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NATURAL ACID ROCK-DRAINAGE IN THE RED DOG - HUSHAMU - PEMBERTON HILLS AREA, NORTHERN VANCOUVER ISLAND (92L/12)

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KEYWORDS: Applied geochemistry, natural acid rock-drainage, porphyry copper-gold, advanced-argillic alteration, acid generation, sulphide weathering, Holberg Inlet, Nahwitti Lowland, Red Dog, Hushamu, Pemberton Hills, Northern Vancouver Island.

INTRODUCTION

Northern Vancouver Island Upper Triassic sediments, Lower Jurassic Bonanza volcanics and related Jurassic Island Plutonic Suite intrusions host significant porphyry copper-gold, base metal skarns and advanced argillic acid-sulphate epithermal mineralization (Panteleyev and Koyanagi, 1993). This geological setting provides the focus for a study of natural acid rock-drainage.

The purpose of the study is to determine the source and demonstrate the extent of natural acid in waters draining areas of altered and mineralized rock. Over a 3-year period beginning in 1991, 248 water sites were sampled for pH, conductivity and total dissolved solids. Selected drainages were measured yearly to evaluate annual variations. Flushing effects after a major rainfall were determined by taking pH measurements before and after rainstorms. A total of twenty-one waters and nine silt samples from selected sites were collected and submitted for analysis of metal content. Data from 1991 and 1992 sampling are presented in Koyanagi and Panteleyev (1993). Analytical data from samples collected in the 1993 season are pending.

LOCATION AND ACCESS

The study area in northern Vancouver Island is located between Nahwitti Lake and Holberg Inlet about 15 kilometres west of the Island Copper mine (Figure 1). The sample area in 1991 and 1992 was centred about Mount McIntosh and the Pemberton Hills. The survey expanded in 1993 to include waters draining the Red Dog deposit, the upper reaches of the Goodspeed River and its major tributaries, and parts of the Wanokana Creek and Nahwitti River drainage systems. Access from Coal Harbor in the south is primarily by well-maintained active logging roads and in the north along the Port Hardy - Holberg road.

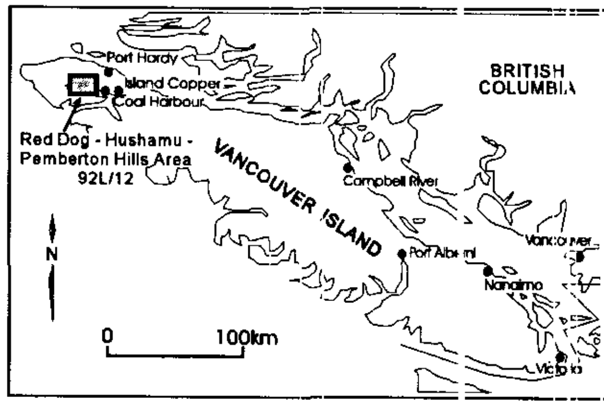

Figure 1. Location Map of the Red Dog - Hushamu - Pemberton Hills area, Northern Vancouver Island.

PHYSIOGRAPHY

The study area falls within the Nahwitti Lowland which forms part of the Hecate Depression (Holland, 1976). The Nahwitti Lowland is characterized by low relief, rounded hills, narrow valleys and broad lowlands and valleys (Gravel and Matysek 1989). Elevations range from sea level up to 700 metres, generally diminishing toward the northwest.

Quaternary geology, as described by Kerr and Sibbick (1992), consists of widespread deposits of till common in both highland and lowland areas attaining tens of metres of thickness in valleys. Sand and gravel deposits of glaciofluvial outwash vary from 1 to 15 metres in thickness as valley-bottom fill. Colluvium derived from till and weathered bedrock occurs as a ubiquitous veneer (<1 m) or blanket (>1 m). A thin layer of ferricrete is widespread in the study area and is commonly exposed as resistant ledges overhanging stream banks and road cuts.

The most recent glaciation in the Nahwitti Lowlands (Wisconsinan) occurred 20 000 to 10 000 years ago. This glaciation is interpreted to have had a regional ice-flow direction generally to the northwest, originating from the Coast Mountains and crossing Queen Charlotte Strait (Kerr and Sibbick, 1992).

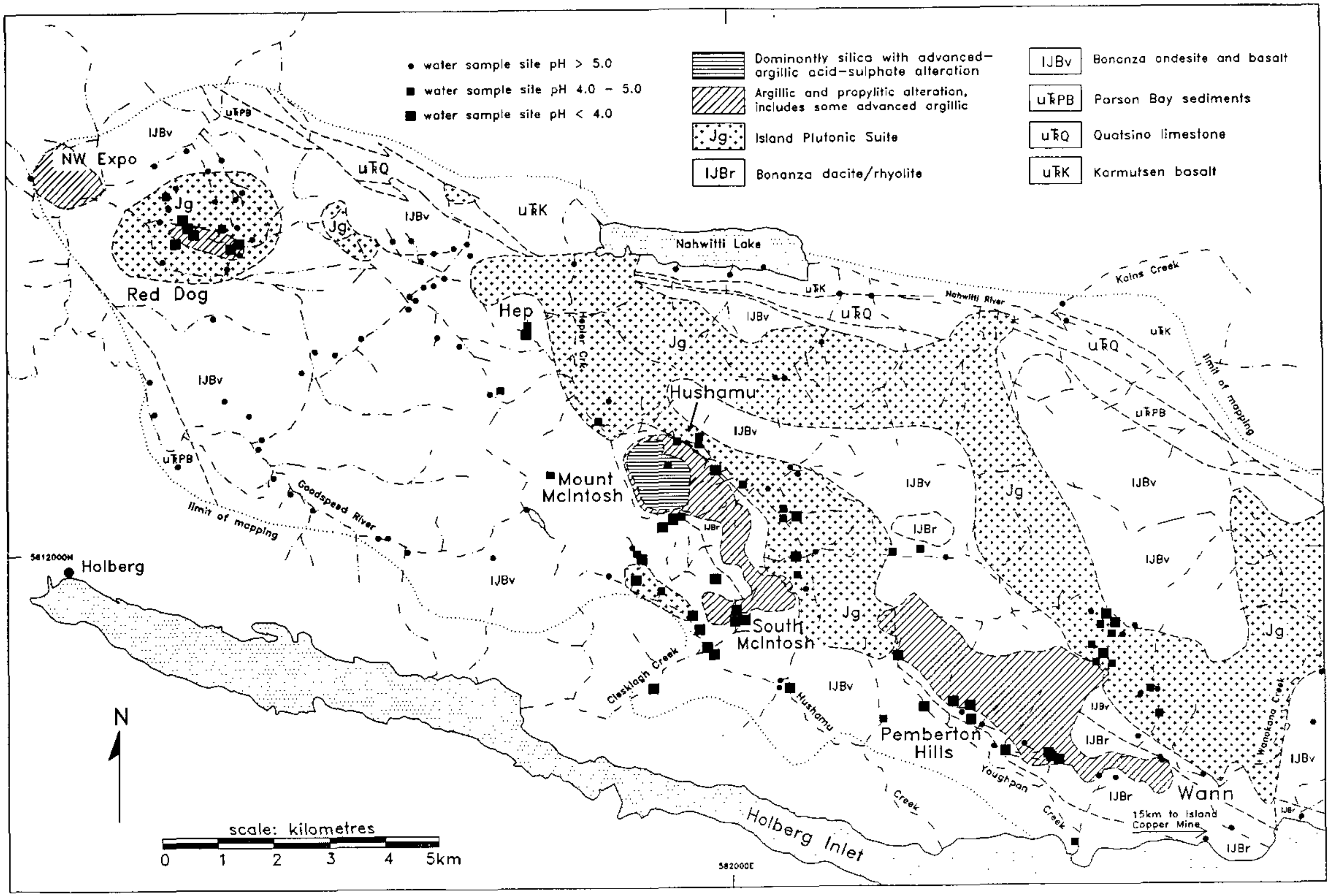

Figure 2. Sample location map illustrating spatial relationship of acidic waters within the study area; water sample data were collected from 1991 to 1993; note consistent trend of acid waters between the Red Dog and the Pemberton Hills correlating acid drainage to mineralization and alteration.

GEOLOGICAL SETTING

The geology in the study area is dominated by Upper Triassic to Lower Jurassic volcanic and sedimentary rocks intruded by plutonic rocks of Jurassic, Island Plutonic Suite affinities (Figure 2). These rocks are unconformably overlain by Cretaceous sedimentary rocks along the north shore of Holberg Inlet. A detailed description of the regional geology is reported by Nixon *et al.* (1994, this volume).

Jurassic Bonanza Group units host porphyry copper-gold deposits (Island Copper mine, Hushamu, Hep, Red Dog) related to intrusion of the Island Plutonic Suite, as well as transitional to epithermal-type alteration and mineralization (NW Expo, Mount McIntosh, South McIntosh, Pemberton Hills, Wann). Advanced-argillic acid-sulphate mineralization transitional between porphyry and epithermal settings occurs in a belt of distinct alteration trending northwesterly from the Pemberton Hills to the Northwest Expo property (Figure 2). Descriptions of the transitional setting and associated alteration and mineralization are provided by Panteleyev (1992), and Panteleyev and Koyanagi (1993; 1994, this volume).

FIELD STUDY AND ANALYTICAL PROCEDURE

Acid levels in waters were measured using a Corning CheckMate™ M90 portable microprocessor-based pH, conductivity and total dissolved solids meter. Readings were taken in the field by submersing the meter directly into waters.

During the 1993 sampling program, 171 waters were measured for pH, conductivity and total dissolved solids. Sampling included remeasuring sites tested in previous years, to determine annual variations. In the Wanokana, Youghpan and Hushamu Creek drainages measurements were taken before and after a major rainfall to determine the effects of short-term flushing.

Waters were surveyed during the month of August. Precipitation levels reported by Environment Canada indicate rainfall for July 1993 was below average with August 1993 rainfall slightly above average (Table 1). The below average rainfall in July resulted in small volumes of water flow in many drainages. In some smaller creeks levels were reduced to flow occurring only below the ground surface. Background acid level, considered to be represented by the acid level in waters draining relatively unmineralized areas and the larger lakes, is about pH 5.6.

RESULTS AND INTERPRETATIONS

A correlation between high acid levels in drainage waters and sulphide-bearing rocks, as reported by Koyanagi and Panteleyev (1993), was further substantiated by 1993 sampling. Acid levels measured in waters draining the Red Dog area provide evidence for this correlation (Figure 3). The Red Dog is a porphyry prospect with low-grade copper-gold-molybdenum mineralization hosted by a porphyritic intrusion of the Island Plutonic Suite. The surrounding country rocks are dominantly mafic to intermediate Bonanza flows with lesser Parson Bay sedimentary rocks cropping out to the north. A "bull's eye" pattern of pH measurements centred on the mineralized zone illustrates the source and

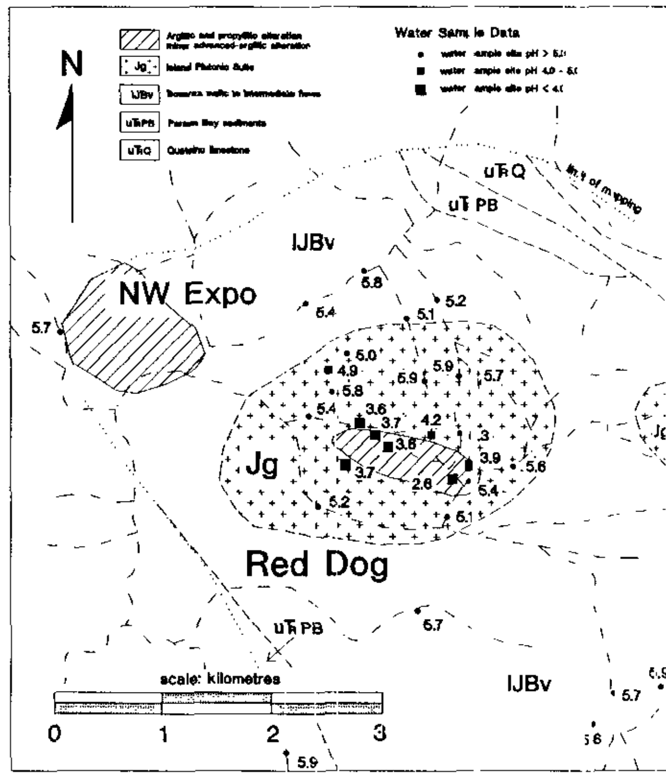

Figure 3. Sample location map of the Red Dog prospect illustrating the spatial relationship of acid waters in relation to alteration and lithologies.

TABLE 1. MONTHLY PRECIPITATION TOTALS FOR 1991 TO 1993.

	January	February	March	April	May	June	July	August
1991	185.8	184.2	104.0	95.0	52.6	61.6	78.6	186.6
1992	409.0	167.2	38.8	92.8	76.8	70.4	13.6	47.6
1993	--------	29.2	258.8	150.0	139.8	82.8	25.0	79.6
Average*	258.8	190.1	175.9	133.1	78.1	71.0	47.0	58.8

*** averages calculated for years 1961 to 1990. All measurements in millimetres**
Reported by Atmospheric Environmental Service, Canada Climate Normals for British Columbia; station located at Coal Harbour 50°36'N 127°30'W, elevation 57 metres.

TABLE 2. WATER DATA FOR NEW 1993 SAMPLE SITES.

Sample Number	Main Drainage	pH	Cond.	TDS	Temp °C	Sample Number	Main Drainage	pH	Cond.	TDS	Temp °C
EC93VKO37	Goodspeed	5.7	49.0	24.4	14.0	EC93VKO20	Red Dog	5.4	86.9	43.6	13.0
EC93VKO38	Goodspeed	6.1	157.6	78.5	19.7	EC93VKO21	Red Dog	5.6	72.0	36.1	13.2
EC93VKO39	Goodspeed	5.9	142.7	71.4	21.3	EC93VKO22	Red Dog	3.9	205.0	102.0	14.9
EC93VKO40	Goodspeed	5.7	63.8	27.5	24.3	EC93VKO23	Red Dog	2.7	1503.0	753.0	14.2
EC93VKO41	Goodspeed	5.7	50.2	20.1	19.8	EC93VKO24	Red Dog	5.1	86.8	43.5	14.2
EC93VKO42	Goodspeed	6.3	160.4	86.2	23.8	EC93VKO25	Red Dog	5.7	46.4	22.7	12.3
EC93VKO43	Goodspeed	5.1	41.5	20.0	22.8	EC93VKO26	Red Dog	5.7	57.1	26.6	16.6
EC93VKO45	Goodspeed	5.9	91.0	45.7	15.6	EC93VKO27	Red Dog	5.6	88.8	47.7	14.2
EC93VKO46	Goodspeed	5.6	97.5	49.9	13.4	EC93VKO60	Clesclagh	4.3	179.0	90.0	14.4
EC93VKO47	Goodspeed	5.9	94.5	47.6	12.4	EC93VKO61	Clesclagh	5.9	93.7	38.6	12.0
EC93VKO48	Goodspeed	5.8	74.2	36.6	13.0	EC93VKO67	Clesclagh	5.5	67.8	34.1	14.1
EC93VKO49	Goodspeed	6.1	173.9	78.9	12.1	EC93VKO77	Hepler	5.8	72.4	43.5	12.2
EC93VKO50	Goodspeed	5.9	230.0	116.0	10.7	EC93VKO78	Hepler	5.5	64.7	31.9	14.8
EC93VKO51	Goodspeed	6.1	296.0	152.0	9.5	EC93VKO79	Hepler	5.8	42.3	20.0	14.7
EC93VKO52	Goodspeed	6.1	153.0	77.7	12.1	EC93VKO172	Hepler	5.5	---	---	11.7
EC93VKO54	Goodspeed	5.7	84.5	42.7	11.6	EC93VKO83	Hushamu	5.5	83.5	50.7	10.6
EC93VKO55	Goodspeed	5.7	68.2	34.1	12.5	EC93VKO87	Hushamu	4.3	137.0	69.6	16.4
EC93VKO56	Goodspeed	5.7	64.5	31.1	10.7	EC93VKO88	Hushamu	5.6	54.9	27.0	13.7
EC93VKO57	Goodspeed	5.6	84.5	41.6	10.9	EC93VKO95	Hushamu	5.3	53.8	26.6	14.1
EC93VKO58	Goodspeed	5.6	38.4	18.6	17.5	EC93VKO96	Hushamu	5.5	55.4	32.6	13.3
EC93VKO75	Goodspeed	5.2	85.5	38.5	8.9	EC93VKO168	Kains	5.6	---	---	12.5
EC93VKO76	Goodspeed	5.6	64.2	33.5	10.5	EC93VKO169	Nahwitti	5.7	---	---	13.6
EC93VKO170	Goodspeed	5.7	---	---	9.5	EC93VKO111	NW Expo	5.7	109.6	55.4	17.4
EC93VKO171	Goodspeed	5.6	---	---	15.5	EC93VKO135	Wakalish	6.4	189.1	95.4	13.2
EC93VKO16	Holberg	6.1	191.0	94.0	16.3	EC93VKO115	Wanokana	5.9	63.5	28.8	12.8
EC93VKO28	Holberg Rd	5.7	64.6	32.5	11.7	EC93VKO116	Wanokana	3.9	151.1	75.7	14.2
EC93VKO29	Holberg Rd	5.9	68.4	34.4	20.5	EC93VKO117	Wanokana	3.3	863.0	450.0	14.2
EC93VKO30	Holberg Rd	5.8	56.3	27.9	15.1	EC93VKO118	Wanokana	5.5	109.4	54.6	12.3
EC93VKO31	Holberg Rd	5.1	102.0	42.9	15.7	EC93VKO119	Wanokana	4.4	147.8	73.3	10.9
EC93VKO32	Holberg Rd	6.1	103.8	47.4	13.5	EC93VKO120	Wanokana	5.3	60.5	29.2	15.8
EC93VKO33	Holberg Rd	5.6	63.6	31.5	12.0	EC93VKO121	Wanokana	4.3	118.7	58.7	12.6
EC93VKO34	Holberg Rd	5.5	44.9	22.9	12.4	EC93VKO122	Wanokana	4.9	117.6	56.2	12.3
EC93VKO35	Holberg Rd	5.6	100.7	50.1	14.9	EC93VKO123	Wanokana	3.9	121.5	60.4	15.3
EC93VKO36	Holberg Rd	5.5	44.7	22.1	10.8	EC93VKO124	Wanokana	4.0	310.0	152.0	15.2
EC93VKO44	Holberg Rd	5.5	99.1	50.0	10.0	EC93VKO125	Wanokana	4.6	43.2	21.5	16.9
EC93VKO1	Red Dog	5.9	66.0	30.8	9.1	EC93VKO126	Wanokana	5.1	77.8	38.9	14.2
EC93VKO2	Red Dog	5.7	58.9	28.4	11.3	EC93VKO127	Wanokana	5.5	80.1	50.2	13.3
EC93VKO3	Red Dog	5.7	41.2	23.6	9.4	EC93VKO129	Wanokana	5.3	61.0	30.5	17.6
EC93VKO4	Red Dog	3.6	206.0	102.0	14.2	EC93VKO130	Wanokana	5.3	81.5	40.5	15.7
EC93VKO5	Red Dog	3.7	510.0	260.0	18.0	EC93VKO131	Wanokana	4.4	142.5	72.0	16.1
EC93VKO6	Red Dog	5.4	76.4	38.4	13.5	EC93VKO132	Wanokana	5.7	114.3	56.3	15.2
EC93VKO7	Red Dog	5.0	86.7	43.1	16.7	EC93VKO164	Wanokana	5.3	61.8	30.6	11.6
EC93VKO8	Red Dog	5.1	51.2	25.8	13.9	EC93VKO165	Wanokana	5.2	1078.0	535.0	11.8
EC93VKO9	Red Dog	5.2	52.4	26.4	13.5	EC93VKO166	Wanokana	5.5	---	---	11.9
EC93VKO10	Red Dog	4.9	50.4	17.7	23.5	EC93VKO167	Wanokana	5.9	---	---	12.0
EC93VKO11	Red Dog	5.8	77.3	38.5	19.6	EC93VKO99	Youghpan	5.9	64.8	31.9	15.1
EC93VKO12	Red Dog	5.4	23.0	10.9	20.3	EC93VKO101	Youghpan	5.3	30.8	15.4	16.7
EC93VKO13	Red Dog	5.8	58.3	27.0	22.1	EC93VKO102	Youghpan	5.3	57.5	28.2	21.2
EC93VKO14	Red Dog	3.7	157.6	75.3	16.2	EC93VKO103	Youghpan	3.5	149.6	70.2	20.5
EC93VKO15	Red Dog	5.2	87.5	42.9	13.6	EC93VKO104	Youghpan	4.2	94.3	44.0	17.9
EC93VKO17	Red Dog	4.2	103.8	44.9	13.6	EC93VKO105	Youghpan	4.0	46.7	23.6	14.2
EC93VKO18	Red Dog	5.3	84.1	41.8	10.6	EC93VKO107	Youghpan	3.4	353.0	157.0	20.9
EC93VKO19	Red Dog	3.6	340.0	170.0	14.2	EC93VKO133	Youghpan	3.7	868.0	433.0	26.3

extent of acid generation (Figure 3). The mineralized area is located on a topographic high which is coincident with the "bull's eye" centre. Acid levels of waters within the mineralized zone average pH 3.8. Within 500 to 1500 metres of the core of the prospect, waters returned neutral (near background) acid levels. The limited range of anomalous acidity in waters appears to reflect the dimensions of the prospect and the amount of sulphide mineralization.

The Goodspeed River watershed is located southwest of the Red Dog - Hushamu - Pemberton Hills mineralized belt. No significant mineral prospects are reported within this drainage system. The area is underlain by a thick package of Bonanza mafic to intermediate flows, Parson Bay sediments and Quatsino limestone. Sample results from this watershed demonstrate the low acid-generating capacity of the volcanic stratigraphy, the acid neutralizing ability of the calcareous sediments and the implicit absence of significant acid-generating mineral deposits. Acid levels in waters measured in this area average pH 5.7, reflecting background to slightly above background levels (Table 2). Similar background levels were measured in the Nahwitti River - Kains Creek area in the northeast part of the study area. This watershed drains Karmutsen basalt, Quatsino limestone, Parson Bay calcareous shales and Bonanza volcaniclastic rocks. Disseminations of pyrite and pyrrhotite in Parson Bay siltstones and locally in calcsilicate-altered calcareous rocks are a potential source of acid generation. The buffering capacity of the calcareous stratigraphy is not exceeded by the acid generated, resulting in background acid levels.

Variations of acid levels in waters were tested over the short term (daily) and at 3-year intervals during the summer months of 1991-1993. Annual measurements revealed a consistency in levels of acid generated into streams over the 3-year period (Table 3). Acidic waters (pH <4.0) draining mineralized areas

TABLE 3. WATER DATA FOR SAMPLE SITES WITH REPEAT MEASUREMNETS.

Sample Number	Main Drainage	1993 Sampling pH	Cond.	TDS	Temp	1993 Resampling pH	Cond.	TDS	Temp	1992 Sampling pH	Cond.	TDS	Temp	1991 Sampling pH	Cond.	TDS	Temp
EC93VKO59	Clesclagh	5.7	52.8	27.2	12.8	5.5	55.5	28.0	11.0	5.4	55.0	27.4	15.6	---	---	---	---
EC93VKO62	Clesclagh	4.2	173.5	87.2	12.2	---	---	---	---	4.3	157.0	78.5	14.0	---	---	---	---
EC93VKO63	Clesclagh	4.9	75.7	37.6	11.6	---	---	---	---	5.3	71.1	35.5	12.0	---	---	---	---
EC93VKO64	Clesclagh	3.2	471.0	240.0	14.9	---	---	---	---	---	---	---	---	4.1	215.0	107.0	12.9
EC93VKO65	Clesclagh	4.0	140.0	68.0	18.4	3.4	360.0	182.0	11.9	---	---	---	---	---	---	---	---
EC93VKO66	Clesclagh	3.8	436.0	219.0	14.4	---	---	---	---	---	---	---	---	3.6	282.0	149.0	12.6
EC93VKO68	Clesclagh	3.4	458.0	233.0	15.7	---	---	---	---	---	---	---	---	3.1	442.0	219.0	14.3
EC93VKO69	Clesclagh	3.9	215.0	87.6	17.7	3.8	251.0	96.5	12.8	---	---	---	---	3.9	159.2	79.2	15.0
EC93VKO70	Clesclagh	4.0	189.3	93.0	17.5	---	---	---	---	---	---	---	---	3.5	255.0	128.0	13.9
EC93VKO71	Clesclagh	4.5	132.5	63.7	20.1	---	---	---	---	---	---	---	---	3.2	459.0	244.0	17.7
EC93VKO72	Clesclagh	4.1	230.0	120.0	14.3	---	---	---	---	3.9	184.2	92.9	14.9	---	---	---	---
EC93VKO80	Hepler	5.7	67.5	33.2	15.6	---	---	---	---	---	---	---	---	5.5	48.4	28.1	10.0
EC93VKO81	Hepler	5.6	72.8	35.1	13.5	3.8	325.0	161.0	12.3	---	---	---	---	4.1	100.0	50.0	11.2
EC93VKO81-1	Hepler	3.8	190.0	96.0	12.8	3.7	335.0	161.0	12.3	---	---	---	---	3.9	119.4	61.7	11.7
EC93VKO82	Hepler	2.9	1017.0	527.0	19.4	2.8	1566.0	781.0	14.9	---	---	---	---	---	---	---	---
EC93VKO112	Hushamu	5.7	64.5	31.9	17.7	5.5	81.7	37.3	12.0	4.8	53.1	25.4	13.7	---	---	---	---
EC93VKO73	Hushamu	5.7	78.5	37.9	18.0	5.6	67.1	33.2	13.3	---	---	---	---	6.0	61.3	36.9	10.6
EC93VKO74	Hushamu	3.4	157.9	79.7	16.5	4.1	131.4	65.5	12.0	---	---	---	---	3.9	163.2	81.8	13.1
EC93VKO84	Hushamu	5.2	105.7	52.3	19.0	---	---	---	---	4.5	92.4	44.9	19.6	---	---	---	---
EC93VKO85	Hushamu	4.4	153.9	72.5	12.8	4.2	180.1	89.4	16.8	---	---	---	---	4.3	141.2	70.8	15.3
EC93VKO86	Hushamu	3.7	509.0	249.0	12.8	3.7	687.0	357.0	11.0	---	---	---	---	3.7	53.9	27.3	9.1
EC93VKO89	Hushamu	5.4	48.7	24.7	13.5	---	---	---	---	---	---	---	---	5.8	48.1	24.2	14.1
EC93VKO90	Hushamu	5.3	58.1	29.1	14.4	5.0	50.0	25.2	11.1	4.7	51.2	25.6	19.1	---	---	---	---
EC93VKO91	Hushamu	3.7	125.6	63.4	13.8	4.1	135.2	63.8	12.3	---	---	---	---	4.3	120.0	61.1	13.7
EC93VKO92	Hushamu	3.7	181.0	90.2	11.9	3.8	129.6	64.9	10.9	---	---	---	---	3.8	176.5	92.0	14.6
EC93VKO93	Hushamu	4.4	70.6	35.2	13.4	---	---	---	---	---	---	---	---	4.0	---	---	11.2
EC93VKO94	Hushamu	3.8	219.0	110.0	11.9	---	---	---	---	---	---	---	---	5.4	---	---	12.2
EC93VKO53	Mt. McIntosh	2.9	420.0	195.0	16.9	---	---	---	---	3.2	259.0	128.0	23.4	3.6	88.0	44.7	12.2
EC93VKO114	Wanokana	5.6	60.9	33.3	16.8	4.8	48.9	22.8	13.0	---	---	---	---	---	---	---	---
EC93VKO128	Wanokana	4.5	117.8	58.9	15.3	4.3	114.3	57.0	11.4	---	---	---	---	---	---	---	---
EC93VKO100	Youghpan	5.4	55.6	27.6	17.9	---	---	---	---	5.3	89.9	28.3	12.6	---	---	---	---
EC93VKO106	Youghpan	3.5	408.0	203.0	17.1	3.4	469.0	234.0	11.0	3.4	347.0	175.0	11.5	---	---	---	---
EC93VKO108	Youghpan	3.4	449.0	232.0	21.9	3.2	298.0	147.0	12.5	2.9	311.0	157.0	15.4	---	---	---	---
EC93VKO109	Youghpan	3.7	250.0	130.0	16.6	---	---	---	---	3.1	252.0	124.0	12.4	---	---	---	---
EC93VKO110	Youghpan	2.9	1870.0	754.0	17.1	2.8	750.0	379.0	11.7	---	---	---	---	---	---	---	---
EC93VKO113	Youghpan	4.2	176.2	88.4	15.3	3.8	103.9	51.7	12.4	5.7	77.7	38.7	19.1	---	---	---	---
EC93VKO134	Youghpan	5.6	---	---	24.1	---	---	---	---	5.5	774.0	385.0	25.3	---	---	---	---
EC93VKO156	Youghpan	4.7	141.6	70.5	15.1	---	---	---	---	5.4	145.7	70.2	17.7	---	---	---	---
EC93VKO157	Youghpan	4.0	589.0	183.0	13.5	---	---	---	---	3.5	264.0	131.0	16.1	---	---	---	---
EC93VKO158	Youghpan	3.5	530.0	264.0	14.6	---	---	---	---	3.5	260.0	130.0	16.5	---	---	---	---
EC93VKO159	Youghpan	3.5	528.0	290.0	15.8	---	---	---	---	3.4	240.0	119.0	16.7	---	---	---	---
EC93VKO160	Youghpan	5.7	522.0	265.0	15.8	---	---	---	---	6.1	348.0	174.0	19.4	---	---	---	---
EC93VKO161	Youghpan	6.0	92.9	46.7	17.6	---	---	---	---	5.7	77.7	38.7	19.1	---	---	---	---
EC93VKO162	Youghpan	4.2	82.6	43.1	13.5	---	---	---	---	3.9	77.2	38.5	17.7	---	---	---	---
EC93VKO163	Youghpan	4.1	92.5	45.3	14.5	---	---	---	---	4.0	90.7	43.1	14.3	---	---	---	---
EC93VKO97	Youghpan	4.5	134.6	67.0	17.3	---	---	---	---	4.4	117.5	57.5	15.4	---	---	---	---
EC93VKO98	Youghpan	4.3	225.0	111.0	15.3	---	---	---	---	5.0	50.0	25.1	11.2	---	---	---	---

Measurements resampled in 1993 are utilized to determine short-term variations during a heavy rainfall, annual measurements are utilized to document long term variations.

invariably return similarly low pH levels in each of the 3 years. Minor fluctuations are commonly observed in weakly acid waters (pH 4.0-5.0). These fluctuations are attributed to flushing of trapped acid or dilution of acidity, either seasonally or daily. Because the pH scale is reverse logarithmic, the addition of small amounts of acid or the dilution of existing acidity in streams is more easily detected at pH levels of 5 to 4 than at pH levels of 4 to 3.

Short-term variations were recognized during a large rainfall in mid-August which lasted several days and resulted in the flushing of major watersheds. Acid in rocks and soils was flushed out concurrent with large scale mass wastage by erosion of stream bank outcrops. The result was a marked drop in pH levels in some creeks (Table 3). In other stream systems dilution effects during flushing by rainwater (pH $\pm$ 5.6) was indicated by a rise in pH levels. The rise or fall of acid levels in waters during rainfall is dominantly lithologically controlled.

Wanokana and Youghpan creeks were considerably swollen during the rainstorm. Water levels rose from tens of centimetres to more than a metre near the mouths of these creeks. The Wanokana watershed drains an area of about 44 square kilometres. Water measured near the mouth of this relatively large drainage system returned pH levels of 5.6 before the rainstorm and 4.8 after flushing occurred. The drainage system is dominantly underlain by a monzodioritic pluton intruding Bonanza volcanics and volcaniclastics. Base metal bearing quartz veins, pyritic fault zones and advanced-argillic dumortierite-bearing hydrothermal alteration zones are reported to occur within the watershed. Although these mineral deposits are potentially acid generating, neutral acid levels (pH 5.6) measured prior to flushing indicate acid added to the system from these sources is negligible. The decrease in pH levels during rainfall is interpreted to be the result of flushing of organic and inorganic generated acid from rocks and soils. An influx of organic material and organic acid is visibly evident as increased turbidity of creek waters during flushing. The decrease in pH in Wanokana Creek reflects the influence of the addition of small amounts of acid on waters with initially neutral pH levels (pH 5.6).

The Youghpan watershed drains an area of about 25 square kilometres and is dominantly underlain by altered and mineralized Bonanza volcanics and minor dioritic intrusions. Advanced-argillic acid-sulphate altered zones occupy a large portion of the drainage area and host massive to disseminated pyrite and marcasite mineralization (Panteleyev and Koyanagi, 1992). Evidence of sulphide dissolution in the Youghpan drainage system as the dominant source of acid generation is provided by high sulphate levels (Koyanagi and Panteleyev, 1992). Acid levels near the mouth of Youghpan Creek measured pH 4.2 prior to the rainstorm and pH 3.8 after flushing. Acidity generated by the strongly mineralized and altered rocks may be trapped within soils, joints, fractures and other open spaces. The heavy rainfall flushes trapped acid resulting in an influx of acid into the stream system. Substantial acid-generating sulphide mineralization throughout the Youghpan system accounts for the amount of flushed acid which exceeds the buffering effects of additional neutral waters such as rain and surface runoff, resulting in the net decrease in pH levels.

The Hushamu watershed drains an area of about 20 square kilometres. Heavy rainfall flushing the system resulted in a decrease in acidity with levels rising from pH 3.4 to 4.1. Tributaries on the west side of the Hushamu watershed drain the Mount McIntosh and South McIntosh areas. These areas comprise advanced-argillic acid-sulphate alteration zones with significant disseminated sulphide mineralization. Acid levels from these tributaries average pH levels of 3.8. A relatively unmineralized diorite intrusion underlies most of the eastern flanks of Hushamu Creek. Tributaries draining the diorite return dominantly background acid levels. The decrease in acid levels after flushing is the result of dilution by neutral waters draining unmineralized areas. Hushamu Lake, at the headwaters of the Hushamu watershed, has an average acid level of pH 4.3. During the heavy rainfall an influx of lake water into the more acidic waters of Hushamu Creek caused dilution and a subsequent rise in pH levels. This rise is reflected by measurements at a sample site located approximately 1 kilometre downstream from Hushamu Lake. Before the rainfall, waters at this site returned acid levels of pH 3.7. After lake waters overflowed into Hushamu Creek, acid levels measured pH 4.1. The overall increase in pH during flushing indicates the amount of acid flushed into the system is more than offset by the addition of less acidic and neutral waters.

CONCLUSIONS

Natural acid rock-drainage is generated from altered and mineralized rocks into waters draining the Red Dog - Hushamu - Pemberton Hills area. The dominant source of acid is the dissolution of sulphides contained within advanced-argillic acid-sulphate alteration zones as well as porphyry copper-gold and skarn-mineralized rocks. Within the study area, the amount of acid generated is proportional to the amount of sulphide mineralization. Detection of acidity several kilometres downstream from the acid-generating source is a also a function of the size of the mineralized system. Acidic streams (pH <4.0) measured annually, returned consistently acidic levels over a 3-year period. Measurements of weakly acidic waters (pH 5-4) fluctuated from year to year. These fluctuations are attributed to flushing of trapped acid by seasonal runoff or during rainstorms. Due to the pH scale being reverse logarithmic, small changes in acid levels are more easily detected in less acid waters. Short term variations of acid levels in selected streams revealed fluctuations to be strongly lithologically controlled. Measurements before and after a large rainfall illustrate the effects of flushing of trapped acid. Acid levels increase or decrease depending on the abundance of acid-generating and acid-neutralizing rocks within the watershed.

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