NATURAL ACIDIC DRAINAGE IN NORTHERN VANCOUVER ISLAND - ITS PLACE IN GEOENVIRONMENTAL ORE DEPOSIT MODELS

By A. Panteleyev, S.J. Sibbick and V.M. Koyanagi

KEYWORDS: acid rock drainage, pH, dissolved metals, northern Vancouver Island, geoenvironmental ore deposit models, acidic water geochemistry, advanced argillic alteration.

INTRODUCTION

During the course of mineral deposits studies in Northern Vancouver Island (Figure 1) as part of an integrated project (Panteleyev *et al.*, 1994), stream waters emanating from, and flowing through, large areas of pyritic rocks were found to be strongly acidic (commonly <4 pH). The bedrock sources for the acidic waters are hydrothermally altered and mineralized Bonanza volcanic rocks and some Island intrusions containing porphyry copper mineralization and large zones of advanced argillic alteration.

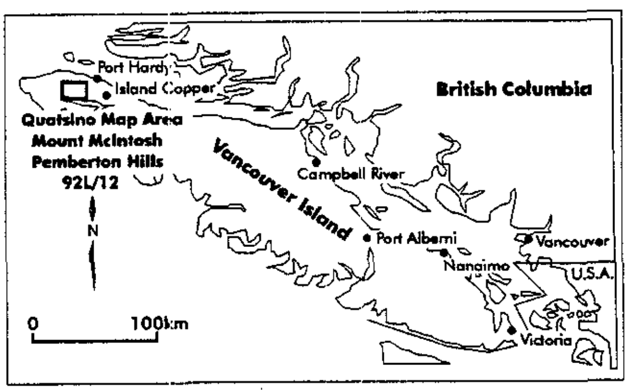

Figure 1. Location of water sampling in Quatsino map area (NTS 92L/12).

GEOLOGICAL SETTING AND MINERALIZATION

The regional geological setting of the Quatsino Sound area is described by Nixon *et al.* (1994) and Hammack *et al.* (1994). The style of mineralization and alteration 15 to 40 kilometres to the west of Island Copper mine, mainly in the Bonanza volcanic rocks and to a lesser extent in the Island intrusions, is discussed by Panteleyev and Koyanagi (1993, 1994). Ages of hostrocks, hydrothermal systems and alteration minerals are summarized by Archibald and Nixon (1995) and Panteleyev *et al.* (1995).

The principal mineral deposits in the study area are the intrusion-related, pyrite-rich Hushamu and Red Dog porphyry copper deposits. A number of related, smaller pyritic zones are also present, for example the Hep deposit. The Hushamu deposit has an overprint of advanced argillic alteration that is expressed as the siliceous "capping" on Mount McIntosh. The alteration (quartz-pyrophyllite-kaolinite-alunite-zunyite-diaspore) is superimposed, together with vuggy quartz, and weakly developed, high-sulphidation epithermal mineralization, on the deeper, underlying Hushamu porphyry copper deposit. The advanced argillic overprinting occurred when the late hydrothermal system collapsed onto the deeper copper-bearing, predominantly quartz-sericite/illite-pyrite and quartz-amphibole-magnetite-chlorite alteration zones. Both the upper Mount McIntosh and the underlying Hushamu zones are cut by younger, siliceous hydrothermal breccias. The weakly developed epithermal mineralization that accompanies the advanced argillic and vuggy quartz alteration contains abundant pyrite with minor enargite, chalcopyrite, covellite and chalcocite (Panteleyev and Koyanagi, 1994; Dasler *et al.*, 1995).

There is widespread advanced argillic alteration to the east of the Hushamu deposit throughout the Pemberton Hills over a distance of about 11 kilometres, and in the western part of the study area at the Red Dog deposit and the nearby Northwest Expo claim area It is evident as pyritic quartz-kaolinite-alunite alteration in the rhyolitic Bonanaza map units. Centres of most intense alteration seem to be associated with rhyolite dome emplacement, associated vent deposits and hydrothermal breccia bodies. In addition to abundant pyrite, quartz-alunite is widespread and there is rare enargite, covellite and chalcocite; native sulphur is locally abundant. The strongly altered, siliceous, aluminous rocks have been hydrothermally acid leached. They lack buffering (acid neutralizing) capacity and weathering of the highly pyritic rocks gives rise to extensive zones of near-surface, secondary (supergene) acid-leached limonitic rocks.

GEOCHEMICAL WATER SAMPLING

Starting in 1991, and continuing in 1992 and 1993, stream and various standing waters were measured directly in the field for pH, conductivity and total dissolved solids (TDS) at 248 sites, using a Corning Checkmate™ M90 portable microprocessor. Preliminary results are summarized by Koyanagi and Panteleyev (1993, 1994). Water geochemical samples were taken

TABLE 1: WATER CHEMISTRY - MOUNT McINTOSH/PEMBERTON HILLS AREA, NORTHERN VANCOUVER ISLAND, IN ppm

Sample No.	pH	Cond µs	TDS g/ml	UTM Zone 10 Easting	UTM Zone 10 Northing	Location	SO4	Fe	Si	Al	Mg	Ca	Mn	Cu	Pb	Zn	Ba	Co	Ni	As
1991 samples																				
EC91AP-16	3.9	163	82	583092	5609526	Hushamu Creek	31	0.01	6.8	1.9	1.7	5.2	0.11	0.01	0.02	0.01	0.03	<0.01	<0.01	0.05
EC91AP-19	3.8	177	92	583209	5611889	Hushamu Ck. tributary	39	0.01	8.7	1.9	2.2	4.0	0.12	0.00	0.01	0.01	0.04	<0.01	<0.01	0.03
EC91AP-20	4.3	120	61	582996	5612577	Hushamu Creek	18	0.01	5.9	1.0	1.9	4.7	0.07	0.01	0.00	0.01	0.01	<0.01	<0.01	0.01
EC91AP-22	3.5	244	126	581785	5613442	Hushamu Ck. tributary	50	0.21	8.9	6.3	1.4	0.2	0.30	0.01	0.02	0.01	0.02	0.01	<0.01	0.06
EC91AP-23	4.3	141	71	581451	5613942	Hushamu Lake	32	0.01	5.8	1.5	2.3	6.4	0.10	0.02	0.02	0.01	0.01	0.01	<0.01	0.03
EC91AP-24	3.7	54	27	581488	5614083	Hushamu Ck. tributary	228	0.55	21.5	16.5	10.9	23.3	0.47	0.32	0.05	0.04	0.01	0.04	0.04	0.09
EC91AP-25	6.2	51	25	582901	5609635	Hushamu Ck. tributary	1	0.10	1.9	0.1	0.6	2.1	0.01	0.00	0.01	0.03	0.05	<0.01	<0.01	0.02
EC91AP-30	4.1	100	50	579683	5614349	Hepler Ck. tributary	18	0.01	3.7	0.8	0.9	3.0	0.30	0.07	0.01	0.01	0.01	<0.01	<0.01	0.04
EC91AP-31	3.9	119	62	579689	5614255	Hepler Ck. tributary	20	0.07	3.7	1.2	1.2	3.2	0.06	0.00	0.01	0.01	0.03	<0.01	<0.01	0.04
EC91AP-34	5.6	40	20	578313	5612787	Goodspeed R. tributary	3	0.01	1.4	0.2	0.5	1.5	0.01	0.00	0.00	0.03	0.01	<0.01	0.01	0.01
EC91AP-35	4.8	15	8	580888	5613535	Mount McIntosh	7	0.29	0.3	0.3	0.1	0.0	0.01	0.00	0.01	0.01	0.01	<0.01	<0.01	0.01
EC91AP-37	3.6	88	45	580956	5612541	Mount McIntosh	14	0.56	0.7	1.0	0.8	0.0	0.01	0.00	0.00	0.01	0.02	<0.01	<0.01	0.01
EC91AP-42	3.9	159	79	581612	5610201	South McIntosh	29	0.01	5.4	1.9	1.7	6.9	0.25	0.00	0.01	0.01	0.03	<0.01	<0.01	0.01
1992 samples																				
EC92AP-1	5.6	76	38	577726	5611934	Goodspeed R. tributary	13	0.13	3.9	0.2	1.2	9.0	<0.01	0.01	0.01	0.03	0.06	<0.01	<0.01	<0.01
EC92AP-3	5.6	23	12	583032	5615140	Mead Creek	10	0.41	2.2	0.5	0.2	1.8	<0.01	0.00	0.01	0.04	0.05	<0.01	<0.01	<0.01
EC92AP-6	6.5	35	18	584095	5616670	Mead Creek	10	0.19	2.9	0.2	0.5	4.3	<0.01	0.01	0.01	0.11	0.03	<0.01	<0.01	<0.01
EC92AP-10	5.0	74	36	579235	5617182	Hepler Creek	26	0.45	5.3	0.5	1.2	5.7	0.04	0.01	0.01	0.01	0.05	<0.01	<0.01	<0.01
EC92AP-13	3.9	152	75	578378	5615969	Hepler Ck. tributary	51	0.35	7.8	3.5	1.1	7.5	0.02	0.03	0.01	0.08	0.05	<0.01	<0.01	0.02
EC92AP-15	4.7	51	26	583015	5612783	Hushamu Ck. tributary	17	0.29	4.5	0.3	0.6	3.8	0.02	0.00	0.01	0.02	0.04	<0.01	<0.01	<0.01
EC92AP-16	4.4	151	75	582246	5613217	Mount McIntosh	54	9.20	8.5	1.6	2.8	7.6	0.07	0.02	0.01	0.02	0.10	<0.01	<0.01	<0.01
EC92AP-18	3.2	259	128	580958	5612530	Mount McIntosh	58	0.14	3.3	0.1	0.7	5.5	0.02	0.01	0.01	0.06	0.30	<0.01	<0.01	0.02
EC92AP-19	5.4	55	27	579806	5611551	Cleskiagh Creek	10	2.30	1.1	2.9	1.8	1.4	<0.01	0.01	0.01	0.01	0.14	<0.01	<0.01	<0.01
EC92AP-20	3.9	184	93	580697	5609698	Cleskiagh Creek	72	0.68	8.2	3.2	2.3	14.3	0.39	0.01	0.01	0.03	0.08	<0.01	<0.01	0.02
EC92AP-21	2.0	2400	1190	580439	5611893	South McIntosh ditch	1300	88.80	36.6	45.7	9.6	165.0	10.00	0.15	0.11	0.65	0.06	0.15	0.03	0.3
EC92AP-24	3.6	219	105	582100	5610975	South McIntosh	67	0.29	5.4	1.7	2.0	14.0	0.79	0.01	0.01	0.02	0.10	<0.01	<0.01	<0.01
EC92AP-26	4.8	53	25	584759	5608931	Hushamu Ck. tributary	12	2.98	3.5	0.6	0.9	4.5	0.08	0.00	0.01	0.01	0.05	<0.01	<0.01	<0.01
EC92AP-27	3.1	252	124	585996	5609231	Youghpan Creek	72	2.23	6.9	3.5	1.3	11.7	0.18	0.01	0.01	0.02	0.09	<0.01	<0.01	0.01
EC92AP-28	2.9	311	157	585514	5609187	Youghpan Ck. tributary	113	5.60	11.3	4.0	2.7	14.7	0.44	0.01	0.01	0.03	0.12	<0.01	<0.01	0.02
EC92AP-30	5.3	90	28	585853	5611835	N. Youghpan Creek	17	0.17	2.9	0.3	0.7	3.0	0.06	0.00	0.01	0.01	0.06	<0.01	<0.01	<0.01
EC92AP-33	4.2	166	83	582226	5606791	Mouth Youghpan Creek	69	0.89	8.4	1.7	1.9	17.9	0.26	0.01	0.01	0.02	0.09	<0.01	<0.01	0.03
EC92AP-52	4.0	91	43	586391	5608915	Youghpan Ck. tributary	18	1.21	5.2	0.7	0.9	2.8	0.07	0.01	0.06	0.01	0.10	<0.01	<0.01	<0.01
EC92AP-55	3.4	240	119	586954	5608357	Youghpan Ck. tributary	60	2.25	7.0	2.4	1.7	5.5	0.14	0.01	0.01	0.03	0.09	<0.01	<0.01	0.02
EC92AP-58	3.5	264	131	587799	5608199	Youghpan Ck. tributary	84	2.73	7.8	3.9	1.8	13.9	0.16	0.01	0.02	0.03	0.11	<0.01	<0.01	0.04
EC92AP-60	5.4	146	70	588699	5607854	Youghpan Ck. tributary	49	1.12	6.7	0.4	1.5	16.4	0.13	0.01	0.01	0.01	0.05	<0.01	<0.01	<0.01
1993 samples																				
S493VK-01	3.6	206	102	572115	5618055	Red Dog	62	0.24	9.0	3.2	3.4	5.4	0.28	0.38	0.01	0.02	0.05	<0.01	<0.01	0.02
S493VK-02	5.4	76	38	571641	5618113	Red Dog	23	0.39	6.6	0.1	1.9	7.8	0.01	0.01	0.00	0.00	0.04	<0.01	<0.01	<0.01
S493VK-03	5.2	88	43	571690	5617375	Red Dog	23	0.49	13.2	5.4	3.8	28.7	0.49	0.02	0.02	0.04	0.08	0.01	<0.01	0.03
S493VK-04	3.2	471	240	580731	5611275	Cleskiagh Ck. tributary	150	1.30	6.2	0.5	1.7	7.2	0.04	0.09	0.01	0.00	0.01	<0.01	<0.01	<0.01
S493VK-05	4.1	230	120	580630	5609747	Cleskiagh Creek	70	0.52	8.6	2.9	2.4	14.6	0.36	0.01	0.02	0.02	0.04	<0.01	<0.01	0.02
S493VK-06	3.4	158	80	583092	5609526	Hushamu Creek	51	0.46	8.7	2.0	2.2	7.9	0.12	0.02	0.03	0.02	<0.01	<0.01	<0.01	<0.01
S493VK-07	3.8	436	219	582069	5610698	South McIntosh	149	0.21	14.2	5.7	4.2	32.2	0.72	0.01	0.03	0.03	0.09	0.01	<0.01	0.06
S493VK-08	5.5	73	35	579603	5614379	Hepler Ck. swamp	76	1.58	5.1	0.4	1.2	4.9	0.02	0.02	0.02	0.00	0.03	<0.01	<0.01	<0.01
S493VK-09	3.8	190	96	579235	5617182	Hepler Creek, S. fork	58	1.44	8.0	1.8	2.5	11.0	0.14	0.01	0.03	0.01	0.04	<0.01	<0.01	<0.01
S493VK-10	2.9	1017	527	58007	5614325	Hushamu deposit ditch	338	2.40	14.8	20.1	9.3	36.1	0.43	1.37	0.08	0.16	<0.01	0.04	0.01	0.12
S493VK-11	4.3	137	70	582034	5613403	Hushamu Ck. headwater	51	1.35	6.9	1.3	2.9	8.1	0.09	0.03	0.03	0.02	<0.01	<0.01	<0.01	<0.01
S493VK-12	5.2	58	29	582993	5612749	Hushamu Creek	14	0.38	4.4	0.3	1.0	3.7	0.09	0.01	0.01	0.01	0.02	<0.01	<0.01	<0.01
S493VK-13	3.7	181	90	583227	5611897	Hushamu Ck. tributary	58	1.48	11.0	2.1	2.9	7.0	0.16	0.01	0.03	0.01	0.02	<0.01	<0.01	<0.01

TABLE 2: WATER CHEMISTRY - MOUNT McINTOSH/PEMBERTON HILLS AREA, NORTHERN VANCOUVER ISLAND, IN ppm

Sample No.	pH	Cond µs	TDS g/ml	UTM Zone 10 Easting	UTM Zone 10 Northing	Location	SO4	Fe	Si	Al	Mg	Ca	Mn	Cu	Pb	Zn	Ba	Co	Ni	As
1993 samples (continued)																				
S493VK-14	3.9	215	88	581533	5610239	Clesklagh Ck. tributary	61	0.47	6.8	1.8	2.9	10.4	0.28	0.02	0.05	0.01	0.19	0.01	<0.01	0.01
S493VK-15	5.9	65	32	585572	5611986	top H600 Road	17	4.03	3.0	0.3	1.2	3.3	0.57	0.00	0.01	0.00	0.04	0.01	<0.01	<0.01
S493VK-16	5.4	56	28	585896	5611834	top H600 Road	12	0.15	3.7	0.2	1.0	2.7	0.08	0.01	0.02	0.00	0.05	<0.01	<0.01	<0.01
S493VK-17	3.5	408	203	585155	5609947	Youghpan Creek, head	138	1.21	15.0	5.9	4.5	20.1	0.51	0.02	0.06	0.05	0.03	0.02	<0.01	0.04
S493VK-18	3.3	449	232	585523	5609163	Youghpan Creek	126	2.53	10.6	3.9	3.4	13.9	0.42	0.02	0.06	0.04	<0.01	0.02	<0.01	<0.01
S493VK-19	3.7	250	130	586195	5609062	Youghpan Creek	65	2.04	6.4	3.2	1.8	10.8	0.17	0.02	0.04	0.02	<0.01	0.01	<0.01	<0.01
S493VK-20	4.2	176	88	582226	5606791	Youghpan Ck. at Main	65	0.41	5.6	1.5	1.8	13.0	0.19	0.01	0.03	0.01	<0.01	<0.01	<0.01	<0.01
S493VK-21	6.4	189	95	593651	5606900	Wakalish Ck. mouth	18	0.01	2.9	0.1	2.8	4.7	0.01	0.01	0.02	0.00	0.02	<0.01	<0.01	<0.01
1995 samples																				
EC95-01	6.2			591015	5606839	Wanokana R. at Main	11	0.39	3.3	0.1	0.7	3.5	0.01	0.01	0.00	0.00	<0.01	<0.01	<0.01	<0.01
EC95-02	4.5			582226	5606791	Youghpan Ck. at Main	56	0.52	6.3	1.1	1.5	13.6	0.15	0.01	0.02	0.01	0.05	0.01	<0.01	<0.01
EC95-03	6.3			584949	5608906	H600 Road, at Main	9	0.99	3.8	<.0.1	1.0	6.0	0.04	0.01	0.03	0.10	0.01	<0.01	<0.01	<0.01
EC95-04	4.2			583092	5609526	Hushamu Ck. at Main	43	0.75	7.4	1.0	1.7	7.1	0.09	0.02	0.06	0.02	0.03	0.01	<0.01	<0.01
EC95-05	3.7			582069	5610698	H1000 Road, S. McIntosh	100	4.00	14.1	4.6	4.2	17.6	0.43	0.01	0.31	0.03	0.04	0.01	0.01	<0.01
EC95-06	4.5			581427	5610561	Clesklagh Ck. tributary	61	0.54	8.1	1.2	2.3	14.6	0.25	0.01	0.00	0.01	0.04	<0.01	<0.01	<0.01
EC95-07	3.8			580731	5611275	Clesklagh Ck at CL130	110	4.14	11.9	3.2	3.5	29.6	0.39	0.02	0.21	0.03	0.04	0.01	<0.01	<0.01
EC95-08	4.2			579235	5617182	Hepler Creek	54	1.61	7.4	1.1	2.0	9.9	0.11	0.01	0.10	0.01	<0.01	<0.01	<0.01	<0.01
EC95-09	4.7			581451	5613942	Hushamu Lake	49	0.44	8.8	1.7	3.0	10.4	0.11	0.05	0.01	0.04	0.01	0.01	<0.01	<0.01
EC95-10	4.6			582996	5612577	Hushamu Ck. headwater	38	0.80	7.1	0.7	2.1	7.1	0.06	0.02	0.00	0.02	0.04	<0.01	<0.01	<0.01

1995 samples were filtered and acidified; 1992 and 1993 samples were acidified but not filtered; 1991 samples were untreated.

Analytical method: ICP. Laboratory: 1991 - MinEn; 1992, 1993 - Eco-Tech; 1995 - CanTech. ICP data for other elements are available, upon request, from the senior author.

TABLE 3: REPLICATE WATER SAMPLES, NORTHERN VANCOUVER ISLAND, IN ppm

Sample No.	pH	Cond µs	TDS g/ml	UTM Zone 10 Easting	UTM Zone 10 Northing	Location	SO4	Fe	Si	Al	Mg	Ca	Mn	Cu	Pb	Zn	Ba	Co	Ni	As
EC95-02	4.5			582226	5606791	Youghpan Ck. at Main	56	0.52	6.3	1.1	1.5	13.6	0.15	0.01	0.10	0.01	0.05	0.01	<0.01	<0.01
EC92AP-33	4.2	166	83	582226	5606791	Mouth Youghpan Creek	69	0.89	8.4	1.7	1.9	17.9	0.26	0.01	0.01	0.02	0.09	<0.01	<0.01	0.03
S493VK-20	4.2	176	88	582226	5606791	Youghpan Ck. at Main	65	0.41	5.6	1.5	1.8	13.0	0.19	0.01	0.03	0.01	<0.01	<0.01	<0.01	<0.01
EC95-04	4.2			583092	5609526	Hushamu Ck. at Main	43	0.75	7.4	1.0	1.7	7.1	0.09	0.02	0.14	0.02	0.03	0.01	<0.01	<0.01
EC91AP-16	3.9	163	82	583092	5609526	Hushamu Creek	31	0.01	6.8	1.9	1.7	5.2	0.11	0.01	0.02	0.01	0.03	<0.01	<0.01	0.05
S493VK-06	3.4	158	80	583092	5609526	Hushamu Creek	51	0.46	8.7	2.0	2.2	7.9	0.12	0.02	0.03	0.02	<0.01	<0.01	<0.01	<0.01
EC95-05	3.7			582069	5610698	H1000 Road, S. McIntosh	100	4.00	14.1	4.6	4.2	17.6	0.43	0.01	0.39	0.03	0.04	0.01	<0.01	<0.01
S493VK-07	3.8	436	219	582069	5610698	South McIntosh	149	0.21	14.2	5.7	4.2	32.2	0.72	0.01	0.03	0.03	0.09	0.01	<0.01	0.06
EC95-08	4.2			579235	5617182	Hepler Creek	54	1.61	7.4	1.1	2.0	9.9	0.11	0.01	0.18	0.01	<0.01	<0.01	<0.01	<0.01
S493VK-09	3.8	190	96	579235	5617182	Hepler Creek, S. fork	58	1.44	8.0	1.8	2.5	11.0	0.14	0.01	0.03	0.01	0.04	<0.01	<0.01	<0.01
EC95-09	4.7			581451	5613942	Hushamu Lake	49	0.44	8.8	1.7	3.0	10.4	0.11	0.05	0.08	0.04	0.01	0.01	<0.01	<0.01
EC91AP-23	4.3	141	71	581451	5613942	Hushamu Lake	32	0.01	5.8	1.5	2.3	6.4	0.10	0.02	0.02	0.01	0.01	0.01	<0.01	0.03
EC95-10	4.6			582996	5612577	Hushamu Ck. headwater	38	0.80	7.1	0.7	2.1	7.1	0.06	0.02	0.06	0.02	0.04	<0.01	<0.01	<0.01
EC91AP-20	4.3	120	61	582996	5612577	Hushamu Creek	18	0.01	5.9	1.0	1.9	4.7	0.07	0.01	0.00	0.01	0.01	<0.01	<0.01	0.01

1995 samples were filtered and acidified; 1993 and 1992 samples were acidified but not filtered; 1991 samples were untreated.

Analytical method: ICP. Laboratory: 1991 - MinEn; 1992, 1993, 1994 - Echo-Tech. ICP data for other elements are available, upon request, from the senior author.

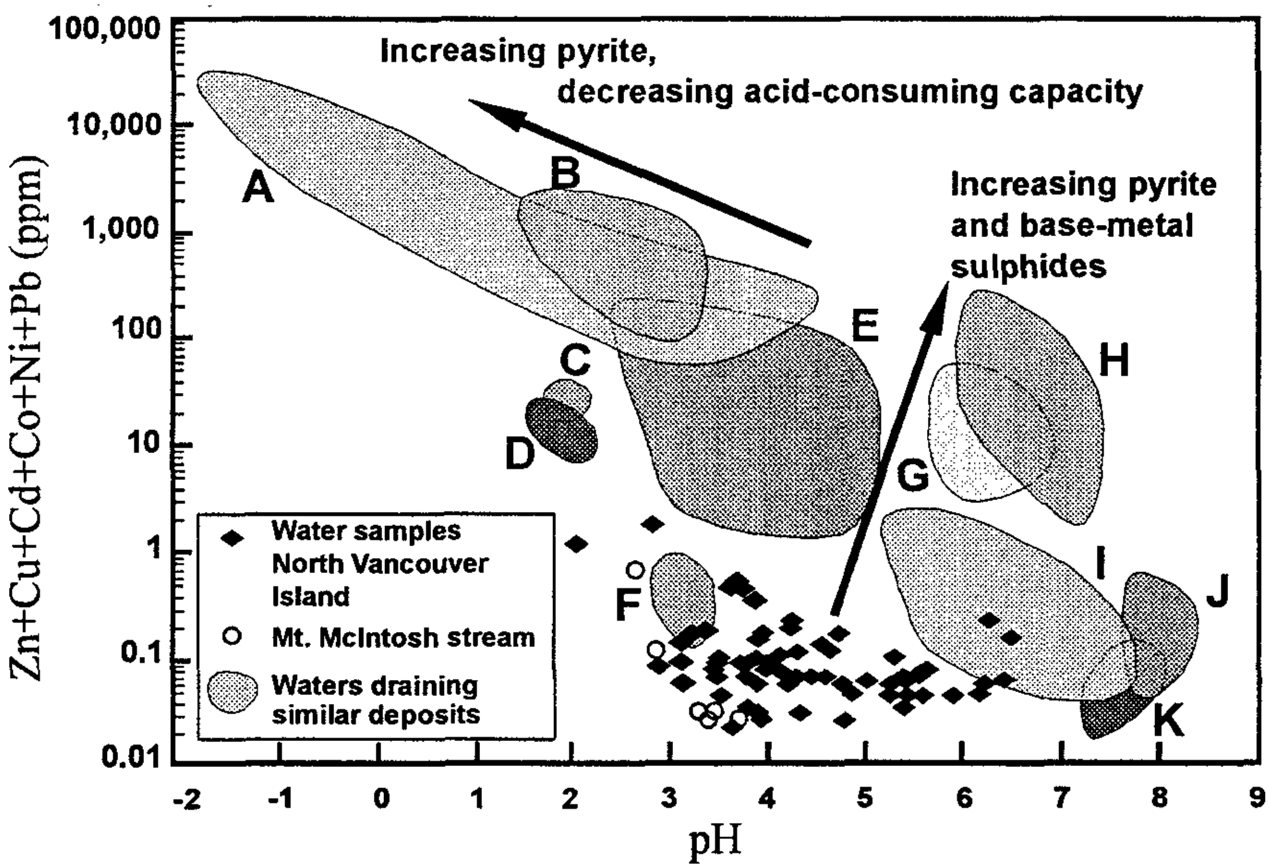

Figure 2. 'Ficklin' diagram of pH and dissolved base metal contents of waters draining diverse mine and mineral deposit types, from Plumlee *et al.* (1994). Fields are: **A** - pyrite-rich massive sulphides; **B** - sulphide-rich ores in silica-alunite-kaolinite-clay altered rocks (advanced argillic alteration); **C** - high-sulphide, low- base metal hotspring ores in acid-altered wallrocks; **D** - high-sulphide, low-base metal porphyry Mo ores in igneous wallrocks; **E** - pyrite and base metal-rich polymetallic veins and disseminations in wallrocks with low acid-buffering capability; **F** - pyrite-rich, base metal-poor veins and disseminations in wallrocks with low acid-buffering capacity; **G** - pyrite and base metal-rich polymetallic veins with carbonate gangue or carbonate-altered wallrocks; **H** - pyrite and base metal-rich, polymetallic replacements and veins in carbonate-rich sediments; **I** - polymetallic veins with moderate to low pyrite and base metal content with carbonate gangue and/or carbonate wallrock alteration; **J** - pyrite-poor polymetallic replacements in carbonate-rich sediments; **K** - pyrite-poor, Au-Te veins and breccias with carbonate gangue.

from 55 of the sites and analyzed for their SO_4 and metal contents. Two water samples were submitted; one for SO_4 and the other, acidified with nitric acid, for dissolved metals. In 1995, ten additional water samples were taken for analysis and the pH measured *in situ* using a Cole Parmer model 5941-00 pocket digital pH meter. All the geochemical analytical results are summarized in Tables 1 and 2.

Water samples taken in 1991 were neither acidified nor filtered. Replicate sampling of some sites in subsequent years with acidified samples shows no appreciable differences between the acidified and non-acidified samples for most metals. However the unacidified waters do appear to have lower iron contents and inconsistent lead values compared to acidified samples taken in later years. The 1995 sample suite provided both acidified and filtered samples and used acid-washed, ultra-clean sample bottles. For most metals there is no evident difference between metal content of these most recent, filtered samples and the earlier unfiltered ones. All waters analyzed contain very little dissolved ore metals though iron, and other metals derived from silicate mineral breakdown such as aluminum, calcium and magnesium, are present in abundance. Results of replicated sampling are given in Table 3.

GEOENVIRONMENTAL ORE DEPOSIT MODEL

Geochemical classification and description of metal distributions within, and in waters derived from, various mineralized environments and ore deposits is currently being undertaken and is referred to as 'geoenvironmental' mineral deposit modeling. The work of the United States Geological Survey, by Ficklin *et al.* (1992) and Plumlee *et al.* (1992, 1994), among others, has documented and classified a large number of mine and natural drainages derived and evolved from various mineralized settings. The information is presented graphically in what has been referred to as a 'Ficklin' plot (Figure 2).

The data from the measured and analyzed natural drainages in this study on Vancouver Island are illustrated on Figure 2. Numerous samples have low pH (pH 2 to 4), elevated iron, magnesium, manganese and aluminum, but low levels of copper and zinc (tens to hundreds of ppb) compared to mine drainages. The waters all display low levels of metal loading, rarely greater than 3 ppm combined Zn+Cu+Cd+Co+Ni+Pb.

The effects of dilution are described by Sibbick and Laurus (1995). Their detailed follow-up work in a stream undisturbed by logging in the the Mount McIntosh area, shows that stream acidity and dissolved metals have their sources, and are most concentrated, in the strongly altered rocks from which the streams emanate or pass over. Downstream from the source areas, metal concentrations and acidity decrease due to dilution by tributary streams. Their results are shown on Figure 2 as open circles. The most acidic samples are at the source of the stream in the altered and mineralized rocks; the other circles are sample sites at 100 to 200-metre intervals downstream, where progressively greater dilution effects are evident over the measured distance of 800 metres.

CONCLUSIONS

The main factors determining the pH and metal contents of drainages are, according to Plumlee *et al.* (1992): the acid-buffering capacity of the gangue minerals and hostrocks in which the mineralization occurs; the types and abundances of metal-bearing sulphide minerals present; the availability of sulphides for weathering; and the availability of dissolved oxygen during sulphide weathering and drainage generation. Geologic factors influencing the stream geochemistry are: deposit size, hostrock composition, wallrock alteration, surrounding geological and surficial terrains, nature of ore, trace element geochemistry, ore and gangue mineralogy and zonation, mineral characteristics, secondary mineralogy, topography and physiography, hydrology and degree of surface disruption or exploitation.

The natural acidity in the northern Vancouver Island study area is due to the abundance of pyrite in the extensive zones of advanced argillic alteration and the locally underlying porphyry copper mineralization. There is a lack of neutralizing capability in the hydrothermally altered, rhyolitic Bonanza volcanic rocks, and their related granitic bodies. Pyrite, mainly as fine-grained disseminations and fracture fillings, is abundant but little ore metal is present in the acidic leaching solutions, due to an apparent lack of ore minerals in the near-surface (weathering) environment.

In the generally wet coastal climate, rainwater with pH of about 5.6, and the augmentation of streams by surface, groundwater and tributary stream additions, results in downstream dilution of pH and metal contents. Nevertheless, streams maintain their acid character (pH <5) over distances of a few kilometres from the sources of acidity unless they flow across neutralizing rocks. In the study area, the most effective neutralization takes place in sedimentary rocks of the Parson Bay and Quatsino limestone map units and the weakly altered, zeolite and calcite-bearing basaltic units of the Bonanza volcanics.

The sources of ferruginous, base metal deficient acidic drainages derived from hydrothermally acid-leached rocks of northern Vancouver Island can be classified as 'pyrite-rich, base metal-poor veins and disseminations in wallrocks with low acid-buffering capacity' (category F on Figure 2), or more simply, (an) "acid, low-metal environment".

REFERENCES

Archibald, D. A. and Nixon, G. T., (1995): $^{40}Ar/^{39}Ar$ Geochronometry of Igneous Rocks in the Quatsino - Port McNeill Area, Northern Vancouver Island (92L/12, 11); *in* Geological Fieldwork 1994, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 49-59.

Dasler, P.G., Young, M.J., Perelló, J. and Giroux, G. (1995): The Hushamu Porphyry Copper-Gold Deposit, Northern Vancouver Island, British Columbia; *in* Porphyry Deposits of the Northern Cordillera of North America, Schroeter, T.G., Editor, *Canadian Institute of Mining, Metallurgy and Petroleum*, Special Volume 46, in press.

Ficklin, W.H., Plumlee, G.S., Smith, K.S. and McHugh, J.B. (1992): Geochemical Classification of Mine Drainages and Natural Drainages in Mineralized Areas; *in* Water-Rock Interaction, Proceedings of the 7th International Symposium on Water-rock Interactions, Kharaka, Y.K. and Maest, A.S., Editors, A.A. *Balkema* , Rotterdam, pages 381-384.

Hammack, J.L., Nixon, G.T., Koyanagi, V.M., Payie, G.J., Panteleyev, A., Massey, N.W.D., Hamilton, J.V. and Haggart, J.W. (1994): Preliminary Geology of the Quatsino - Port McNeill Area, Northern Vancouver Island, NTS 92L/11W,12; *B. C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1994-26, Scale 1:50 000, 2 sheets.

Koyanagi, V.M. and Panteleyev, A. (1993): Natural Acid Rock-drainage in the Red Dog - Hushamu - Pemberton Hills Area, Northern Vancouver Island (92L/12); *in* Geological Fieldwork 1992, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 445-450.

Koyanagi, V.M. and Panteleyev, A. (1994): Natural Acid Rock-drainage in the Red Dog - Hushamu - Pemberton Hills Area, Northern Vancouver Island; *in* Geological Fieldwork 1993, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 119-125.

Nixon, G.T., Hammack, J.L., Koyanagi, V.M., Payie, G.J., Massey, N.W.D., Hamilton, J.V. and Haggart, J.W. (1994): Preliminary Geology of the Quatsino - Port McNeill Map Areas, Northern Vancouver Island (92L/12, 11); *in* Geological Fieldwork 1993, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 63-85.

Panteleyev, A. and Koyanagi, V.M. (1993): Advanced Argillic Alteration in Bonanza Volcanic Rocks, Northern Vancouver Island - Transitions Between Porphyry Copper and Epithermal Environments; *in* Geological Fieldwork 1992, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 287-293.

Panteleyev, A. and Koyanagi, V.M. (1994): Advanced Argillic Alteration in Bonanza Volcanic Rocks, Northern Vancouver Island - Lithologic and Permeability Controls; *in* Geological Fieldwork 1993, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 101-109.

Panteleyev, A., Bobrowsky, P.T., Nixon, G.T. and Sibbick, S.J. (1994): Northern Vancouver Island Integrated Project; *in* Geological Fieldwork 1993, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 59-62.

Panteleyev, A., Reynolds, P.H. and Koyanagi, V.M. (1995): $^{40}Ar/^{39}Ar$ Ages of Hydrothermal Minerals in Acid Sulphate-altered Bonanaza Volcanics, Northern Vancouver Island; *in* Geological Fieldwork 1994, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 61-65.

Plumlee, G.S., Smith, K.S., Ficklin, W.H. and Briggs, P.H. (1992): Geological and Geochemical Controls on the Composition of Mine Drainages and Natural Drainages in Mineralized Areas; *in* Water-Rock Interaction, Proceedings of the 7th International Symposium on Water-rock Interactions, Kharaka, Y.K. and Maest, A.S., Editors, *A.A. Balkema*, Rotterdam, pages 419-422.

Plumlee, G.S., Smith, K.S., and Ficklin, W.H (1994): Geoenvironmental Models of Mineral Deposits, and Geology-Based Mineral-Environmental Assessments of Public Lands; *U. S. Geological Survey*, Open-File Report 94-203, 7 pages.

Sibbick, S.J. and Laurus K.A. (1995): Investigation of a Natural Acid Rock Drainage and an Anomalous Mercury-bearing Stream, Northern Vancouver Island; *in* Geological Fieldwork 1994, Grant, B. and Newell, J. M., Editors, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 67-70.