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SEASONAL AND MINING INFLUENCES ON STREAM-WATER GEOCHEMISTRY IN THE RAMBLER MINES AREA: IMPLICATIONS FOR MINERAL EXPLORATION AND ENVIRONMENTAL MONITORING

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ABSTRACT

To assess the impact of the former operations at Consolidated Rambler Mines on the Baie Verte Peninsula on water quality in the surrounding drainage system, stream-water samples were collected in June and late August 1993 for chemical analysis. The mines exploited copper, zinc, gold and silver from volcanogenic massive sulphide deposits. Samples were collected in both background areas and from sites downstream of mine workings and tailings. Results indicate that concentrations of most elements are higher in the August samples. The increase is remarkably uniform, suggesting that results obtained from different sampling periods could be compared by reference to a few calibration samples collected from the same sites during both sampling periods. Ore elements have detectable levels in waters from most streams, including those regarded as background. The implication of this for mineral exploration is that water containing a component dissolved from mineralized till or bedrock could yield a geochemical anomaly. Analyses of ore-related elements (e.g., Cu, Pb, Zn, Co, As, S) are much higher from sites downstream of mining activity indicating that the safeguards designed to protect the area's watersheds have been inadequate. Of the elements analyzed, Cu appears to be the most detrimental to water quality, exceeding environmental guidelines for maintaining aquatic life by up to 1000-fold in some streams.

INTRODUCTION

A geochemical sampling program was undertaken in 1993 in and around the former Consolidated Rambler Mines property on the Baie Verte Peninsula (Figure 1). Samples of stream-water, stream-sediment and overbank samples were collected during the first week of June and again in the last week of August; the results of the water-samples are discussed here. The objectives of the water-sampling component are a) to determine if stream-water geochemistry can be used as an exploration method, b) if water chemistry varies seasonally, and c) what affect past mining activity is having on the stream-water quality at present. Preliminary results of a stream-water survey conducted in 1992 at a lower density over a larger area on the Baie Verte Peninsula were reported previously (Hall, 1993).

The study area lies within the Notre Dame Subzone of the Dunnage Zone (Williams, 1979; Williams *et al.*, 1988). It is an area characterized by island-arc volcanism and back-arc basins. The study area itself is underlain predominately by Ordovician mafic volcanic and volcaniclastic rocks with numerous felsic volcaniclastic rocks in the immediate mine area, all of them belonging to the Paquet Harbour group (Hibbard, 1982). Some of the streams sampled in the survey also rise in areas underlain by the Burlington granodiorite. The mining operations exploited volcanogenic massive-sulphide type ore. Approximately 4 300 000 tonnes of polymetallic ore were recovered during the period 1967 to 1982 from four separate orebodies (Coates, 1990): Main Mine

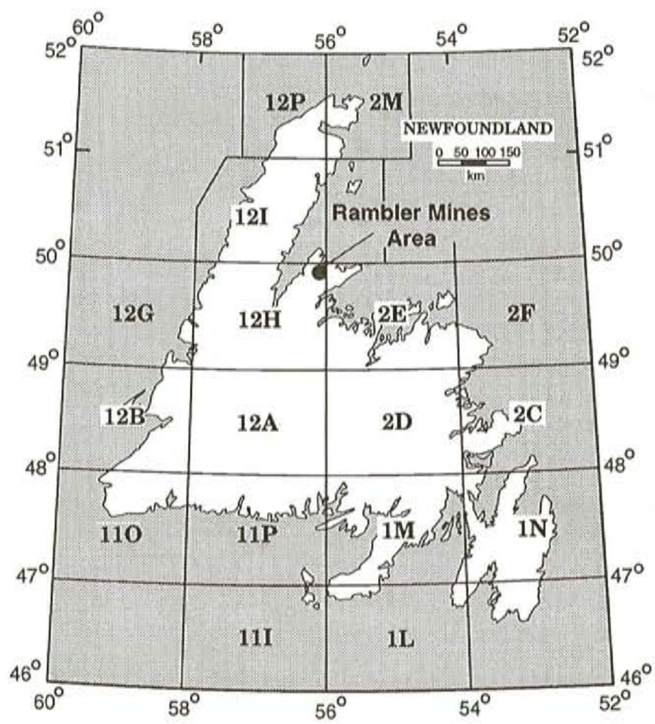

Figure 1. *Location of study area.*

(400 000 tonnes of 1.30 percent Cu, 2.16 percent Zn, 5.14 g/t Au and 29.14 g/t Ag); East Mine (1 900 000 tonnes of 1.04 Cu); Big Rambler Pond, not shown (45 000 tonnes of 1.20

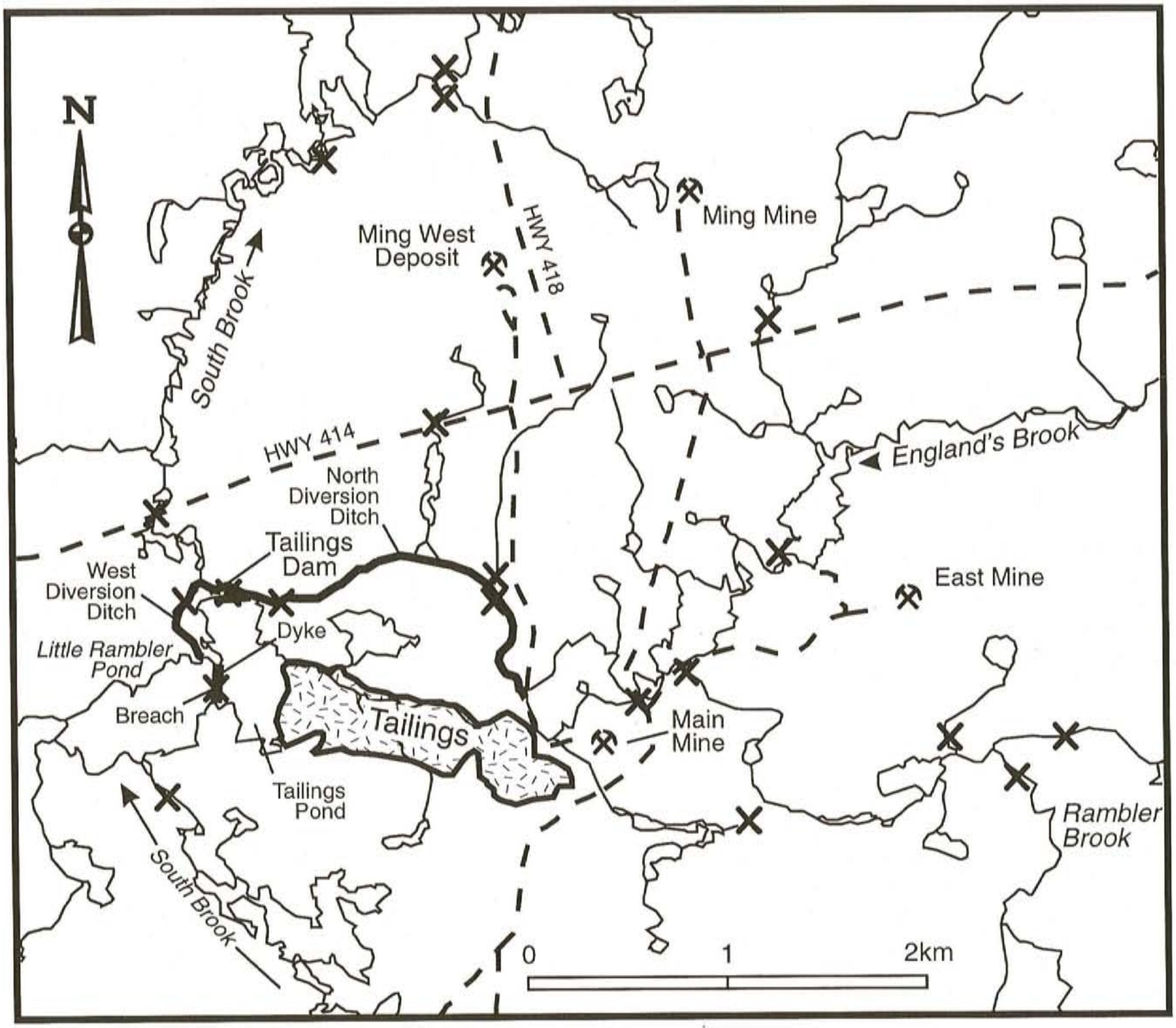

Figure 2. *Locations of mine workings, tailings, diversion ditches and dykes. X—sample location sites; ⚒ —mine workings (abandoned); ⁄⁻ —road.*

percent Cu) and Ming Mine (1 900 000 tonnes of 3.5 percent Cu, 2.40 g/t Au and 20.57 g/t Ag) (Figure 2). Additional estimated reserves include the Ming Footwall Deposit (underlying the Ming Mine) with 3 000 000 tonnes of 1.6 percent Cu and the Ming West Deposit with 110 000 tonnes of 5.6 percent Cu, 2.47 g/t Au, 18.4 g/t Ag and 0.37 percent Zn (Newfoundland Department of Mines and Energy, 1994).

The terrain has a gentle to moderate relief. Most streams flow toward the northwest and are tributaries of South Brook, which empties into the east side of Baie Verte. The area is forest covered except in areas logged recently. Surficial cover consists mainly of glacial till deposited by north-flowing ice sheets (Liverman and St. Croix, 1989).

The natural drainage system in the Rambler area was modified to accommodate the mine tailings and isolate them so as not to affect the stream-water quality. A tailings compound was made by constructing a dyke across Little Rambler Pond and excavating a diversion ditch to permit South Brook to bypass the tailings to the west (Figure 2). Additional dykes and a second diversion ditch were constructed along the north side of the tailings area to re-route the flow of Rambler Brook and England's Brook around the compound. A few years ago, however, the western diversion ditch was reportedly dammed by beavers causing the newly created western half of Little Rambler Pond to breach the dyke and re-route South Brook into the tailings pond. The breach rapidly eroded the dyke and today South Brook continues to flow into the tailings pond and then out over a dam on the north side of the tailings area.

Table 1. Analytical methods for stream waters

ANALYSIS	METHOD	PREPARATION
pH	Corning combination pH electrode	None
Conductivity	Corning conductivity sensor	None
Ca, Fe, K, Mg, Mn, Na, Si, SO_4	ICP-ES	Filtration (0.45 μm) and HNO_3 acidification in field laboratory
Al, Ba, Be, Co, Cr, Cu, Li, Mo, Ni, P, Sr, Ti, Y, Zn	ICP ultrasonic nebulizer	Filtration (0.45 μm) and HNO_3 acidification in field laboratory
Ag, Al, As, Ba, Be, Bi, Br, B, Ca, Cd, Ce, Cl, Co, Cr, Cs, Cu, C, Fe, Hg, I, La, Li, Mg, Mn, Mo, Ni, N, Pb, P, Rb, Sb, Si, Sr, S, Ti, Tl, U, Zn	ICP-MS	Filtration (0.45 μm) and HNO_3 acidification in field laboratory

Ore was brought to the surface at four locations and trucked to a mill that was located near the east end of the tailings area. Some waste rock was dumped at the surface, near the ore bodies located north of Highway 414; this may be creating an acid drainage problem separate from the tailings compound. The tailings themselves are mostly above water, and thus are exposed to oxidation. In addition, windborne tailings are dispersed about the area during dry, windy conditions. The results of this dispersion have been observed for a 2 to 3 km radius around the tailings as reflected by high concentrations of metals including Cu, Zn and Au in the bark and twigs of black spruce (Dunn, 1993).

SAMPLING AND ANALYTICAL METHODS

Eighty-six stream-water samples were collected in clean, 250 ml, nalgene bottles. Fifty-four of these are from 28 sites that were sampled in early June and again in late August (seasonal duplicates) in order to determine whether, and how, water chemistry varied seasonally. As well, pairs of samples were collected from 13 sites (site duplicates) to determine the combined effect of sampling and analytical errors for various elements. Samples were collected both from areas considered to be free of the effects of mining activity as well as from drainages downstream from mine workings and tailings.

Conductivity determinations were done in the evening following sample collection using a Corning meter with a conductivity sensor. Acidity (pH) was measured in the Department's geochemical laboratory using a Corning meter with a combination pH electrode. Water samples for geochemical analyses were filtered in the field through 0.45 μm filter paper and then acidified. The filter papers from all samples from South Brook collected downstream of the tailings dam became clogged with a thick layer of fine brown material and required fresh replacements to complete filtration. Samples were analyzed for a broad range of elements using three techniques. The Department's geochemical laboratory employed both inductively-coupled-plasma-emission-spectrometry (ICP-ES) and inductively-coupled-plasma-emission-spectrometry using an ultrasonic nebulizer (ICP-USN). The Department of Earth Sciences at Memorial University of Newfoundland analyzed samples for thirty-eight elements by inductively-coupled-plasma-mass-spectrometry (ICP-MS). The elements determined by each method are summarized in Table 1. Analytical methods were described in detail by Finch *et al.* (1992).

RESULTS

SEASONAL VARIATION

Data from seasonal duplicates obtained from streams considered to be affected by mining activity are treated separately from data obtained from seasonal duplicate sites located on background streams. Both sets of data indicate that concentration levels of most elements are higher in the late summer stream water. Figure 3 shows the mean concentrations of 10 elements for 13 background sites and 9 mine-affected sites sampled in June and again in August. For example, the mean concentration of aluminum in August from contaminated streams is more than twice the mean value for the same sites sampled in June. The figure also shows that metal levels in the mine-effected streams are much higher than in background streams. For instance, the mean copper value in background August streams is 3 ppb compared to the corresponding value of about 500 ppb in mine-effected streams. Figures 4 and 5 show the seasonal variation for copper and arsenic in background streams in which all samples, except one pair for copper, have higher values in the August samples. The correlations for the two elements are strong, with Cu having a correlation coefficient of 0.79 and As having a coefficient of 0.93.

STREAM GEOCHEMISTRY IN MINING AND SURROUNDING AREA

Samples were collected from a wide region around the Rambler Mines but results presented here focus on a 30 km²

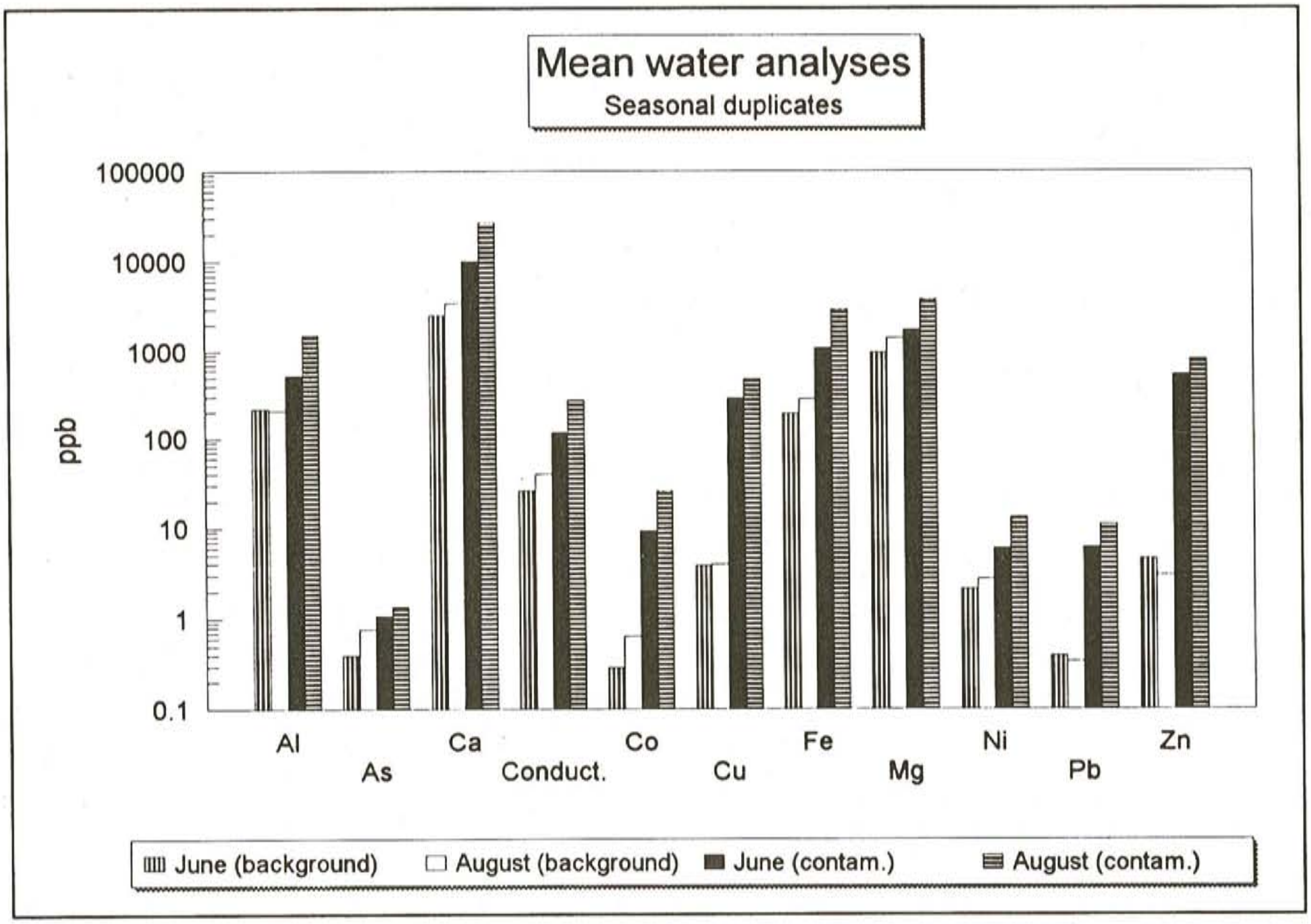

Figure 3. *Mean water analyses from sites sampled in June and August on background and mine-effected streams.*

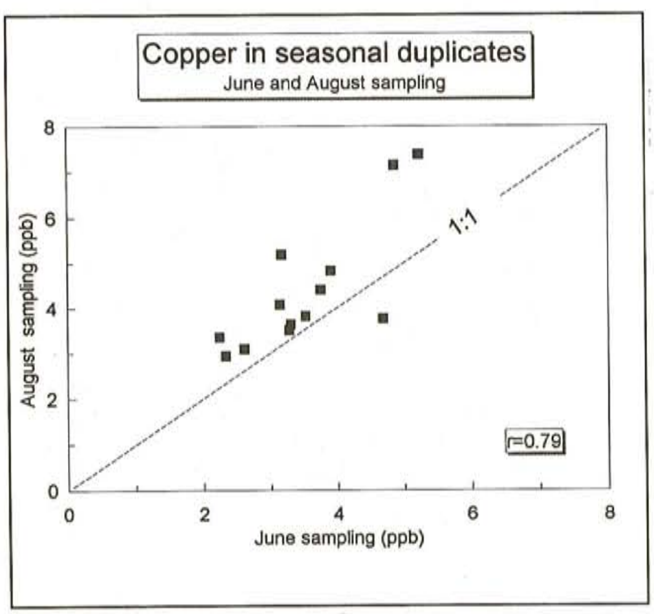

Figure 4. *Seasonal duplicates; copper in water from 13 sites on background streams sampled in both June and August.*

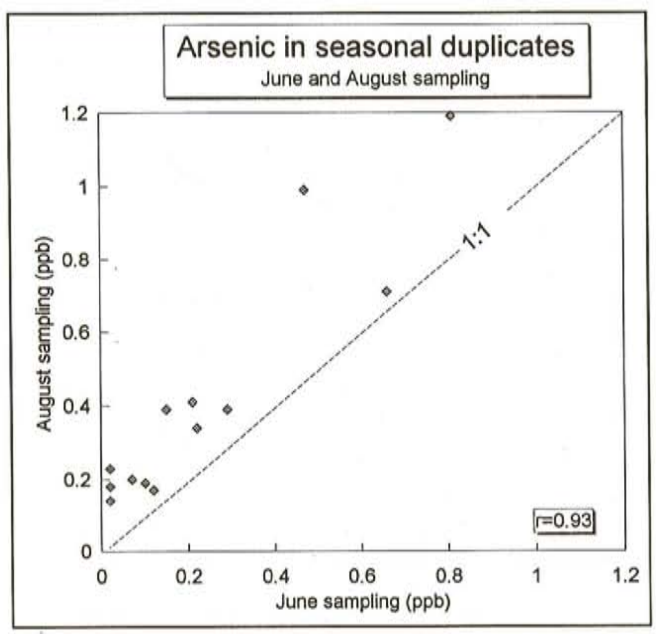

Figure 5. *Seasonal duplicates; arsenic in water from 13 sites on background streams sampled in both June and August.*

area centred on the old mining area. Not surprisingly, the base metals show high values in waters collected down-drainage from the damaged tailings reservoir. The highest values, however, are from streams draining the mines located north of Highway 414. The distribution of pH, Cu, Pb, and Zn in stream water from 20 sites sampled in August are shown in Figures 6 to 9. The histograms included in these figures are data from all sites sampled in August. Analyses of pH (acidity) and a histogram of their distribution are shown in Figure 6. The histogram shows a bimodal distribution with one mode at 4.6 and a second at 6.4. The first population corresponds mainly to the mine-effected streams and the second to the background streams. The most acidic samples (pH <4.5) are all from sites downstream of the tailings and the mine workings. The most extreme acidification is seen in samples from streams draining the area around the Ming Mine and the Ming West deposit. The lowest pH analysis (3.2) is from the south-flowing stream that joins the diversion ditch 750 m north of the tailings. A second very acidic stream (3.7) is the one that flows northwest from its source near the Ming Mine. The three samples in South Brook downstream of the tailings are also very acidic.

The two highest Cu analyses (1980 and 1330 ppb, Figure 7) are from the two most acidic streams described previously. All sites upstream of the tailings and mining locations have near background concentrations of Cu. The histogram, which is bimodal, also shows two extreme samples. The two main subpopulations consist of background samples <12 ppb and mine-effected streams >50 ppb; the two extreme samples are >1000 ppb. The highest 'background' sample is 10.3 ppb Cu (not shown) and is from a site on a small stream about 50 m upflow of a small (45 000 tonnes) mined-out, satellite orebody about 1 km south of the map boundary. A sample obtained downflow of the mineralization on the same stream has 181 ppb Cu. The high downstream value is doubtlessly due to the exposure of the mineralization to surface water by mining. The high upstream value of 10.3 ppb, however, suggests that mineralized till or bedrock is giving rise to a weak but significant anomaly.

The map of Pb distribution (Figure 8) is similar to that of Cu although differs in detail. The highest Pb analysis (34 ppb) is from the same sample with the highest Cu. The second highest Pb (19 ppb), however, is from a sample obtained at the dam draining the tailings pond and the third highest corresponds to the 1330 ppb Cu sample. The distribution of Zn (Figure 9) is similar to that of the other base metals. The two highest analyses (3090 and 1350 ppb) are from the two samples with the highest Cu analyses. The histogram is extremely bimodal with complete separation between background and mine-effected streams indicated by <15 ppb and >300 ppb respectively.

STREAM GEOCHEMISTRY ALONG SOUTH BROOK

South Brook is the major drainage system in the area. After discharging over the tailings dam, it flows through a series of small lakes and ponds for 10 km before emptying into Baie Verte. It was sampled along its length from its source to near its mouth and the results of the August sampling are presented in Figure 10 for Cu, Zn, Pb and pH. The guideline concentration levels for survival of aquatic life for Cu, Pb and Zn are shown as dashed lines. These are levels above which metal contents are increasingly toxic to many freshwater organisms for water hardness below 60 ppm (Environment Canada, 1991). Water hardness in South Brook varies from 5.3 to 6.3 ppm above the tailings pond and from 27.3 to 34.3 ppm downstream of the pond. Note that the base metals (left-hand Y-axis) are shown using a logarithmic scale; pH units are also log based. The distributions of base metals in the stream from its source (-8 km) to 9 km downstream of the tailings show very similar patterns differing only in magnitude and detail. Zn, for example, has a range of 2 to 4 ppb in the three samples upstream of the tailings and increases to about 400 ppb downstream of the tailings. Concentrations decrease only slightly over the 9 km distance that was sampled downstream of the tailings. Cu and Pb show similar patterns to Zn although the concentration of Pb in the river declines more rapidly downstream. The shape of the pH pattern is the reverse of the base metals. Values of about 6.0 upstream fall to 3.8 at the dam and then increase gradually downstream to 4.7 at the most distant sample.

SUMMARY AND CONCLUSIONS

The results of a study to measure seasonal variations in stream-water chemistry indicate that for many elements the late summer concentration levels are higher than those of the spring. This shift is noted in samples from both background and mine-effected streams. These higher concentration levels coincide with lower rainfall and water levels. The resultant slower transit time from precipitation to stream discharge gives ground water more opportunity to dissolve metals from till, bedrock and tailings. However, the results of the seasonal duplicate samples indicate that seasonal shifts are very consistent throughout the area. Thus, water samples collected at different times of the year could be levelled by reference to the results a few monitoring sites resampled during each collection period.

The histograms of pH and ore-related elements in water are strongly bimodal. The concentration levels in water downstream of mine workings and tailings are much higher (sometimes hundreds-fold as in Cu and Zn) than in background streams. The high concentrations presumably result from two main factors: first, the presence of waste rock and tailings expose a large surface area of material with high metal contents; and, second, oxidation of the abundant sulphide leads to acidification of the surface water and a marked increase in its ability to dissolve metals. This two-fold effect would also lead to higher metal contents in water contacting undisturbed, sulphide-rich bedrock or till derived from such rock. Streams that included a component of such water could be expected to have anomalous metal concentrations although not nearly as pronounced as the levels encountered downstream of mining operations.

Finally, the acidity and the concentration levels of some elements in the mine-effected streams are lethal to freshwater

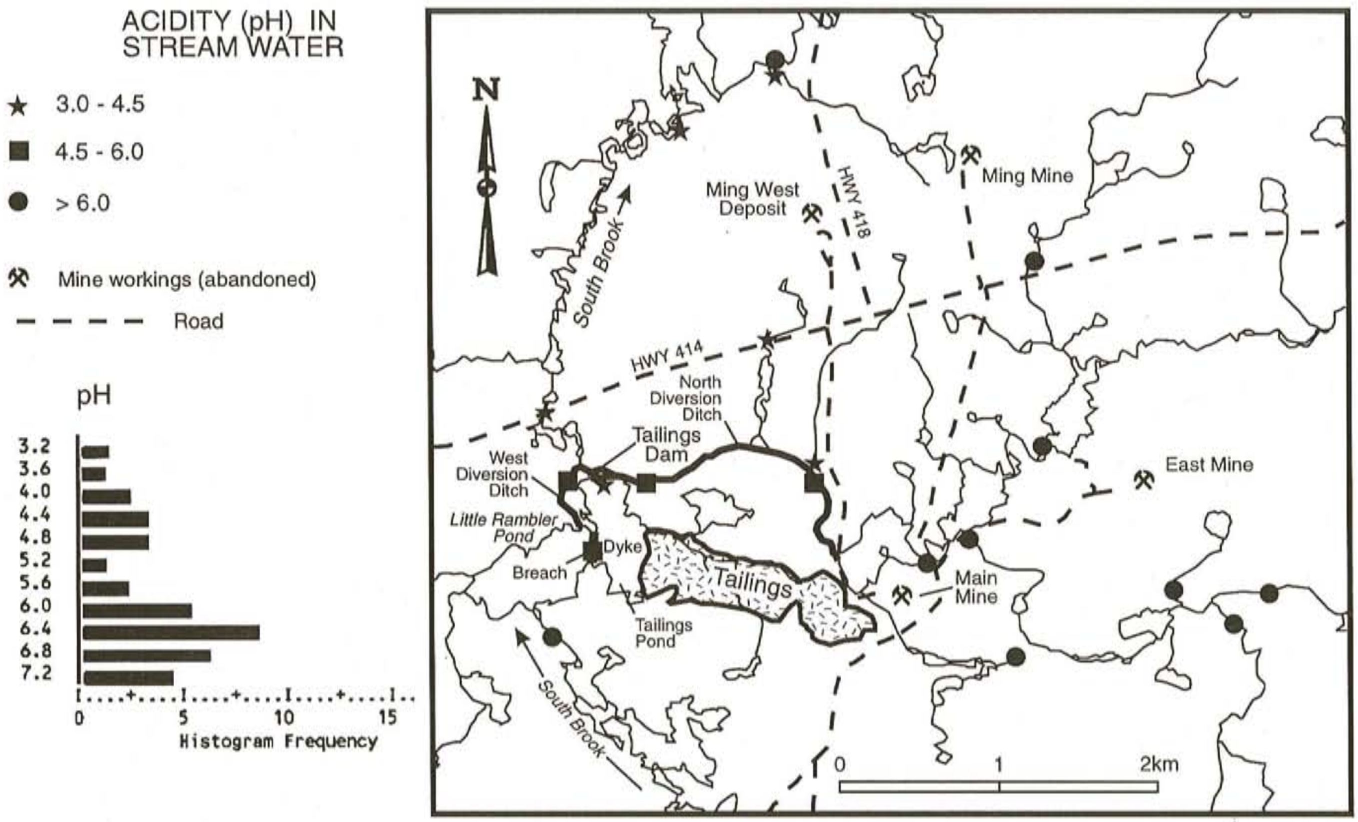

Figure 6. *Distribution of pH analyses of stream waters in the Rambler Mines area.*

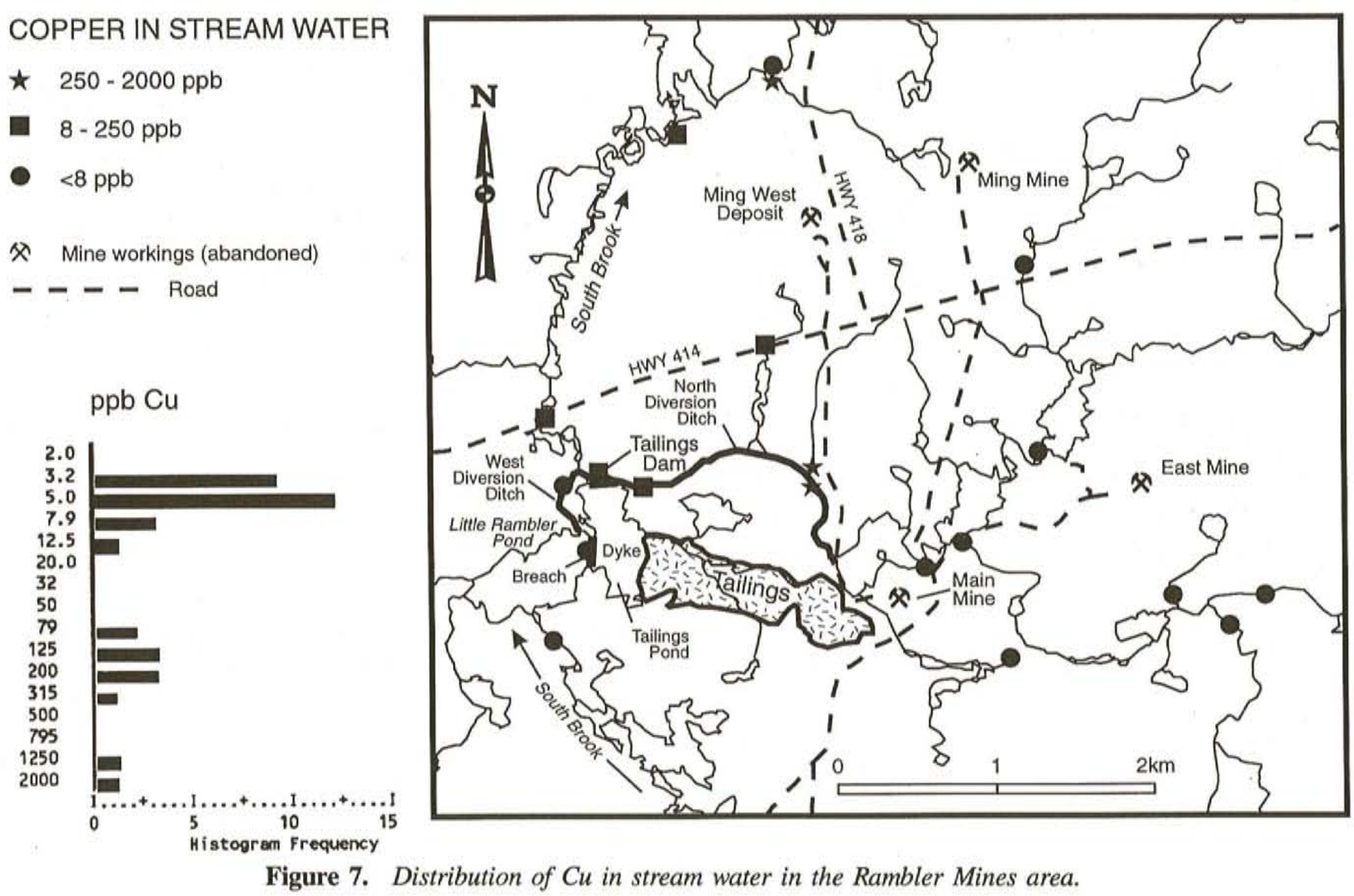

Figure 7. *Distribution of Cu in stream water in the Rambler Mines area.*

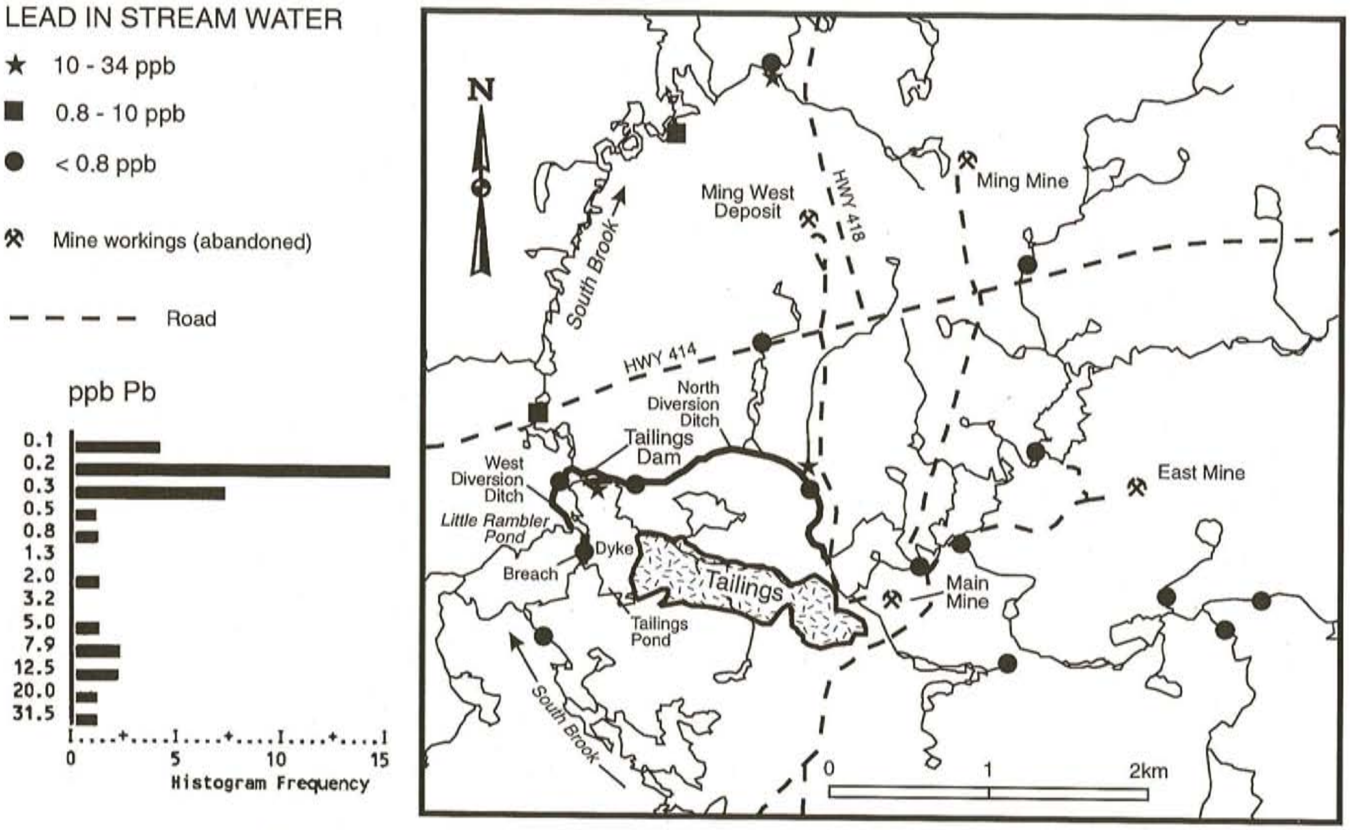

Figure 8. *Distribution of Pb in stream water in the Rambler Mines area.*

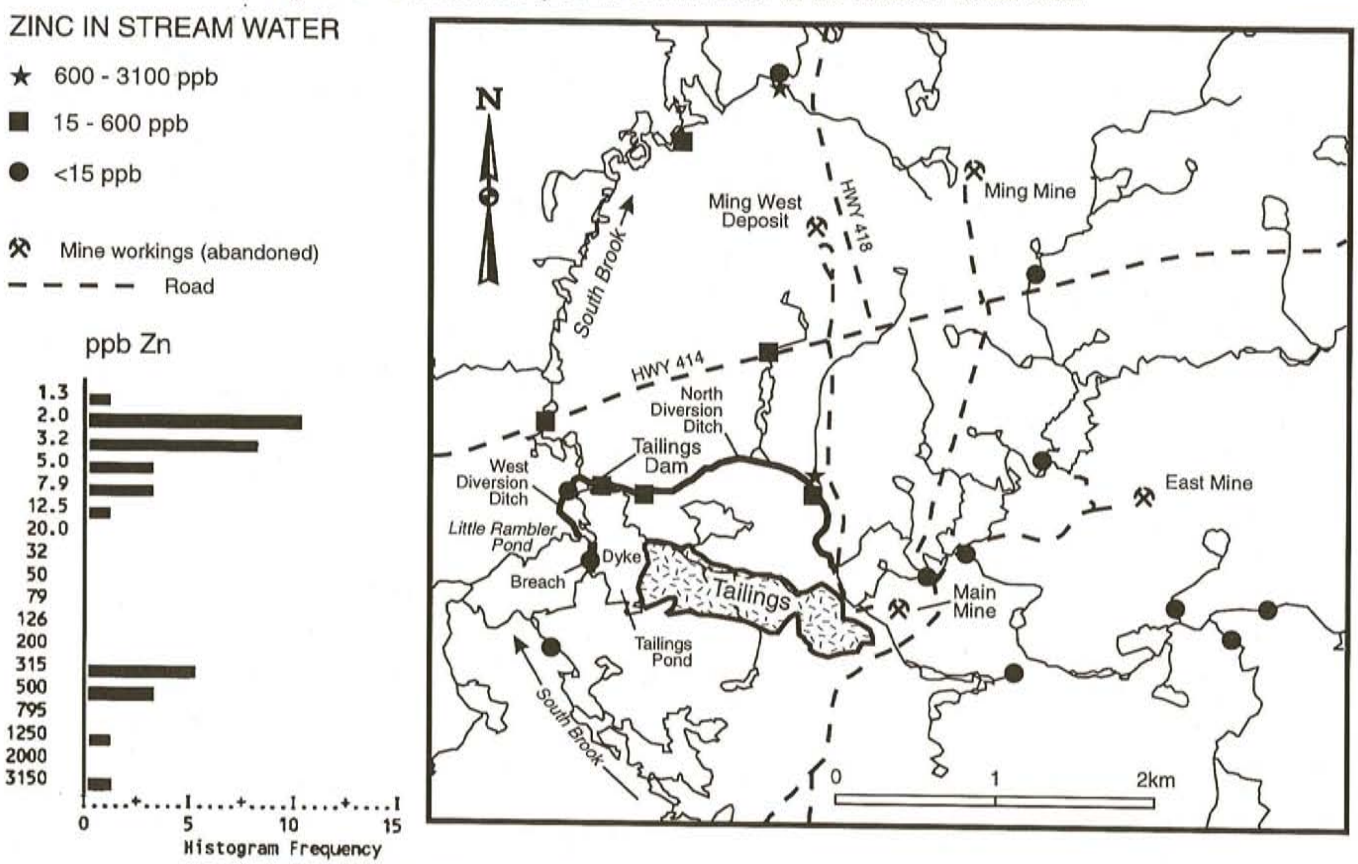

Figure 9. *Distribution of Zn in stream water in the Rambler Mines area.*

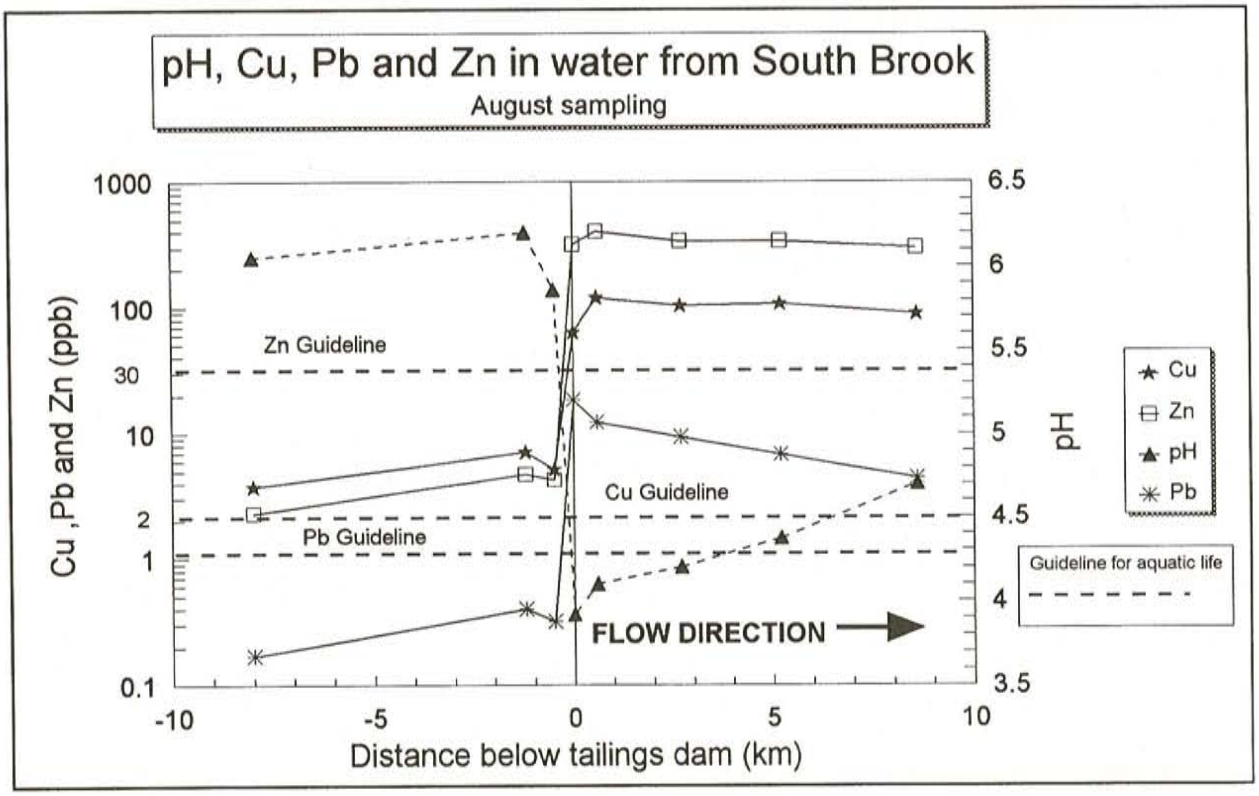

Figure 10. *Distribution of pH, Cu, Pb and Zn in water from South Brook.*

aquatic life. The most serious contaminant measured is Cu, which exceeds the guideline levels in some streams by 1000 times. Particularly effected are two small streams draining mines north of Highway 414, the northern diversion ditch and South Brook downstream of the tailings pond.

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REFERENCES

Coates, H.
1990: Geology and mineral deposits of the Rambler Property. *In* Field Trip Guidebook. 8th IAGOD Symposium, metallogenic framework of base and precious metal deposits, central and western Newfoundland. *Edited by* H.S. Swinden, D.T.W. Evans and B.K. Kean. Geological Survey of Canada, Open File 2156, pages 184-193.

Dunn, C.E.
1993: The relationship of metals in spruce trees to geology and mineralization in the Baie Verte area, Newfoundland. *In* Report of Activities. Newfoundland Department of Mines and Energy, Geological Survey Branch, pages 7-11.

Environment Canada
1991: Canadian Water Quality Guidelines, Inland Waters Directorate, Environment Canada, pages 3-1 to 3-54.

Finch, C., Hall, G.E.M. and McConnell, J.W.
1992: The development and application of geochemical analyses of water. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 92-1, pages 297-307.

Hall, G.E.M.
1993: Elemental signatures in stream waters from the Baie Verte Peninsula, Newfoundland. *In* Report of Activities. Newfoundland Department of Mines and Energy, Geological Survey Branch, pages 19-24.

Hibbard, J.
1982: Geology of the Baie Verte Peninsula. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 82-4.

Liverman, D. and St. Croix, L.
1989: Quaternary geology of the Baie Verte Peninsula. *In* Current Research. Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 89-1, pages 237-247.

Newfoundland Department of Mines and Energy
1994: Call for proposals: exempt mineral land, Ming Mine area, Baie Verte Peninsula. Newfoundland Department of Mines and Energy, 22 pages.

Williams, H.
1979: The Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, Volume 6, pages 163-174.

Williams, H., Colman-Sadd, S.P. and Swinden, H.S.
1988: Tectonic-stratigraphic subdivisions of central Newfoundland. *In* Current Research, Part B. Geological Survey of Canada, Paper 88-1B, pages 91-98.