NATURAL ACID-DRAINAGE IN THE MOUNT McINTOSH / PEMBERTON HILLS AREA, NORTHERN VANCOUVER ISLAND (92L/12)

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INTRODUCTION

Natural acid-drainage can be generated from acidic atmospheric precipitation (acid rain) and by both organic and inorganic acid-generating processes. The greater extent of natural acid generation occurs as the product of oxidation of sulphide minerals when rock is exposed to water and air.

The purpose of this study is to identify and measure the source and extent of natural acid waters draining from the altered and mineralized rocks in the Mount McIntosh - Pemberton Hills area of northern Vancouver Island. An advanced-argillic, acid-sulphate, copper-gold system of alteration and mineralization related to a porphyry intrusion forms a belt trending northwesterly across the area of study. During the 1991 and 1992 field seasons, a total of 77 water samples were tested for pH, and 34 selected waters analyzed for sulphate and metal content. Waters draining altered and mineralized areas are contrasted with those from relatively unmineralized areas revealing a focused mineralization-related acid-generating system.

LOCATION AND ACCESS

The Mount McIntosh - Pemberton Hills area is located on northern Vancouver Island about 25 kilometres west of Port Hardy on the north side of Holberg Inlet (Figure 4-6-1). The area encompasses watersheds bordered by Hushamu and Clesklagh creeks to the south, Hepler Creek on the west, Nahwitti Lake to the north and the Pemberton Hills to the east (Figure 4-6-2). Well-maintained logging roads provide access to the area from either Coal Harbour (southern access) or Port Hardy (northern access).
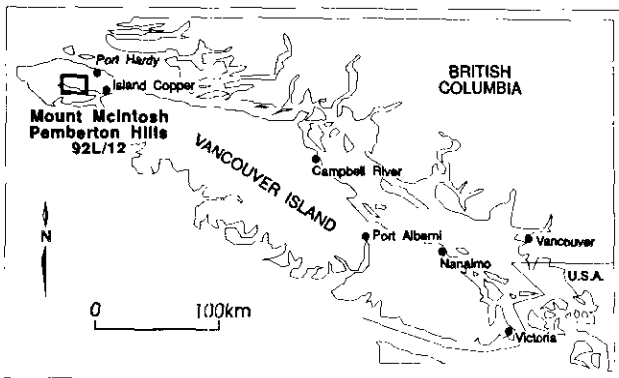

Figure 4-6-1. Location map.

GEOLOGIC SETTING

The study area is underlain by Upper Triassic to Lower Jurassic rocks of the Vancouver Group and Lower Cretaceous Kyuquot Group sediments (Figure 4-6-2). Muller et al., (1974) describes the Vancouver Group as a sequence of Karmutsen basalt, Quatsino limestone, Parson Bay sediments and Bonanza volcanics. Upper Triassic (Carnian) Karmutsen basalts crop out along the south side of Nahwitti Lake and extend northward from the study area. This formation consists of basalt flows, pillow basalts, breccia, aquagene tuff, greenstone and minor limestone. East-trending outcrops of Upper Triassic (Carnian) Quatsino Formation limestones overlie the Karmutsen basalts and grade upward to calcareous siltstones, argillite and locally chert. These limestones are typically massive, locally fossiliferous and altered to skarn. The Quatsino limestone is an easily identifiable marker between Karmutsen volcanics and Parson Bay sediments. The Upper Triassic (Norian) Parson Bay Formation consists of well-bedded calcareous siltstone, shale, limestone, greywacke, conglomerate and breccia. Locally these sediments are skarn altered and mineralized. Lower Jurassic Bonanza Formation volcanics stratigraphically overly the Parson Bay sediments. In the study area the lower part of the Bonanza Formation consists of well-layered, tuffaceous, commonly pyroxene-bearing, epiclastic and pyroclastic volcanics. Higher in the section Bonanza rocks are dominated by massive pyroxene-bearing andesite to basalt flows, tuffs and volcaniclastics with minor and localized dacite to rhyolite flows and pyroclastics (Panteleyev and Koyanagi, 1993, this volume) Lower Cretaceous Kyuquot Group conglomerate, siltstone and greywacke (Muller et al., 1974) crop out in the southeast part of the study area along the shore of Holberg Inlet. Intrusive rocks are mainly the Jurassic Island Plutonic Suite (Muller, 1974 et. al.). These intrusions are commonly quartz diorite to granodiorite in composition and intrude all rocks of the Vancouver Group.

ALTERATION AND MINERALIZATION

The study area includes mineral prospects and deposits of various types, mainly porphyry copper-gold, base metal skarns and advanced-argillic acid-sulphate epithermal mineralization.

Lower Jurassic Bonanza Formation volcanics host advanced-argillic, acid-sulphate alteration and mineralization that is transitional between porphyry and epithermal environments. This alteration and mineralization is related to the emplacement of the Jurassic Island Plutonic Suite. Hydrothermally altered and leached silica caps form physiographically prominent bluffs outcropping from Mount McIntosh to the Pemberton Hills, revealing a linear system
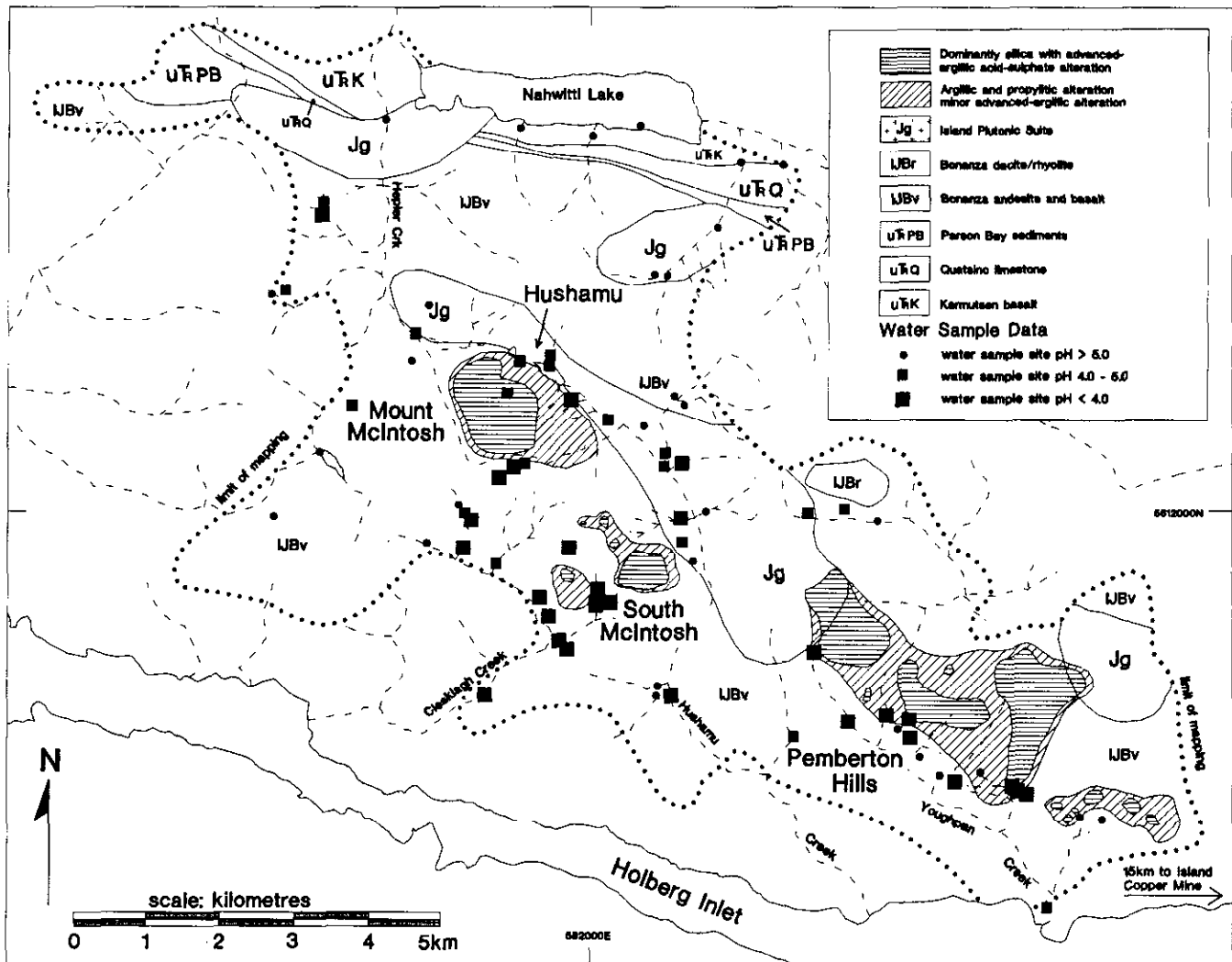
Figure 4-6-2. Geology and alteration map of the Mount McIntosh - Pemberton Hills area (92L/12) with water sample sites.

of alteration zones (Figure 4-6-2). Advanced-argillic, acid-sulphate alteration with quartz-alunite-kaolinite-pyrophyllite-zunyite mineral assemblages underlie and extend beyond higher level, barren siliceous rocks. The acid-sulphate environment is confirmed by the presence of sulphate minerals including alunite, jarosite, gypsum, anhydrite, barite and melanterite. The acidic and strongly oxidized character of the hydrothermal system creates an environment for high-sulphidation base and precious metal deposition. Sulphide mineralization consists of abundant disseminated and massive stratabound iron sulphides (dominantly pyrite and probably marcasite) with minor amounts of enargite and copper sulphides. Propylitic zones with characteristic epidote-chlorite-zeolite-pyrite mineral assemblages have formed peripheral to the advanced-argillic alteration zones. Sulphide mineralization of propylite is significant but occurs in lesser amounts than within the argillic zone. Rare phyllic alteration with quartz and sericite occur locally.

Porphyry copper mineralization close to the contact with a granodiorite stock of the Island Plutonic Suite occurs west of Hepler Creek. There propylitic Bonanza volcanics host*

small, massive lenses and disseminations of pyrite representing an outer alteration envelope of a porphyry system. Outcrops of quartz diorite near Hushamu Lake also host porphyry copper-gold mineralization.

Calcareous sediments of the Upper Triassic Parson Bay and Quatsino formations contain extensive calcsilicate alteration and host skarn mineralization related to the Island Plutonic Suite (Dasler, 1990). Parson Bay sediments are also host to bedding-replacement massive pyrite mineralization.

## ACID GENERATION FROM SULPHIDE OXIDATION

The largest source of natural acid generation is the oxidation of sulphide minerals. This oxidation process begins with the exposure of sulphide-rich rock to air and water. Stumm and Morgan (1970) describe the reaction process as follows:

Iron sulphides, mainly pyrite, react with oxygen and water to produce ferrous iron, sulphate and free hydrogen (reaction A).

$$2FeS_2(s)+7O_2-2H_2O = 2Fe^{2+}+4SO_4^{2-}+4H^+$$
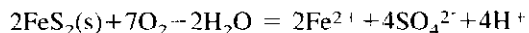
With continued oxidation the ferrous iron will oxidize to ferric iron (reaction B).

$$4Fe^{2+}+O_2+4H^+ = 4Fe^{3+}+2H_2O$$
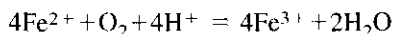
As the level of acidity increases (to around pH of 3.2) ferrous iron oxidation may be catalyzed by certain acidophillic bacteria, primarily *Thiobacillus ferrooxidans* (Steffen, Robertson and Kirsten (B.C.) Inc., 1989, pp. 2-5) and *Ferrobacillus ferrooxidans* (Stumm and Morgan, 1970, p. 542). When combined with water, ferric iron will precipitate ferric hydroxide that coats stream beds and creates additional acidity (reaction C).

$$Fe^{3+}+3H_2O = Fe(OH)_3(s)+3H^+$$
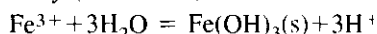
Ferric iron then combines with additional pyrite to produce ferrous iron, sulphate and hydrogen (reaction D).

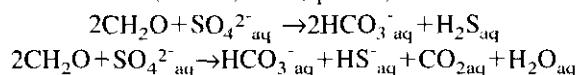$$FeS_2(s)+14Fe^{3+}+8H_2O=15Fe^{2+}+2SO_4^{2-}+16H^+$$
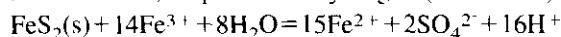
Provided that there are no other major external sources of sulphate, sulphate concentrations may be used as an overall indicator of the amount of acid generated from sulphide dissolution (Stumm and Morgan, 1970 p. 540). If acidity is neutralized, sulphate content is not affected (unless mineral saturation with respect to gypsum is attained) and the correlation is preserved (Steffen, Robertson and Kirsten (B.C.) Inc., 1989, pp. 2-7). Alternatively, if conditions of high acidity and low sulphate coincide, the source of acid is most likely not sulphide oxidation. Overall, if an extensive amount of pyrite is dissolved and the buffering capacity of the surrounding environment is exceeded, the result will be *sustained acid generation*.

The decomposition of pyrite is among the most acidic of all weathering reactions. Marcasite, a dimorph with pyrite and common in the study area, usually disintegrates more easily than pyrite, generating acid at a higher rate (Hurlbut and Klein, 1977).

The rate of dissolution of sulphides within stream drainages is variable. Extensive surface area exposure of sulphide-rich rock to air and water combined with low pH levels and elevated temperatures accelerates the process of acid generation. Under acidic conditions the presence of abundant acidophylic bacteria can also accelerate the process.

Organic generation of acid is also a contributor to natural acid-drainage. In our study area this process is likely to be much less significant than the weathering of sulphide minerals. Fermentation reactions and sulphate reduction results in acid generation. Sulphate introduced into an area of decomposing organic material will undergo bacterial reduction (by genus *Desulfovibrio*, Berner, 1971, p. 123). This bacteria utilizes *organic carbon as a reducing agent*. The reduction of sulphate forms acid by the following generalized reactions (Berner, 1971, p. 123):

$$2CH_2O+SO_4^{2-}{}_{aq} \rightarrow 2HCO_3^-{}_{aq}+H_2S_{aq}$$
$$2CH_2O+SO_4^{2-}{}_{aq} \rightarrow HCO_3^-{}_{aq}+HS^-{}_{aq}+CO_{2aq}+H_2O_{aq}$$

ACID NEUTRALIZING PROCESS

The level of acidity produced from sulphide oxidation is dependent upon the ability of the surrounding environment to neutralize acid. Carbonate bedrock such as limestone is an excellent acid neutralizer. Soils rich with carbonate minerals also have neutralizing capacities. The neutralization of acid by calcium carbonate is as follows (Steffen, Robertson and Kirsten (B.C.) Inc., 1989 p. 2-7):

$$CaCO_3+H^+ \rightarrow Ca^{2+}+HCO_3^-$$
and,
$$CaCO_3+2H^+ \rightarrow Ca^{2+}+H_2CO_3$$
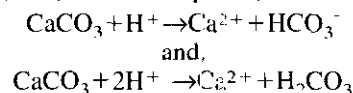
FIELD STUDY AND ANALYTICAL PROCEDURE

Acidity levels in stream drainages were measured using a Corning CheckMate™ M90 portable microprocessor-based pH, conductivity and dissolved oxygen meter. Readings were taken and recorded in the field submersing the meter directly into streams.

Samples were collected during the summer months of 1991 and 1992. Low rainfall and warmer temperatures during July and August of 1992, in comparison to the same months in 1991, resulted in a reduced volume of water in many streams. This, in some instances, may result in higher acid levels as well as elevated conductivity and total dissolved solids (TDS) in 1992. Standing water in a swamp on Mount McIntosh was measured in 1991 and 1992 (samples EC91AP-37 and EC92AP-18, Table 4-6-1). Acid levels were slightly higher in 1992 with conductivity and TDS significantly higher.

The pH sensor was calibrated on a daily basis using prepared standard solutions. Plastic 250-millilitre bottles were used to collect water samples from selected sites. Samples were preserved with nitric acid but were not filtered.

RESULTS

Natural acid levels in drainages throughout the Mount McIntosh - Pemberton Hills area range between pH 6.5 and 2.0 (Table 4-6-1). Background acidity is considered to be the acid level in waters draining relatively unmineralized areas and lake waters in some of the larger lakes, for example Nahwitti Lake. This level is about pH 5.6 (sample EC92AP-01, Table 4-6-1). Atmospheric precipitation, organic fermentation and the oxidation of ubiquitous pyrite in the underlying rocks are contributors to acid generation resulting in the lower pH background level in the study area.

A strong correlation between high acidity (low pH) in waters and sulphide-bearing rocks is recognized. Several locations within the study area contain vast amounts of sulphides reflecting this correlation (Figure 4-6-2). Youghpan Creek for example, drains fine-grained, advanced-argillic altered Bonanza rocks hosting disseminated and massive stratabound pyrite and marcasite (Panteleyev and Koyanagi, 1993, this volume). This creek system transports a relatively high volume of water and drains a large watershed. Within a stream system of this size it may be expected that acidity is diluted by the large volume of water. Contrary to this prediction, measurements within the main course of Youghpan Creek returned acid levels of pH 3.1 (sample EC92AP-27, Table 4-6-1). A tributary to

TABLE 4-6-1
WATER CHEMISTRY DATA FOR THE MOUNT McINTOSH – PEMBERTON HILLS AREA, QUATSINO MAP AREA, NORTHERN VANCOUVER ISLAND (92L/12)

Sample No.	pH	Cond µs	TDS g/ml	Temp °C	Location	SO4	Fe	Si	Ba	Ca	Cu	Pb	Zn	Al	Mg
EC91AP-16	3.9	163.2	81.8	13.1	Hushamu Creek	31	0.01	6.78	0.03	5.18	0.12	0.02	0.01	1.89	1.70
EC91AP-17	5.4			12.2	Hushamu Creek Trib.										
EC91AP-18	4.0			11.2	Hushamu Creek Trib.										
EC91AP-19	3.8	176.5	92.0	14.6	Hushamu Creek Trib.	39	0.01	8.66	0.04	4.01	0.00	0.01	0.01	1.90	2.18
EC91AP-20	4.3	120.0	61.1	13.7	Hushamu Creek	18	0.01	5.90	0.01	4.66	0.01	0.00	0.01	0.96	1.88
EC91AP-21	5.8	48.1	24.2	14.1	Hushamu Creek Trib.										
EC91AP-22	3.5	244.0	126.0	9.4	Hushamu Creek Trib.	50	0.21	8.92	0.02	0.19	0.01	0.02	0.01	6.26	1.38
EC91AP-23	4.3	141.2	70.8	15.8	Hushamu Lake	32	0.01	5.84	0.01	6.43	0.02	0.02	0.01	1.48	2.28
EC91AP-24	3.7	53.9	27.3	9.1	Hushamu Creek Trib.	228	0.55	21.49	0.01	23.31	0.32	0.05	0.04	16.49	10.90
EC91AP-25	6.2	50.5	25.3	13.0	Hushamu Creek Trib.	1	0.10	1.86	0.05	2.06	0.00	0.01	0.03	0.08	0.64
EC91AP-26	6.0	61.3	36.9	10.6	Hushamu Creek Trib.										
EC91AP-29	5.5	48.4	28.1	10.0	Hepler Creek Trib.										
EC91AP-30	4.1	100.0	50.0	11.2	Hepler Creek Trib.	18	0.01	3.67	0.01	2.98	0.07	0.01	0.01	0.82	0.93
EC91AP-31	3.9	119.4	61.7	11.7	Hepler Creek Trib.	20	0.07	3.73	0.03	3.24	0.00	0.01	0.01	1.16	1.21
EC91AP-32	5.8	133.7	67.2	8.4	Hepler Creek Trib.										
EC91AP-33	4.8	47.3	24.0	10.4	Goodspeed RiverTrib.										
EC91AP-34	5.6	40.1	19.9	17.0	Goodspeed RiverTrib.	3	0.01	1.41	0.01	1.54	0.00	0.00	0.03	0.18	0.49
EC91AP-35	4.8	15.3	7.6	10.8	Mount McIntosh	7	0.29	0.31	0.01	0.01	0.00	0.01	0.01	0.28	0.12
EC91AP-36	4.7	28.0	14.0	11.3	Mount McIntosh										
EC91AP-37	3.6	88.0	44.7	12.2	Mount McIntosh	14	0.56	0.72	0.02	0.01	0.00	0.00	0.01	1.02	0.78
EC91AP-38	3.6	111.1	55.8	9.5	Mount McIntosh										
EC91AP-39	3.3	342.0	176.0	13.1	South McIntosh										
EC91AP-40	3.2	459.0	244.0	17.7	South McIntosh										
EC91AP-41	3.5	255.0	128.0	13.9	South McIntosh										
EC91AP-42	3.9	159.2	79.2	15.0	South McIntosh	29	0.01	5.36	0.03	6.89	0.00	0.01	0.01	1.87	1.65
EC91AP-43	4.1	215.0	107.0	12.9	South McIntosh										
EC91AP-44	3.1	442.0	219.0	14.3	South McIntosh										
EC91AP-45	3.6	282.0	149.0	12.6	South McIntosh										
EC91AP-46	5.1	44.4	22.3	9.6	Hushamu Creek Trib.										
EC91AP-47	5.9	43.7	15.9	10.4	Hushamu Creek Trib.										
EC91AP-48	5.8	60.0	30.3	12.2	Hushamu Creek Trib.										
EC91AP-49	3.8	198.0	98.5	14.3	Hushamu Creek Trib.										
EC92AP-1	5.6	75.7	37.9	11.5	Goodspeed River Trib.	13	0.13	3.92	0.06	9.04	0.01	0.01	0.03	0.19	1.18
EC92AP-2	5.2	21.9	10.9	11.0	Mead Creek										
EC92AP-3	5.6	23.4	11.7	9.9	Mead Creek	10	0.41	2.19	0.05	1.83	0.00	0.01	0.04	0.52	0.23
EC92AP-4	5.7	56.4	28.1	19.6	Mead Creek										
EC92AP-5	6.0	57.3	28.2	12.2	Nahwitti River Trib.										
EC92AP-6	6.5	35.1	17.6	11.7	Mead Creek	10	0.19	2.93	0.03	4.30	0.01	0.01	0.11	0.20	0.47
EC92AP-7	5.7	38.3	19.0	19.4	Nahwitti Lake										
EC92AP-8	6.1	64.8	30.0	16.8	S. Nahwitti Lake										
EC92AP-9	6.0	65.9	32.8	12.5	S. Nahwitti Lake										
EC92AP-10	5.0	73.5	36.4	13.8	Hepler Creek	26	0.45	5.29	0.05	5.73	0.01	0.01	0.01	0.52	1.20
EC92AP-11	4.7	58.6	29.5	15.2	Hepler Creek Trib.										
EC92AP-12	5.1	55.1	27.5	14.3	Hepler Creek Trib.										
EC92AP-13	3.9	152.1	75.4	15.3	Hepler Creek Trib.	51	0.35	7.83	0.05	7.48	0.03	0.01	0.08	3.47	1.07
EC92AP-14	4.2	77.0	38.7	13.6	Hepler Creek Trib.										
EC92AP-15	4.7	51.2	25.6	19.1	Hushamu Creek Trib.	17	0.29	4.47	0.04	3.80	0.00	0.01	0.02	0.29	0.61
EC92AP-16	4.4	151.3	75.2	12.8	Mount McIntosh	54	9.20	8.49	0.10	7.59	0.02	0.01	0.02	1.59	2.83
EC92AP-17	4.5	92.4	44.9	19.6	Hushamu Lake										
EC92AP-18	3.2	259.0	128.0	23.4	Mount McIntosh	58	0.14	3.29	0.30	5.51	0.01	0.01	0.06	0.10	0.70
EC92AP-19	5.4	55.0	27.4	15.6	Clesklagh Creek	10	2.30	1.08	0.14	1.43	0.01	0.01	0.01	2.90	1.83
EC92AP-20	3.9	184.2	92.9	14.9	Clesklagh Creek	72	0.68	8.21	0.08	14.30	0.01	0.01	0.03	3.22	2.33
EC92AP-21	2.0	2400.0	1190.0	28.9	South McIntosh	1300	88.80	36.60	0.06	165.00	0.15	0.11	0.65	45.70	9.62
EC92AP-22	4.3	157.0	78.5	14.0	South McIntosh										
EC92AP-23	5.3	71.1	35.5	12.0	South McIntosh										
EC92AP-24	3.5	219.0	105.0	12.7	South McIntosh	67	0.29	5.37	0.10	14.00	0.01	0.01	0.02	1.74	1.96
EC92AP-25	3.4	197.0	97.8	12.9	South McIntosh										
EC92AP-26	4.8	53.1	25.4	13.7	Hushamu Creek Trib.	12	2.98	3.50	0.05	4.45	0.00	0.01	0.01	0.61	0.94
EC92AP-27	3.1	252.0	124.0	12.4	Youghpan Creek	72	2.23	6.94	0.09	11.70	0.01	0.01	0.02	3.54	1.28
EC92AP-28	2.9	311.0	157.0	15.4	Youghpan Creek Trib.	113	5.60	11.30	0.12	14.70	0.01	0.01	0.03	3.95	2.72
EC92AP-29	3.4	347.0	175.0	11.5	Youghpan Creek Trib.										
EC92AP-30	5.3	89.9	28.3	12.6	N. Youghpan Creek	17	0.17	2.93	0.06	2.96	0.00	0.01	0.01	0.27	0.73
EC92AP-31	4.4	117.5	57.5	15.4	N. Youghpan Creek										
EC92AP-32	5.0	50.0	25.1	11.2	N. Youghpan Creek										
EC92AP-33	4.2	165.7	82.8	14.9	Mouth Youghpan Creek	69	0.89	8.38	0.09	17.90	0.01	0.01	0.02	1.71	1.91
EC92AP-50	5.1	40.4	20.3	13.3	Youghpan Creek Trib.										
EC92AP-51	3.9	77.2	38.5	17.7	Youghpan Creek Trib.										
EC92AP-52	4.0	90.7	43.1	14.8	Youghpan Creek Trib.	18	1.21	5.16	0.10	2.81	0.01	0.06	0.01	0.68	0.94
EC92AP-53	5.7	77.7	38.7	19.1	Youghpan Creek Trib.										
EC92AP-54	6.1	348.0	174.0	19.4	Youghpan Creek Trib.										
EC92AP-55	3.4	240.0	119.0	16.7	Youghpan Creek Trib.	60	2.25	6.98	0.09	5.45	0.01	0.01	0.03	2.35	1.69
EC92AP-56	5.4	82.9	42.0	16.1	Youghpan Creek Trib.										
EC92AP-57	3.7	330.0	171.0	18.8	Youghpan Creek Trib.										
EC92AP-58	3.5	264.0	131.0	16.1	Youghpan Creek Trib.	84	2.73	7.83	0.11	13.90	0.01	0.02	0.03	3.87	1.80
EC92AP-59	3.5	260.0	130.0	16.5	Youghpan Creek Trib.										
EC92AP-60	5.4	145.7	70.2	17.7	Youghpan Creek Trib.	49	1.12	6.68	0.05	16.40	0.01	0.01	0.01	0.40	1.48
EC92AP-61	5.5	774.0	385.0	25.3	Youghpan Creek Trib.										
VICT.RAIN	4.1	188.8	92.8	24.5	Victoria Rain										

TABLE 4-6-2

PEARSON CORRELATION MATRIX FOR ELEMENT PAIRS, pH, CONDUCTIVITY (COND) AND TOTAL DISSOLVED SOLIDS (TDS)

	Al	Ba	Ca	COND	Cu	Fe	Mg	Pb	pH	Si	SO4	TDS	Zn
Al	1.000												
Ba	-0.100	1.000											
Ca	0.562	0.176	1.000										
COND	0.181	0.494	0.402	1.000									
Cu	0.822	-0.192	0.477	-0.108	1.000								
Fe	0.084	0.315	0.212	0.290	-0.061	1.000							
Mg	0.905	0.089	0.662	0.077	0.872	0.154	1.000						
Pb	0.536	0.024	0.265	-0.029	0.569	0.001	0.526	1.000					
pH	-0.403	-0.293	-0.322	-0.777	-0.187	-0.181	-0.301	-0.203	1.000				
Si	0.854	-0.031	0.750	0.397	0.716	0.235	0.869	0.511	-0.492	1.000			
SO4	0.880	0.168	0.817	0.431	0.725	0.236	0.876	0.457	-0.540	0.916	1.000		
TDS	0.195	0.476	0.395	0.997	-0.101	0.289	0.086	-0.030	-0.785	0.409	0.433	.000	
Zn	0.093	0.221	0.130	-0.018	0.101	-0.053	0.019	-0.027	0.203	0.076	0.156	-.013	1.000

Level of significance (95th percentile)=0.306 calculated for N=30

Youghpan Creek transports a lower volume of water and returns a pH value of 2.9 (sample EC92AP-28, Table 4-6-1). These low pH levels indicate the presence of an extensive amount of sulphide minerals that are being leached into the drainage system. Sample EC92AP-33 (Table 4-6-1) is located near the mouth of Youghpan Creek, 3 to 4 kilometres downstream from the sample sites mentioned above. A pH level of 4.2 indicates dilution, but continues to reflect a large source of acid upstream.

Clesklagh Creek drainages include streams flowing from the South McIntosh area where abundant silicified and advanced-argillic altered Bonanza flows and tuffaceous volcanics strongly mineralized with disseminated pyrite are present. A sample of standing water in a ditch at the base of a sulphide-bearing, argillic-altered and strongly weathered outcrop (sample EC92AP-21, Table 4-6-1) returned a pH value of 2.0. Creeks draining the South McIntosh area average pH levels of 3.3. Upstream from South McIntosh, a southeasterly trending tributary of Clesklagh Creek drains unmineralized and unaltered Bonanza volcanics. Measurements in this tributary returned pH values of 5.4 (sample EC92AP-19, Table 4-6-1) indicating acid contributions limited to background levels. Downstream, below South McIntosh, Clesklagh Creek holds acid concentrations of pH 3.9 (Sample EC92AP-20, Table 4-6-1). The slight dilution of acidity at this location is a result of mixing waters from mineralized and unmineralized sources. These results indicate that the source of acid in the Clesklagh drainage is the altered and mineralized rocks of the South McIntosh area.

A tributary on the west side of Hepler Creek returned acid levels of pH 3.9 (sample EC92AP-13, Table 4-6-1). The sample site is flanked by propylitically altered Bonanza volcanics containing disseminated and massive pyrite in a porphyry copper setting. Acid here is being visibly generated by oxidizing iron sulphides adjacent to the stream.

Acidity of waters draining Parson Bay and Quatsino calcareous sediments (samples EC92AP-05 to EC92AP-09, Table 4-6-1) average well above pH 6.0. The Parson Bay Formation is locally mineralized with bedding-replacement iron sulphides, and Quatsino limestones are skarn altered

and mineralized. Acid is most likely generated from these sulphide-bearing rocks but the presence of the carbonate bedrock neutralizes this added acidity. The presence of carbonate strata produces pH levels generally well above the defined regional background levels.

WATER CHEMISTRY

Under natural weathering conditions, in which acid neutralization does not take place, there is a correlation between acidity and sulphide dissolution. Sulphate content can be correlated to levels of sulphide dissolution under neutralizing or non-neutralizing conditions. Sulphate minerals within acid-sulphate alteration zones (such as alunite, melanterite and gypsum) contribute some sulphate to the drainages. However, their insolubility and relative spaiseness compared to pyrite suggests that their significance is negligible in comparison to contributions from pyrite oxidation. Water sample analyses in the study area show sulphate levels varying between 1 and 1300 ppm (Table 4-6-). The sulphate levels show a strong positive correlation with acidity (Table 4-6-2). This correlation indicates that acid-producing sulphide oxidation takes place in a non-neutralizing environment. A low-acidity (high pH) high-sulphate relationship would indicate sulphide-generated acid in a neutralizing or diluted environment. Conversely, a high-acid (low pH) low-sulphate relationship reflects acid generation originating from a non-sulphide source of possibly organic origins. A Pearson correlation matrix (Table 4-6-2) illustrates correlations between pH and sulphate as well as other correlation data.

CONCLUSIONS

Natural acid is generated in surface waters in the Mount McIntosh - Pemberton Hills area. Clear-cut logging and road building indirectly increase acid generation by increasing the amount of fresh rock exposed to weathering. The primary source of acidity is the oxidation of the abundant iron sulphides contained within advanced-argillic acid-sulphate altered rocks as well as nearby porphyry copper

and skarn-mineralized rocks. Measurements of acidity in conjunction with sulphate levels can be used to locate sulphide-rich rocks that may contain ore deposits.

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