

Ash portions weighing 0.5-1 g were transferred into plastic vials and submitted for multi-element instrumental neutron activation analysis (INAA) at Activation Laboratories Ltd., Ancaster, Ontario. In addition, an ash split of similar size was submitted for analysis by ICP-ES at Min-En Laboratories, Vancouver, in order to obtain data for elements of interest that are not readily determined by INAA, notably the base metals. Several elements were determined by both techniques.

**SEDIMENT STUDY (A. Mudroch)**

**Introduction**

Thirteen sediment samples were collected from near-shore sites in the Sound (Fig. 1). The number of sediment samples was limited by the great depth of water, the nature of the bottom sediments (commonly coarse sand, pebbles, and bark fragments) and the type of sampling device. Samples were taken to: (i) examine the nature and possible source of the materials sedimenting in the bays; and (ii) determine their geochemical signature and identify natural background versus point source contamination.

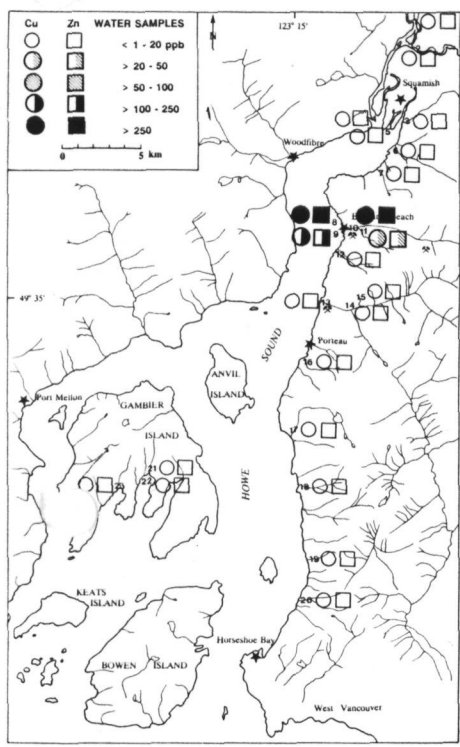


Figure 2. Concentrations of Cu and Zn (in ppm) in surface waters from stream mouths and bays in Howe Sound.

Table 2. Analyses of water samples from the Howe Sound drainage basin. Values for Ca, Mg, Na, and K are in ppm, and for Fe and Mn in ppb. Electrical conductivity (COND.) measurements are in  $\mu\text{S}/\text{cm}$ . Site numbers correspond to those on Figure 2.

Site No.	pH	Cond.	Ca	Mg	Na	K	Fe	Mn
1	8.1	20	2.29	0.25	0.74	0.52	139	10
2	6.6	1060	3.54	0.36	0.94	0.26	40	ND
3	6.8	19	2.14	0.23	0.67	0.19	34	10
4	6.5	24	2.10	0.51	2.93	0.54	51	22
5	6.3	3400	25.6	75	630	24.3	64	13
5-10m	5.9	49400	313	1020	7800	360	ND	18
5-20m	5.7	21400	335	1060	8325	375	ND	17
6	6.5	9	1.14	0.09	0.35	0.11	10	ND
7	6.3	7	0.74	0.09	0.33	0.11	22	ND
8	5.3	521	7.45	10	76	2.97	113	48
9	6.7	2560	20.0	52	450	17	26	37
10	5.8	39	4.13	0.67	0.52	0.11	68	53
11	5.4	8	12.3	0.60	1.14	0.18	36	ND
12	6.2	25	2.93	0.26	0.93	0.24	ND	ND
13	6.0	17	2.18	0.21	0.58	0.14	ND	ND
14	7.1	25	2.46	0.50	2.04	0.35	ND	ND
15	6.7	29	3.20	0.50	1.32	0.36	ND	ND
16	6.0	9	0.90	0.16	0.43	0.16	ND	ND
17	5.9	17	1.89	0.19	0.61	0.14	26	10
18	5.8	29	2.91	0.38	1.15	0.11	ND	ND
19	5.9	52	7.52	0.51	1.29	0.39	ND	ND
20	6.3	12	1.22	0.16	0.70	0.11	28	ND
21	6.0	465	10.6	8.25	63	2.65	ND	ND
22	7.4	19300	123	390	3045	119	ND	ND
22-10m	7.2	34600	244	780	6075	270	ND	15
22-20m	7.1	41400	309	990	7665	330	ND	13
22-50m	6.9	45800	342	1110	8460	375	ND	13
23	5.7	74	8.00	1.08	3.81	0.27	ND	ND

**Results and discussion**

Results of the chemical analyses of the sediment samples are listed in Table 1 with Cu and Zn values plotted in Figure 1. Concentrations of Cu and Zn range from 12 to 1750 ppm and 32 to 1500 ppm ( $\mu\text{g}/\text{g}$ ), respectively. The highest values occur in the two most northerly Britannia Beach samples (sites 3 and 4) and reflect the presence of Britannia mine tailings in recent (post 1974) sediments, and probably the continuous input of these metals from the mine site. In the southern basin two sites (6 and 8) are slightly richer in Cu and Zn than the other sites probably because these two samples contained a substantially higher component of clay-sized particles providing greater surface area for metal adsorption. Zinc concentrations are generally higher than Cu, reflecting the greater natural abundance of Zn.

Barium and cadmium concentrations appear to mirror Cu and Zn levels in the sediments, and Pb and Sb levels are generally higher at Britannia Beach than elsewhere. Most other trace elements represent background values. The sediments are composed of quartz, feldspar, chlorite, mica, and amphibole reflecting the mineralogy of the source rocks. Syvitski and Macdonald (1982) have shown that the presence of mica indicates a Squamish River sediment source whereas chlorite is derived from the Fraser River.

**WATER STUDY (G.E.M. Hall)**

**Introduction**

A total of 44 water samples were collected, 20 focusing on the drainage in the area of the Britannia Cu mine as it was anticipated that this source would provide the major contribution of inorganic pollutants to the Sound. The regional sites (23 in number) of the water survey are shown

in Figure 2. Samples were collected at various depths (e.g., surface, 10m, 20m) at sites 5 and 22 to examine the effect of mixing river or creek outflow with seawater. Surface waters in the Sound have low salinity due to the high influx of fresh waters from the surrounding mountains. This vertical stratification of the waters has a significant effect on the vertical profile of the water chemistry.

**Results and discussion**

Analyses of the drainage basin waters are shown in Table 2 for Ca, Mg, Na, K, Fe, and Mn; Table 3 lists values for trace elements determined to date. Not shown in Table 3 are data for Cd, Ni, and Pb as concentrations of these elements in all waters were less than detection limits of 2, 10, and 20 ppb, respectively. Concentrations of Cu and Zn are shown in Figure 2. With respect to the data in Table 2, the high levels of major cations and, hence, conductivity in samples taken at the Squamish River harbour mouth (sites 5, 5-10m, and 5-20m; see Fig. 2 for location), Britannia Creek side channel (site 9) and Gambier Island (sites 21, 22, 22-10m, 22-20m, and 22-50m) are due to mixing with seawater. The influence of the Britannia mine is seen in the

Table 3. Trace element analyses (in ppb) of water samples from the Howe Sound drainage basin. Site numbers correspond to those of Figure 2.

Site No.	As	Bi	Cu	Sb	Zn
1	ND	0.1	ND	ND	ND
2	ND	0.1	ND	ND	ND
3	ND	ND	9	0.3	3
4	0.1	ND	ND	ND	3
5	0.5	ND	ND	ND	6
5-10m	1.0	ND	21	0.1	26
5-20m	1.1	ND	7	4.33	26
6	0.2	ND	ND	ND	ND
7	ND	0.2	ND	0.1	3
8	ND	ND	378	ND	323
9	ND	0.1	192	0.2	214
10	0.1	ND	276	ND	267
11	ND	ND	30	ND	24
12	0.1	ND	ND	ND	ND
13	ND	ND	11	0.2	7
14	ND	0.1	ND	0.1	4
15	0.1	0.1	ND	0.1	2
16	ND	ND	ND	0.1	2
17	0.1	ND	ND	0.1	ND
18	0.1	ND	5	ND	ND
19	0.2	ND	6	ND	ND
20	ND	0.2	ND	ND	3
21	0.1	0.1	ND	ND	ND
22	ND	0.3	7	ND	5
22-10m	0.9	ND	ND	0.2	5
22-20m	1.1	0.1	ND	0.1	ND
22-50m	1.1	0.1	ND	0.1	4
23	ND	0.3	ND	ND	ND

ND — Not detected, at levels below: 20 ppb for Fe and 10 ppb for Mn

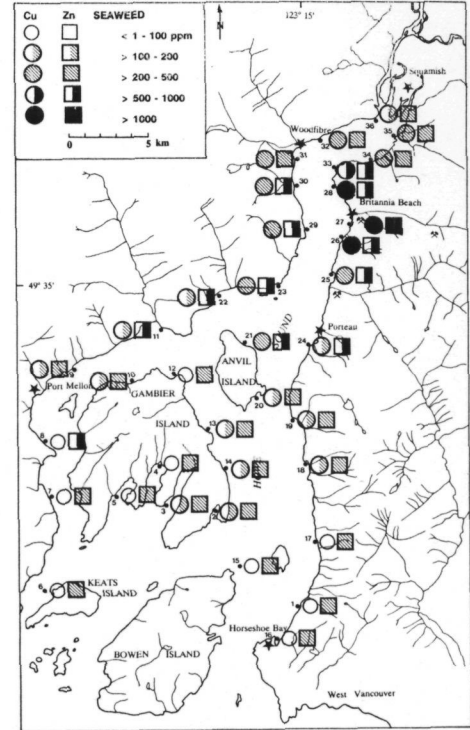


Figure 3. Concentrations of Cu and Zn (in ppm) in the ash of common rockweed (*Fucus gardneri*) from the shores of Howe Sound.

more acidic pH levels at sites 8 to 10 and in the elevated contents of major cations due to acid leaching. Iron and Mn concentrations show little variation throughout the Sound and are in the low ppb ( $\mu\text{g}/\text{L}$ ) range.

With reference to Table 3, the waters in the Sound contain insignificant amounts of Bi and Sb, or at near the analytical method detection limit of 0.1 ppb. The high value of 4.33 ppb of Sb at site 5-20m (Table 3) was confirmed by re-analysis but the source is perplexing as the values above and below in this water column are low. Although values for As are also at or near the detection limit of 0.1 ppb for most samples, they approach 1 ppb with depth due to the influence of more saline waters (sites 5, 5-10m, 5-20m, 22, 22-10m, 22-20m, and 22-50m). Arsenic is certified at 1.65 ppb in the seawater reference material, NASS-2 (Certificate of Analysis for NASS-2, National Research Council of Canada, 1986). The only significant levels of Cu and Zn in the drainage basin waters occur, not surprisingly, in samples taken at the mouth of Britannia Creek where they rise to a few hundred ppb (sites 8 to 10; Fig. 2).



Table 7. Major, minor, and trace element concentrations in precipitates - Britannia mine area.

	1	2	3	4	5	6	7	8	9	10A	10B	11
"Whole rock" analysis (LiBO <sub>2</sub> fusion + ICP-ES), values in %												
SiO <sub>2</sub>	5.23	17.51	21.20	12.30	17.55	38.50	0.55	1.77	8.24	57.16	62.90	12.50
TiO <sub>2</sub>	0.09	0.08	0.09	0.19	0.28	0.08	0.04	0.06	0.14	0.72	0.52	0.01
Al <sub>2</sub> O <sub>3</sub>	5.01	29.05	34.45	3.95	4.70	28.40	2.20	1.13	7.15	17.20	14.25	21.18
Fe <sub>2</sub> O <sub>3</sub>	54.16	1.14	2.10	35.70	42.00	2.20	58.82	56.80	41.60	8.30	6.50	3.04
MnO	0.20	0.07	0.04	0.65	1.16	0.30	0.01	0.01	0.03	0.53	0.40	0.05
MgO	0.20	0.30	0.38	0.65	0.61	0.92	0.04	0.13	0.57	2.83	2.10	0.11
CaO	0.15	0.76	0.41	1.44	0.61	0.92	0.04	0.12	0.77	3.06	6.47	1.45
Na <sub>2</sub> O	0.20	0.25	0.36	1.16	0.63	1.48	0.02	0.08	0.38	4.30	2.55	0.02
K <sub>2</sub> O	0.17	0.19	0.19	0.53	0.58	0.95	0.02	0.05	0.15	2.51	0.95	0.03
P <sub>2</sub> O <sub>5</sub>	0.32	ND	ND	ND	0.09	ND	ND	ND	ND	0.21	0.11	ND
LOI	33.00		24.62	32.01		37.60	37.74		0.93	1.82	31.31	
	98.55	49.35	59.22	80.58	99.65	72.86	100.37	97.89	59.03	97.75	98.57	80.70
Trace element analysis (aqua regia digestion + ICP-ES), values in ppm												
As	143	56	132	149	172	32	69	22	46	27	31	35
Ag	2.2	0.3	10.5	3.3	2.92	4.62	1.2	1.1	1.4	0.4	0.8	0.3
Ba	15	108	30	43	165	128	5	9	20	458	190	34
Bi	5	43	49	231	ND	13	ND	ND	ND	ND	5	210
Cd	2.1	12.8	7.7	8.3	4.2	13.2	3.2	5.4	4.8	0.6	1.7	17.9
Co	ND	11	10	14	2	3	ND	ND	2	13	11	ND
Cr	108	39	357	45	23	72	7	19	32	21	17	23
Cu	1876	19733	17602	13.1%*	1565	17333	607	3759	5323	98	165	12.3%*
La	5	23	75	ND	3	67	6	5	9	6	6	33
Mo	46	7	6	5	7	1	11	24	55	7	18	8
Mn	108	788	346	323	349	194	31	29	163	2892	2070	315
Ni	68	55	238	55	22	48	2	1	28	21	15	14
Pb	128	226	576	227	169	480	ND	80	419	108	118	1572
S'	91	82	83	96	12	33	ND	ND	20	17	15	99
Sn	61	47	ND	72	57	ND	64	63	64	ND	ND	47
Sr	3	43	7	5	12	13	1	2	16	59	124	76
Tc	50	51	43	110	12	20	10	ND	16	ND	ND	89
V	1	16	14	25	26	5	1	9	74	99	71	1
W	ND	ND	ND	53	ND	ND	ND	ND	ND	ND	ND	35
Y	5	53	273	4	2	189	2	2	10	13	13	48
Zn	95	3027	2397	393	297	3991	60	31	177	180	388	9890

\* estimated value

ND - Not detected

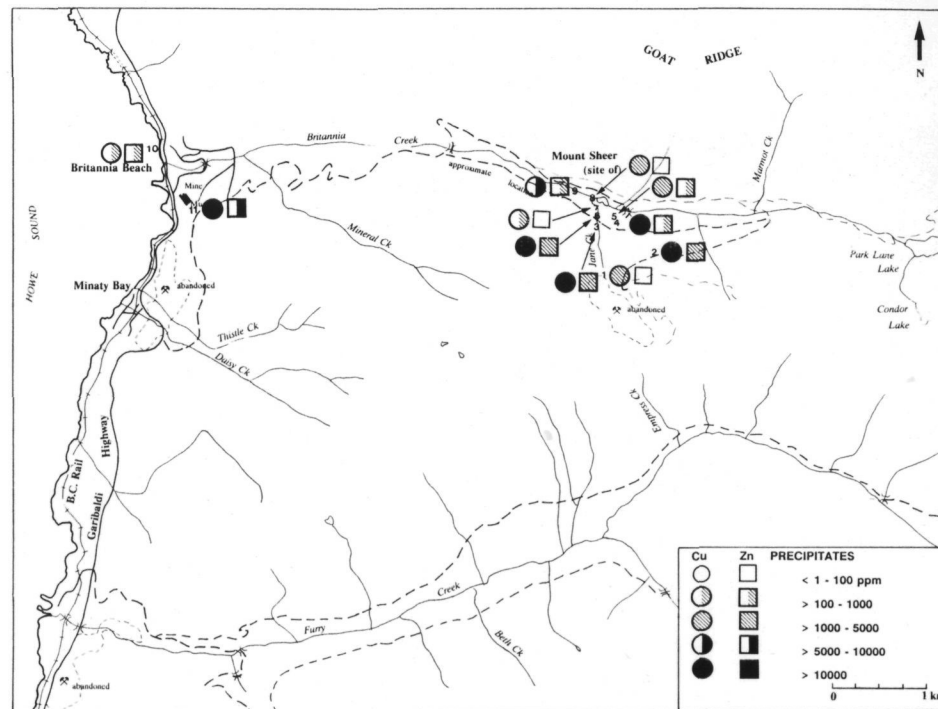
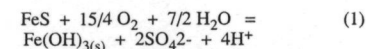


Figure 5. Concentrations of Cu and Zn (in ppm) in the precipitates collected in the detailed study of the Britannia Mine area.

were deposited by hydrothermal and exhalative solutions. They were emplaced into the Britannia shear zone, which is a northwest-trending zone of flattening (Payne et al., 1980; Lynch, 1991). Copper was first reported in 1888 by Forbes, and in 1898 Oliver Furry staked five claims (Ebbutt, 1935). Underground and open pit production began in 1905 by the Britannia Mining and Smelting Company and continued until 1963, when the Anaconda Mining Company operated the mine until closure in 1974. About 50 million tonnes of ore grading 1.1% Cu, 0.65% Zn, 6.8 g/tonne Ag, and 0.68 g/tonne Au were produced (Payne et al., 1980).

During the mining operations, mine waters from the 2200 and 4100 levels (sites 6-7 and 13-15, respectively in Fig. 4) flowed through two Cu precipitation plants which contained scrap metal (tin and iron). This process reduced the amount of dissolved Cu discharged to receiving waters. Currently, acidic mine waters exiting from the 2200 and 4100 levels supply high concentrations of Cu and other metals to nearby surface waters. The acidic water results from the oxidation of

pyrite by O<sub>2</sub> and is characterized by low pH, high SO<sub>4</sub><sup>2-</sup> in solution, and the presence of a yellowish-red precipitate of amorphous Fe-oxide (limonite) (Eq. 1).



The low pH results in leaching of metals in the mine workings and their concomitant transport to receiving waters though their concentrations in solution may be reduced by co-precipitation or sorption with limonite.

### Results and discussion

Results from the water analyses are shown in Tables 5 and 6. Copper and Zn data are plotted separately in Figure 4. The highest metal and lowest pH values occur in waters emanating from the mine portals at the 2200 (site 6) and 4100 (site 13) levels and in the mine museum tunnel (site 16). The lowest concentrations occur in waters above and slightly east of the open pit area (sites 1 and 2), in Britannia Creek near

Marmot Creek (site 3), in Mineral Creek (site 12), and in the town drinking water (site 17). All other samples show elevated levels of Cu and Zn. All samples have low to non-detectable As, Bi, and Sb, and Cd appears to follow the Zn trend. The acidic mine waters have elevated levels of the major elements, especially Fe and Mn (sites 6 to 9 and 13 to 16).

The effects of dilution by receiving waters is readily observed at the Mount Sheer site. Water emanating from the 2200 level portal (site 6) is highly acidic and carries high concentrations of dissolved metals. Over a short distance (<10 m) the Cu concentration drops from 43 950 to 29 975 ppb (site 7). When the mine water mixes with Jane Creek (site 8) the concentration of Cu decreases again, down to 19 850 ppb. The Cu level is stable until the combined waters mix with Britannia Creek (site 10). At this point, a major decrease from over 19 000 ppb to 1170 ppb indicates strong dilution by the larger creek.

The decrease in dissolved metal loadings may also reflect co-precipitation or sorption of metals by amorphous Fe-oxides (light brown; yellowish red) or Al oxides (white) that occur ubiquitously in the stream bed as coatings or precipitates on pebbles. Chemical data for the precipitates are shown in Table 7 and those for Cu and Zn are plotted in Figure 5. Zinc concentrations correspond to high Al<sub>2</sub>O<sub>3</sub> values; elevated Cu levels are associated with both high Fe<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>O<sub>3</sub> concentrations. Levels of the other trace elements are highly variable, ranging from nondetectable to more than 1000 ppm (e.g., Pb). Major element concentrations, other than those of Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub>, are very low. These samples may contain trace amounts of clay (kaolinite or chlorite), quartz, and feldspar but are dominated by the amorphous oxides.

Although there is a natural decrease in the loadings of the metals from the Britannia mine to the Sound, the data show that levels of metals entering Howe Sound are elevated relative to the background values. The concentrations of Cu and Zn emanating from Britannia Creek are within the drinking water guidelines (Cu <1 ppm; Zn <5 ppm, Canadian Water Quality Guidelines, 1987) but exceed safe limits for freshwater aquatic life (Cu <2-4 ppb; Zn <30 ppb; Canadian Water Quality Guidelines, 1987). Also, Britannia Creek experiences high flows in the spring and fall as well as periodic flooding (last event was August 29-30, 1991). During these events, it is highly probable that the precipitates were flushed out and released or deposited in Howe Sound. It is clear that the Britannia mine area needs periodic sampling to monitor seasonal and temporal changes in water and sediment quality.

## SUMMARY

Reconnaissance geochemical studies of the Howe Sound drainage basin involved the collection and analysis of near-shore bottom sediments, stream waters, waters at several depths from within the Sound, and the brown seaweed known as rockweed (*Fucus gardneri*). A more detailed study was conducted around the abandoned Britannia Cu mine to examine local variations in stream water

chemistry, and the precipitates on rock surfaces. This study places emphasis on the distribution of Cu and Zn in and around the Sound, because of the significant influence of the Britannia area from where these metals were mined.

High levels of Cu and Zn were found in all sample media from the vicinity of the mine; no seaweed grows on the shores either side of Britannia for a total distance of 3 km presumably because of metal poisoning. In the southern basin Zn concentrations in sediments and seaweeds are higher than those of Cu in accord with the relative crustal abundances of these metals.

Except near Britannia Beach, waters of the Sound contain low concentrations of most of the elements determined, although major cations are enriched at the north end. Surface waters have low salinity due to the influx of fresh waters from the surrounding mountains, and concentrations of some elements (e.g., As) increase with depth and increasing salinity. The rockweed appears to be a sensitive indicator of the chemistry of the environment exhibiting enrichment of Cu, Zn, Fe, U, and Ba in the north basin.

Waters flowing from the mine portals are acidic and contain high concentrations of dissolved metals, and the study demonstrates clearly the dilution effect by receiving waters, frequently associated with co-precipitation of metals with the Fe or Al oxides that coat pebbles in the stream beds. Periodic flooding probably flushes the precipitates into the Sound, resulting in temporal variations in the chemistry of the Howe Sound waters, sediments, seaweeds, and biota. Consequently, monitoring of these media is required in order to establish long term patterns of chemical variability.

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