$^{40}Ar/^{39}Ar$ AGES OF HYDROTHERMAL MINERALS IN ACID SULPHATE-ALTERED BONANZA VOLCANICS, NORTHERN VANCOUVER ISLAND (NTS 92L/12)

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INTRODUCTION

The occurrence of acid sulphate, advanced argillic alteration in extensive zones within Bonanza volcanic rocks in Northern Vancouver Island has been long known (Clapp, 1913, 1915). The alteration zones have been examined at various times for their precious and base metal potential as well as for sources of various industrial minerals. The most extensive recent exploration has been carried out to the north of Holberg Inlet and west of Island Copper mine (Figure 1) by BHP Minerals Limited and associated companies, and in the recent past by BHP Minerals' corporate predecessors. Ministry work in the belt of altered Bonanza rocks has been conducted since 1991, primarily to investigate relationships between subvolcanic intrusions and related, high-level advanced argillic alteration. This setting is considered to be 'transitional' between porphyry copper and epithermal environments. This work has been discussed by Panteleyev (1992) and Panteleyev and Koyanagi (1993, 1994). The $^{40}Ar/^{39}Ar$ data reported here provide ages for hydrothermal minerals in altered rocks within the belt of Bonanza rocks to the north of Holberg Inlet and to the west of Island Copper mine. If the hydrothermal minerals are products of subvolcanic hydrothermal activity, their ages should be similar to that of the Bonanza (rhyolite) hostrocks and the supposedly coeval Island intrusions. A conventional K-Ar date obtained on hornblende from the Mead Creek stock, a typical intrusion of the Island Plutonic Suite, is 168±4 Ma (Panteleyev and Koyanagi (1994).

The $^{40}Ar/^{39}Ar$ dating technique is a variation of the K-Ar method in which samples are irradiated with fast neutrons to convert ^{39}K to ^{39}Ar. The argon is extracted by incremental step-heating to fusion, and the resulting gas is processed much as in the conventional K-Ar technique. Cumulative ^{39}Ar released and apparent age are presented in the form of age spectrum plots (Figure 2). A 'plateau age' is defined by contiguous steps that together comprise more than 50% of the total ^{39}Ar gas released, provided

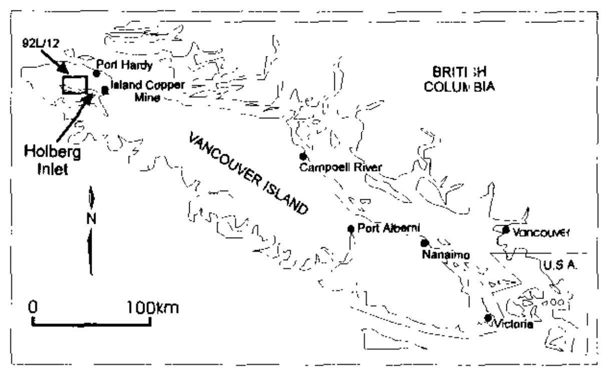

Figure 1: Location Map

that they exhibit no diffeences in apparent age beyond that expected from experimental uncertainty. Detailed discussions of the $^{40}Ar/^{39}Ar$ method, among many, are by Lanphere *et al.* (1981), Parrish and Roddick (1985), McDougall and Harrison (1988) and Reynolds (1992).

SAMPLING AND ANALYTICAL METHODS

Seven samples were selected for $^{40}Ar/^{39}Ar$ dating. The sample suite includes two hornblendes, one from the copper-mineralized Hushamu stock (91AP12/19), and the other from the Mead Creek stock (92AP3/-7) located about 3 kilometres to the northeast; a hydrothermal mica from the Hushamu stock; and four alunite concentrates from acid-leached rhyolitic Bonanza volcanic rocks in the Pemberton Hills and southern Mount McIntosh (Table 1). The alunites exhibit differences in their appearance and habit. Two of the samples (92AP-EC-150 and 92AP15/4-73a) contain well crystallized, euhedral grains, one formed as vug fillings, the other as replacement of feldspar phenocrysts. The other two are earthy, compact, white to pink in colour and occur in patches and irregular masses as replacements of porous bedded rocks and vein fillings. The differences in habit of hypogene and supergene alunites have been outlined by Sillitoe (1994).

Clean mineral concentrates were prepared for all samples and purity was checked by X-ray analysis. All argon isotopic analyses were made using a VG 3600 mass spectrometer coupled to an internal tantalum resistance furnace of the double-vacuum type. Hornblende

TABLE 1: $^{40}Ar/^{39}Ar$ SAMPLE DESCRIPTIONS

Sample Number	UTM Zone 9 Easting	UTM Zone 9 Northing	Location	Mineral Analyzed	Description
91AP12/49	-----	-----	Hushamu stock	hornblende	Hushamu stock, possibly dike
91AP-12/50	581000	5614660	Hushamu stock 1700 Road	sericite, quartz	bleached and clay-altered fault zone in pyritic zeolite-rich diorite, sericite mineral separate
92AP-EC-150	-----	-----	South McIntosh	alunite, minor topaz	DDH EC-150, South McIntosh drill core, silica rock with alunite-filled vugs, (collected by J. Fleming)
92AP15/1-71B	585999	5609291	Youghpan Creek	alunite	thin-bedded tuffs, pink/tan patches along bedding
92AP15/2-72B	585758	5609490	Youghpan Creek	alunite	relict tuff/breccia, massive silica hydrothermal overprint; pink, massive, earthy, fracture filling is alunite
92AP15/4-73a	585166	5610046	West Youghpan Creek	alunite	clay-altered basalt, remnant feldspars, breccia at base of silicified knob
92AP3/1-7	583839	5615892	Mead Creek stock	hornblende	hornblende mineral separate from fresh diorite

***This age corresponds to a 168±4 conventional K-Ar date (Panteleyev and Koyanagi, 1994)**

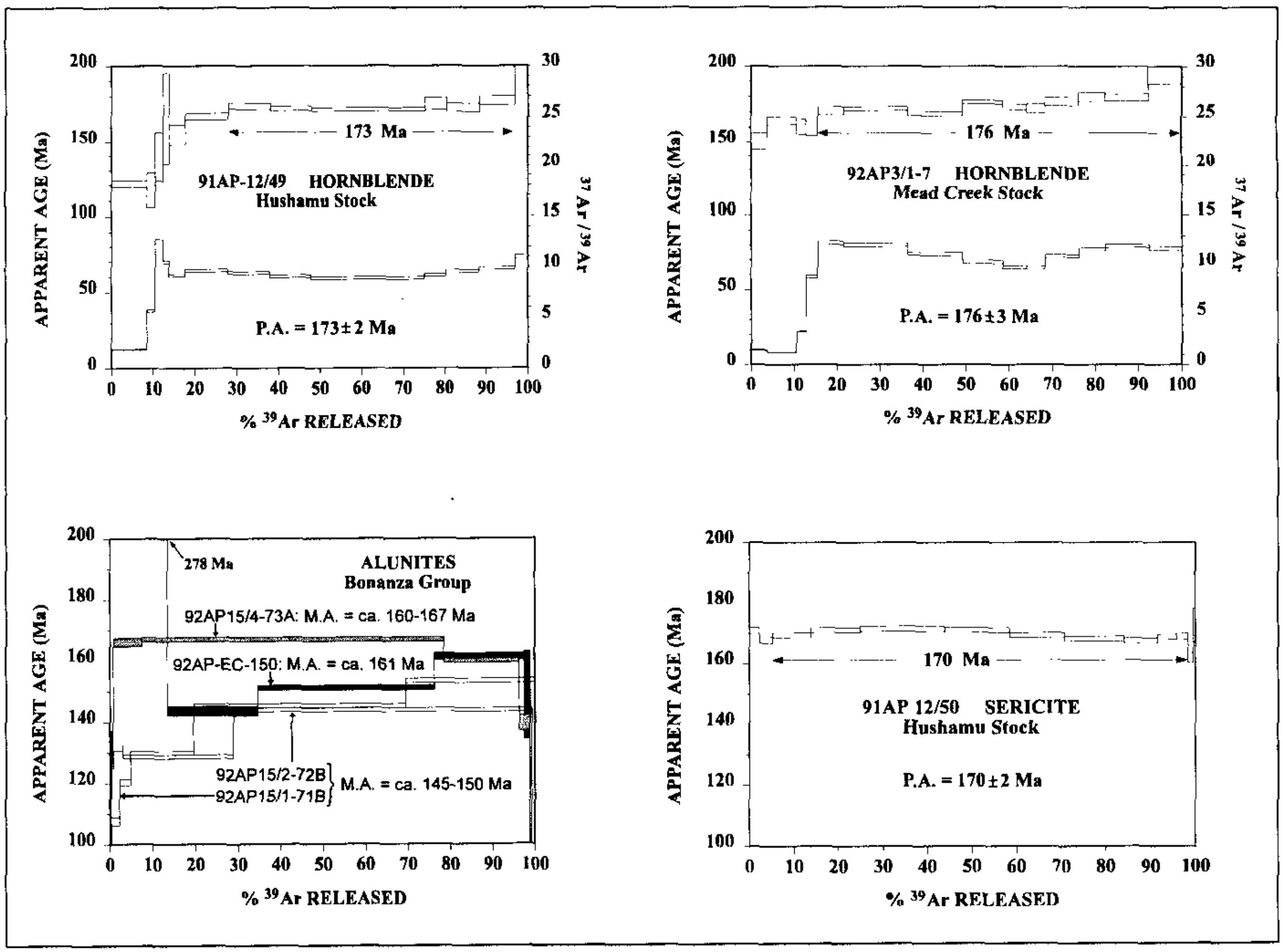

Figure 2. Age spectrum diagrams and $^{37}Ar/^{39}Ar$ ratio plots. Half-heights of open rectangles designate the 1σ relative (between-step) uncertainties. Age spectra for the two well-crystallized alunites are stippled. P.A. indicates 'plateau age'; M.A. is maximum age of segment. All errors are quoted at the 2σ level of confidence.

TABLE 2: ANALYTICAL DATA

Temp °C	mV ^{39}Ar	%^{39}Ar	AGE (Ma)	AGE +/-	%ATM	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{40}Ar$	$^{39}Ar/^{40}Ar$	%IIC
Sample 91AP12/49 Hornblende									
750	16.8	8.3	120.8	2.1	33.2	1.87	0.001125	0.022353	0.59
900	4.1	2.0	116.9	11.3	56.6	5.70	0.001918	0.015000	1.86
950	3.7	1.8	139.5	16.8	58.6	12.53	0.001984	0.011936	3.55
975	2.9	1.4	164.8	30.5	48.6	10.49	0.001646	0.012453	2.61
1000	7.6	3.8	155.0	6.7	38.1	9.16	0.001291	0.015992	2.39
1025	20.6	10.2	167.3	2.1	22.0	9.62	0.000747	0.018605	2.36
1050	20.0	10.0	173.8	1.8	13.6	9.38	0.000463	0.019801	2.24
1075	19.7	9.8	172.4	1.4	12.0	9.06	0.000409	0.020341	2.17
1100	54.9	27.3	171.7	1.0	7.7	8.86	0.000262	0.021425	2.13
1125	10.1	5.0	175.3	3.9	21.6	9.19	0.000732	0.017817	2.18
1200	16.0	8.0	172.8	2.7	24.8	9.54	0.000840	0.017351	2.28
1275	17.2	8.5	177.3	2.7	31.2	9.84	0.001057	0.015446	2.31
1350	6.4	3.2	287.2	13.8	54.7	10.99	0.001853	0.006081	1.83
Total Gas Age = 169.5 Ma; J = 0.02321									
Sample 91AP12/50 Sericite									
550	52.8	2.1	170.9	0.9	7.8	0.00	0.000266	0.020462	0.00
600	76.8	3.0	167.7	0.9	5.7	0.00	0.000195	0.021347	0.00
660	213.0	8.5	169.3	0.8	1.8	0.00	0.000063	0.022002	0.00
700	276.8	11.0	171.1	0.8	1.8	0.00	0.000063	0.021771	0.00
750	474.0	18.9	171.5	0.8	1.0	0.00	0.000035	0.021899	0.00
780	362.2	14.5	171.1	0.8	1.3	0.00	0.000047	0.021876	0.00
810	306.3	12.2	169.4	0.8	1.1	0.00	0.000040	0.022150	0.00
850	334.2	13.3	168.2	0.7	1.7	0.00	0.000059	0.022188	0.00
890	183.6	7.3	167.6	0.8	3.1	0.00	0.000105	0.021971	0.00
950	105.8	4.2	168.8	0.8	4.1	0.00	0.000139	0.021568	0.00
1025	67.2	2.6	168.9	1.0	8.1	0.00	0.000274	0.020667	0.00
1100	27.9	1.1	161.8	1.6	22.8	0.00	0.000772	0.018143	0.00
1200	14.6	0.5	173.6	4.6	34.7	0.00	0.001174	0.014266	0.00
Total Gas Age = 169.8 Ma; J = 0.002208									
Sample 92AP-EC-150 Alunite									
525	29.7	13.3	277.6	25.2	85.1	0.07	0.002882	0.001821	0.01
550	47.0	21.1	143.6	1.5	29.0	0.01	0.000984	0.017486	0.00
575	92.6	41.6	151.2	0.8	9.8	0.01	0.000331	0.021072	0.00
600	47.2	21.2	161.2	1.1	12.5	0.05	0.000423	0.019116	0.01
625	3.1	1.3	148.6	14.2	55.8	0.70	0.001890	0.010502	0.17
800	2.6	1.1	---	---	---	0.85	0.003479	0.010665	2.38
Total Gas Age = 167.3 Ma; J = 0.002044									
Sample 92AP15/1-71B Alunite									
500	27.4	2.2	107.4	1.4	30.0	0.12	0.001016	0.023345	0.04
525	30.9	2.5	120.2	0.9	10.6	0.03	0.000360	0.026543	0.01
550	181.6	14.8	129.8	0.6	2.7	0.02	0.000092	0.026706	0.00
575	610.9	49.8	145.3	0.6	0.6	0.02	0.000021	0.024269	0.00
600	372.3	30.3	153.4	0.7	0.8	0.03	0.000027	0.022885	0.00
625	0.7	0.0	65.5	105.0	86.2	0.97	0.002919	0.007610	0.47
700	2.0	0.1	63.8	24.7	86.9	0.39	0.002941	0.007427	0.19
Total Gas Age = 143.8 Ma; J = 0.002049									
Sample 92AP15/2-72B Alunite									
550	70.9	3.0	131.5	0.8	16.4	0.03	0.000557	0.022520	0.00
575	604.4	25.8	128.5	0.6	2.1	0.01	0.000072	0.026998	0.00
600	1646.8	70.3	143.9	0.6	2.0	0.02	0.000068	0.024048	0.00
625	12.4	0.5	77.3	3.0	57.0	0.46	0.001931	0.019970	0.02
800	5.8	0.2	151.5	22.4	87.4	0.27	0.002959	0.002917	0.06
Total Gas Age = 139.2 Ma; J = 0.002039									
Sample 92AP15/4-73A Alunite									
450	4.2	0.2	---	---	---	1.15	0.003546	0.009063	1.57
500	7.0	0.4	131.0	6.1	52.9	0.17	0.001792	0.012743	0.04
550	96.9	6.5	166.0	1.4	10.0	0.09	0.000341	0.019033	0.02
600	1044.[illegible]	71.0	166.9	0.7	1.0	0.04	0.000035	0.020819	0.00
625	261.[illegible]	17.7	160.0	0.7	5.3	0.04	0.000181	0.020819	0.01
700	36.[illegible]	2.4	139.6	2.5	49.3	0.09	0.001670	0.012837	0.02
1000	19.7	1.3	54.2	4.1	79.4	0.21	0.002688	0.013738	0.12
Total Gas Age = 162.8 Ma; J = 0.002041									
Sample 92AP3/1-7 Hornblende									
750	19.0	3.8	150.3	5.6	65.8	1.52	0.002227	0.008784	0.39
900	33.8	6.7	164.3	2.6	39.6	1.25	0.001342	0.014133	0.30
950	11.1	2.2	160.3	4.9	46.1	3.37	0.001560	0.012958	0.83
1000	13.5	2.7	159.0	4.7	48.5	8.82	0.001642	0.012476	2.19
1025	29.4	5.9	170.8	2.4	31.2	12.24	0.001058	0.015467	2.88
1050	74.2	14.8	172.1	1.2	20.0	12.07	0.000677	0.017851	2.82
1075	63.6	12.7	168.9	1.2	17.8	11.09	0.000606	0.018693	2.63
1100	46.8	9.4	176.5	1.2	11.9	10.28	0.000405	0.019130	2.36
1125	27.5	5.5	173.1	1.6	17.2	9.76	0.000583	0.018367	2.27
1150	21.1	4.2	172.5	3.0	23.1	9.68	0.000784	0.017100	2.26
1200	38.6	7.7	176.9	2.5	35.9	10.90	0.001216	0.013896	2.50
1250	30.8	6.1	179.9	2.8	39.2	11.60	0.001330	0.012933	2.62
1325	50.3	10.0	179.5	2.1	35.0	11.98	0.001187	0.013864	2.71
1400	38.0	7.6	194.9	7.2	68.7	11.71	0.002328	0.006110	2.49
Total Gas Age = 173.5 Ma; J = 0.002235									

Error estimates at 1σ level; %IIC = Interfering Isotopes Correction
$^{37}Ar/^{39}Ar$, $^{36}Ar/^{40}Ar$, and $^{39}Ar/^{40}Ar$ ratios are corrected for interfering isotopes
--- not determined

MMhb-1, with an assumed age of 520±2 Ma (Sampson and Alexander, 1987), was the standard used for all analyses. Other experimental procedures follow those described by Muecke *et al.* (1988). Analytical data are presented in Tables 1 and 2.

INTERPRETATION

Roughly the first 10% of gas released from both hornblendes yielded relatively young and variable apparent ages and low apparent $^{37}Ar/^{39}Ar$ (proportional to Ca/K) ratios. Subsequent gas defined an age plateau at 173±2 (2σ) Ma for 91AP12/49 and a near plateau at 176±3 (2σ) Ma for 92AP3/1-7, both characterized by relatively high and uniform $^{37}Ar/^{39}Ar$ ratios, and hence probably the best estimates of the ages of the hornblendes. The age spectrum obtained for the hydrothermal sericite sample 91AP12/50 is concordant at 170±2 (2σ) Ma over all but the first and last few per cent of gas released. The four alunites yielded relatively discordant age spectra. The least discordant alunite, 92AP15/4-73A, one of the samples that has well crystallized grains, has an apparent age between 160 and 167 Ma over 95% of the gas release. The remaining three alunite spectra have apparent age gradients, a pattern generally attributed to gas loss resulting from one or more later thermal events. The maximum age attained by 92AP-EC-150, the other well crystallized sample, is 161 Ma. Maximum ages attained by the two poorly-crystallized samples are lower at *circa* 145 to 150 Ma.

DISCUSSION

Analytically distinguishable differences in apparent age were detected in this suite of hornblende, sericite and alunite samples. The age range is at least *circa* 173-176 Ma from the amphibole data to *circa* 160-165 Ma from alunite data. The younger 160-170 Ma ages are probable lower limits for the times of late-stage hydrothermal alteration. Still younger ages from the poorly crystallized alunites are consistent with textural criteria that distinguish a later supergene origin. Similar age spectra are described by Vasconcelos *et al.* (1994), including discussions of supergene alunite and jarosite specimens. Thermal events subsequent to all of these may be reflected in the early gas release from these two alunites and from one of the hornblendes.

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