1985). This mill is now owned by Agnico Eagle, and it could be reopened if mining resumes.

The tailings deposit on the site is about 0.8 to 1.0 acres in area. These tailings are coarse grained and are almost completely revegetated (Hawley 1977). Descriptions of the site are conflicting since Anderson (1985) says that all of the tailings at the site were produced by the mill built in 1952, but Hawley (1977) implies that these tailings are much older. Thus, the age of the tailings is unclear.

# A.3.2.1.8 Nova Scotia Tailings

The Nova Scotia Mine was located on the east shore of Peterson Lake. The mine opened in 1908, and a cyanide mill was built at the site in 1910 and operated until 1922, custom milling ore and tailings from other mines from late 1912 on (Anderson 1985). From 1910 to 1918, tailings were deposited in the lake, and from 1918 to 1922 they were deposited in a small valley adjacent to the site. (Tailings deposited in the lake are discussed further on in this appendix.) The onland tailings have been sampled on several occasions, but have never been reworked (Anderson

1985).

The deposit covers an area of 2.4 to 3.3 ha to a depth of 6 m and is estimated by Hawley (1977) to contain 13,875 m<sup>3</sup> of tailings. The containing dam is in very poor condition and considerable migration of tailings into the lake has occurred. A small seasonal stream runs across the deposit, eroding it during the spring run-off, and most of the surface has been naturally revegetated (Hawley 1977).

# A.3.2.1.9 Beaver and Temiskaming Mine Tailings

The Beaver and Temiskaming mines are about 5 km east south east of Cobalt, about 500 m east of Brady Lake. The Temiskaming mill began operating in 1910, and remained in operation until 1921. About 226,289 tons of ore were processed (Anderson 1985), and tailings were deposited west of the mine, in an area draining into Giroux Lake. Between 1948 and 1956 an unknown quantity of tailings from the Brady Lake Silver Miller mill were added to the Temiskaming tailings.

In 1951 removal of tailings for reprocessing at the Hellens mill on Cobalt Lake began. The amount of tailings removed and the year in which the operation ended are not known. Anderson (1985) reports that only a thin layer of tailings remains.

The Beaver Mine is about 200 m north of the Temiskaming Mine, and a mill was built at the Beaver Mine in 1912. The mill operated continuously until 1920, and 40,000 to 50,000 tons of tailings were produced. Tailings were deposited in a creek valley east of the mill. The swift flowing stream drains north to Kirk Lake, and many of the tailings have migrated along the stream and have been redeposited in Kirk Lake. A second stream flows north from Kirk Lake into Crosswise Lake, and tailings migration along this stream has also occurred (Anderson 1985). The author observed that a small area of largely unvegetated tailings is still present at the original site of deposition.

# A.3.2.1.10 Green-Meehan Tailings

The Green-Meehan property is located in Bucke Township, adjacent to Highway 567, about 0.5 km west of the road to Bucke Park. A mill operated on the site from 1925 to 1928, using a wet gravity process. A total of 25,191 tons of ore were processed. Tailings were deposited in a shallow depression on the north side of the highway, and they spread out in a thin layer over a large area (about 390 m by 150 m). The tailings are now vegetated, but the area has also been used for many years as a garbage dump, and much of the tailings are covered by refuse (Anderson 1985).

# A.3.2.2 Tailings Deposited in Lakes

# A.3.2.2.1 Cobalt Lake

Several mills deposited their tailings in Cobalt Lake: the Cobalt Lake Mill, Cobalt Reduction Company, McKinley-Darragh Concentrator, McKinley-Darragh tailings mill, the Hellens Mill and the Agnico tailings mill (Anderson 1985).

The McKinley-Darragh Concentrator was built in 1907, and it operated until 1927. All tailings were dumped in the southern end of the lake (Anderson 1985).

In 1917, a mill was built on the McKinley-Darragh property specifically to reprocess tailings. Some of the McKinley-Darragh tailings had been contained by a coffer dam built in the lake. Some of these tailings were removed and reprocessed in the mill, but the operation stopped in 1920 with the drop in Ag prices and was not resumed.

The Cobalt Lake Mill was built on the southeast shore of the lake, just east of the McKinley-Darragh complex, in 1911, and it operated until 1916 (Anderson 1985).

The City of Cobalt Mining Company built a mill on the lake in the south end of the town in 1907. This mill changed ownership, becoming the Cobalt Reduction Company mill in 1914. This mill custom processed ore for other mines, and operated until 1932. Initially, the mill used an amalgamation process with Hg, as well as cyanide. In 1915 a cyanide annex was added to treat slimes, and in 1916 a high grade mill was added. About 329,000 tons of tailings from the complex were deposited in the southwest corner of the lake (Anderson 1985).

Like other tailings deposits in the area, improved milling techniques turned the tailings in the lake from waste into resource. In 1914, the Cobalt Reduction Company drained the lake and began removing tailings in 1915. Tailings were treated with cyanide, and new tailings were returned to the lake. Low Ag prices brought the operation to an end in 1920, but it resumed in 1922 and continued until 1930, and then occurred sporadically until 1932. In 1932 a cave-in occurred in the Cobalt Mine, underneath the lake, which allowed tailings to flood into the workings. After this incident, tailings reprocessing ended.

Interest in reprocessing the tailings from the lake renewed after World War II. In 1951 the Hellens Mill was built on the southeast shore of the lake, on the site of the Cobalt Lake Mill, in order to reprocess tailings. This mill included a cyanide circuit. The lake was pumped dry, and several shafts around the lake were dewatered. Recovery of tailings started in 1952. Initially, the new tailings were deposited in the north end of the lake, but because of their high cyanide content, it was decided to deposit them in Cart Lake instead. Cyaniding was discontinued in 1954, and the operation stopped in 1955 due to recurring difficulties in the processing (Anderson 1985).

In 1966, Agnico Mines pumped the lake dry for the third time, and began removing tailings for reprocessing in 1967. Agnico acquired the Hellens Mill and tailings were processed at that site. This operation continued until 1969, and all of the new tailings produced were deposited in the

north end of the lake and some of these tailings  $(26,300 \text{ m}^3)$  now form the foundation of the Cobalt Lion's Club Park, which bisects the lake (Hawley 1977). During the cleanup following a major fire in 1977, mine waste rock from around the town and rubble from buildings destroyed in the fire were dumped in the lake to increase the size of the park from one baseball diamond to two (Anderson 1985).

Despite the amount of tailings which have been removed for reprocessing, the lake, particularly the southern end of the lake, still contains a considerable amount of tailings. Hawley (1977) estimates that there are well in excess of 300,000 tons of tailings in the lake, and that the depth of tailings averages 10 to 11.5 m.

# A.3.2.2.2 Cart Lake Tailings

Cart Lake is a small lake southeast of Cobalt. It has been used for tailings disposal since 1910, and is now almost completely filled with tailings.

The first mill built on the lake was the Savage Mill, built in 1910 by the McKinley-Darragh-Savage Mines of Cobalt, on the southeast shore of the lake. This was a sorting mill, with most of the ore processing being done at the McKinley-Darragh Mill on Cobalt Lake. Some gravity processing was done, and a small amount of tailings were produced and deposited in the southern end of the lake. This mill closed in 1912 (Anderson 1985).

In 1912 a mill was built on the west side of the lake by Seneca-Superior Silver Mines. This was also a sorting mill, but in 1914 it was expanded to produce concentrate. Tailings and waste rock were deposited in the lake. The mill closed in 1916, but reopened in the summer of 1918 and 1919 to reprocess tailings from the lake. New tailings were redeposited in the lake (Anderson 1985).

A third mill was built on the lake in 1911 by the Cobalt Provincial Mine. This mill operated as a sorting plant until 1917, dumping small amounts of waste rock and tailings into the lake. In 1917 the mill was expanded to include a concentrating circuit, and it operated until 1920. Tailings were deposited in the lake (Anderson 1985).

These operations were all quite small relative to many others in the area, and the lake remained quite clean and was used for fishing and duck hunting until after World War II (Bill McKnight, per. comm. 1991). The lake remained free of further mining activity until 1954 and 1955, when an unknown quantity of cyanide rich tailings from the Hellens Mill on Cobalt Lake were deposited in the lake.

In the early 1960's a large mill was built by Silver Summit Mines on the site of the old Savage Mill. This mill closed in 1964, but was bought by Silverfields Limited in 1965 and reopened. The mill operated until 1983, and deposited about 1.2 million tons of tailings in the lake, almost completely filling the lake, and burying all tailings previously deposited in the lake (some older waste rock is still present along the western shore of the lake)(Anderson 1985). This mill used flotation separation, and there was no cyanide or Hg in the process (Hawley 1977). A chemical

analysis performed by the company in 1973 indicated that the tailings contained 0.21% As (Hawley 1977).

In 1977, a small pile of waste rock was dumped in a ridge in the northern part of the lake. Hawley (1977) states that this was the beginning of a containment dam which was never completed, although it did serve to limit migration of tailings around the mill water intake, which was located at the north end of the lake. No other attempt was made to limit the northward migration of the tailings, and as a result, the tailings now migrate north into a wetland area between Cart Lake and Peterson Lake. There is also a problem at this site with wind blown tailings, and at the southern end of the lake tailings have been blown into small dunes. Some natural revegetation has occurred and a small area was revegetated by Mine Waste Reclamation of Guelph, Ontario, in the late 1970's (Anderson 1985).

# A.3.2.2.3 Peterson Lake Tailings

The Nova Scotia Mill deposited between 220,000 and 400,000 tons of tailings in the eastern lobe of Peterson Lake between 1910 and 1918. In addition, migration of tailings into the lake from the land disposal site adjacent to the lake has occurred (Anderson 1985).

Starting in 1920, tailings from the lake were removed and reprocessed. This operation continued until 1922, and a total of 25,770 tons of tailings were reprocessed. The lake was not drained to facilitate tailings removal (Anderson 1985). In 1965 there were estimated to be 275,242 tons of tailings in the lake, and in 1968, the eastern lobe of the lake was drained, and removal of tailings for reprocessing began. The operation continued until 1969, removing a total of 54,831 tons of tailings (Anderson 1985). New tailings were deposited in Crosswise Lake. The current volume of tailings in the lake is not known since migration of tailings into the lake is continuing. Despite this, the lake appears to be quite healthy and there is a breeding pair of loons on the lake.

# A.3.2.2.4 Crosswise Lake Tailings

Crosswise Lake is the largest lake in the area, and hosts the largest accumulation of tailings. Tailings were deposited in the north end of the lake by at least five different mills.

The first mill to deposit tailings in the lake was the Colonial Mill, built in 1908, which used mechanical separation methods. The mill closed in 1914, but was reopened in 1922 and operated until 1926. The mill reopened again in 1938 under new ownership. It was expanded and operated until 1953, and in 1948, 9,128 tons of tailings were removed from the lake and reprocessed. The mill was sold in 1954 and operated intermittently until 1958. In 1962 the mill was destroyed by fire, just before it was to resume operations (Anderson 1985).

The King Edward-National Mill was built on the west shore of Crosswise Lake in 1908, and operated until 1910 using a gravity process. The mill opened again in 1915, and operated until 1918, reprocessing tailings from the lake. New tailings were redeposited in the lake (Anderson 1985).

The O'Brien Mill was built at the O'Brien Mine site. This mill was the first in the area to use cyanide. The mill operated until 1922 when it was destroyed by fire. Tailings were pumped to Crosswise Lake, near the mouth of Peterson Creek. In 1952, a new mill was built at the site, and this mill operated until 1958 when it was bought by Agnico Mines. Renamed the Deerhorn Mill, it continued to operate until 1970. Tailings were pumped to the lake via the same route (Anderson 1985).

In 1910, the Silver Cliff Mill was built at the north end of Crosswise Lake, and operated using a gravity concentrator. The mill was closed sometime thereafter, and was reopened briefly in 1912. In 1918, tailings from the lake were reprocessed at the mill, but little is known about this operation. The mill was reopened in 1944 and operated until 1948. It milled just 13,874 tons of ore during that time. The mill was reopened in 1951, and operated until 1954. In 1968 and 1969 the mill was used to reprocess tailings removed from Peterson Lake. All tailings from this mill were deposited in Crosswise Lake (Anderson 1985).

The final mill built near the lake was the Northern Customs Concentrator, which opened in 1913 and operated until 1943 under various names, milling 1,005,702 tons of ore. A cyanide circuit was added to this mill in 1917 (Anderson 1985).

This tailings deposit is very large, although estimated tonnage is not known. Crosswise Lake is significantly smaller than it used to be. A dam was built across Farr Creek in order to limit northward migration of tailings along the Creek, but this dam failed in the 1970s and has not been rebuilt (Hawley 1977). North of this failed dam, which is also a road to the east side of the lake, the tailings are vegetated and the area is largely swampy, with Farr Creek meandering through the swamp. At the north end of this swamp, which is apparently the northern limit of tailings migration, there is a small water level control dam maintained by the province. It is not known when this dam was constructed.

# A.3.2.3 Tailings Outside the Farr Creek Drainage Basin

There are two large tailings deposits in the Cobalt area which are outside the Farr Creek drainage basin. These deposits are not relevant to the current study, and were not examined by the author. However, Anderson (1985) examined these tailings, and her unpublished data are summarized in this section.

# A.3.2.3.1 Glen Lake Tailings

Glen Lake is located about 1 km east of Cart Lake. The lake is fed by Kerr Lake, to the east, and it drains south to Giroux Lake. These lakes drain into the Montreal River.

The first mill on Glen Lake was the Cobalt Central Mill, which opened in 1907, on the east shore of the lake. This mill, which used a wet gravity separation process, operated until 1910, and then was reopened under new ownership in 1912 and operated until 1919. An estimated 135,000 tons of tailings were deposited in the lake during the life of the mill.

A second mill, the Foster Mill, owned by Agnico mines, became operational in 1957, and operated until 1966, when it was renamed the Penn Mill. From 1966 to 1986 the mill operated on a seasonal basis. The mill burned down in 1986. All tailings from the mill were deposited in the lake, but the total amount produced is not known.

In 1962, the Bailey Mill was built on the west side of Glen Lake. Ownership changed several times, but the mill operated almost continuously until 1975, when it was destroyed by fire. During that time, about 300,000 tons of tailings from the mill were deposited in the lake.

Like Cart Lake, Glen Lake is now almost completely filled with tailings, and in places the tailings reach an estimated thickness of 15 to 20 m.

# A.3.2.3.2 Canadaka Tailings

The Canadaka Mill was built at the north end of Giroux Lake in 1977, and operated intermittently until 1980. The mill resumed operations in 1983 and 1984, processing tailings from the Chamber-Ferland property. The mill is currently owned by Agnico Eagle Mines, and is maintained in standby condition.

A total of 347,870 tons of tailings from the mill were deposited in a containment area in a valley at the northeast end of the lake. This area consisted of several containment dams and a settling pond. In 1985 the run-off from the tailings into the lake was of acceptable quality.

# A.3.2.4 Tailings Revegetation and Reclamation

Tailings deposits are hostile environments for plants. The substrate is toxic, water availability is often a problem, and the deposits are often completely exposed to the wind. However, vegetation can play a very important role in stabilizing the tailings, helping to reduce the amount of erosion which occurs. This, in turn, helps to limit the impact which the tailings have on the local environment. Despite the difficulties, most of the tailings in the Cobalt area have been partially revegetated through the natural processes of colonization by pioneer plants. In addition, since 1979 there have been limited attempts to actively revegetate some of the tailings in the Cobalt area.

As was discussed previously, many of the tailings deposits in the Cobalt area have been reworked. This was done for economic rather than environmental reasons, but in some cases reprocessing has improved the state of the local environment, and can thus be considered a form of tailings reclamation.

# A.3.2.4.1 Natural Revegetation

Whether or not a tailings deposit is naturally revegetated depends on a number of factors: time, toxicity of the tailings, local plant species, drainage, organic content of the material, grain size,

pH, and soil moisture content. The metals in the tailings which are most toxic to plants are As, Ni, Co, Zn, Cu and Pb, as well as Hg which is a byproduct of milling processes. The affect of cyanide is not known, since there has been no investigation of cyanide in Cobalt (Anderson 1985).

Experience in Bancroft and Elliot Lake has shown that the species most likely to colonize tailings are birches, thistles, sedges, horsetails, grasses, rushes, buckwheat, roses, willows and poplars and cattails. Of these pioneering species, sedges and rushes are the most adaptable, and many of these plants have been observed on tailings in the Cobalt area (Anderson 1985).

Most of the tailings in the area are revegetated to some degree. The Nipissing low grade mill tailings present one of the most hostile tailings environments in the area. They contain high levels of all of the metals which occur in the area, and the surface is hard, very compact, and very dry all summer. However, in the northeast part of the deposit, in a small area hydraulically separated from the rest of the deposit by a "bedrock dam", water is available, and a rich covering of small rushes is growing. On the west side of the deposit, there are small low areas where grasses are slowly encroaching onto the tailings. The Cart Lake tailings are not as toxic, and support healthy cattails at the north end, along the lake shore. However, further south, above lake level, the material is so well drained because of the high porosity of the sandy tailings that desert like conditions prevail. As a result, there is no water for growing plants, and seeds cannot germinate because they are easily blown away or buried in the blowing, drifting sand (Anderson 1985).

Analyses of plants growing on tailings have shown that As levels in the plants are routinely elevated, as are Ni, Cu, Mo and Co. Lead was elevated in some samples. Mercury was not found, but it remains a concern (Anderson 1985).

Thus, the major limiting factor for vegetation growth is water availability, rather than the toxicity of the tailings. Natural revegetation will occur if water is present, and this is also the key to the success of any attempt to actively revegetate the tailings.

# A.3.2.4.2 Active Revegetation and Reclamation

Since 1979, there have been two experimental projects in tailings reclamation.

In 1979 a firm from Guelph, called Mine Waste Reclamation, carried out a revegetation experiment over a 1520 m<sup>2</sup> test plot on the Cart Lake tailings, near the south end of the lake. The ground for the test plot was first levelled, and drainage channels were dug. A layer of topsoil was then added to the plot, and after the application of fertilizer and mulch, the plot was seeded. Two different seed combinations were used to see which grew the best, and different soil thicknesses and fertilizer concentrations were also used. The best seed combination proved to be a meadow mixture of 40% annual rye grass, 30% tall fescue and 30% creeping red fescue. The experiment ended in July 1979 when the water line used for irrigation ruptured (Anderson 1985).

An examination of the site in 1984 by Anderson showed that the vegetation had taken hold but

had not spread (Anderson 1985). As of 1991, this vegetation is still healthy, but the area is getting smaller as the tailings slowly encroach on the vegetation plot as a result of wind migration.

A second experiment was started at the Chambers-Ferland tailings in 1982, the objective being to establish a cattail marsh on the site and improve the quality of raw sewage from the town which was dumped on the tailings. This project was initiated by the Ontario Ministry of Northern Affairs, and was funded by Northern Affairs and the Ministry of the Environment. The engineering firm of Knox, Martin and Kretch designed the project and initially operated it. At the time, the mineral rights were held by Sulpetro Mines, who were experimenting with tailings reprocessing (Miller and Young 1985).

Two sites were planted, one directly on the tailings, and the other on a tailings base with a clay lining. Each plot was 310 m long and 3 m wide. Local cattails were planted in each of the plots. Water flow and sewage flow through Sasaginaga Creek was controlled to aid the growth. In 1983 the marsh was healthy, and limited water sampling was carried out to see if the water quality was improving. Samples were analysed for biological oxygen demand, suspended solids, filtered total nitrates, filtered total ammonia, total nitrogen, pH, total phosphorus, conductivity and sulphates, as well as bacteriological quality. No consideration was given to metals, in order to determine whether or not metals concentrations were changing.

Initial results for the plot with the clay liner were promising, with the analyses showing that the final effluent was of acceptable quality for the parameters considered. The plot without the clay liner was not successful since most of the water infiltrated into the tailings, and attempts to plug the plot to limit infiltration were not successful. The experiment showed that it is feasible to treat Cobalt town sewage using an engineered cattail marsh. As of 1985, it was intended to go ahead with a larger scale planting over a 10 Ha area. The area was to be levelled, tailings were to be mixed with organic muds and planted with cattails to create a natural sewage treatment area for the town (Anderson 1985). It is not clear why this project did not proceed further.

The most recent attempt at active revegetation of tailings occurred in June 1991, when Agnico Eagle planted on a plot about 100 m by 50 m on the Nipissing low grade mill tailings. A mixture of seeds was planted, and the area was fertilized with a chemical fertilizer. The author visited the site about one week after the planting was carried out, and estimated that about 25% of the seeds germinated. The plants which grew were 5 to 8 cm tall and looked healthy. Within a short period of time however, all of plants were dead. No attempt had been made to cultivate or aerate the material, no organic matter was added, and no irrigation was provided.

Currently, a local resident is carrying out an interesting, informal experiment. Mr. Gerrit VanLaar, who lives beside the Buffalo Mill tailings, is planting different tree and shrub types in the tailings to see which ones will grow the best. His goal is to try all of the different species which occur in the area. Most of the planting took place in the summer of 1991, and he has transplanted a large number of plants from the local forests, including mint, saskatoon berry, willow, poplar, birch, oak, black spruce, jack pine and white pine. Most plants were doing well, but some had already died. It is too early to draw any conclusions from this, as the deaths may be related to the stress of transplanting. In addition, the plants were planted in holes which had been

filled with topsoil, so in most cases they had probably not yet picked up any metals from the tailings. However, this is certainly a site which should be revisited in the future in order to assess the growth of the plants. Mr. VanLaar has also expressed an interest in doing some planting at the another site, likely the Chamber-Ferland property.

#### A.3.2.4.3 Tailings Reprocessing

The reprocessing of tailings is a form of active reclamation, and it has been occurring almost since the outset of mining in the area. Unfortunately, while reprocessing removes the Ag, and more recently the Co, it does not remove the As, which is the most abundant toxin in the tailings (Anderson 1985).

One recent project which has resulted in a considerable improvement is the draining of Cobalt Lake and the reprocessing of tailings by Agnico Mines in the 1960's. Prior to this project, Cobalt Lake was nearly full of tailings and it was an eyesore. A large volume of tailings were removed, resulting in deeper water levels after the lake was refilled. New tailings were all deposited in one area, to serve as the foundation for the Cobalt Lion's Club Park, which bisects the lake. This park is used extensively by the local residents, and the surface of the playing fields in the park is very low in As and heavy metals.

Tailings reprocessing projects hold promise for making money and helping to clean up the area. However, they are often fraught with problems. The fine grained tailings from cyanide mills, often called slimes, are extremely difficult to work with. When dry, these tailings are as hard as concrete, making them difficult to remove. When wet, they are extremely sticky, and quickly clog whatever type of equipment is being used to move them. Heavy equipment often cannot be used because the vibration caused by even small engines causes the material to liquify. Thus, the greatest challenge with the slimes is to find an economical and relatively easy way to remove them and put them into the first stage of a mill circuit.

# A.3.2.5 Tailings Grain Size

As part of her work in the area, Anderson completed a number of grain size distribution analyses for tailings in the camp. Half kilogram samples were collected, dried and mechanically shaken in Tyler sieves. Samples with high clay content tend to clog the sieves so they gave less reliable results. Mesh sizes correspond to the following grain sizes:

Mesh/in.	millimetres	Phi
60	0.246	2.0
80	0.210	2.25
100	0.150	2.75
150	0.104	3.25
200	0.074	3.75
325	0.043	4.50

The results of these grain size distribution analyses are given in Table A.3.1. There is a wide range of distributions, but many of the tailings samples are composed primarily of very fine grained material.

Tailings Sampled	60	80	100	150	200	<200	Reliability
Buffalo (coarse)	30.93	8.25	6.28	12.01	9.98	32.54	fair
Buffalo (fine)	5.20	3.57	6.70	12.10	23.22	49.20	poor
Tretheway (coarse)	53.79	9.60	5.47	10.11	5.98	14.96	good
Tretheway (fine)	31.13	5.83	0.03	4.80	9.41	45.84	fair
Hudson Bay	58.96	9.09	7.88	4.40	8.51	10.27	good
Coniagas	65.83	11.89	6.10	8.51	3.70	3.98	good
Nipissing	2.80	15.96	4.09	9.15	22.48	46.72	poor
Cobalt Lake, North	42.93	18.64	11.00	11.84	4.86	7.73	good
LaRose	8.91	9.82	6.07	10.97	7.82	56.41	fair
Cart Lake	0.42	10.93	24.71	33.87	16.64	13.43	fair
Nova Scotia	0.82	15.88	14.29	20.21	22.54	26.26	poor
Crosswise Lake, south	0.52	1.85	7.55	27.17	39.93	22.98	poor
Crosswise Lake, north	4.67	17.34	7.88	16.07	20.15	33.89	poor

**Table A.3.1:** Grain size distributions of tailings samples from various deposits in the Cobalt area (after Anderson 1985)

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# Appendix 4:

# **Summary of Previous Environmental Research in the Cobalt Area**

#### A.4.1 Surface Water Contamination

A report on surface water contamination in the Cobalt area was written by the Ontario Water Resources Commission (OWRC) in 1967. This report presented data on pH, suspended and dissolved solids concentrations, total dissolved As, chemical oxygen demand, biological oxygen demand and Co, Cu, Ni, Ag and H<sub>2</sub>S concentrations for samples from local lakes and streams (see Figure A.4.1 for sampling sites and Table A.4.1 for analytical data).

#### A.4.1.1 Cobalt Lake

Cobalt Lake has borne the brunt of water pollution in the area. Water draining from Short Lake into Cobalt Lake was analysed in 1967 (OWRC 1967). The total dissolved solids were 50 ppm, and the sample contained no detectable As or heavy metals. At that time, the southern half of the lake was drained and Agnico Mines was reprocessing tailings from the lake bed. New tailings were being deposited in the northern part of the lake. The tailings mill discharge was sampled twice by the OWRC, and the total dissolved solids from these two samples were 326 ppm and 370 ppm, and the dissolved As concentrations were 2.48 ppm and 0.50 ppm. These samples also had very high total suspended solids. As a result, total suspended and dissolved solids in the water draining from the lake into Mill Creek were high for all four samples collected at this location. Total As in these samples was as high as 4.55 ppm, and total dissolved As was as high as 2.02 ppm (OWRC 1967).

From 1988 to 1990 the Ontario Ministry of the Environment collected monthly samples at the outlet from Cobalt Lake (unpublished data, obtained from the MOE office in North Bay). These samples were analysed for a number of water quality parameters (see Table A.4.2). For the period January 19, 1988 to March 18, 1990, the As concentration (unfiltered) ranged from 0.520 to 1.700 ppm; the average was 0.938 ppm.

#### A.4.1.2 Sasaginaga Lake

Sasaginaga Lake had no active mines on it, and the only tailings in it are near the outlet to Sasaginaga Creek. The lake is the town's drinking water reservoir, and under the Cobalt Municipal Water Act, the town has the right to limit use of the water and the lake shore, in order to protect the water supply. This act also covers Clear Lake, which drains into Sasaginaga Lake (J. Gore, pers. comm. 1991). Water from the lake was not sampled by the OWRC, but 5 samples



Site Description	Solids		pН	C.O.D.	5-day	As		Со	Cu	Ni	Ag	H <sub>2</sub> S
	Susp.	Diss.			B.O.D.	Tot.	Diss.					
Flow from Short Lake to Cobalt Lake	5	50	7.8	N/A	1.8	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Agnico Tailings Mill discharge	400586 527798	326 370	8.0 8.0	4680 6320	N/A N/A	98.50 1.29	2.48 0.50	N/A N/A	N/A N/A	N/A N/A	N/A N/A	N/A N/A
Agnico Tailings Mill, mine water discharge	57	317	7.9	8	N/A	2.40	2.40	N/A	N/A	N/A	N/A	N/A
Flow from Cobalt Lake to Mill Creek	11 54	107 334	8.3 8.3	N/A 16	3.6 N/A	2.4 1.38	0.59 1.38	0.2 N/A	0.03 N/A	0.19 N/A	N/D N/A	N/D N/A
Mill Creek at 11B	7566	244	7.5	41900	N/A	3.42	0.96	N/A	N/A	N/A	N/A	N/A
Silverfields Mine discharge	279	871	7.6	12	N/A	1.92	0.32	N/A	N/A	N/A	N/A	N/A
Flow from Cart Lake to Peterson Lake	12 12	56 186	8.2 7.6	N/A 4	1.6 N/A	1.23 0.96	0.31 0.96	0.1 N/A	0.03 N/A	0.06 N/A	N/D N/A	N/D N/A
Peterson Lake, N.E. corner	3	181	8.2	12	N/A	0.47	0.32	N/A	N/A	N/A	N/A	N/A
Crosswise Lake	6	130	7.8	8	N/A	0.80	0.06	N/A	N/A	N/A	N/A	N/A
Peterson Creek at Farr Creek	171	97	8.3	N/A	3.2	1.81	0.25	0.2	0.15	0.11	0.03	N/D
Tailings from Deer Horn Mill to Crosswise Lake	99468 195738	170 310	8.1 8.1	N/A 7020	N/A N/A	27.25 13.50	0.15 0.13	1.0 N/A	0.90 N/A	0.87 N/A	0.10 N/A	N/D N/A
Flow from Crosswise Lake to Farr Creek	372	58	8.1	N/A	4.4	2.38	0.14	0.15	0.04	0.14	0.01	N/D
Farr Creek at bridge	5796	340	8.0	6130	N/A	11.8	0.59	N/A	N/A	N/A	N/A	N/A
Farr Creek south of North Cobalt	114	56	8.1	N/A	3.8	0.48	0.48	0.2	0.03	0.07	0.01	N/D
Farr Creek in North Cobalt	506	200	8.1	20	N/A	2.68	0.80	N/A	N/A	N/A	N/A	N/A
Farr Creek at Lake Temiskaming	94	85	8.1	N/A	2.4	0.53	0.53	0.1	0.25	0.06	0.01	N/D

Table A.4.1: Results of Analyses of Samples Collected by the Ontario Water Resources Commission, 1967

all concentrations are in parts per million

N/A: not analysed N/D: not detected

C.O.D.: chemical oxygen demand B.O.D.: biological oxygen demand

Date	Т	pН	Cond	Diss. O2	Alk	As	Fe	Cl	SO <sub>4</sub>	Hg	Zn	Cu	Pb	Ni
m/d/y	°C		μS/cm	mg/L	mg/L as CaCO <sub>3</sub>	μg/L	μg/L	mg/L	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L
01/19/88	N/A	8.15	413.0	10.00	144.3	1050	570	N/A	22.20	0.04	29.0	11.0	11.0	37.0
02/28/88	N/A	8.22	416.0	N/A	150.1	950	39	N/A	22.00	0.01	9.4	4.4	3.0	29.0
03/22/88	N/A	8.04	410.0	12.00	145.8	980	250	N/A	21.00	0.14	10.0	7.4	4.0	35.0
05/31/88	N/A	8.30	396.0	N/A	131.0	690	60	N/A	20.56	< 0.03	5.0	4.0	2.0	21.0
06/19/88	21.0	8.40	388.0	10.00	131.0	600	370	N/A	22.70	0.06	5.6	4.9	4.0	26.0
07/17/88	21.0	8.30	387.0	7.00	125.0	840	43	N/A	20.87	< 0.03	25.0	0.5	2.0	17.0
08/14/88	27.0	8.40	372.0	11.00	120.0	720	670	N/A	19.60	0.04	14.0	11.0	7.5	30.0
09/20/88	18.0	8.60	373.0	10.00	124.0	880	39	N/A	19.10	0.03	2.0	1.5	2.5	15.0
10/24/88	7.0	8.10	406.0	10.00	134.0	680	170	N/A	20.70	0.11	5.0	4.8	4.0	25.0
11/20/88	3.0	8.10	435.0	13.00	140.0	590	120	N/A	20.30	0.03	9.4	3.3	3.5	26.0
12/14/88	N/A	7.40	414.0	N/A	135.0	700	43	N/A	24.30	0.02	11.0	4.4	12.0	32.0
01/15/89	1.0	7.80	404.0	12.00	148.0	670	150	N/A	21.30	N/A	12.0	5.2	2.0	25.0
02/13/89	1.0	7.90	374.0	11.00	141.0	520	240	N/A	20.20	N/A	18.0	7.4	3.0	27.0
03/13/89	1.0	7.60	409.0	3.50	142.0	520	1100	N/A	20.90	N/A	20.0	21.0	9.0	52.0
05/23/89	17.0	8.20	378.0	12.00	129.0	1000	2900	N/A	17.90	N/A	37.0	56.0	30.0	130.0
06/17/89	17.0	8.20	341.0	10.00	123.0	1000	2400	N/A	17.20	N/A	27.0	41.0	24.0	91.0
07/16/89	23.0	8.20	338.0	6.00	121.0	750	N/A	N/A	18.00	0.13	3.5	N/A	N/A	N/A
08/12/89	N/A	8.50	341.0	N/A	128.0	1100	N/A	N/A	13.00	0.01	0.0	N/A	N/A	N/A
09/24/89	16.0	8.00	348.0	10.00	116.0	1400	N/A	N/A	15.70	0.11	4.9	N/A	N/A	N/A
10/18/89	5.0	8.10	365.0	5.00	124.0	1400	N/A	N/A	16.40	0.07	2.8	N/A	N/A	N/A
11/19/89	2.0	8.60	380.0	10.00	129.0	1300	N/A	N/A	17.50	0.25	9.5	N/A	N/A	N/A
12/12/89	1.0	8.30	387.0	5.00	129.0	1100	N/A	N/A	17.90	0.19	6.0	N/A	N/A	N/A
01/23/90	1.0	7.80	401.0	6.00	133.0	1300	N/A	N/A	19.20	0.14	6.6	N/A	N/A	N/A
02/24/90	1.0	7.90	388.0	4.00	134.0	980	N/A	N/A	19.50	0.15	12.0	N/A	N/A	N/A
03/18/90	1.0	7.80	381.0	N/A	132.0	1700	N/A	N/A	20.00	2.14	54.0	N/A	N/A	N/A

Table A.4.2: Trace element concentrations in samples from Cobalt Lake at Mill Creek (Unpublished MOE Data)

were collected in 1977 by the Ontario Ministry of the Environment as part of a study of the occurrence of As and heavy metals in drinking water supplies of the Cobalt area (see Table A.4.3). For these samples, the average As concentration was 0.003 ppm and the average Hg concentration was 0.18 ppb.

The Ontario Ministry of the Environment Guide to Eating Sport Fish (1991) states that there are restrictions on the consumption of northern pike over 35 cm in length taken from the lake because of Hg levels in the 0.5 to 1.0 ppm range in the flesh of these fish. Children under 15 and women of child-bearing age should not eat these fish, and other residents should not eat more than 0.2 kg per week.

Date	As (ppm)	Hg (ppb)	Pb (ppm)	Zn (ppm)	Ni (ppm)
01/05/77	0.004	N/A	N/A	N/A	N/A
01/25/77	0.003	0.16	< 0.01	< 0.01	< 0.01
02/04/77	N/A	0.31	N/A	N/A	N/A
02/23/77	0.002	0.23	0.02	0.06	0.05
03/10/77	0.004	0.04	< 0.01	0.02	0.01

**Table A.4.3:** Metal Concentrations in the Cobalt Town Water Supply, 1977 (after Ontario<br/>Ministry of the Environment 1977)

N/A: not analysed

# A.4.1.3 Sasaginaga Creek

Sasaginaga Creek has two branches. One branch flows eastward from Sasaginaga Lake, passing the Hudson Bay and Tretheway mines, then joining with the southern branch which rises north of the town. The creek then flows for about 1 km east where it joins Mill Creek (Hawley 1977). The 1967 the OWRC report did not include an analysis of water from Sasaginaga Creek, but the creek does carry a high load of suspended solids and the stream valley contains numerous tailings deposits (Anderson 1985). In addition, Cobalt town sewage flows into the system via the southern branch of Sasaginaga Creek.

# A.4.1.4 Mill Creek

Mill Creek flows north from Cobalt Lake along a valley defined by the Cobalt Lake Fault for 1.6 km, where it joins Sasaginaga Creek on the Chambers-Ferland tailings. This stream is contaminated by tailings from Cobalt Lake and the Nipissing low grade mill. There has been a lot of migration of tailings along Mill Creek, and it carries a high suspended solids load (OWRC 1967). From the confluence with Sasaginaga Creek, Mill Creek flows 1.6 km to the east where it joins Farr Creek on the Crosswise Lake tailings. Water from Mill Creek was sampled by the

OWRC, and found to contain 3.42 ppm total As and 0.96 ppm dissolved As (see Figure A.4.1 and Table A.4.1).

# A.4.1.5 Cart Lake

Water from Cart Lake was not analysed for the OWRC report, but at that time, disposal of tailings in the lake by the Silverfields mill had started only a couple of years before, and the report states that the north end of the lake appeared unaffected (OWRC 1967). Discharge from the Silverfields Mine into the lake was sampled, and found to contain 871 ppm total dissolved solids and 0.32 ppm dissolved As. Cart Lake drains north to Peterson Lake via a short stream. Water from this stream was analysed twice by the OWRC (1967) and found to contain an average of 1.09 ppm total As and 0.63 ppm dissolved As (see Figure A.4.1 and Table A.4.1).

# A.4.1.6 Peterson Lake

Water from the northeast corner of Peterson Lake was sampled by the OWRC (see Figure A.4.1). This sample contained 0.47 ppm total As and 0.32 ppm dissolved As (OWRC 1967)(see Table A.4.1). The Ontario Ministry of the Environment Guide to Eating Ontario Sport Fish (1991) states that there are restrictions on the consumption of white suckers from the lake which are over 45 cm in length, due to Hg concentrations in the 0.5 to 1.0 ppm range in the flesh of these fish. Children under 15 and women of child-bearing age should not eat these fish, and other residents should not eat more than 0.2 kg per week.

# A.4.1.7 Peterson Creek

This creek flows from the east lobe of Peterson Lake, north for about 1.1 km, and then flows across the tailings deposit for about 700 m, where it joins Farr Creek (OWRC 1967). Boyle *et al.* (1967) sampled the creek and found it to contain 0.47 ppm As (see Figure A.4.2 and Table A.4.5). The stream was sampled at its outlet to Farr Creek by the OWRC and that sample contained 0.25 ppm dissolved As.

# A.4.1.8 Crosswise Lake

A sample collected from the west shore of Crosswise Lake by the OWRC (1967) contained 0.80 ppm total As and 0.06 ppm dissolved As (see Figure A.4.1 and Table A.4.3). Crosswise Lake is a popular lake for fishing, and the Ontario Ministry of the Environment Guide to Eating Ontario Sport Fish (1991) states that the consumption of the following fish from the lake is restricted because of Hg concentrations in the range of 0.5 to 1.0 ppm in the flesh of these fish: smallmouth bass over 20 cm in length, yellow perch over 15 cm in length, white suckers over 20 cm in length and northern pike over 35 cm in length. Children under 15 and women of childbearing age should not eat these fish, other residents should not eat more than 0.2 kg per week and visitors should not eat more than 2.3 kg during a one week stay or more than 1 kg per week

during a three week stay. There are further restrictions on smallmouth bass over 35 cm, yellow perch over 20 cm and northern pike over 55 cm because of Hg concentrations in the range of 1.0 to 1.5 ppm. Residents should not eat more than 0.1 kg of these fish per week, and visitors should not eat more than 1.5 kg during a one week stay or more than 0.6 kg per week during a three week stay. Finally, yellow perch over 25 cm are completely restricted because of Hg concentrations in excess of 1.5 ppm.

# A.4.1.9 Farr Creek

Farr Creek flows north from Crosswise Lake for 2 km across tailings. Peterson Creek joins Farr Creek about 500 m from the lake and about 450 m further downstream, Mill Creek joins Farr Creek. From this point on, Farr Creek is carrying all of the drainage from all of the area discussed. The creek flows across tailings until it reaches a point just south of North Cobalt. From that point to the mouth of the creek at Lake Temiskaming, about 6.5 km, the creek flows across bedrock (OWRC 1967).

At the north end of the tailings there is a small water control dam, and Environment Canada monitored the stream flow at that point on a daily basis from March 1971 until October 1983. The stream drains an area of 62.9 km<sup>2</sup>, and the average annual discharge was 21,100,000 m<sup>3</sup>, with annual values ranging from 14,900,000 m<sup>3</sup> in 1978 to 26,400,000 m<sup>3</sup> in 1973. The highest discharges occur in April, with an average of 2.64 m<sup>3</sup>/sec (range 1.23 to 4.20 m<sup>3</sup>/sec), and the lowest discharges occur in August, with an average of 0.143 m<sup>3</sup>/sec (range 0.049 to 0.396 m<sup>3</sup>/sec). Low discharges also occur July, January and February. The highest daily average recorded was 16.3 m<sup>3</sup>/sec on May 3, 1972, and the lowest occurred on several days in July and August 1982, when there was no flow (Environment Canada 1992).

Samples were collected at five points along this stream by the OWRC (see Figure A.4.1 and Table A.4.1). The data indicate that throughout its length, Farr Creek carries a high suspended solids load and is contaminated with As. At the outlet from Crosswise Lake into Farr Creek the As concentration was 0.14 ppm. The As concentration rose to 0.59 ppm mid way through the tailings deposit, as a result of ongoing deposition of tailings from the Deer Horn Mill in the area south of this sampling site. At the location of the control dam, the northern limit of tailings migration, the As concentration was 0.48 ppm. At North Cobalt, the dissolved As concentration in Farr Creek was 0.80 ppm, and several kilometres downstream, at the outlet to Lake Temiskaming, the As concentration was 0.53 ppm.

From 1988 to 1990, the Ontario Ministry of the Environment collected monthly samples from Farr Creek upstream from Crosswise Lake (unpublished data obtained from the MOE office in North Bay). The actual sampling location is not known, but it may have been at the north end of the tailings deposit, a site corresponding to the OWRC sampling site described as "Farr Creek south of North Cobalt" (the northern limit of tailings migration). For the period January 19, 1988 to March 18, 1990, the As concentration (unfiltered) ranged from 0.150 to 4.000 ppm, and the average was 0.633 ppm (see Table A.4.4).

Date m/d/y	T °C	рН	Cond µS/cm	Diss. O2 mg/L	Alk mg/L as CaCO3	As μg/L	Fe μg/L	Cl mg/L	SO4 mg/L	Hg μg/L	Zn μg/L	Cu µg/L	Ρb μg/L	Ni µg/L
01/19/88	N/A	7.89	376.0	12.00	125.4	410	300	27.10	27.40	0.03	14.0	4.4	5.0	36.0
02/28/88	N/A	7.61	320.0	12.00	119.7	500	1100	15.70	21.80	0.05	32.0	9.2	10.0	35.0
03/22/88	N/A	7.67	368.0	11.00	133.6	900	2100	23.10	22.40	0.12	32.0	12.0	12.0	36.0
05/31/88	N/A	8.40	243.0	N/A	100.0	400	920	9.10	13.81	0.04	10.0	6.0	3.0	19.0
06/19/88	22.0	8.20	267.0	8.00	107.0	320	520	13.0	17.20	< 0.03	4.6	4.2	5.0	19.0
07/17/88	21.0	9.10	266.0	12.00	94.0	600	150	19.0	18.26	< 0.03	2.4	2.1	2.0	15.0
08/14/88	26.0	8.00	315.0	12.00	111.0	560	460	20.0	19.70	0.06	6.5	5.0	4.5	18.0
09/20/88	17.0	8.00	345.0	11.00	126.0	470	170	18.0	24.40	0.03	4.5	3.4	3.0	21.0
10/24/88	7.0	7.60	250.0	6.00	97.0	150	130	8.0	20.00	0.03	7.8	5.0	3.5	20.0
11/20/88	2.0	7.80	238.0	12.00	91.0	170	230	N/A	16.40	0.04	13.4	3.9	2.0	18.0
12/14/88	N/A	7.50	265.0	N/A	97.0	230	190	N/A	20.50	0.04	12.0	5.6	2.0	22.0
01/15/89	1.0	7.40	232.0	7.50	86.0	190	200	N/A	16.40	N/A	14.0	5.5	2.5	19.0
02/13/89	1.0	7.50	310.0	9.00	114.0	380	410	N/A	21.30	N/A	16.0	5.4	3.0	30.0
03/13/89	1.0	7.30	441.0	7.00	149.0	290	370	N/A	30.50	N/A	23.0	8.5	2.5	36.0
05/23/89	15.0	7.90	221.0	10.00	87.0	410	600	N/A	12.10	N/A	5.7	6.7	2.5	20.0
06/17/89	17.0	8.00	197.0	11.00	81.0	380	210	N/A	11.00	N/A	4.3	4.6	2.0	21.0
07/16/89	21.0	9.00	242.0	8.00	101.0	410	N/A	N/A	11.80	0.01	1.5	N/A	N/A	N/A
08/12/89	N/A	8.60	331.0	N/A	112.0	1200	N/A	N/A	13.20	0.23	3.9	N/A	N/A	N/A
09/24/89	11.0	7.90	394.0	7.00	140.0	840	N/A	N/A	23.40	0.08	5.4	N/A	N/A	N/A
10/18/89	2.0	8.10	446.0	7.00	124.0	950	N/A	N/A	34.10	0.07	7.1	N/A	N/A	N/A
11/19/89	1.0	7.80	318.0	9.00	148.0	560	N/A	N/A	23.10	0.06	11.0	N/A	N/A	N/A
12/12/89	1.0	7.70	283.0	7.00	110.0	420	N/A	N/A	19.40	0.03	12.0	N/A	N/A	N/A
01/23/90	1.0	7.50	338.0	8.00	104.0	560	N/A	N/A	21.10	0.03	12.0	N/A	N/A	N/A
02/24/90	1.0	7.50	383.0	7.00	113.0	4000	N/A	N/A	29.30	3.87	720.0	N/A	N/A	N/A
03/18/90	1.0	7.70	272.0	N/A	127.0	530	N/A	N/A	N/A	0.20	17.0	N/A	N/A	N/A

Table A.4.4: Trace element concentrations in samples from Farr Creek at the Water Control Dam (Unpublished MOE Data)

# A.4.2 Groundwater Contamination

Two reports have been published which document the occurrence of contaminated groundwaters in the Cobalt area. The first was the Geological Survey of Canada Paper 67-35, written by R.W. Boyle and others in 1967: <u>Research in Geochemical Prospecting Methods for Native Silver Deposits, Cobalt Area, Ontario, 1966</u>. The second report, <u>A Report on the Continued Investigations into the Occurrence of Metals and Arsenic in Private Drinking Water Supplies of the Tri-Town Area</u>, was produced by the Ontario Ministry of the Environment in 1977.

#### A.4.2.1 Geological Survey of Canada Report, 1967

Boyle *et al.* (1967) sampled water from 244 locations during the period from June to August of 1966, 38 of which were taken within the current study area (see Figure A.4.2). Sampling included water from wells, springs, and diamond drill holes, and 55 surface water samples. In addition, 35 samples were collected at underground locations in 4 different mines. For all of these samples, temperature was measured, pH and Eh were measured using a Beckman Model N pH meter, and Ni and Co concentrations were determined in the field (see Table A.4.5). Seventy-one of these samples were analysed using atomic absorption to measure Zn, Cu, Pb, Ni, Co, Ag and Cd, and using colorimetric methods to measure As and Sb (see Table A.4.5). Along with water samples, samples of precipitate forming around the discharge points were collected from 17 of these sites and analysed for Pb, Zn, Cu, As, Sb, Mo using colorimetric methods, and Ag, Ni, Co and Mn using spectrographic methods (see Table A.4.6).

Arsenic was found in a large number of the samples analysed. Some of the more notable As occurrences are as follows (from Boyle, *et al.*, 1967; numbers correspond to sample numbers in Boyle, *et al.*, see Figure A.4.3 for locations):

**#1)** Spring water from the Coleman conglomerate. Spring is near the confluence of the west and south branches of Sasaginaga Creek. This water contains 1.16 ppm As and 96 ppb Co.

**#59)** Spring water from the Coleman conglomerate. Located adjacent to the Aguanico mine on Lake Temiskaming. Water contains 0.118 ppm As.

**#66)** Water from a 25 ft well in the Coleman conglomerate. Located in North Cobalt, off Hwy 567 on Groom Rd. Water contains 0.076 ppm As.

**#67)** Water from a well in the Coleman conglomerate. Adjacent to #66. Water contains 0.079 ppm As.

**#72)** Water from a spring fed open pit in the Archean volcanics, malachite and other carbonates are precipitating around the spring. Located near the Nipissing high grade mill. Water contains


Site Number and Description	T	pН	Eh	Total Motols	Pb	Zn	Cd	Cu	As	Sb	Ag	Ni (field)	Ni (Lab)	Co (field)	Co (lab)	Mn	Fe
	°C		mV	ppm							bbp	(lielu)	(Lab)	(neiu)	(IaD)		
#1 spring water, conglomerate	6	7.1	+360	0.250	<5	45	< 0.2	14	1.16	37	<1.5	70	73	60	96	70	430
#55 well, 11.5' deep, diabase	10	7.8	+450	0.007	<5	16	< 0.2	5	< 0.002	0.3	0.8	<5	1	<10	<2	50	180
#56 well, diabase	7	7.1	+665	0.005								<5		<10			
#58 well, 15' deep, diabase	10	6.1	+620	0.020								<5		<10			
#59 spring water, conglomerate	16	7.9	+590	0.010	<5	23	< 0.2	22	0.118	0.1	0.5	<5	<1	<10	<9	22	270
#60 well, 5' deep, volcanics	13	7.2	>+665	0.100								<5		<10			
#61 mine shaft, volcanics	16	6.9	>+665	0.175								<5		<10			
#62 well, 10' deep, volcanics	13	7.5	>+665	0.125								<5		<10			
#63 spring water, in pit in volcanics, high organics	20	6.6	>+665	0.025								<5		<10			
#64 well, 14' deep, conglomerate	14	7.2	+450	0.125								<5		<10			
#65 well, 10' deep, conglomerate	13	7.0	+460	0.005								<5		<10			
#66 well, 25' deep, conglomerate	8	7.3	+350	0.400	5	260	0.3	5	0.076	0.7	0.8	<5	16	50	9	50	580
#67 well, conglomerate	7	6.9	+450	0.150	<5	114	1.2	13	0.079	1.7	0.7	<5	5	<10	6	10	250
#68 well, 5' deep, volcanics	14	6.6	+520	< 0.001								<5		<10			
#69 spring water, diabase	6	7.1	+460	< 0.001								<5		<10			
#70 well, 30' deep, diabase	7	6.8	+440	0.400								<5		<10			
#71 spring water, volcanics, carbonates precipitating around spring	20	7.8	+480	0.500								20		<10			
#72 mine water, volcanics, carbonates precipitating around shaft	18	8.2	+440	0.450	<5	136	<0.2	59	0.741	14	4.3	70	52	60	98	5	80
#73 drill hole, diabase, sulfurous taste, iron precipitate around collar	10	7.9	+230	0.007	<5	<5	<0.2	1	< 0.002	7	0.7	<5	<1	100	1	10	440
#74 well, diabase	10	7.7	+440	0.100								<5		<10			
#75 well, 8' deep, conglomerate	13	6.6	+480	0.004	<5	<5	< 0.2	5	< 0.002	0.3	0.8	<5	1	<10	<2	10	<50
#76 stream water, conglomerate	17	7.2	+470	0.007								<5		<10			
#77 stream water, conglomerate	19	8.1	+420	0.003								<5		<10			

 Table A.4.5: Trace element concentrations in samples collected by Boyle et al. (1967)

Site Number and Description	T	pН	Eh	Total Motels	Pb	Zn	Cd	Cu	As	Sb	Ag	Ni (field)	Ni (Lab)	Co (field)	Co (lab)	Mn	Fe
	°C		mV	ppm				-			nnh	(neiu)	(LaD)	(lielu)	(IaD)		
	10	0.5		-0.001							phn	1 .5	1	.10	1		
#/8 stream water, volcanics	18	8.5	+410	< 0.001							5	<5		<10			
#79 well, 10' deep	14	7.9	+230	0.010								<5		<10			
#80 well, 10' deep, conglomerate	12	7.4	+400	0.125								<5		<10			
#81 well, 10' deep, volcanics	12	7.4	+440	0.025								<5		<10			
#82 well, 12' deep, volcanics	11	7.4	+390	0.035								<5		<10			
#83 well, 15' deep, diabase	12	7.3	+460	0.150								<5		<10			
#84 drill holes, conglomerate	7	7.2	+250	0.175	<5	18	< 0.2	8	9.10	17.0	0.5	500	360	250	700	130	630
#85 drill holes, conglomerate	7	7.5	+290	0.005								<5		<10			
#222 stream water, conglomerate	14	7.5	+420	< 0.001								<5		<10			
#234 stream water, diabase	20	8.0	+360	0.0015	<5	7	<0.2	9	0.53	14.0	0.6	30	18	<10	2	<5	80
#235 stream water, diabase	19	7.3	+360	0.002								30		<10			
#236 mine water, diabase	18	7.2	+390	0.025								20		<10			
#237 stream water, diabase	18	7.9	+410	0.003	5	<5	<0.2	6	0.47	9.0	0.7	20	17	<10	2	20	120
S-3 Silverfields Mine, lamprophyre dike	7	7.7	+340	0.160	10	270	1.6	19	0.293	4.5	0.5	20	7	<10	12	100	80
S-4 Silverfields Mine	7	7.5	+320	0.005	<5	8	< 0.2	21	0.174	3.6	0.6	5	2	<10	4	20	250
S-6 Silverfields Mine, volcanics	7	7.4	+350	0.025	5	15	< 0.2	42	0.042	12.0	0.5	10	2	<10	2	50	100
S-9 Silverfields Mine, greywacke	7	7.8	+390	0.250	53	46	0.3	190	8.04	0.484	1.0	1250	600	90	230	420	60
S-11 Silverfields Mine, greywacke	7	7.7	+360	0.007	<5	6	< 0.2	46	0.286	0.004	0.7	<5	3	<10	7	20	700
GL-1 Glen Lake Mine, diabase	8	8.5	+30	< 0.001	<5	<5	0.3	<1	0.097	0.0003	0.5	<5	<1	<10	2	<5	50
GL-3 Glen Lake Mine, volcanics	9	8.5	+80	< 0.001	<5	<5	<0.2	<1	0.015	0.0004	0.5	<5	<1	<10	<1	5	80
GL-5 Glen Lake Mine, greywacke	9	7.5	+290	< 0.001	<5	<5	0.3	2	0.085	0.0008	1.0	<5	1	<10	1	20	80

Table A.4.5 (continued): Trace element concentrations in samples collected by Boyle *et al.* (1967)

0.741 ppm As and 98 ppb Co. A similar precipitate from an adjacent sampling point, #71, contains 200 ppm As, 70 ppm Ni and 150 ppm Co.

**#84)** Water from a diamond drill hole in the Coleman conglomerate, a yellow precipitate is forming on rocks around the hole. The hole is located beside Lake Temiskaming, within the Bucke Park campground, owned by Bucke Township. The water contains 9.10 ppm As, 360 ppb Ni and 700 ppb Co, and the precipitate contains more than 10,000 ppm As, 2,000 ppm Ni and 5,000 ppm Co. This water was being used to supply drinking water to the campground, and it was used for cooking, cleaning and consumption at the park snack bar (Rychlo, 1977). Rychlo states that, as of 1977, the use of this water by the campground had been discontinued.

**#S-3)** Collected underground at the Silverfields Mine. Water was taken from a fracture in a mafic dike and contains 0.293 ppm As. A red-brown precipitate from around this fracture contains 10,000 ppm Pb, more than 2,000 ppm As, 200 ppm Ni and 100 ppm Co.

**#S-4)** Collected underground at the Silverfields Mine, rock type not known. The As concentration is 0.174 ppm.

**#S-9)** Collected underground at the Silverfields Mine. Water was taken from a fault zone in the Coleman greywacke and contains 8.04 ppm As.

**#S-11)** Collected underground at the Silverfields Mine. Water was taken from a diamond drill hole in the Coleman greywacke and contains 0.286 ppm As.

**#GL-1)** Collected underground at the Glen Lake Mine. Water was taken from a diamond drill hole in the Nipissing Diabase and contains 0.097 ppm As.

**#GL-5)** Collected underground at the Glen Lake Mine. Water was taken from a diamond drill hole in the Coleman greywacke and contains 0.085 ppm As.

## A.4.2.2 Ontario Ministry of the Environment Report, 1977

The second major report on groundwater contamination, completed by the Ontario Ministry of the Environment, focused on private well water supplies within several townships in the Tri-Town region, including Coleman Township, which Cobalt is within, and Bucke Township, to the north. This was a two part study: in the first part, completed in 1976, 188 wells were sampled. In the second part of the study, completed in 1977, 187 additional wells were sampled, and 43 wells sampled in the first part of the study were resampled. In total, 375 private and 5 communal water supplies were sampled, leaving only a small, undetermined number of wells unsampled (see Figure A.4.4). The MOE report does not describe the analytical techniques used for their analyses.

All of the samples collected were analysed for As (see Table A.4.7). Of the 188 wells sampled in the first part of the study, 59 wells had detectable As, of which 12 had As concentrations in



excess of 0.01 ppm, the provincial water quality objective for As. This part of the report identified seven regions of concern. Of the 187 samples collected during the second part of the study in 1977, 15% were collected within these seven regions, while the other 85% were collected in new areas, particularly Harris Township. Forty-one of these samples had detectable As, one of which had an As concentration between 0.01 to 0.05 ppm and one of which had an As concentration in excess of 0.05 ppm, the maximum allowable As concentration for drinking water. It should be noted that while this report mentions the water supply at Bucke Park (sample #84 from Boyle *et al.* 1967, 9.01 ppm), and indicates that the supply does contain very high As levels, this site was not included in the study.

One of the areas of concern identified in this study was a community called Mileage 104, about 3 km northeast of Cobalt. Of 17 wells sampled in this area, 13 had detectable As, with levels ranging from 0.001 ppm to 0.010 ppm. These wells were all dug wells ranging in depth from 9 to 30 feet. Also of concern was the community of West Cobalt, about 2 km southwest of Cobalt. Six wells were tested in this area, 5 of which had measurable As, ranging from 0.001 ppm to 0.93 ppm. A third area of concern which is relevant to the current study is the area to the east of North Cobalt, along Highway 567. Of fourteen samples collected, 8 contained As, with concentrations ranging from 0.001 ppm to 0.08 ppm.

The authors of this report identified possible sources of As contamination in these wells. In the West Cobalt area, mine waste rock was used as fill, and the drilled wells intersected greywacke units of the Coleman Member of the Gowganda Formation. Waste rock from driveways was analysed and found to contain in excess of 500 ppm As. The most contaminated well in this area, with an As concentration of 0.93 ppm (not used for consumption), was a hand pump constructed above an exploration pit. In the shallow dug wells of Mileage 104, the probable source was identified as mine waste rock used as fill material, and this fill material also had As concentrations in excess of 500 ppm. The authors also drew a possible link with the Crosswise Lake tailings deposit, located just east of this community. In general, the authors concluded that there is a clear link between contaminated wells and the Coleman greywacke, and on the basis of this, local well drillers and the Regional Well Inspector were informed of this connection, and advised to sample water from wells which intersect this unit.

As well as As, samples were analysed for Cd, Co, Pb, Ni, Ag and Zn. Of the 187 samples from the second part of the study, only three had elevated levels of any of these metals. Two samples contained Pb and one contained Zn. These wells were not resampled to determine whether or not these metals were coming from the solder in the pipes. Neither Cd nor Zn were found in any of the wells tested.

Well	Location	As	Со	Pb	Zn	Cd	Ni	Ag
#					mg/L			
J123	Mileage 104	0.007	< 0.01	< 0.02	< 0.01	< 0.01	< 0.02	< 0.01
J124	Mileage 104	0.001	< 0.01	< 0.02	0.26	< 0.01	< 0.02	0.01
J125	Mileage 104	0.001	< 0.01	< 0.02	0.06	< 0.01	< 0.02	0.01
J127	Mileage 104	0.010	< 0.01	< 0.02	0.74	< 0.01	< 0.02	0.01
J128	Mileage 104	0.005	< 0.01	< 0.02	1.9	< 0.01	< 0.02	< 0.01
J129	Mileage 104	0.001	< 0.01	< 0.02	2.8	< 0.01	< 0.02	< 0.01
J130	Mileage 104	0.001	< 0.01	< 0.02	1.8	< 0.01	< 0.02	< 0.01
J178	North Cobalt	0.080	< 0.02	< 0.03	0.30	< 0.005	< 0.02	< 0.01
J179	North Cobalt	0.001	< 0.02	< 0.03	0.62	< 0.005	< 0.02	< 0.01
J71	Sharp Lake	0.003	< 0.01	0.02	0.25	< 0.005	< 0.02	< 0.01
J126	Mileage 104	0.001	< 0.01	< 0.02	0.17	< 0.01	< 0.02	< 0.01
J131	Mileage 104	< 0.001	< 0.01	< 0.02	0.65	< 0.01	< 0.02	< 0.01
J132	East Cobalt	< 0.001	< 0.01	< 0.02	2.2	< 0.01	< 0.02	< 0.01
J133	Mileage 104	0.002	< 0.01	< 0.02	1.8	< 0.01	< 0.02	< 0.01
J134	Mileage 104	0.005	< 0.01	< 0.02	0.07	< 0.01	< 0.02	0.01
J135	Mileage 104	< 0.001	< 0.01	< 0.02	0.04	< 0.01	< 0.02	0.01
J136	East Cobalt	< 0.001	< 0.01	< 0.02	4.2	< 0.01	< 0.02	0.01
J137	East Cobalt	< 0.001	< 0.01	< 0.01	0.04	< 0.01	< 0.02	< 0.01
J138	Mileage 104	0.003	< 0.01	< 0.02	2.6	< 0.01	< 0.02	< 0.01
J139	Mileage 104	0.004	< 0.01	< 0.02	0.19	< 0.005	< 0.02	0.01
J140	Mileage 104	0.003	< 0.01	< 0.02	0.24	< 0.005	< 0.02	0.01
J203	West Cobalt	0.001	< 0.04	< 0.06	0.41	< 0.01	< 0.04	< 0.02
J16	Gillies Lake	0.002	< 0.01	< 0.01	0.05	< 0.005	< 0.01	< 0.01
J17	Gillies Lake	0.002	< 0.01	< 0.01	0.10	< 0.005	< 0.01	< 0.01
J18	Gillies Lake	0.002	< 0.01	< 0.01	0.16	< 0.005	< 0.01	< 0.01
J19	Gillies Lake	0.002	< 0.01	< 0.01	0.20	< 0.005	< 0.01	< 0.01
J20	Gillies Lake	< 0.001	< 0.01	< 0.01	1.2	< 0.005	< 0.01	< 0.01
J62	Gillies Lake	0.002	< 0.02	< 0.02	0.22	< 0.01	< 0.02	< 0.01
		0.002	< 0.02	< 0.03	0.10	< 0.005	< 0.02	< 0.01
J4	Gillies Lake	0.001	< 0.02	< 0.03	0.06	< 0.005	< 0.02	< 0.01
J5	Gillies Lake	0.001	< 0.02	< 0.03	< 0.02	< 0.005	< 0.02	< 0.01
L58	North Cobalt	0.001	< 0.01	< 0.01	0.20	< 0.005	< 0.01	< 0.02
		0.002	< 0.03	< 0.03	0.03	< 0.005	< 0.02	< 0.01
F44	West Cobalt	0.93	< 0.01	< 0.01	0.14	< 0.005	< 0.01	< 0.02
		0.001	< 0.01	< 0.01	0.07	< 0.005	< 0.01	< 0.02
		0.02	< 0.03	< 0.02	0.18	< 0.005	< 0.02	< 0.01
		0.03	< 0.01	< 0.02	0.29	< 0.005	0.02	< 0.01

**Table A.4.7:** Arsenic and heavy metal concentrations in groundwater samples collected by the Ontario Ministry of the Environment 1977

Well	Location	As	Со	Pb	Zn	Cd	Ni	Ag
#					mg/L			
F42	West Cobalt	< 0.002	< 0.01	< 0.01	0.40	< 0.005	0.01	< 0.02
		0.003	< 0.01	< 0.01	0.08	< 0.005	< 0.01	< 0.02
		0.30	N/A	< 0.03	0.16	< 0.005	< 0.02	< 0.01
F46	West Cobalt	0.001	< 0.01	< 0.01	0.40	< 0.005	< 0.01	< 0.02
		0.002	< 0.01	< 0.01	0.18	< 0.005	< 0.01	< 0.02
		0.002	< 0.03	< 0.03	0.12	< 0.005	< 0.02	< 0.01
F32	Gillies Lake	0.002	< 0.01	< 0.01	0.04	< 0.005	< 0.01	< 0.02
		0.003	< 0.01	< 0.01	0.05	< 0.005	< 0.01	< 0.02
		0.001	< 0.03	< 0.03	< 0.02	< 0.005	< 0.02	< 0.01
F33	Gillies Lake	0.001	0.01	0.02	0.26	< 0.005	< 0.01	< 0.02
		0.002	< 0.01	< 0.01	0.11	< 0.005	< 0.01	< 0.01
		0.001	< 0.02	< 0.03	0.28	< 0.005	< 0.02	< 0.01
F31	Gillies Lake	0.001	< 0.01	< 0.01	0.37	< 0.005	0.01	< 0.02
		0.002	< 0.01	< 0.01	0.12	< 0.005	0.01	< 0.01
		0.001	< 0.03	< 0.03	0.90	< 0.005	< 0.02	< 0.01
L3	East Cobalt	0.002	< 0.01	< 0.01	0.27	< 0.005	< 0.01	< 0.02
		0.002	< 0.01	< 0.01	0.21	< 0.005	< 0.02	< 0.02
		0.002	< 0.03	< 0.03	0.06	< 0.005	< 0.02	< 0.01
L9	Mileage 104	0.002	< 0.01	< 0.01	0.18	< 0.005	< 0.01	< 0.02
		0.002	< 0.01	< 0.01	1.2	< 0.005	< 0.01	< 0.02
		0.002	< 0.03	< 0.03	0.30	< 0.005	< 0.02	< 0.01
L15	North Cobalt	0.004	< 0.01	< 0.01	0.10	< 0.005	< 0.01	< 0.02
		0.002	< 0.01	< 0.01	0.03	< 0.005	< 0.01	< 0.02
		0.002	< 0.03	< 0.03	< 0.02	< 0.005	< 0.02	< 0.01
L14	North Cobalt	< 0.001	< 0.01	< 0.01	< 0.01	< 0.005	< 0.01	< 0.02
		0.001	< 0.01	< 0.01	0.16	< 0.005	< 0.01	< 0.02
		< 0.001	< 0.03	< 0.03	< 0.02	< 0.005	< 0.01	< 0.02
L59	North Cobalt	0.002	< 0.01	< 0.01	0.24	< 0.005	< 0.01	< 0.02
		0.003	< 0.01	0.04	0.04	< 0.005	< 0.01	< 0.02
L5	East Cobalt	< 0.008	< 0.01	< 0.01	2.5	< 0.005	< 0.01	< 0.02
		0.02	< 0.01	< 0.01	0.27	< 0.005	< 0.01	< 0.02
		0.006	< 0.03	< 0.03	0.78	< 0.005	< 0.02	< 0.01
J21	North Cobalt	< 0.001	< 0.01	0.05	8.0	< 0.005	< 0.01	< 0.01
		< 0.001	< 0.02	< 0.03	4.2	< 0.005	< 0.02	< 0.01
J22	North Cobalt	< 0.001	< 0.01	0.04	7.1	< 0.005	< 0.01	< 0.02
		< 0.001	< 0.01	0.01	6.2	< 0.005	< 0.01	< 0.01
I		< 0.001	< 0.02	< 0.03	3.2	< 0.005	< 0.02	< 0.01
L60	North Cobalt	0.023	< 0.01	< 0.01	0.06	< 0.005	< 0.01	< 0.02
I		0.13	< 0.02	< 0.03	0.04	< 0.005	< 0.02	< 0.01
L16	North Cobalt	0.001	< 0.01	< 0.01	1.6	< 0.005	< 0.01	< 0.02
L		0.001	< 0.02	< 0.03	0.89	< 0.005	< 0.02	< 0.01
J3	East Cobalt	0.001	< 0.01	< 0.01	2.6	< 0.005	< 0.01	< 0.02
		0.04	< 0.02	< 0.03	0.08	< 0.005	< 0.01	< 0.02

 Table A.4.7 (continued):
 Arsenic and heavy metal concentrations in groundwater samples collected by the Ontario Ministry of the Environment 1977

#### A.4.4 Arsenic and Cobalt Contamination in Garden Produce Grown in Metal-Rich Soils

In 1990, The Ontario Ministry of the Environment collected samples of vegetables grown in Cobalt in order to assess the health risks associated with eating produce grown in metal-rich soils. In this study, potatoes, beets and carrots were collected from four gardens. The actual locations of these gardens are not given in the report and the soils in which the plants were growing were not analysed. Samples were analysed for As and Co content. In three of the gardens, all of the samples were close to or below the detection limit of 0.2 ppb dry weight for both As and Co. In the fourth garden, As and Co concentrations were as high as 5.00 ppb dry weight and 11.0 ppb dry weight, respectively (Fleming 1991). Fleming (1991) used three food consumption models to determine the average daily As and Co doses for the residents of the home with the fourth garden. The report concluded that As consumption could exceed the World Health Organization provisional maximum acceptable daily As intake of 2  $\mu$ g of As per kg of body weight. Fleming (1991) considers these levels to be of concern, with cancer risk predicted to be "moderately above the negligible range". There are no suggested dosage levels for Co, and Fleming (1991) concluded that the Co dosages are not of concern for any of the gardens tested.

# **Appendix 5:**

## Chemistry and Toxicity of Contaminants of Concern in the Cobalt Area

Arsenic, mercury, nickel, cobalt and cyanide are all of concern as contaminants in the Cobalt area. In this appendix, the environmental chemistry and toxicity of these contaminants is reviewed.

## A.5.1 Arsenic

## A.5.1.1 Characteristics of Arsenic

Arsenic (As) is a metalloid element. Chemically, it behaves like both metals and nonmetals, particularly sulphur. It can exist in four oxidation states: As(-III), As(0), As(III) and As(V), but in nature, only As(III) and As(V) are important. The primary inorganic forms of As in the environment are sulphide, sulpharsenide and arsenide minerals, particularly realgar (AsS), orpiment (As<sub>2</sub>S<sub>3</sub>), arsenopyrite (FeAsS), cobaltite (CoAsS), and the skutterudite series ((Co,Ni)As<sub>2-3</sub>)(Berry *et al.* 1983). In these minerals, As occurs as As(III). Under oxidizing conditions, these minerals alter to secondary minerals such as scorodite (FeAsO<sub>4</sub>·2H<sub>2</sub>O), which are slightly water soluble, and which can further alter to water soluble arsenates (Boyle and Dass 1971).

In soil and sediments, As exists as dissolved species, and it can be absorbed onto or coprecipitated with Fe and Mn oxyhydroxides. It can also be fixed in clay minerals and organic matter (Cullen and Reimer 1989). Soil microorganisms can metabolize 17 to 60% of As available into arsine gas phases (NRCC 1978).

In aerobic waters, arsenate  $(AsO_4^{-3})$  is the most common form of As, but under anaerobic conditions, arsenite  $(AsO_3^{-3})$  is the more common form. Under reducing conditions, bacteria can methylate arsenic, producing methyl-, dimethyl- or trimethylarsine gases (*e.g.* (CH<sub>3</sub>)<sub>3</sub>As), which are eventually oxidized to methylarsinic acid ((CH<sub>3</sub>)H<sub>2</sub>AsO<sub>3</sub>), dimethylarsinic acid ((CH<sub>3</sub>)<sub>2</sub>HAsO<sub>2</sub>) and trimethylarsine oxide ((CH<sub>3</sub>)<sub>3</sub>AsO) (Cullen and Reimer 1989).

In tissue, As can exist as dissolved species, or in a number of organoarsenicals such as arsenosugars, arsenobetaine and arsenocoline (Cullen and Reimer 1989).

Due to its complex chemistry, As transformations are common. Transformations can occur as a result of changes in pH, Eh, temperature and concentration, as well as biological activity. The ultimate sink for As is ocean sediments.

## A.5.1.2) Environmental Occurrences

<u>Freshwater</u>: natural As concentrations are typically less than 2  $\mu$ g·L<sup>-1</sup>, and concentrations ranging from less than 0.1 to 2.5  $\mu$ g·L<sup>-1</sup> have been reported in the Canadian Great Lakes (Nriagu 1983, Traversy *et al.* 1975). In areas of arsenic mineralization, As concentrations in surface water can be higher. In areas affected by mining and smelting, As concentrations in lake water range from 20  $\mu$ g·L<sup>-1</sup> near a copper smelter in Noranda, PQ, to 3000  $\mu$ g·L<sup>-1</sup> in Kam Lake near Yellowknife, NWT (Azzaria and Frechette 1987, CPHA 1977). Concentrations as high as 19800  $\mu$ g·L<sup>-1</sup> have been reported in river water near Yellowknife (CPHA 1977).

<u>Groundwater</u>: natural groundwater normally contains more As than surface water, but in most areas of the country, As concentrations in groundwater are below 50  $\mu$ g·L<sup>-1</sup>, the maximum acceptable limit for drinking water and for freshwater aquatic life (Boyle and Jonasson 1973, Michel 1990). In some As-mineralized areas of NB and NS, As concentrations in well water range from less than 50 to 700  $\mu$ g·L<sup>-1</sup> (Grantham and Jones 1977, Meranger *et al.* 1984).

<u>Soil</u>: normal soils in Canada contain less than 10 mg·kg<sup>-1</sup> of As, although natural concentrations can be as high as 55 mg·kg<sup>-1</sup> in mineralized areas (Frank *et al.* 1976, Webber and Shamess 1987, Boyle and Jonasson 1973).

In areas affected by mining soil As concentrations can be higher. Reported As concentrations range from 9 mg·kg<sup>-1</sup> in soils around Sudbury and Noranda, to 600 mg·kg<sup>-1</sup> in soils around Yellowknife, and 7,600 mg·kg<sup>-1</sup> in soils adjacent to mines and mills in the Yellowknife area (Azzaria and Frechette 1987, Gemmill 1977).

## A.5.1.3 Effects on Biota

## A.5.1.3.1 Uptake and Accumulation

Arsenic can by taken up by plants through absorption in the roots and on the leaves, with the amount of uptake depending on the form of As and whether the absorption is through the roots or the leaves. Arsenic can be taken up by animals by ingestion, inhalation, or through permeation of the skin or mucous membranes (Eisler 1988).

In aquatic systems, As is bioaccumulated from the water by organisms, but it is not biomagnified through the foodchain (CCREM 1987). The degree of bioaccumulation depends on the species, the age of the organism, As concentration and water temperature (US EPA 1979, Demayo *et al.* 1979). Lower forms of aquatic life tend to accumulate greater amounts of As than fish, and bottom feeding fish accumulate greater amounts than other fish (CPHA 1977). In marine environments, biodiminution of As, relative to phosphorus, which has similar biochemical properties, has been reported (Andreae 1986).

## A.5.1.3.2 Toxicity of Arsenic

The toxicity of As varies with the form in which it occurs. The toxicity of As species conforms to the following order, from most toxic to least toxic: arsines > inorganic arsenites > organic As(III) compounds > inorganic arsenates > organic As(V) compounds > arsonium compounds > elemental As (Eisler 1988). The mechanisms of toxicity differ between species but all cause similar results. The toxicity of As appears to be related to is biochemical resemblance to phosphorus (NRCC 1978).

A large number of As toxicity studies have been conducted. Results of some of these studies are summarized in Table A.5.1.

Species	Concentration/ Exposure period	Response	Reference
	producing response		
Rainbow trout eggs Salmo gairdneri	540 μg As·L <sup>-1</sup> , 28 days, as sodium arsenite	LC50	Birge 1978
Rainbow trout	30 mg As·kg <sup>-1</sup> diet, 8 weeks	weight gain 69% of control	Oladimeji <i>et al.</i> 1984
Rainbow trout	961 μg As·L <sup>-1</sup> , 28 days, arsenic trioxide	no effect	Spehar et al. 1980
Rainbow trout	973 μg As·L <sup>-1</sup> , 28 days, arsenic pentoxide	no effect	Spehar et al. 1980
Brook trout Salvelinus fontinalis	27800 μg As·L <sup>-1</sup> , sodium arsenite	LC50	Cardwell <i>et al.</i> 1976
Muskellunge Esox masquinongy swim up fry	1100 μg As·L <sup>-1</sup> , 96 hours, sodium arsenite	LC50	Spotila and Paladino 1979
freshwater perch Colisa fasciatus	8000 μg As·L <sup>-1</sup> , 96 hours, arsenic trioxide	LC50 or EC50	Pandey and Shukla 1982
Mallard ducklings Anus platyrhynchos	300 mg As·kg <sup>-1</sup> bw, 10 weeks, sodium arsenate	decreased brain ATP, altered growth	Camardese <i>et al.</i> 1990

## Table A.5.1. Selected toxicity data for arsenic

## A.5.1.4 Concentration Limits for Arsenic

Under the Canadian Water Quality Guidelines, the maximum acceptable concentration of As in drinking water is 0.050 mg/L. The maximum concentration considered acceptable for freshwater aquatic life is also 0.050 mg/L (CCREM 1987). There is no Guideline for the As concentration in waters used for recreation.

## A.5.1.5 References for Arsenic

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## A.5.2 Mercury

## A.5.2.1 Characteristics of Mercury

Mercury (Hg) is a metal which can exist in one of three oxidation states, Hg(0), Hg(+I) and Hg(+II). Mercury is unique because elemental Hg exists as a liquid at room temperature (NRCC 1980). Elemental Hg is rare in nature, but it commonly occurs in solid solution with native Au and Ag (Berry *et al.* 1983). The most common primary Hg mineral is cinnabar, HgS, which is an important ore of Hg but is rare in Canada (Eckstrand 1984). Mercury can also occur in a number of sulphide minerals, particularly tetrahedrite (Cu<sub>12</sub>Sb<sub>4</sub>S<sub>13</sub>), an ore of Cu which can contain up to 1000  $\mu$ g·g<sup>-1</sup> Hg (NRCC 1980). Few secondary Hg minerals exist. Historically, Hg was used as an amalgam in the recovery of Au and Ag, so Hg can be present in the mine wastes from such operations, which are frequently abandoned.

Once released to the environment, the biogeochemical cycling of Hg is complex, with bacterially mediated transformations playing an important role in the cycling. In natural, aerobic waters elemental Hg is normally oxidized so that the dominant inorganic species are Hg(+II) species, typically complex ions (CCREM 1987). An important process in the removal of inorganic Hg from the water column is the sorption of Hg(+II) onto suspended solids and bottom sediments. This process is dependent on the organic content of the sediment, and pH has little affect. Desorption rates from sediment are low (CCREM 1987).

Microorganisms in sediment, the water column and within organisms can methylate Hg(+II) under both aerobic and anaerobic conditions, although rates tend to be higher in aerobic systems (CCREM 1987). The rate of methylation is pH dependant. The methylation rate in lake water at a pH of about 4.5 has been reported to be about seven times faster than the methylation rate at a pH of about 8.5 (D'Itri 1991). Dimethylmercury ((CH<sub>3</sub>)<sub>2</sub>Hg) tends to be formed at high pH and low Hg(+II) concentrations, while lower pH and higher concentrations favour the formation of methylmercury (CH<sub>3</sub>Hg<sup>+</sup>)(CCREM 1987). Once formed, some methylmercury is lost to the atmosphere through volatilization, but almost all methylmercury is absorbed by organisms. Excretion from organisms is very slow, and the biological half life of Hg in fish is about 2 years

(D'Itri 1991, CCREM 1987).

Bacteria in sediments and possibly the water column are capable of demethylating methylmercury, producing elemental Hg and methane. This process helps to reduce methylmercury concentrations, but the rate of demethylation tends to be lower than the rate of methylation, so an excess of methylmercury is almost always available for absorption by organisms (D'Itri 1991).

Atmospheric cycling is very important in the biogeochemical cycle of Hg, since elemental Hg, and some other forms of Hg are volatile. The predominant Hg species in the atmosphere is elemental Hg, but methylmercury has been reported. Mercury also occurs in airborne particulate matter, although the particulate fraction is normally less than 4 % of the total Hg in the atmosphere (D'Itri 1991). Volatilization of Hg from water bodies can be a mechanism for the removal of Hg, but Hg is removed from the atmosphere by means of particulate fallout and dissolution in precipitation, resulting in the recontamination of soil and surface water (D'Itri 1991). Atmospheric transport of Hg from contaminant sources can be an important source of surface water contamination (NRCC 1980).

## A.5.2.2 Environmental Occurrence of Mercury

<u>Freshwater</u>: background concentrations in Canadian surface waters are usually close to 0.05  $\mu g \cdot L^{-1}$ . In the Great Lakes, mean Hg concentrations range from 0.13 to 0.18  $\mu g \cdot L^{-1}$  (CCREM 1987). Near Hg deposits, concentrations in streams and rivers can contain up to 100  $\mu g \cdot L^{-1}$  Hg (CCREM 1987).

<u>Groundwater:</u> background concentrations normally range from 0.01 to 0.10  $\mu$ g·L<sup>-1</sup>, but concentrations ranging from 1 to 1000  $\mu$ g·L<sup>-1</sup> have been reported in mineralized areas (NRCC 1980).

## A.5.2.3 Effects on Biota

## A.5.2.3.1 Uptake and Accumulation

Mercury (II) and methylmercury forms of Hg are available to organisms for uptake, and bioconcentration occurs. Bioconcentrations factors (BCFs) for Hg (II) in fish range from 1800 in rainbow trout (*Salmo gairdneri*) to 4994 in fathead minnow (*Pimphales promelas*), but BCFs for methylmercury are much higher, ranging from 11000 to 85700 for rainbow trout, and 44130 to 81670 for fathead minnow (U.S. EPA 1984). Mercury has also been shown to be biomagnified in ecosystems, meaning that higher order consumers contain higher Hg concentrations as a result of consuming organisms lower in the chain and containing lower Hg concentrations. Therefore, higher order consumers are at greater risk from Hg contamination (Cuthbert, 1991).

## A.5.2.3.2 Toxicity of Mercury

<u>Freshwater Plants:</u> concentrations at which effects occur range from 5  $\mu$ g·L<sup>-1</sup> Hg (8-day incipient inhibition in blue alga *Microcystis aeruginosa*) to an LC<sub>50</sub> of 1000  $\mu$ g·L<sup>-1</sup> (alga *Chlorella vulgaris*)(U.S. EPA 1984).

Freshwater Invertebrates:

<u>Acute:</u>  $LC_{50}$  for Hg(II) range from 4.4  $\mu$ g·L<sup>-1</sup> in *Daphnia magna* to 2100  $\mu$ g·L<sup>-1</sup> for the embryo of the snail *Amnicola* sp. (U.S. EPA 1984).

<u>Chronic</u>: chronic effects on *Daphnia magna* have been reported at Hg(II) concentrations of 0.72 to 1.82  $\mu$ g·L<sup>-1</sup>, and for methylmercury at concentrations of <0.04 to 0.87  $\mu$ g·L<sup>-1</sup> (U.S. EPA 1984).

Freshwater Vertebrates:

<u>Acute:</u>  $LC_{50}$  for Hg(II) have been reported to range from 150 to 420 µg·L<sup>-1</sup> (fathead minnow and rainbow trout, respectively), but lower  $LC_{50}$ , ranging from 24 to 84 µg·L<sup>-1</sup> (rainbow trout and juvenile brook trout, respectively) have been reported for methylmercury (U.S. EPA 1984).

<u>Chronic</u>: chronic effects on fathead minnow have been reported at Hg(II) concentrations of  $<0.23 \ \mu g \cdot L^{-1}$ , and effects on brook trout have been reported at methylmercury concentrations ranging from 0.29 to 0.93  $\mu g \cdot L^{-1}$  (U.S. EPA 1984).

## A.5.2.4 Concentration Limits for Mercury

Under the Canadian Water Quality Guidelines, the maximum acceptable concentration of Hg in drinking water is 1  $\mu$ g·L<sup>-1</sup>. The maximum concentration considered acceptable for freshwater aquatic life is 0.1  $\mu$ g·L<sup>-1</sup> (CCREM 1987). There is no Guideline for the Hg concentration in waters used for recreation.

## A.5.2.5) References for Mercury

Berry, L.G., B. Mason and R.V. Dietrich (1983): <u>Mineralogy</u>. W.H. Freeman and Company, San Francisco.

CCREM (1987): <u>Canadian Water Quality Guidelines</u>. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environment Ministers.

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NRCC (1978): <u>Effects of arsenic in the Canadian environment</u>. National Research Council of Canada, No. 15391. Associate Committee on Scientific Criteria for Environmental Quality. Ottawa.

U.S. EPA (1984): <u>Ambient Water Quality Criteria for Mercury</u>. Office of Water Regulations and Standards, United states Environmental Protection Agency. (EPA 440/5-84-026). Washington, D.C.

## A.5.3. Nickel

## A.5.3.1 Characteristics of Nickel

Nickel (Ni) has six possible oxidation states, from Ni(-I) to Ni(+IV), but the most common oxidation states in nature are Ni(0) and Ni(II)(Stoeppler 1980). The Ni(III) and Ni(IV) states are relatively stable, but are comparatively rare (NRCC 1981). Primary Ni minerals include sulphides such as pentlandite ((Fe,Ni)<sub>9</sub>S<sub>8</sub>), arsenides and sulpharsenides such as nickeline (NiAs) and gersdorffite (NiAsS), and in a number of silicates (Berry *et al.* 1983). Chemically, Ni is very similar to both Fe and Co, so it can replace Fe and Co in primary minerals such as pyrite (FeS<sub>2</sub>), pyrrhotite (Fe<sub>1-x</sub>S) and cobaltite (CoAsS) (Berry *et al.* 1983). Secondary minerals in which Ni can occur include sulphates, arsenates, carbonates, oxides and clay minerals. Oxidation and dissolution of secondary Ni minerals result in the release of Ni to the environment.

In aquatic systems, Ni can occur as dissolved species, or as soluble salts adsorbed onto or associated with clay minerals, iron and manganese oxides, or organic matter. Factors affecting the form in which Ni occurs in aquatic systems, as well as its fate in such systems include pH, Eh, ionic strength, type and concentration of organic and inorganic ligands, and the presence of solid surfaces for adsorption (Nriagu 1980). In natural waters, at a pH of 5 to 9, Ni<sup>+2</sup> is the dominant Ni species, and where  $SO_4^{-2}$  concentrations are high, highly soluble NiSO<sub>4</sub> may be the dominant Ni species (Nriagu 1980). Below a pH of 6 Ni is highly mobile, and sorption plays a minor role in Ni transport and availability (CCREM 1987).

## A.5.3.2 Environmental Occurrences

<u>Freshwater</u>: concentrations of Ni in freshwater systems are generally less than 2 to 10  $\mu$ g·L<sup>-1</sup> (NRCC 1981). In lakes unaffected by anthropogenic contamination, Ni concentrations are typically 1 to 3  $\mu$ g·L<sup>-1</sup> (Nriagu 1980). Lakes within 20 km of Sudbury had average Ni concentrations of 44  $\mu$ g·L<sup>-1</sup> between 1974 and 1976, and 37  $\mu$ g·L<sup>-1</sup> between 1981 and 1983 (Keller and Pitblado 1986). In mine effluents, Ni concentrations as high as 6300  $\mu$ g·L<sup>-1</sup> have been reported (Clarke 1974).

<u>Groundwater:</u> groundwater contains Ni at levels ranging from 2.5 to 8443  $\mu$ g·L<sup>-1</sup> (McNamara *et al.* 1981).

<u>Lithosphere:</u> Ni concentrations in igneous rocks range from 2 to 60  $\mu$ g·g<sup>-1</sup> in felsic rocks to 10 to 2000  $\mu$ g·g<sup>-1</sup> in ultramafic rocks (NRCC 1981). The average Ni concentration in soil is 16  $\mu$ g·g<sup>-1</sup> (Nriagu 1980). Concentrations of up to 4860  $\mu$ g·g<sup>-1</sup> have been reported in the surface litter of soils in the vicinity of smelters (NRCC 1981).

## A.5.3.3 Effects on Biota

## A.5.3.3.1 Uptake and Accumulation

In aquatic biota, it is generally assumed that Ni can be taken up either directly from the water (or sediment porewater) by lower food chain aquatic organisms, flora and herbivores (Stokes 1988) and/or from the ingestion of solid material, as seen in bivalves and fish. In fish, Ni appears to be taken up via gills through blood-water contact and accumulates in the viscera, particularly heompoietic organs such as the liver, kidneys and spleen (EIFAC 1984). According to Calamari *et al.* (1982) concentrations of less than 1 to 4  $\mu$ g·g<sup>-1</sup> wet weight can cause biochemical damage (EIFAC 1984).

## A.5.3.3.2 Toxicity of Nickel

Water hardness has a significant affect on the toxicity of Ni to all freshwater organisms including fish, invertebrates, plants and microbiota. Toxicity decreases with increasing water hardness (Spry *et al.* 1981, Nebeker *et al.* 1986).

## Toxicity to Various Biota

<u>Freshwater Invertebrates:</u> there is a large amount of data on the toxicity of Ni to freshwater invertebrates. The reported 96-h LC<sub>50</sub> values for molluscs include 200  $\mu$ g·L<sup>-1</sup> Ni for *Anodonta imbecilis* and 238  $\mu$ g·L<sup>-1</sup> Ni *Juga plicifera* in soft water (Keller and Zam 1991, Nebeker *et al.* 1986). A large number of toxicity data were compiled by the U.S. EPA (1986), and LC<sub>50</sub> values were adjusted to a hardness value of 50 mg·L<sup>-1</sup> as CaCO<sub>3</sub>, facilitating the comparison of results of different studies. From the data compiled, the most sensitive invertebrate species is *Daphnia magna*, with adjusted LC<sub>50</sub> ranging from 554 to 1770  $\mu$ g·L<sup>-1</sup> for damselflies, to 40460  $\mu$ g·L<sup>-1</sup> for stoneflies (*Acroneuria lycorias*).

In life cycle tests conducted on *Daphnia magna*, chronic Ni values range from 15  $\mu$ g·L<sup>-1</sup> at a hardness of 51 mg·L<sup>-1</sup> as CaCO<sub>3</sub> to 357  $\mu$ g·L<sup>-1</sup> at a hardness of 205 mg·L<sup>-1</sup> as CaCO<sub>3</sub>. In a study of 4 generations of *Daphnia magna*, the chronic Ni value for each generation was 7  $\mu$ g·L<sup>-1</sup> (U.S. EPA 1986).

Freshwater Vertebrates: the 96-h LC<sub>50</sub> for adults of North American fish species generally fall

within the ranges of 1000 to 100000 and 25000 to 250000  $\mu$ g·L<sup>-1</sup> Ni for soft and hard waters respectively (U.S. EPA 1981, EIFAC 1984).

Among the most sensitive fish species are the fathead minnow (*Pimephales promelas*) with adjusted  $LC_{50}$  ranging from 5695  $\mu g \cdot L^{-1}$  to 11250  $\mu g \cdot L^{-1}$ , and the striped bass (*Morone saxatilis*), with  $LC_{50}$  ranging from 4710 to 7569  $\mu g \cdot L^{-1}$  (U.S. EPA 1986). Adjusted  $LC_{50}$  for rainbow trout (*Salmo gairdneri*) range from 11510  $\mu g \cdot L^{-1}$  for fish 12 months old to 15490  $\mu g \cdot L^{-1}$  for fish 3 months old (U.S. EPA 1986).

In early life stage chronic toxicity tests conducted on rainbow trout (*Salmo gairdneri*) chronic Ni values range from <35 to 240 µg·L<sup>-1</sup>, with all tests conducted in water of similar hardness. A similar test on fathead minnow (*Pimephales promelas*) gave a chronic Ni value of 217 µg·L<sup>-1</sup> (U.S. EPA 1986).

## A.5.3.4 Concentration Limits for Nickel

Under the Canadian Water Quality Guidelines, there is no Guideline for the concentration of Ni in drinking water. The maximum concentration considered acceptable for freshwater aquatic life varies with water hardness. Guidelines are given in Table A.5.2. There is no Guideline for the Ni concentration in waters used for recreation.

Hardness (mg·L <sup>-1</sup> as CaCO <sub>3</sub> )	Concentration of Ni μg·L <sup>-1</sup>
0-60 (soft)	25
60-120 (medium)	65
120-180 (hard)	110
>180 (very hard)	150

**Table A.5.2:** Maximum acceptable nickel concentrations

## A.5.3.5 References for Nickel

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Calamari, D., G.F. Gaggino and G. Pacchetti (1982): Toxicokinetics of low levels of Cd, Cr, Ni and their mixture in long-term treatment in *Salmo gairdneri* Rich. *Chemosphere*. 11:59-70.

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Stokes, P.M. (1975): <u>Adaption of green algae to high levels of copper and nickel in aquatic</u> <u>environments</u>. International Conference on Heavy Metals in the Environment, Toronto, Ontario, Canada. p.137-154.

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U.S.EPA (1981): <u>Exposure and Risk Assessment for Nickel</u>. Office of Water Regulations and Standards, United states Environmental Protection Agency. (EPA-440/4-85-012). Washington, D.C.

U.S. EPA (1986): <u>Ambient Water Quality Criteria for Nickel</u>. Office of Water Regulations and Standards, United states Environmental Protection Agency. (EPA/5-86-004). Washington, D.C.

## A.5.4. Cobalt

## A.5.4.1 Characteristics of Cobalt

Cobalt (Co) has six oxidation states, but only two are common in aqueous solution, Co +II and Co +III (CCREM 1987). Metallic Co is extremely rare in nature, and in almost all cases, Co occurs with Ni and Fe. The average Co:Ni:Fe ratio is 1:10:2100 (Izmerov 1986). Cobalt sulphide minerals do occur (eg. linnaeite, Co<sub>3</sub>S<sub>4</sub>), but the most common primary Co minerals are arsenide and sulpharsenide minerals such as cobaltite (CoAsS), skutterudite ((Co,Fe)As<sub>3</sub>) and safflorite ((Co.Fe,Ni)As<sub>2</sub>)(Guilbert and Park 1986). Due to its chemical similarity to, and common occurrence with Ni, Co can also occur in Ni sulfide minerals. About 1% Co has been reported in pentlandite, (Fe,Ni)<sub>9</sub>S<sub>8</sub>, the most important ore of Ni, and such substitution accounts for the small Co production in Sudbury (Berry *et al.* 1983). Upon oxidation of Co arsenides and sulpharsenides the arsenate mineral erythrite (Co<sub>3</sub>(AsO<sub>4</sub>)<sub>2</sub>·8H<sub>2</sub>O) is formed. Further oxidation releases Co and AsO<sub>4</sub> to the environment.

The predominant Co species in fresh water environments are Co(+II), carbonate, hydroxide, sulphate, absorbed forms, oxide coatings and crystalline sediments. In oxygenated fresh water at a pH of 8.0, about 45% of the Co is free ion, and about 45% is carbonate. Absorbed forms account for about 8%. Cobalt can occur in stable organic complexes, enhancing the solubility and mobility of Co in aqueous systems. As a result of this tendency to form organic complexes, organic contamination can increase the solubility of Co in fresh water (CCREM 1987).

Cobalt can be removed from solution by adsorption to suspended particulates and bottom sediment, particularly the clay minerals illite and montmorillonite. In experiments with artificial river water at a pH of 8, and Co concentrations ranging from 80 to 200  $\mu$ g·L<sup>-1</sup>, 95% of the Co was adsorbed by illite in suspension. At a pH of 4, 20% adsorption occurred. Model calculations predict that less than 2% of Co is adsorbed by silica, and Fe and Mn oxides. The presence of organic compounds may cause desorption and solubilization of Co from clays and other inorganics. For example, increased sewage loading can result in decreased sorption, and in increased Co solubility (CCREM 1987).

## A.5.4.2 Environmental Occurrences

<u>Freshwater</u>: Co usually occurs in surface waters in concentrations ranging from 0.1 to  $5 \ \mu g \cdot L^{-1}$  (Elinder and Friberg 1986). The ranges of Co concentrations in Canadian surface waters over the years 1980 to 1985, were,  $<1 \ \mu g \cdot L^{-1}$  for the Pacific and Atlantic regions of the country, and between 1 - 47  $\mu g \cdot L^{-1}$  for the western region (CCREM 1987).

## A.5.4.3 Effects on Biota

## A.5.4.3.1 Uptake and Accumulation

Cobalt is readily accumulated by several aquatic organisms. Concentration factors for freshwater alga can range between 400 to  $2 \times 10^6$ , although it is not clear how much of the concentration is related to uptake, and how much is related to adsorption. Rooted freshwater plants generally have concentration factors less than 10 (CCREM 1987).

Benthic organisms tend to have high concentration factors than pelagic organisms. Freshwater molluscs have concentration factors between 100 and 14000, but oligochaetes have concentration factors of about 30. Insects and insect larvae can have concentration factors as high as  $10^6$  (CCREM 1987).

Concentration factors tend to diminish further up the trophic scale, so biomagnification of Co is not considered to be significant (CCREM 1987).

## A.5.4.4 Concentration Limits for Cobalt

Under the Canadian Water Quality Guidelines, there are no recommended limits for Co, either for drinking water, or for freshwater aquatic life.

## A.5.4.5 References for Cobalt

Berry, L.G., B. Mason and R.V. Dietrich (1983): <u>Mineralogy</u>. W.H. Freeman and Company, San Francisco.

CCREM (1987): <u>Canadian Water Quality Guidelines</u>. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environment Ministers.

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## A.5.5 Cyanides

## A.5.5.1 Characteristics of Cyanides

Cyanides are a group of organic and inorganic compounds characterized by the cyano chemical group,  $-C \equiv N$  (Leduc *et al.* 1982). Inorganic cyanides, particularly Na-cyanide and Ca-cyanide are used in the recovery of precious metals (Marshall 1982). Spent cyanide solutions are discharged into tailings containment areas.

In water cyanide may occur as free cyanide (hydrocyanic acid (HCN) or cyanide ion (CN<sup>-</sup>)), simple cyanides (general formula M(CN)x, examples include alkali cyanides such as Na-cyanide and Ca-cyanide), metallocyanide complexes or organic cyanide compounds (U.S. EPA 1980, Leduc et al. 1982). Degradation of cyanide species occurs, resulting in the removal of cyanide from aquatic systems, but these processes are influenced by a number of variables, including cyanide speciation and concentration, pH, temperature, bacterial activity, sunlight, aeration, and water depth (TW Higgs Associates Ltd. 1992). Where sulphur is present, cyanide ion can react with sulphur to form thiocyanate, SCN, a more stable species (TW Higgs Associates Ltd. 1992). Bacterially mediated processes can result in the conversion of dissolved HCN into thiocyanate (Leduc et al. 1982). Simple cyanides are readily soluble in water, and dissolution will result in the generation of cyanide ion, although this dissolution is strongly dependant on temperature and pH. Metallocyanide complexes have varying stabilities, with dissolution yielding complex cyanide ions, which can further dissociate to yield CN<sup>-</sup>. Metallocyanide complexes with Zn and Cd dissociate rapidly and completely, while complexes with Cu, Ni and Fe have varying stabilities. Some metallocyanide complexes, such as ferrocyanide, are dissociated in the presence of ultraviolet light. Complexes are also known to form with Ag, Hg, Au, Cr, Co and Pb (Leduc et al. 1982, TW Higgs Associates Ltd. 1992).

## A.5.5.2 Environmental Occurrence

<u>Freshwater:</u> in a study of gold mines in Ontario and Quebec, Harrison (1979) reported free cyanide, total cyanide and thiocyanate concentrations in tailings pond effluent ranging from <500, 200 and  $<2000 \ \mu g \cdot L^{-1}$  respectively, to 6600, 1300 and 64000  $\mu g \cdot L^{-1}$  respectively. Melis Consulting Engineers Ltd. (1987) reported total cyanide in effluent from gold tailings ranging from 230 to 85900  $\mu g \cdot L^{-1}$ , and reported total cyanide in downstream surface waters ranging from 250 to 80000  $\mu g \cdot L^{-1}$ . Free cyanide concentrations in downstream surface water ranged from 143 to 17400  $\mu g \cdot L^{-1}$ .

## A.5.5.3 Effects on Biota

At lethal levels, free cyanide is rapidly effective toxicant. Concentrations in the range of 30 to 150  $\mu$ g ·L<sup>-1</sup> HCN are lethal to most fish. Exposed to a lethal dose, many fish will come to the water surface, and die within a short time. If removed to fresh water before death, fish of some species will recovered with no ill effects, although some fish, such as brook trout (*Salvelinus fontinalis*) are too sensitive to recover (Leduc *et al.* 1982). Fish embryos and sac fry tend to be

less sensitive than adult fish and most invertebrate species are much less sensitive to cyanide contamination, although *Daphnia pulex* has comparable sensitivity (U.S. EPA 1980). Cyanide can also be a chronic toxicant, with detrimental effects observed at HCN concentrations of 5  $\mu g \cdot L^{-1}$ , and growth of various fish species was reported to be seriously reduced at free cyanide concentrations of 20 to 50  $\mu g \cdot L^{-1}$  (Leduc *et al.* 1982, U.S. EPA 1980). At the concentration ranges at which fish are acutely sensitive to cyanide aquatic plants and algae are unlikely to be effected (U.S. EPA 1980).

## A.5.5.4 Concentration Limits for Cyanide

Under the Canadian Water Quality Guidelines, the maximum acceptable concentration of CN in drinking water is 200  $\mu$ g·L<sup>-1</sup>. The maximum concentration considered acceptable for freshwater aquatic life is 5.0  $\mu$ g·L<sup>-1</sup> (CCREM 1987). There is no Guideline for the cyanide concentration in waters used for recreation.

## A.5.5.5 References for Cyanide

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# **Appendix 6:**

# **Descriptions of Solid Phase Samples and Sampling Sites**

## Nipissing Low Grade Tailings

#### <u>NLGM #1</u>

• surface tailings, collected north of dam #1, near P26

#### <u>NLGM #2</u>

- taken from about 35-45 cm deep below NLGM #1
- sample includes material from the greenish layer which occurs at this depth over most of the NLGM tailings

#### <u>NLGM #3</u>

• taken below NLGM #2

#### <u>NLGM Pail</u>

• plastic 5 gallon pail of NLGM tailings, collected near dam #2

#### NLGM Crust #1

- collected south of dam #1
- white material and flakey material from around mud cracks

#### NLGM Crust #2

- collected south of dam #1
- taken in between mud cracks

#### NLGM Subcrust #2

• taken about 8 cm below NLGM Crust #2

#### NLGM Crust #3

- taken north of dam #1, near P29
- sample of crunchy crust which is widespread in this area
- like little snowcapped hills about 5-8 mm high
- "snow" is a lighter coloured crust material

#### NLGM Subcrust #3

• taken about 8-12 cm below NLGM Crust #3

#### NLGM Crust #4

- taken north of dam #1
- very thin, dry flakey layer which covers much of the surface.

#### NLGM Subcrust #4a

• taken about 3 cm below NLGM Crust #4

#### NLGM Subcrust #4b

- taken 5-8 cm below NLGM Subcrust #4a
- damp to wet

#### NLGM Crust #5

- blue-green material near B2
- material is very isolated -- 1 small patch about 1 m<sup>2</sup>
- about 2 cm deep

#### NLGM Subcrust #5

- taken below NLGM Crust #5
- this crust may have resulted from water from B2 or some other source being dumped on the surface

#### NLGM Crust #6

- near P33
- light grey crust which occurs like little raised islands a few cm in diameter

#### NLGM Crust #7

• white material which crusts the surface around the islands of NLGM Crust #6

#### NLGM Subcrust #6

• taken 3-5 cm below where NLGM Crust #6 & #7 were taken

#### NLGM Crust #8

- taken north of dam #2
- light grey to reddish blister-like material

#### NLGM Subcrust #8

• taken 3-5 cm below NLGM Crust #8

#### NLGM Crust #9

- taken north of dam #2
- reddish surface crust, but not blister-like -- thin friable layer

#### NLGM Crust #10

- taken near P49/P38
- rusty orange to grey blister-like crust

#### NLGM Subcrust #10

• taken 3-5 cm below NLGM Crust #10

## Nipissing High Grade Mill Tailings

## <u>NHGM #1</u>

- taken from the surface
- very dark grey

#### <u>NHGM #2</u>

- taken from about 45 cm below the surface
- lighter grey than NHGM #1

#### <u>NHGM Pail</u>

• plastic 5 gallon pail collected from the surface to a depth of about 40 cm

## **Cart Lake Tailings**

Cart Crust #1

• collected near PC2

## Cart Crust #2

• collected near PC24

#### Cart Pail

• metal 5 gallon rock pail, lined with a plastic bag, collected about 20 m east of PC19

## Cart Lake Weird Stuff #1

Cart Lake Weird Stuff #2

- #1 is greyish brown, flakey
- #2 is chocolate brown, moist and spongy
- collected on a small rise near the reed beds, near the lake.
- area is spongy and bouncy, about 2 m x 5 m, and is surrounded by tailings
- looks like an extinct reed bed
- active reed beds are composed of similar material and are also spongy.

## Cart Lake Surface Alteration

- taken about 2.5 m from weird stuff, in tailings.
- alteration layer 6-7 cm down
- green in the middle, black on both sides

Dug a 120 - 150 cm deep trench in the vegetated patch near the old mill -- S.E. corner of the pile. Four well defined horizons are developed. Each horizon was sampled. Horizon A: about 7 cm thick

- lots of roots, with a thin organic mat on the top
- very sandy, with poor structure -- probably mostly wind blown tailings
- low water content

- medium brown colour, greyer when dry because of the tailings
- collected <u>Cart Soil A</u>

Horizon E: about 7.5 cm thick

- a few roots penetrate this layer
- hard and compact, with a well developed micro structure -- finely laminated with thin layers
- less than 1 mm thick, with smaller air spaces between the layers
- silty, with some sand grains
- light grey to brownish grey to greyish brown
- damp
- collected <u>Cart Soil E</u>

Horizon B: about 10 cm thick

- some roots
- reddish brown colour
- sandy, with numerous larger, rounded pebbles
- fairly dry
- collected <u>Cart Soil B</u>

Horizon C: sandy grey tailings

- not really a true C horizon since this is not the parent material, but there has likely been some chemical interaction between the tailings and the soil layers
- collected <u>Cart Soil C</u>

## **Other Solid Samples**

## NLGM Concrete

• collected near the base of the foundation

## NLGM Slag

• collected near the fence around the workings to the northwest of the mill foundation

## NHGM Concrete

• collected from small piece of exposed concrete west of the main foundation, in the area where the slag occurs

## <u>NHGM Slag</u>

• collected from the top of the slag pile, about 20 m west of the main mill foundation

## NHGM "Stuff"

• collected from a small pile of reddish brown material which is located about 20 m south of the main mill foundation, on an area of concrete floor, about 5 m from the road to the Nip Lookout at the low grade mill foundation.

## McKinley-Darragh Concrete

• collected from the foundation of the McKinley-Darragh Concentrator, from a section of light grey, crumbly concrete at the south end of the foundation

Pails from LaRose

• dark grey metallic material collected from pails which were found near the LaRose property, on an old foundation located about 20 m west of the railway tracks, about 200 m north of the bridge over the tracks

## Logs of Cores Collected from the NLGM and NHGM Tailings

## Core Taken Near P51:

0-15 cm:

- uniformly lt. to med. brownish grey
- some sediment deformation evident, especially 10 to 15 cm

#### 15-19 cm:

- greenish layer
- deformed. actually about 1.5 cm thick

## 19-32 cm:

- as above the greenish layer
- appears finer grained
- layering and sediment deformation evident

#### 32-33 cm:

- dark brown to black with rusty tone
- fine grained alteration layer
- individual black blebs are visible

#### 33-42 cm:

• rusty coloured zone with a few small black blebs evident, especially near the top and bottom

42-44 cm:

• like 19-32 cm

#### 44-48 cm:

• gap due to deformation after core collection

48-57 cm:

- like 19-32 cm
- one small near vertical zone of greenish brown alteration

#### 57-60 cm:

• khaki coloured layer

#### 60-70 cm (end):

• like 19-32 cm

## Core Taken Near P26

## 0-5 cm:

- unstable and crumbly
- difficult to define top of core
- fine grained, brownish grey

## 5-9 cm:

• greyish brown, streaky appearance

## 9-14 cm:

• like 0-5 cm, but greyer

## 14-20 cm:

• grey, but becoming progressively more greenish

## 20-24 cm:

- irregularly shaped greenish layer
- a browner green than the layer in the previous core
- a small, angular pebble in this layer is coated with erythrite 23-24 cm

## 24-35 cm:

- similar colour to 14-20 cm
- zone ends quite abruptly

35-41 cm:

- lt. to med. grey, with irregular zones of alteration
- some patches are quite bright green, others duller and browner
- some smaller. reddish green streaks and patches

41-47 cm:

• brownish grey

47-94 cm (end):

- fairly uniform med. brownish grey layer
- deformation evident, 66-70 cm

## Core Taken Near P35

unknown amount of material missing from the top of the core, as a result of disturbance after opening

0-10 cm:

- brownish grey tailings with some coarser sandy material, and a pebble at 6.5-8.5 cm
- patches of reddish green alteration present, especially around 2-3 cm and 7-10 cm
- pebble partially covered with rusty looking alteration

10-31 cm:

- lt. tan to grey
- layering and some deformation evident

31-52 cm:

• darker, greyer layer

52-64 cm:

• deformed looking zone, with some lt. and med. grey material

64-76 cm (end):

- some grey tailings, but mostly dk. grey to black, vertically streaked organic looking material
- some small rusty patches
- small piece of wood at 68-72 cm
- wood is intact, but the surface is covered with a thin layer of limonite

## Core Taken from NHGM Tailings

• top surface of core has small spots of a secondary mineral, possibly erythrite

0-9 cm:

- dk. grey
- some erythrite on the core surface

9-25 cm:

- dk. grey with some brownish layers
- more compacted than the top portion appears
- somewhat finer grained and more laminated
- some erythrite in one layer at about 23 cm

## 25-29 cm:

- slightly coarser grained
- brownish grey

29-30 cm:

• greenish brown layer

## 30-42 cm:

- like 25-29 cm, with a couple of darker grey layers
- somewhat finer grained

42-47 cm:

• like 25-29 cm

47-49 cm:

- fine grained, dk. grey to almost black, with some lt. grey material like a nodule of clay
- some erythrite at 48-49 cm

49-53 cm (end):

- sandy with some small pebbles
- greyish brown

# Appendix 7:

## Piezometer Installation Procedures, and the Logs of Holes Drilled for the Installation of Piezometers in the Nipissing Low Grade Mill Tailings and the Cart Lake Tailings

## A.7.1 Piezometer Installation Procedures

To monitor the tailings groundwater, piezometers were installed in the NLGM tailings and Cart Lake tailings. The material used for the piezometers was 1" or 1.5" diameter rigid PVC pipe. During May and June, 1991, 56 piezometers were installed in the NLGM tailings, and 26 in the Cart Lake tailings. Ten additional piezometers were installed in the Cart Lake tailings in August, 1991.

Piezometers were installed at 20 m spacings in the NLGM tailings, and 50 m spacings in the Cart Lake tailings, in order to determine the direction of horizontal groundwater flow. Most piezometers were installed to a depth of about 3 m. A smaller number were installed to a depth of 2 m, for one of two reasons: i) the tailings were too shallow for the piezometer to be installed to a greater depth; or ii) the 2 m piezometer was installed adjacent to a 3 m piezometer to determine the direction of vertical groundwater flow. Similarly, a small number were installed to a depth of 1 m or less. Note that no paired piezometers were installed at Cart Lake.

The bottom 15 cm of the piezometers were slotted with a hack saw prior to installation. Slotting permits the inflow of water, and the slotted portion was surrounded by a pack of clean, coarse quartz sand, to prevent the piezometers from filling with tailings and becoming clogged. The piezometers permit the monitoring of the piezometric surface for a small interval at depth in the tailings, and permit the sampling of groundwater from that depth.

Piezometer	Depth (cm)	Notes
P1	253	installed in old mine trench at S.E. end of tailings. Surface is <u>very</u> wet - drill sank into the mud while running
P2	168	"
P3	99	"
P4	141	"
P5	74	"
P6	210	in old trench, just south of remnants of old headframe
P7	248	in old trench
P8	112	gravel and sand underlie tailings
Р9	205	all tailings
P10	239	all tailings
P11	197	hit gravel and soil underneath the tailings
P12	124	hit gravel underneath tailings. Greenish alteration material occurs in tailings. Collected samples NLGM #1, NLGM #2 and NLGM #3 from the cuttings of this hole
P13	213	hit gravel and pebbles underneath the tailings
P14	78	hit gravel underneath the tailings
P15	56	"
P16	164	hit gravel and pebbles underneath tailings
P17	181	"
P18	195	all tailings
P19	279	hit a hard, compact layer at a depth of about 45 cm - difficult to drill through
P20	98	only about 15 - 20 cm of tailings. About 60 cm of sand and gravel underlie the tailings, and a layer of soil occurs underneath the sand and gravel
P21	95	15 - 20 cm of tailings, the rest is sand. White crust starting to develop (June 3)
P22	83	all tailings, hit bedrock at bottom
P23	73	hard, compact layer at 15 - 20 cm - difficult to drill through
P24	38	all tailings, hit bedrock at bottom
P25	87	in stream channel along west side of tailings. Hit sand underneath tailings, and bedrock underneath sand. No alteration zones south of dam
P26	268	drilled to 4 m, with no end in sight. Backfilled hole, then installed piezometer. Dug a small trench nearby - exposed greenish layers
P27	238	all tailings
P28	287	all tailings. Top 30 cm was dry, but below that tailings were very wet.
P29	280	all tailings
P30	167	Installed in stream bed along western edge of tailings. Top 20 - 25 cm is a mixture of

## A.7.2 Nipissing Low Grade Mill Tailings
Piezometer	Depth (cm)	Notes
		sand and tailings, and the rest is tailings
P31	85	all tailings, very wet at surface
P32	265	all tailings
P33	169	bottom 30 - 35 cm is a dense, chocolate coloured mud which was drier than the overlying tailings
P34	259	all tailings
P35	202	about 45 cm of tailings, then organic material. Possibly from swamp which was here before. Material is wet and cohesive. Roots and seed cases are evident.
P36	193	all tailings
P37	193	all tailings, with a little bit of organic material
P38	188	all tailings
P39	184	"
P40	189	"
P41	176	all tailings, but lots of large, angular pebbles throughout. Possible from the adjacent road along the powerline
P42	182	all tailings
P43	153	sand mixed with the tailings near the top. Hit bedrock at the bottom. Green material evident in cuttings
P44	185	all tailings
P45	181	"
P46	178	"
P47	136	"
P48	269	all tailings, some organics at the bottom
P49	263	all tailings
P50	261	"
P51	182	mixture of sand and tailings, top few cm has a sponge like texture
P52	85	"
P53	51	mixture of tailings and sand. Very wet
P54	150	n
P55	67	n
P56	158	mixture of tailings and sand. Hit bedrock at bottom
P57	200	installed in September, 1991, in old mine working at S.E. end of deposit, adjacent to P3

### A.7.3) Cart Lake Tailings

Piezometer	Depth (cm)	Notes
PC1	273	all tailings. Located about 3 m north of an old dam at the S. end of the lake
PC2	285	all tailings
PC3	284	"
PC4	289	"
PC5	291	all tailings. Surface is wetter than at PC1 to PC4 which are further south
PC6	189	all tailings. Wetter again. Due east of a small island in the "lake"
PC7	192	all tailings. Greenish alteration occurs at 30 to 45 cm depth. Same colour as that at the NLGM tailings
PC8	163	all tailings. Greenish alteration occurs
PC9	193	"
PC10	100	"
PC11	50	all tailings
PC12	130	all tailings. At time of installation, this piezometer was about 10 m offshore, in about 15 cm of water
PC13	111	PVC tube driven straight into the tailings - not slotted, and no gravel pack used
PC14	55	"
PC15	202	all tailings. Wet at bottom
PC16	74	all tailings? Surface is very wet
PC17	192	all tailings
PC18	190	n
PC19	111	"
PC20	288	n
PC21	197	all tailings. About 5 m from stream bed on the west side of the deposit.
PC22	44	all tailings. Installed in stream bed. Installed like PC13 and PC14
PC23	54	n
PC24	289	all tailings
PC25	287	all tailings
PC26	285	top portion is soil: 15-20 cm A-horizon, 8-10 cm B-horizon, then tailings
PC27	290	installed by field camp students, no log kept
PC28	284	n
PC29	284	n
PC30	286	n
PC31	187	"
PC32	283	"

Piezometer	Depth (cm)	Notes
PC33	288	"
PC34	285	11
PC35	285	"
PC36	286	11

# **Appendix 8:**

## Water Level Data from Piezometers in the Nipissing Low Grade Mill Tailings and the Cart Lake Tailings

Piezometer	Elevation	Jun	ie 9	Jun	e 26	July	y 24	Sep	ot. 3	Oct	. 17
	m.a.s.l.	Water Level (cm)	Total Depth (cm)								
P1	313.595	32	253	43	255	90	256	15	261	+19	259
Р2	313.560	49	168	56	169	115	168	18	167	+9	167
Р3	313.570	55	99	54	97	DRY	102	9	92	+5	92
P4	313.565	41	141	53	144	97	143	18	143	+9	141
P5	313.580	DRY	74	63	74	DRY	73	17	73	+9	73
P6*	313.680	27	210	20	207	-	-	-	-	21	168
P7*	313.845	27	248	37	236	-	-	-	-	18	298
P8	308.060	DRY	112	DRY	112	DRY	110	DRY	111	7	100
Р9	307.900	96	205	107	205	156	205	85	205	+3	205
P10	307.740	83	239	82	226	132	226	62	227	+26	227
P11	307.590	79	197	89	196	139	196	66	197	+16	197
P12	308.665	112	124	DRY	124	DRY	124	92	124	+6	124
P13	307.595	70	213	80	214	121	213	57	217	+8	216
P14	307.560	56	78	DRY	78	DRY	78	36	78	+17	78
P15	307.720	DRY	56	DRY	56	DRY	56	DRY	56	+6	56
P16	308.170	119	164	127	164	DRY	164	102	164	24	164
P17	308.615	163	181	171	181	DRY	180	146	181	64	181
P18	308.380	159	195	171	195	DRY	195	153	196	55	196
P19	309.845	DRY	279	DRY	279	DRY	279	DRY	280	214	280
P20	313.800	79	98	84	98	DRY	98	89	99	-	-
P21	314.625	82	95	DRY	96	DRY	95	DRY	95	-	-
P22	314.745	DRY	83	DRY	83	DRY	83	DRY	83	-	-
P23	314.940	DRY	73	DRY	73	DRY	73	DRY	73	-	-
P24	314.820	DRY	38	DRY	38	DRY	37	DRY	36	-	-
P25	314.445	68	87	67	87	DRY	186	53	86	-	-
P26	308.820	146	268	166	269	229	271	210	271	93	270
P27	308.600	153	283	172	275	225	272	203	273	75	272

#### A.8.1 Nipissing Low Grade Mill Tailings

Piezometer	Elevation	Jun	ie 9	Jun	e 26	July	y 24	Sep	ot. 3	Oct	. 17
	m.a.s.l.	Water Level (cm)	Total Depth (cm)								
P29	308.895	138	280	163	279	207	278	201	278	68	256
P30	308.165	97	167	125	164	DRY	164	122	164	+12	164
P31**	308.565	DRY	85	DRY	85	-	-	-	-	-	-
P32	308.310	147	265	167	256	204	253	173	252	46	252
P33	308.085	141	169	130	163	149	161	DRY	162	47	161
P34	309.020	214	259	230	259	DRY	259	DRY	259	146	259
P35	307.830	92	202	88	202	122	202	136	202	91	202
P36	307.780	158	203	178	203	DRY	203	DRY	203	42	203
P37	307.540	137	204	151	202	DRY	202	189	202	15	202
P38	307.530	161	198	181	198	DRY	197	DRY	197	37	202
P39	307.315	150	194	168	194	DRY	194	182	195	24	194
P40	307.065	121	199	DRY	199	DRY	185	DRY	185	70	185
P41***	306.625	92	186	-	-	-	-	-	-	-	-
P42	306.505	100	192	125	192	163	192	104	192	+6	192
P43	306.400	99	163	107	163	DRY	163	114	163	+9	156
P44	308.860	152	195	177	195	DRY	195	DRY	195	95	195
P45	308.595	153	191	178	191	DRY	190	DRY	190	-	-
P46	308.480	178	188	DRY	187	DRY	187	DRY	187	68	188
P47	308.105	136	277	117	277	169	277	162	277	101	277
P48	307.765	156	279	169	277	228	278	198	278	42	278
P49	307.595	160	273	180	273	226	273	196	273	39	273
P50	307.050	109	271	101	240	156	251	152	252	17	141
P51	306.785	91	192	52	173	DRY	179	112	177	+7	177
P52	306.755	DRY	95	50	62	DRY	61	DRY	61	-	-
Р53	306.700	8	61	DRY	61	DRY	58	DRY	59	+9	59
P54	306.695	6	160	50	157	111	157	60	158	+11	157
P55	306.720	8	77	42	77	DRY	76	DRY	77	42	76
P56	306.690	118	168	26	168	94	169	63	175	+12	170
P57	-	-	-	-	-	-	-	-	-	8	210
B1****	308.560	121	144	128	144	-	-	DRY	188	83	188
B2****	308.425	88	180	89	181	114	180	148	180	82	180

Notes:

 $\ast$  P6 and P7 were destroyed by vandals in July, 1991, and replaced in September, 1991

\*\* P31 collapsed in July 1991

\*\*\* P41 was destroyed by vandals in July, 1991, not replaced

\*\*\*\* B1 and B2 were installed by Beak consultants in 1990

Piezometer	Elevation	Jun	e 11	Jun	e 25	Jul	y 22	Aug	g. 30	Oct	. 18
	m.a.s.l.	Water Level (cm)	Total Depth (cm)								
PC1	304.775	123	283	135	283	165	283	181	285	156	284
PC2	304.940	147	295	160	295	188	295	211	290	198	293
PC3	304.560	111	294	121	295	143	294	160	294	150	294
PC4	304.235	116	299	122	299	139	298	151	194	138	291
PC5	303.775	144	281	151	300	165	299	167	300	148	300
PC6	303.345	126	199	132	199	144	199	141	201	112	200
PC7	302.740	115	202	119	201	129	201	117	202	88	202
PC8	301.865	73	173	78	173	80	175	53	175	36	174
PC9	301.625	101	203	109	183	104	182	60	183	53	182
PC10	301.050	DRY	110	DRY	109	DRY	108	63	109	26	109
PC11	300.865	49	60	37	56	38	55	39	56	39	50
PC12*	300.665	53	140	50	140	-	-	-	-	-	-
PC13*	300.690	88	121	71	122	-	-	-	-	-	-
PC14*	300.690	50	65	44	65	-	-	-	-	-	-
PC15	301.650	65	212	74	205	68	204	38	206	20	205
PC16	301.310	37	84	73	83	DRY	82	-	-	-	-
PC17	302.115	77	202	83	201	87	201	64	201	52	199
PC18	302.360	81	200	88	200	92	200	75	198	59	197
PC19	302.575	85	121	78	122	96	122	92	122	54	122
PC20	303.425	102	298	105	298	170	297	111	296	90	296
PC21	302.970	98	207	102	207	-	-	99	195	82	186
PC22	301.910	10	54	6	54	-	-	6	54	0	53
PC23	302.635	47	64	-	-	45	65	54	66	-	-
PC24	305.120	145	299	158	298	186	298	218	298	218	298
PC25	306.095	216	297	238	291	276	289	DRY	290	DRY	291
PC26	307.045	283	295	DRY	295	DRY	295	DRY	295	DRY	295
PC27		-	-	-	-	-	-	-	-	182	300
PC28		-	-	-	-	-	-	-	-	207	294
PC29		-	-	-	-	-	-	-	-	175	294
PC30		-	-	-	-	-	-	-	-	87	296
PC31		-	-	-	-	-	-	-	-	96	197
PC32		-	-	-	-	-	-	-	-	46	293
PC33		-	-	-	-	-	-	-	-	33	298
PC34		-	-	-	-	-	-	-	-	29	295
PC35		-	-	-	-	-	-	-	-	42	295
PC36		-	-	-	-	-	-	-	-	75	296

### A.8.2 Cart Lake Tailings

Notes:

\* PC12. PC13 and PC14 were installed by driving sections of pipe into the ground by hand. They were not screened. All three were destroyed in July, 1991.

PC27 - PC36 were installed in August, 1991

# **Appendix 9:**

## **Description of Surface Water Sampling Sites**

**Site 1:** Outlet from NLGM tailings. Sampled north of the bridge which crosses the stream at the northeast corner of the tailings deposit.

**Site 3:** Mill Creek at Hwy 11B (Mileage 104). Sampled 5 m west of the culvert under the highway.

**Site 4:** Mill Creek at Ontario Northland tracks. Sampled 20 m south of the point where Mill Creek crosses under the railway tracks, about 300 m north the Hwy 11B bridge.

**Site 5:** Mill Creek at LaRose. Sampled near the fence of the Agnico Eagle property, about half way between the two bridges.

**Site 6:** Mill Creek at Right-of-Way Mine. Sampled 1 m south the culvert under the road to the Right-of-Way mine.

**Site 7:** Cobalt Lake, south end. Sampled at the end of a small pile of waste rock in the lake, about 10-30 m south of the area where discharge from the NHGM tailings enters the lake.

Site 8: Outlet from NHGM tailings. Sampled 3 m east of the retaining wall.

**Site 9:** Outlet from Cart Lake. Sampled at the culvert where the lake drains under Ragged Chutes Road, into the swampy area to the north.

**Site 10:** Peterson Lake at Nova Scotia Mine. Sampled 2-3 m offshore, in the area of the lake into which tailings from the Nova Scotia Mine have migrated.

**Site 11:** Surface drainage at Nova Scotia Mine -below dam. Sample collected from the small surface stream, about half way between the dam and the road.

**Site 12:** Crosswise Lake, north end. Sampled 2-3 m offshore, in a beach like area where the lake bottom is tailings.

**Site 13:** Farr Creek midway through tailings. Sampled 3 m north of a dam built across the tailings, about halfway between the points where Peterson and Mill creeks join Farr Creek.

Site 15: Short Lake. Sampled at the east side of the peninsula at the north end of the lake.

**Site 16:** Sasaginaga Lake at town water intake site. Sampled at the lake shore, about 25 m north of the pump house. The intake point for the water is about 200 m offshore.

Site 18: Cobalt Lake, north end. Sampled halfway along the road to the Cobalt Lion's Club Park.

**Site 22:** Pond at south end of Cart Lake. Sampled at a small pond in western portion of the swampy area at the south end of Cart Lake.

**Site 23:** Outlet from Cart Lake into Peterson Lake. Sampled at a small pond just west of an access road to the west side of Peterson Lake.

**Site 24:** Swamp below the O'Brien Mine, along Peterson Creek. Sampled at the southeast end of the pond, near the road to Crosswise Lake.

**Site 28:** Farr Creek at North Cobalt. Sampled at a site off Groom Rd, at a small parking lot on the south side of the road, about 150 m west of the Roman Catholic church.

**Site 29:** Farr Creek about 300 m from Lake Temiskaming. Site accessed by a road which goes east to Lake Temiskaming from the south end of Haileybury, then turns south and turns into a farm field. Road turns east, then follows the perimeter of the farm field for about 500 m, to a point where a small trail goes over the riverbank and down to the river. Followed the river east, and collected the samples just below a small set of waterfalls.

**Site 33:** Farr Creek at dam, 4th Street, North Cobalt. Sampled at the south side of a water level control dam which is at the end of Fourth St. in North Cobalt.

**Site 34:** Peterson Creek east of Violet Mine. Sampled 2 m west of the road from Crosswise Lake to Mileage 104, about 150 m east of the Violet Mine waste rock pile.

**Site 35:** West arm of Sasaginaga Creek at the road. Sampled 2 m east of a culvert under the road to the town dump.

**Site 36:** South arm of Sasaginaga Creek, 15 m from confluence with West arm. Sampled 15 m south of the point where the two branches of the creek join, in an area underlain by the Chambers-Ferland tailings. This is the arm of the creek which carries the town sewage discharge.

**Site 37:** Sasaginaga Creek midway through swamp. Sampled about 500 m from the confluence of the two arms of the stream, in an area underlain by the Chambers-Ferland tailings.

**Site 38:** Sasaginaga Creek 75 m north of confluence. Sampled 75 m northeast of the point where the two arms of the stream meet, in an area underlain by the Chambers-Ferland tailings.

**Site 40:** Sasaginaga Creek, upstream from mine shaft. Sampled at the south arm of the creek, about 20 m upstream from the point where groundwater from a mine shaft discharges into the stream (GW Site #31). Near the Town of Cobalt garage.

**Site 41:** Sasaginaga Creek, downstream from mine shaft. Sample collected from the south branch of the creek, about 50 m downstream from the point where groundwater from a mine shaft discharges into the stream.

**Site 42:** Mill Creek, under the Hwy. 11B bridge. Sample collected about 15 m downstream from the confluence of the outlet from the LaRose tailings and Mill Creek. Collected underneath the Hwy. 11B bridge and the ONR tracks, and collected about 2 m east of the tracks.

**Site 43:** Pond at LaRose. Sample collected from a small stream draining the pond on the LaRose property. The pond is fenced off, and the sample was collected just outside the fence.

**Site 44:** Mill Creek, 100 m downstream from confluence with Sasaginaga Creek. Creek is about 4 m wide, and flowing slowly. Tailings are in the creek bed.

**Note:** There are no surface water sampling sites with numbers 2, 14, 17, 19, 20, 21, 25, 26, 27, 30, 31, 32 and 39.

# **Appendix 10:**

## **Descriptions of Groundwater Sampling Sites**

note: the postal code for all addresses is P0J 1C0

#### Site #1: water well, Bucke Park

The park is located off Hwy 567, about 4 km from the junction of Hwy 11B and Hwy 567. The well is enclosed in a small shed about 3 m from Lake Temiskaming. Samples were collected from an overflow hole in the concrete well casing, accessed by reaching in from a small door at the back of the shed.

#### **GW Site #2:** water well, Mileage 104

Dean Gagnon, Box 894, Cobalt

- small, new bungalow on Montreal Ave. in O'Brien
- well drilled in August 1990, 250' deep

#### **GW Site #3:** water well, Mileage 104

Morin, Montreal Ave., Box 174, Cobalt

- last house down on the left, closest to the tailings
- old, hand dug, bedrock well, about 20' deep
- old house on the opposite side of the street has a similar well.

#### GW Site #4: water well, West Cobalt

Ron Bigelow, Box 265, Cobalt

- West Cobalt Rd., two story house with green and white awnings and white shutters. South side of road.
- old well, about 45' deep

#### **GW Site #5:** water well, West Cobalt

Anna Caza, RR #1, Cobalt

- West Cobalt Rd., white bungalow with brown window frames, next to GW Site #4.
- old well, about 45' deep.

#### **GW Site #6:** water well, North Cobalt

Gaston Dessureault, Box 78, Fourth St., North Cobalt

- 10' 11' deep well, non flowing artesian
- quite old

#### **GW Site #7:** water well, North Cobalt

- cream and brown house on right on Second St., North Cobalt
- 2 yr. old well, over 200' deep.

#### **GW Site #8:** water well, North Cobalt

Gordon Davies, Box 35, North Cobalt

- Hwy 567, first house on right past race track
- age unknown, 45' deep

#### **GW Site #9:** water well, North Cobalt

Mrs. deHaas, Box 74, North Cobalt

- Third St., North Cobalt
- age & depth unknown, likely a new deep well according Mr. Dessureault, who lives next door.

#### **GW Site #10:** water well, North Cobalt

Bob Green, Box 118, North Cobalt

- north side of Hwy 567
- two story farm house with fenced in pool
- age unknown, probably 22' deep

#### **GW Site #11:** water well, North Cobalt

Mable Glassford, Box 83, North Cobalt

- north side of Hwy 567
- white house about 1 km past Bucke Park Road.
- well is shallow & very close to the road -- possible salt contamination

#### **GW Site #12:** water well, North Cobalt

Ross Elliott, Box 209, North Cobalt

- south side of Hwy 567
- farm across hwy from entrance to Bucke Park

#### **GW Site #13:** water well, North Cobalt

Alex Duchesne, Box 54, 03 Groom Dr., North Cobalt

- first or second house on east side of Groom Rd., off of Hwy 567.
- less than 1 km from Pansilver Mine

#### **GW Site #14:** water well, West Cobalt

Montgomery, Box 44, West Cobalt

- two story white house on a fenced in lot, with lots of shrubs around the house
- across the street from the Stewart residence
- 63' DDH, drilled into bedrock in 1958

#### **GW Site #15:** water well, West Cobalt

Roy Stewart, Box 337, West Cobalt

- older, white bungalow on West Cobalt Road, with a barn and small pasture with horses out behind
- water drawn from a mine shaft on the property
- <u>not</u> used for drinking or cooking -- family hauls water from Clear Lake or Sasaginaga Lake for consumption

#### **GW Site #16:** water well, Mileage 104

Ernie Taylor, Box 398, Cobalt

- Mileage 104, white house with separate garage on the west side of Hwy 11B.
- old well, 8' to 12' deep, in overburden

#### **GW Site #17:** water well, Mileage 104

E. Ouillette, Box 342, Cobalt

- Mileage 104, white 2 story house with brown veranda, on west side of Hwy. 11B
- well supplies this home, and smaller green home immediately to the north
- well is 15'(?), in overburden

#### **GW Site #18:** water well, Mileage 104

Joe Moise, Box 1067, Haileybury

- brown, brick bungalow on east side of 11B, just past Mileage 104, just south of the Silverland Cemetery
- water comes from a spring near the cemetery, about 900' to the north

#### GW Site #19: water well, Mileage 104

hand pump in the Silverland Cemetery

- likely a shallow dug well
- well was pumped for several minutes before sample was collected.
- spring below cemetery was not found, but a beaver pond fed by the spring was seen in the valley

#### **GW Site #20:** water well, North Cobalt

Roger Lapointe, Box 78, North Cobalt

- house is a adjacent to the Dessureault's, on 4th Street
- new well (drilled in August or September 1991), about 350' deep. Supplies two homes

#### **GW Site #21:** water well, North Cobalt

- home is owned by the Glassfords (Well#10) and the mailing address is the same -- across the street from the Glassfords
- shallow well
- well had about 2000 gals of city water added during the summer since the water level was so low.

#### **GW Site #22:** water well, North Cobalt

Lucien Bujold, Box 115, North Cobalt

- white bungalow on Hwy 567, on the north side, between the Silversides road and the Bucke Park road
- mine workings underneath the home have affected water level and water quality (according to Mr. Glassford)
- water is filtered with a Brita filter before drinking

#### GW Site #23: water well, North Cobalt

**GW Site #24:** water well, North Cobalt

Gordon Peckover, Box 338, Haileybury

- house at the end of the Silversides Mine access road.
- Well#23 is a deep, dug well used for cooking and drinking -- filtered with a charcoal filter
- Well#24 is a shallower well used for washing only
- there is also a third well on the property, but is was not functioning at the time of sampling

**GW Site #25:** water well, Gillies Lake

- located at Camp Monde Ami, a summer camp at the south end of Gillies Lake
- accessed by the Gillies Lake Road

#### GW Site #26: diamond drill hole,

Sharp Lake

- 1100' hole, 700'-800' vertical
- drilled into conglomerates by the Firstbrook Mining Company
- age unknown
- hole is flowing artesian

GW Site #27: diamond drill hole, midway between Sharp & Sasaginaga Lakes

- accessed by an old drill road, now used by the Tri-Town Snowmobile Club
- age unknown, but the road has been there since the 1930's
- hole is flowing artesian, and used for drinking water by the snowmobile club
- water has a sulfurous odour

**GW Site #28:** mine working, Nipissing Mine

- located north-northeast of the NLGM
- the most easterly of 4 trenches in a fenced off area
- water level in trench fell during the summer

GW Site #29: mine working, Nipissing Mine

- located between Ragged Chutes Road and Cobalt Lake, about 200 m northwest of the NHGM tailings
- a small amount of water is flowing from the shaft.

GW Site #30: mine working, Provincial #1 Mine

- located at the south end of Cart Lake, west of the Silverfields Mill
- samples collected from the base of the headframe over the shaft
- the water level is about 3 m below the shaft opening

**GW Site #31:** mine working, Nipissing Mine

- adjacent to the south arm of Sasaginaga Creek
- located about 200 m northeast of the vehicle garage for the Town of Cobalt
- significant volumes of water are discharging from the shaft into the creek

• there is bright green moss growing are around the discharge point

# Appendix 11:

## **Techniques Used for the Preparation and Analyses of Solid Samples and Water Samples**

#### A.11.1 Sample Preparation Procedures for Solid Samples

Core samples were prepared by cutting through the ABS tubing on each side of the core using a circular table saw. A length of wire was then drawn through the tailings, splitting the core into two sections. Open cores were covered with plastic wrap, and stored at room temperature. The cores were examined visually.

Subsamples of 22 of the solid phase samples collected were prepared for geochemical analysis. Material was transferred to plastic vials using a stainless steel spatula. To make the samples as representative as possible the material was transferred in small portions, and each portion was taken from a different area of the sample bag. Vials were sealed and stored at room temperature.

Subsamples of 20 tailings samples were prepared for X-ray diffraction analysis to identify the minerals present. Samples were prepared by grinding 3 to 5 g of tailings in a mortar and pestle, in methanol, until a fine grain size was achieved. A thin layer of this slurry was poured onto a glass slide and allowed to air dry.

The pH of 16 samples from the NLGM tailings was measured using the following procedure: 20 g of tailings were put in a 50 ml beaker, and 20 ml of distilled water was added; the mixture was stirred frequently over a period of 30 minutes; after 30 minutes of settling, the pH of the clear suspension above the solids was measured using a Corning 106 pH meter which was calibrated using pH 7 and pH 10 buffer solutions (Carleton University Department of Geography 1989).

#### A.11.2 Analytical Methods for Solid Samples

Samples were sent to Bondar-Clegg and Company Ltd. in Ottawa for geochemical analysis. Inductive coupled plasma - atomic emission spectroscopy analysis was used to measure concentrations of 32 metals: Al, Fe, Mn, Mg, Ca, Na, K, Sc, V, Cr, Co, Ni, Cu, Zn, As, Sr, Y, Mo, Ag, Cd, Sn, Sb, Te, Ba, La, W, Pb and Bi. Preparation procedures used by Bondar-Clegg are as follows: 0.1 g of sample was put in a glass test tube, to which 0.5 ml of HNO<sub>3</sub> and 1.5 ml of HCl were added. Sample test tubes were then heated for two hours in a hot water bath. After heating, samples were diluted to 10 ml with deionized water and shaken. Samples were then analysed. The precision of these analyses varies with concentration:

- at the detection limit, the precision is  $\pm 100\%$  variation
- at 10x the detection limit, precision is  $\pm$  30% variation
- at 50x the detection limit, precision is  $\pm$  15% variation

• at 100x the detection limit, precision is  $\pm$  10% variation

The As, Sb and Se concentrations were measured using a hydride generation process followed by atomic absorption spectroscopy. In the hydride generation process, 0.5 g of sample was added to a glass test tube, to which 1 ml of HNO<sub>3</sub> and 3 ml of HCl were added. Sample test tubes were then heated for two hours in a hot water bath. After heating, samples were diluted to 10 ml with deionized water and shaken. For As and Sb analysis, testing aliquots were made using 10x dilutions of the sample solution, 0.6% KI and 10% HCl. For Se, testing aliquots were made using 5x dilutions of the sample solution and 10% HCl. Testing aliquots were then taken into a hydride generation flow injection system. In this system, the test aliquot, 50% HCl and 2% NaBH<sub>4</sub>, were taken up by a peristaltic pump and mixed in a mixing coil, where hydrides and H<sub>2</sub> gas are generated. The hydrides and H<sub>2</sub> gas are then carried by Ar gas through a gas-liquid separator and introduced into a heated quartz cell. The As, Sb and Se hydrides were decomposed into atoms and measured by an atomic absorption spectrometer. The precision of these analyses varies with concentration:

- at the detection limit, the precision is  $\pm 100\%$  variation
- at 10x the detection limit, precision is  $\pm$  30% variation
- at 50x the detection limit, precision is  $\pm$  15% variation

Concentrations of Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup> were measured by ion chromatography. To prepare samples for analysis, 5 g of sample were added to 50 or 100 ml of deionized water and heated on a hot plate for 30 minutes. Six millilitres of this test solution were then analysed on an ion chromatograph.

Samples were prepared for Hg analysis by digesting 0.5 g of sample in a HNO<sub>3</sub>/HCl solution for two hours. To reduce Hg to volatile metallic form SnCl was added. Samples were then analysed on a cold vapour atomic absorption spectrometer. The linear working range for these analyses is 5 to 400 ppb.

Cyanide levels in tailings were measured by adding 50 ml of deionized water to 10 g of sample, then adding NaOH. Sample solutions were filtered and the CN<sup>-</sup> concentration was measured by an ion selective electrode. The detection limit for this measurement is 2.00 ppm and the upper limit is 10.00 ppm.

Five large tailings samples from the pails were analysed for SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, total Fe, MnO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O and P<sub>2</sub>O<sub>5</sub> using DC plasma analysis.

Detection limits for each of these analyses are given in Table A.11.1.

Mineralogical analyses were completed at Carleton University using a Philips x-ray generator and diffractometer. X-rays were generated at a voltage of 40 kV and a current of 40 mA. The diffractometer went through a rotation of  $3^{\circ}$  to  $65^{\circ}$  at a speed of  $2^{\circ}$  per minute and the x-ray detector operated at 1000 counts per second. Shorter scans at 2000 counts per second were used to bring the large peaks on scale.

#### A.11.3 Collection of Tailings Groundwater Samples

Piezometers which contained a column of water more than 1 m deep were used to obtain samples for chemical analysis. Water samples were collected using a bailer made of rigid PVC. The bailer was first lowered into the piezometer and filled about half full of water, then raised and shaken to rinse the interior of the bailer with the sample water, and then drained into a sample bottle. The sample bottle was then closed and shaken to rinse the interior with the sample water. The rinse water was then discarded. Once this rinsing procedure was complete, as large a sample volume as possible was collected. Samples rarely exceeded 1 L in size. Some of the piezometers on the NLGM tailings had to be sampled on two consecutive days to collect a sufficient amount of water. The piezometers were not purged prior to sample collection because recharge rates were so low, particularly in the NLGM tailings, that the samples would have to be collected the following day, making the purging ineffective. The bailer and sample jars were only rinsed once because the piezometers could not produce enough water to allow a normal triple rinsing with sample water. After the sample was collected, the bailer was disassembled and rinsed with distilled water, then placed in a clean plastic bag for transport.

The sample bottles used were glass apple juice bottles which had been cleaned with soapy water, tap water, methanol, dilute hydrochloric acid, and finally distilled water. These bottles served as temporary containers; within 12 hours the water was filtered and transferred to polyethylene bottles.

#### A.11.4 Analytical Methods for Water Samples

#### A.11.4.1 Field Geochemical Measurements

For each water sample, five parameters were measured in the field: pH, Eh, conductivity, alkalinity and temperature. Temperature was measured only during the May sampling, and for sampling completed after September 1991.

All pH measurements were completed using a Corning 106 pH meter. The instrument was standardized using pH 7 and pH 10 buffer solutions prior to use.

The Eh measurements were taken using an Orp Eh meter. The Eh was not measured during June and July due to instrument problems. Difficulties were experienced with this instrument since it rarely settled to a given value or range of values; usually, the Eh readings continued to drop with time, although the rate of change did decrease with time. Generally, measurements were taken after 4 to 5 minutes, unless the readings stabilized sooner. Thus, the Eh values measured give an estimation of the Eh of the sample, rather than an accurate measurement.

Conductivity was measured using a Canlab conductivity meter. The instrument was not calibrated during the period of use.

Alkalinity was measured using a Hack field titration kit. Alkalinity was measured as total mg/L of CaCO<sub>3</sub> by diluting the sample to one part sample and four parts distilled water, then adding

phenolphthalein and bromcresol green - methyl red indicators. The solution was then titrated using  $1.6N H_2SO_4$  until the pink endpoint was reached.

#### A.11.4.2 Laboratory Analyses

Samples were sent to Bondar-Clegg & Company Ltd. in Ottawa for detailed geochemical analysis. To prepare samples for analysis the water was filtered in the field, within 12 hours of collection of the sample, using 45  $\mu$ m millipore filters. The filtered samples were collected in 250 mL sample bottles. Samples for metal and anion analyses were collected in polyethylene bottles, and samples for Hg analysis were collected in dark brown glass bottles. After filtering, the samples were preserved in preparation for analysis. Samples for metal analysis were preserved with 69% HNO<sub>3</sub>, while those for Hg analysis were preserved with a mixture of 69% HNO<sub>3</sub> and K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>. Samples for cyanide analysis were collected in 500 mL polyethylene bottles and preserved with 6 - 10% NaOH. No preservative was added to samples being analysed for anions. All bottles were completely filled, leaving as little air in the bottles as possible, and all were tightly capped. Samples were not refrigerated in the field. Within one week of collection, samples were delivered to Bondar-Clegg, where they were refrigerated until analysis. After analysis, the samples were returned to Carleton University and frozen at -15°C.

At Bondar-Clegg, inductive coupled plasma - atomic emission spectroscopy analysis was used to measure concentrations of 32 metals: Al, Fe, Mn, Mg, Ca, Na, K, Sc, V, Cr, Co, Ni, Cu, Zn, As, Sr, Y, Mo, Ag, Cd, Sn, Sb, Te, Ba, La, W, Pb and Bi. Water samples were not treated prior to analysis, as were the soil samples. The precision of these analyses varies with concentration:

- at the detection limit, the precision is  $\pm 100\%$  variation
- at 10x the detection limit, precision is  $\pm$  30% variation
- at 50x the detection limit, precision is  $\pm$  15% variation
- at 100x the detection limit, precision is  $\pm$  10% variation

The As, Sb and Se concentrations were measured using a hydride generation process followed by atomic absorption spectroscopy. For As and Sb analysis, testing aliquots of each water sample were made using 10x dilutions of the sample, 0.6% KI and 10% HCl. For Se, testing aliquots were than taken into a hydride generation flow injection system. In this system, the test aliquot, 50% HCl and 2% NaBH<sub>4</sub>, are taken up by a peristaltic pump and mixed in a mixing coil, where hydrides and H<sub>2</sub> gas are generated. The hydrides and H<sub>2</sub> are then carried by Ar gas through a gas-liquid separator and introduced into a heated quartz cell. The As, Sb and Se hydrides were decomposed into atoms and measured by an atomic absorption spectrometer. The precision of these analyses varies with concentration:

- at the detection limit, the precision is  $\pm 100\%$  variation
- at 10x the detection limit, precision is  $\pm$  30% variation
- at 50x the detection limit, precision is  $\pm$  15% variation

Concentrations of Cl<sup>-</sup> and SO<sub>4</sub><sup>-2</sup> were measured by ion chromatography using 6.0 mL of each

sample.

Samples were prepared for Hg analysis by mixing 100 mL of each sample with 5 mL of  $HNO_3$  and SnCl. Samples were then analysed on a cold vapour atomic absorption spectrometer. The linear working range for these analyses is 0.01 to 2.0 ppb.

Cyanide concentrations in samples were measured by first distilling 50 mL of sample into an NaOH solution. The CN<sup>-</sup> concentration was then measured by an ion selective electrode. The detection limit for this measurement is 0.005 ppm and the upper limit is 10.00 ppm.

The detection limits for all parameters are given in Table A.11.2.

### **Table A.11.1:**Detection limits for analyses of solid samples

Element/Compound	Analytical Method	<b>Detection Limit</b>		
As	hydride gen - A.A.S.	0.001 ppm		
Sb	hydride gen A.A.S.	0.001 ppm		
Se	hydride gen A.A.S.	0.001 ppm		
Cl	ion chromatography	0.10 ppm		
$SO_4^{-2}$	ion chromatography	0.01 ppm		
Hg	cold vapour A.A.S.	0.01 ppm		
Al	ICP	0.01%		
Mg	ICP	0.01%		
Ca	ICP	0.01%		
Na	ICP	0.01%		
K	ICP	0.01%		
Total Fe	ICP	0.01%		
Mn	ICP	1 ppm		
Sc	ICP	5 ppm		
V	ICP	1 ppm		
Cr	ICP	1 ppm		
Со	ICP	1 ppm		
Ni	ICP	1 ppm		
Cu	ICP	1 ppm		
Zn	ICP	1 ppm		
As	ICP	5 ppm		
Sr	ICP	1 ppm		
Y	ICP	1 ppm		
Мо	ICP	1 ppm		
Ag	ICP	0.2 ppm		
Cd	ICP	0.2 ppm		
Sn	ICP	20 ppm		
Sb	ІСР	5 ppm		
Te	ICP	10 ppm		
Ba	ICP	2 ppm		
La	ICP	1 ppm		
W	ICP	20 ppm		
Pb	ICP	2 ppm		
Bi	ICP	5 ppm		

### **Table A.11.2:**Detection limits for analyses of water samples

Element/Compound	Analytical Method	Detection Limit		
As	hydride gen - A.A.S.	0.001 ppm		
Sb	hydride gen A.A.S.	0.001 ppm		
Se	hydride gen A.A.S.	0.001 ppm		
Cl	ion chromatography	0.10 ppm		
$SO_4^{-2}$	ion chromatography	0.01 ppm		
Hg	cold vapour A.A.S.	0.01 ppm		
cyanide	ion selective electrode	0.005 ppm		
Al	ICP	5 ppm		
Mg	ICP	5 ppm		
Ca	ICP	5 ppm		
Na	ICP	5 ppm		
K	ICP	5 ppm		
Total Fe	ICP	5 ppm		
Mn	ICP	5 ppm		
Sc	ICP	10 ppb		
V	ICP	10 ppb		
Cr	ICP	50 ppb		
Со	ICP	10 ppb		
Ni	ICP	50 ppb		
Cu	ICP	50 ppb		
Zn	ICP	20 ppb		
As	ICP	200 ppb		
Sr	ICP	10 ppb		
Y	ICP	10 ppb		
Мо	ICP	50 ppb		
Ag	ICP	50 ppb		
Cd	ICP	2 ppb		
Sn	ICP	200 ppb		
Sb	ICP	100 ppb		
Te	ICP	100 ppb		
Ba	ICP	50 ppb		
La	ICP	10 ppb		
W	ICP	100 ppb		
Pb	ICP	200 ppb		
Bi	ICP	20 ppb		

# Appendix 12:

## **Additional Photos of the Cobalt Area**

Note: This appendix was not included in the original version of this thesis, published in 1993. Some of the photos in this appendix are historic photos taken while the mines were in operation. Others were taken during the main period of field work for this study, in 1991 and 1992. In addition, some photos were taken in the course of follow-up work in the area, from 1993 to 1997.



Photos taken by the author in 1993 or 1994. Top photo taken looking north-west from the road. Bottom photo taken looking south from the dam (location 1 in top photo). See also Figure 2.4 for location.

Nipissing High Grade Mill Tailings





Top photo shows rubble and waste material immediately south of the Nipissing high grade mill foundation. The photo to the left is a close-up the pile that was the source of the sample called Nipissing High Grade Mill "Stuff". The origins of this material are not known, but samples contained over 200,000 ppm of arsenic. Photos taken by the author in 1993 or 1994.

Nipissing High Grade Mill "Stuff"



Top photo shows the Nipissing low grade mill in operation, 1913 (Ontario Archives 15380-30). Aerial buckets carry ore to the mill from a Nipissing mine on the west side of Cobalt Lake. Steel netting was used to prevent injuries if any ore fell from the buckets. Bottom photo, by the author shows the mill foundation in 1991. The mill burned down in 1934.

Nipissing Low Grade Mill



This photo, taken by the author in 1991, illustrates dust blowing from the Nipissing low grade mill tailings. Photo is taken looking north, with the tailings blowing to the east. Note the home in the background. Homes are also located close to the tailings on the west side, and over the hill to the east, less than 1 km away. See a further discussion of dust problems in Section 5.4.1, and related recommendations in Section 6.2.1.

#### Dust on Nipissing Low Grade Mill Tailings



Top photo shows a crew from the Nipissing Mining Company, stripping the hillside of soil to uncover silver veins. Because veins were so close to surface, removal of trees and soil was a common prospecting method in Cobalt. Bottom photo shows Cobalt Lake in 1910. Water quality is poor, at least in part to outcrop stripping activities. (photo credit: Cobalt Mining Museum)

Outcrop Stripping – and the Result



In 1914, Cobalt Lake was drained to access silver veins under the lake. At the time, there was much local concern about the risk of disease, but a local doctor refuted this: "Were there not fish in the lake and did not gulls eat them without ill effect." He reminded residents "that the waters were a gift of nature, but since they were now so polluted there was no real drawback to draining the lake." Top photo taken looking south from the east side of the lake (photo credit: source unknown. Scanned from Baldwin and Dunn, 1988). Bottom photo taken looking east. The Nipissing Low Grade Mill is in the background. (photo credit: Ontario Archives 13390-43)

Draining of Cobalt Lake



Top photo: Right-of Way Mine (photo credit: Teck Centennial Library). Mill Creek is to the left side of the photo. Bottom photo was taken by the author in 1991. Building 1 is the same in both photos.

Mill Creek at the Right-of-Way Mine





Top photo: LaRose Mine (photo credit: Ontario Archives 15409-4). Bottom photo was taken by the author in 1991. Building 1 is the same in both photos. Note the lack of trees on the hill in the top photo. Trees and soil were removed to find silver veins.



The date of the top photo is not known (photo credit: Cobalt Mining Museum). The bottom photo was taken by the author in 1992. Building 1 appears to be the same in both photos, though trees now partially obscure it. The extent of the tailings upon which the mobile homes in the bottom photo are built is clearly visible in the top photo. Location 2 on the top photo is also tailings, corresponding to location 2 in plate A.12.11. An elementary school is now at this location, not visible in the bottom photo. See also Figure A.3.2. Locations in this photo are labelled in that map. The camera icon on the mill foundation west of the tailings indicates the approximate location from which these photos were taken.

Buffalo Mill and Tailings


View of the Coniagas property, looking southwest from the Cobalt water tower, spring of 1992. The town arena is just off the left side of the photo, and the Coniagas mill foundation and tailings are visible at location 1. Towards the centre of the photo, an open pit from the Coniagas operation is visible (2). The headframe from the Nipissing 73 mine is at the far right (3). Note the houses visible just behind the open pit, as well as the house close to the mill foundation. The proximity of tailings to residential areas is further illustrated in Plate A.12.11

Coniagas Property, 1992



Scan of a postcard from the Cobalt Mining Museum, published by Temiskaming Printing Co. Ltd., New Liskeard. Photo was taken in the late 1960s, looking south-east. In the right foreground, the tailings of the Buffalo Mine can be seen (1). In the centre foreground are two other tailings deposits within the town (2&3). At location 2, Cobalt Public School can be seen. Tailings immediately east of the school had not been revegetated or covered in any way. In the centre Cobalt Lake can be seen, and the south end of the lake is drained to recover tailings for reprocessing (4). Further east, Cart Lake can be seen (5). Tailings in the lake are much less extensive than in 1992. The Nipissing low grade mill tailings are visible at (6).

Aerial View of Cobalt - Late 1960s



Bucke Park well in 1992. Samples from this well, discussed in Section 4.7.1, were taken from inside the shed. The concrete casing of the well head is near the small door visible in the photo. Samples collected had a mean As concentration of 6.97 ppm. At the time samples were collected, the Canadian Water Quality Guideline for arsenic in drinking water was 0.05 ppm. The current (2005) guideline is 0.025 ppm.

In the late 1990s, this well in Bucke Park was shut down by the local Medical Officer of Heath, based on data from this study and follow-up studies.

The bottom photo shows significant iron staining on rocks adjacent to the well shed. Overflow from the well flows across the rocks to Lake Temiskaming, a short distance away. Changes in redox conditions result in the precipitation of iron oxides, causing the staining.



Bucke Park Well

## Appendix 13:

## Updated Photos of the Cobalt Area, July 2005

This appendix contains photos taken by the author on a visit to Cobalt in July 2005. These photos document changes that have taken place since this thesis was completed, particularly progress in reclamation activites in the area. The photos also document some features that have not changed, but which were not photographed at the time the field work for this study was conducted.



This composite photo shows the results of the efforts to revegetate the Nipissing low grade mill tailings. Compare this view with Plate 3.2a. Tailings were revegetated in the late 1990s. However, no effort appears to have been made to add any cover material over the tailings, and in bare areas, crusts like those described in section 3.5.2 are still evident. Thus, while the revegetation has likely helped to reduce dust from the tailings, further study is required to assess whether or not water quality has improved as a result of the revegetation efforts.

NLGM tailings from mill foundation, July 2005



Top photo: NLGM Dam #1 looking west, taken by the author in 1991. See also Figure 2.4. Bottom photo: NLGM Dam #1 looking east, taken by the author in July 2005. Comparison of these photos suggests that some of the

wood around the dam was removed as part of the revegetation project. It is not known how this wood was disposed of. NLGM tailings from dam #1



This photo illustrates ongoing tailings erosion on the NLGM tailings, just above Dam #1. When tailings were revegetated there appears to have been no effort to recontour the tailings or take other steps to help reduce erosion during spring runoff or high rainfall events. As a result, some transport of tailings and contaminants is likely continuing, and the long term success of the revegetation efforts may be questionable. Revegetation efforts were not in accordance with what would be considered best practice.

This photo also illustrates the possible ongoing formation of surface crusts on the tailings, as described in Section 3.5.2. Field examination of the light areas in this photo suggests that these areas are very similar to the crusts observed before the tailings were revegetated. Further testing would be needed to confirm this.

NLGM tailings, above Dam #1, July 2005



Outlet from the Nipissing low grade mill tailings, looking south. This is the location of surface water sampling station #1. The top photo was taken in 1992, the bottom photo in 2005. As part of reclamation work on the tailings, the dam in the top photo (Dam #3, see Figure 2.4) has been removed. Riprap has been added. Culverts under the road carry runoff water down to Mill Creek.

Outlet from the Nipissing Low Grade Mill Tailings



This photo illustrates the condition of wood used in the construction of Dam #1 on the NLGM tailings. At the top of the photo, sawdust and wood shavings are visible. This area is enlarged in the inset photo, bottom right. Observations of the dam during this study suggested that it was constructed at least in part of wooden boxes, and that sawdust and wood shavings were used as fill material. At the time this study was conducted, in some places along the dam, it was possible to pick of handfuls of sawdust that looked freshly cut. Note also the condition of the fabric.

As discussed in section 5.2.1.1, it is likely that this wood is in such good condition after over 90 years of exposure at least in part because of the preservative effects of arsenic. No samples of wood were collected for analysis as part of this study. The potential for high levels of arsenic in the wood means that this material needs to be disposed of with care, unless analysis indicates a low arsenic content. Wood from NLGM Tailings. Dam #1

unless analysis indicates a low arsenic content. Opening burning, in particular, could result in significant releases of arsenic. See also Plate A.13.10 for further evidence of the preservative effects of arsenic. Wood from NLGM Tailings, Dam #1 July 2005



Top photo shows the author drilling a hole to install a piezometer in the Nipissing low grade mill tailings, in the summer of 1991. This is either piezometer #6 or #7 (see Figure 4.2). Bottom photo shows the same location in the summer of 2005, taken from the rock cut in the background of the top photo. At this location, tailings fill an old mine shaft of unknown depth.

Piezometers in Nipissing low grade mill tailings



These photos illustrate the slow progress of natural vegetation reclaiming Nip Hill. Both photos were taken from the Nipissing low grade mill foundation. The top photo was taken in 1991, and the bottom photo in 2005.

Nip Hill Recovery



Composite image of the Nipissing high grade mill, looking northwest. Clean-up of debris around this site has occurred since the last visit by the author in 1997, including the removal of the NHGM "stuff". The area in the foreground, marked by the oval, is the approximate location of the NHGM "stuff". It is not known how this material was disposed of. See also plate A.12.2. This photo was taken from the road to the Nipissing low grade mill, illustrating the proximity of the high grade mill to the road, and in particular, indicating how close the "stuff" was to the road. This road is used by tourists visiting the low grade mill as part of the Heritage Silver Trail.

Nipissing high grade mill, July 2005





Top photo shows the Nipissing high grade mill foundation from the top of the slag pile, now largely revegetated. There are concerns about metal contamination around this foundation, and others in the area. A sample of concrete collected from this foundation as part of this study contained over 10,000 ppm of arsenic. Soil samples collected around the site by the Ontario Ministry of the Environment in 2003 contained high levels of arsenic. Of 48 samples collected, 29 had As concentrations greater than 10,000 ppm and 4 samples had As concentrations greater than 100,000 ppm, or 10% As (Ontario Ministry of the Environment, 2005, Technical Report: Screening Level Health Risk Assessment of the Historical Mining Tour of Cobalt, Ontario)

The photo on the left is a close up of a small room on the lower part of the foundation, illustrating the debris the still remains on the site. This is the room in which the newspapers in Plate A.13.10 are located.

Nipissing high grade mill, July 2005





Top left photo illustrates a stack of newspapers at the Nipissing high grade mill, first discovered by the author in 1993. The bottom left and top right photos show the remarkable condition of these newspapers, dated November 1957. For some papers, it is still possible to turn the pages. Samples of these newspapers were not collected for analysis as part of this study. However, it is likely that arsenic has helped to preserve these 50 year old newspapers, which have been exposed to the elements.

Newspapers from the Nipissing high grade mill, July 2005





Top left photo is looking down the hill from the Nipissing high grade mill to the depression on the other side of the road where the Nipissing high grade mill tailings are located. See also Figure 2.4. The area in the bottom photo is approximately indicated by the white square in the top photo.

Bottom photo shows the Nipissing high grade mill tailings, as seen from the road. Compare this with the top photo of Plate A.12.1. The tailings are now partially vegetated, though it is not known if this is a result of reclamation activities by the site owner, or a result of natural revegetation. Given the very high concentrations of arsenic in these tailings (ranging from 15,000 ppm to 100,000 ppm, see section 3.5.3.1) it would seem that the best reclamation strategy for this material is to remove it for safe re-disposal elsewhere.





View of the Cart Lake tailings, taken from a lookout on the Silver Heritage Trail on the west side of the lake. Compare this with plate 2.4a, which was taken from the road at the north end of the lake and at a lower elevation. Like the NLGM tailings, efforts have been made to revegetate the Cart Lake tailings. As at the NLGM tailings, this has helped to reduce dust from the tailings, but effects on water quality are not known.

Cart Lake Tailings, July 2005



Photo looking south, from the east side of the Cart Lake tailings, towards the Provincial #2 headframe. This photo is looking towards the same are illustrated in the top photo of Plate 3.6, which was taken from the Silverfields mill site, at the southeast corner of the tailings.

Cart Lake tailings revegetation, July 2005



Composite image of the Crosswise Lake tailings, looking southwest. These tailings are located adjacent to the foundation of the King Edward Mill, on the west side of the lake (see Figure 1.3). The main body of tailings in Crosswise Lake extends north from this point (see Figure 2.3).

Crosswise Lake tailings, July 2005



Composite image of the Coniagas tailings, looking west. As illustrated in Figure 2.3, these tailings are within the town. See location number 3 in Plate A.12.9. They are immediately behind the arena, and at least one home is located within 20 m of the tailings. These tailings were not sampled as part of this study, but are further discussed in section A.3.2.1.2.

Coniagas tailings, July 2005



In the summer of 2005, the Timiskaming Health Unit posted signs around Cobalt Lake, warning people not to use, play, swim or fish in the waters of the lake. This warning was posted as a result of water sampling conducted by the Ontario Ministry of the Environment and the Health Unit. Section 6.2.1 of this thesis includes a recommendation that "the health risks associated with swimming in surface waters in the Cobalt area, particularly Cobalt Lake, should be assessed."

Note that in this round of sampling As concentrations in samples from the lake ranged from 0.66 to 0.69 mg/L. Comparison with results in Table 4.13 show that concentrations are unchanged from the period 1991 to 1993. Mean As concentrations for samples collected in this study for two locations in Cobalt Lake were 0.64 and 0.69 mg/L.

Warning signs around Cobalt Lake, July 2005