Age Constraints of Mineralization at the Brenda and Woodjam Cu-Mo±Au Porphyry Deposits – An Early Jurassic Calcalkaline Event, South-Central British Columbia

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KEYWORDS: Brenda mine, Woodjam, calcalkaline porphyry, copper-molybdenum-gold deposit, Early Jurassic mineralization, alteration, geochronology, isotopic age, U/Pb zircon, Re/Os molybdenum, $^{40}Ar/^{39}Ar$, Quesnel arc

INTRODUCTION

British Columbia is well endowed with porphyry deposits, including calcalkaline Cu-Mo±Au and alkaline Cu-Au±Ag porphyry deposits. Most of the well-known deposits display geological characteristics consistent with formation in an island-arc setting, primarily in the Mesozoic arc successions. As a result, exploring for British Columbia Cordilleran porphyry deposits has traditionally focussed in the Mesozoic arc terranes, Stikine and Quesnel, of the Intermontane Belt (Figure 1).

Within this extensive area, explorationists have historically been constrained by "commodity" and/or "deposit model" driven exploration often resulting in missed opportunities for discovery or left large areas under-explored and requiring re-evaluation when "new models" appear. For example, calcalkaline Cu-Mo±Au deposits not only have different alteration/mineralization footprints than alkaline Cu-Au±Ag porphyry deposits, they are associated with different plutonic suites and may form either along and/or orthogonal to the arc axis. Therefore knowledge of the paleo-architecture and the age and type of porphyry target is important when planning an exploration strategy or interpreting the regional and/or property scale geophysical, geochemical and mineral assemblage data. In addition, large areas of Stikine and Quesnel terranes are mantled by younger basalts and overburden. Exploration is particularly difficult and expensive in these areas, necessitating highly focused programs that rely on subtle techniques for recognition and evaluation of mineral/alteration vectors that characterize different styles of porphyry deposits.

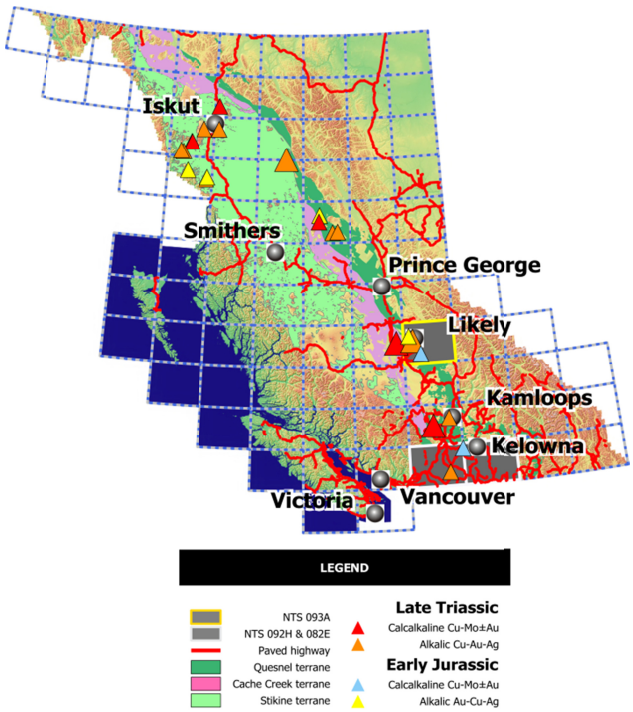

Figure 1. Location of Woodjam (southwest of Likely) and Brenda mine (west of Kelowna) areas, south-central British Columbia. The areas covered by Figure 2 and 3 are shown on the respective NTS map sheets as blue triangles. Also shown are pre-185 Ma calcalkaline Cu-Mo±Au (red), alkaline Cu-Au±Ag (orange) and Au-Cu±Ag (yellow) porphyry deposits in Quesnel and Stikine terranes (after Wheeler and McFeely, 1991).

Southern Quesnel contains at least three main Mesozoic magmatic suites that display copper porphyry mineralization. The Guichon and Copper Mountain suites are well known and relatively well explored in the exposed parts of Quesnel (Woodsworth *et al.*, 1991). The youngest suite, the Takomkane/Wildhorse is not.

Calcalkaline plutons in Southern BC that were emplaced in the middle to late parts of the Early Jurassic (Takomkane/Wildhorse suites, Breitsprecher *et al.*, 2010) have historically been ignored or designated as "poorly mineralized" (*e.g.* Breitsprecher *et al.,* 2010). Herein we show that plutons of this age can be significant Cu-Mo-Au producers. Geochronological evidence is presented that shows Cu-Mo±Au mineralizing events at Brenda

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(Pennask batholith) and Woodjam-Southeast zone (Takomkane batholith) to be essentially synchronous. We assert that the Takomkane/Wildhorse magmatic belt is not an exploration dud, but rather is highly prospective along its length – currently known to extend 375 km.

This report aims to briefly outline the geological setting, age, mineralization and alteration within the Takomkane/Wildhorse magmatic belt as displayed at two deposits, the past producing Brenda mine, and the actively developing Woodjam prospect.

LOCATION & GEOLOGICAL SETTING

The Brenda mine and the Woodjam property are located within the Quesnel terrane (Figure 1), a stack of Paleozoic and Mesozoic arcs that nucleated on a crustal ribbon that lay adjacent to ancestral North America (ANA). Subduction of ancient Pacific Ocean crust to form the proto-Quesnel and conjoined Stikine arcs is believed to have begun in the Devonian (*e.g.* Logan *et al.*, 2000; Beatty *et al.*, 2006). Arc growth continued sporadically with a significant pulse in the Late Triassic–Early Jurassic (212-192 Ma). Na-and K-rich volcanic arc magmatism evolved during this 20 Ma epoch with the emplacement into the arc of three main Cordilleran-wide plutonic suites: the Late Triassic Guichon batholith (212-208 Ma), Latest Triassic Copper Mountain (206-200 Ma) and Early Jurassic Takomkane/Wildhorse (197-193 Ma) suites (Woodsworth *et al.* 1991; Logan and Mihalynuk , in review) and their associated porphyry mineralizing events. In southern British Columbia these respective mineralizing events produced Highland Valley and Gibraltar; Copper Mountain, Afton and Mountain Polley; and Brenda and Woodjam. Normal arc subduction beneath the composite Quesnel terrane ceased following its accretion to ANA in Early Jurassic time (~186 Ma, Nixon *et al.*, 1993; herein we use the Jurassic time scale of Palfy *et al.*, 2000).

Brenda mine (MINFILE 092HNE047)

The Brenda copper-molybdenum deposit is hosted within the "Brenda stock", an informal subdivision of the much larger, polyphase granodiorite and quartz diorite of the Early Jurassic Pennask batholith. It is located about 22 km west of Peachland. Carr (1967) mapped five, northerly-trending textural phases of quartz diorite, in the vicinity of the Brenda mine distinguished by slight variations in grain size and modal mineralogy. Progressing eastward from the hornfelsed contact with Nicola Group volcaniclastic rocks, the five phases are:

1) medium quartz diorite,
2) speckled quartz diorite,
3) uniform quartz diorite,
4) porphyritic quartz diorite, and
5) fine quartz diorite (Figure 2).

Typical mineral contents average: quartz (25%), plagioclase (50%), potassium feldspar (5-20%), hornblende (5-7%) and biotite (5-7%). Later work by Soregaroli and Whitford (1976) simplified the geology to only two units. Unit 1, is a marginal phase with more abundant mafic minerals (hornblende>biotite) and angular quartz grains, that embraces most of Carr's phases 1, 2, and 3. Unit 2 is characterised by fewer mafic minerals (biotite>hornblende), euhedral biotite phenocrysts and subhedral quartz grains, that include Carr's phases 4 and 5 (Figure 2). The contact between the two units is described as typically diffuse, but where sharp, Unit 2 is chilled against Unit 1(Soregaroli and Whitford, 1976). Several ages and compositions of pre and post-ore dikes cut the stock. The deposit is approximately 390 m from the contact with Nicola Group rocks to the west (Figure 2).

Mineralization is confined almost entirely to veins which cut relatively unaltered quartz diorite. Vein walls can be sharp and/or diffuse where gangue and sulphides have variably infiltrated and replaced the wall rock. Vein density within the Brenda Mines orebody is not uniform. It ranges from less than 9 veins per metre near the periphery of the orebody to 63 per metre and locally 90 per metre near the centre (Oriel, 1972). Potassic alteration forms narrow potash feldspar or biotite alteration envelopes related to sulphide mineralization, where as propylitic alteration predates and accompanies some of the late-stage veining events. Soregaroli (1968) and Oriel (1972) studied the mineralogy, geometry and crosscutting relationships of veins at Brenda and developed the following paragenesis:

Stage 1. Biotite-chalcopyrite

Stage 2. Quartz-potassium feldspar-sulphide. These veins form the bulk of the mineralization. They are composed of quartz and potassium feldspar, with variable quantities of chalcopyrite, molybdenite and pyrite (Figure 3).

Stage 3. Quartz-molybdenite-pyrite

Stage 4. Epidote-sulphide-magnetite

Stage 5. Biotite; calcite; quartz.

Production at the mine began in early 1970 and officially ceased June 08, 1990 after milling 181.7 Mt of ore grading 0.22% Cu and 0.064% Mo (mill head grades; Weeks *et al.*, 1995). Production totalled 0.27 Mt of copper, 0.068 Mt Mo and 2.28 t Au (MINFILE).

Woodjam (MINFILE 093A 078)

The Woodjam property is located 35 km southeast of the Mount Polley copper-gold mine. It is underlain by hornfelsed Late Triassic Nicola Group volcanic and related sedimentary rocks within the contact metamorphic aureole of the Late Triassic to Early Jurassic Takomkane batholith (~202-193 Ma); a composite, quartz-saturated calcalkaline intrusion composed of hornblende monzodiorite to hornblende-biotite monzogranite (Figure 4). Intrusive rocks dominate the eastern portion of the

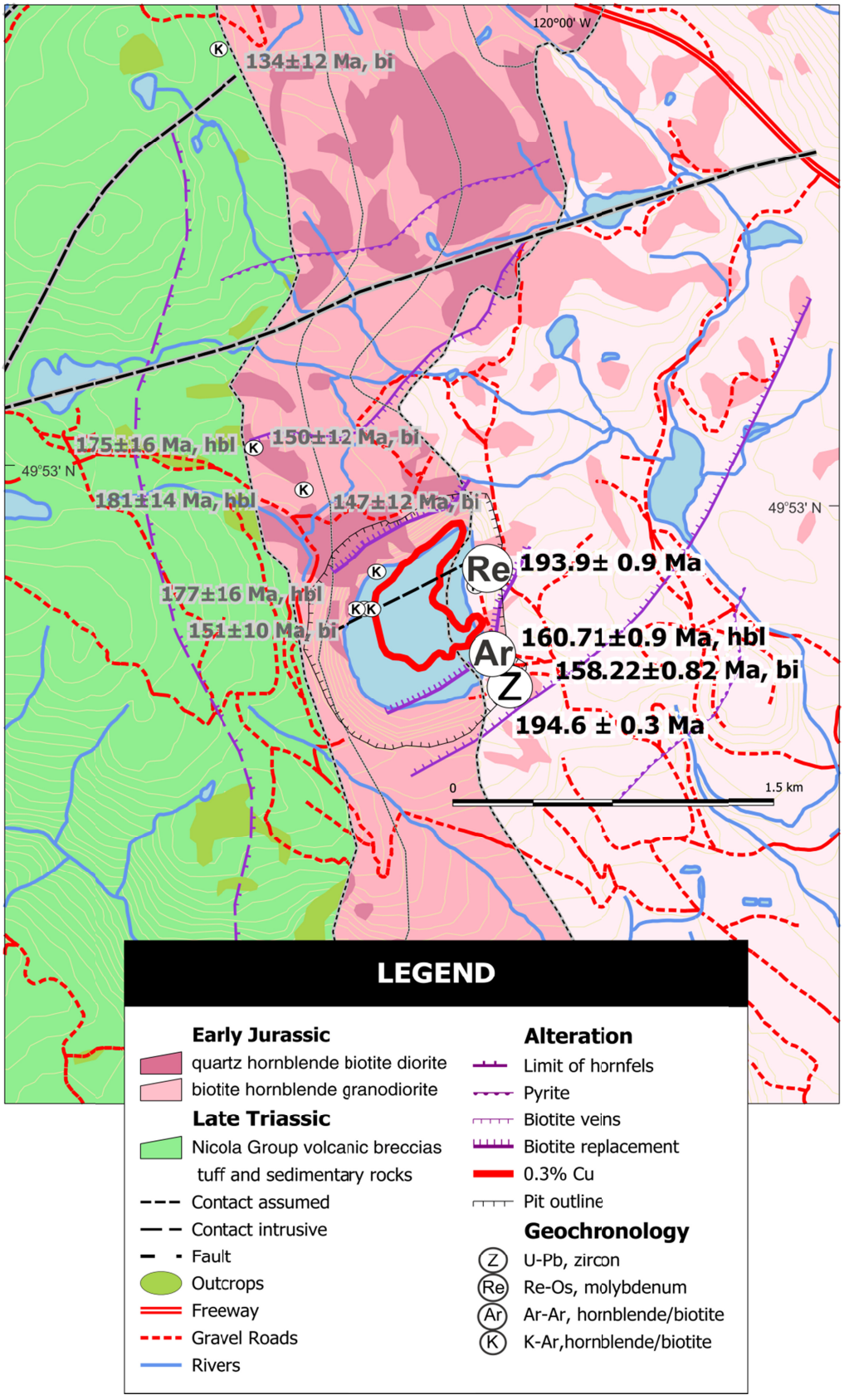

Figure 2. Local geology of the Brenda mine area showing location of geochronological samples collected as part of this study (large symbols) and those collected previously by other authors (smaller symbols) as reported by Breitsprecher and Mortensen (2004). Geological contacts adapted from Carr (1967), Soregaroli and Whitford (1976) and Dawson and Ray (1988).

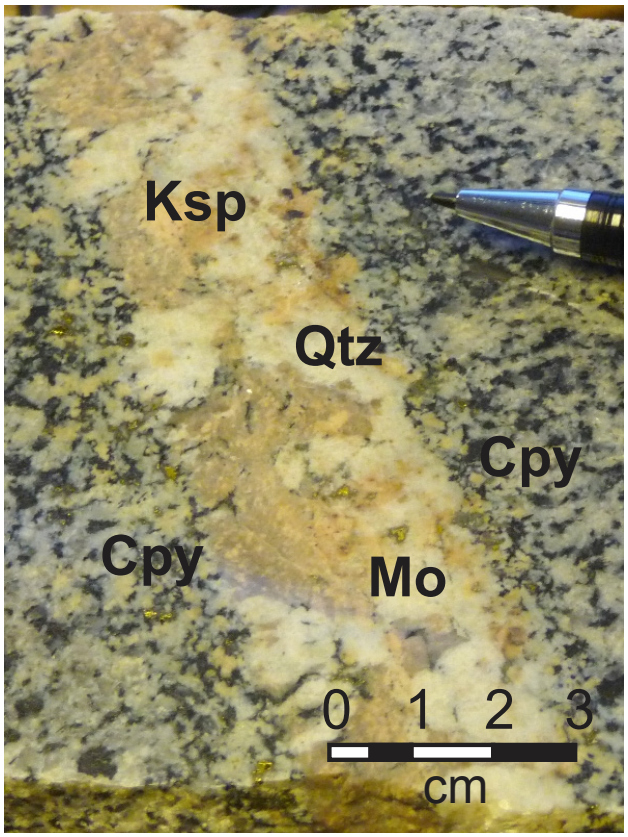

Figure 3. Stage 2 quartz-potassium feldspar-sulphide vein cutting hornblende±biotite granodiorite of the Brenda stock - Pennask batholith. Note diffuse vein boundary with chalcopyrite (Cpy) >>pyrite replacement peripheral to vein as well as chalcopyrite and molybdenite (Mo) interstitial to potassium feldspar (Ksp) and quartz (Qtz) vein gangue.

property. To the west, Miocene to Pleistocene alkali olivine flood basalts of the Chilcotin Group overlie Nicola Group volcanic rocks (Wetherup, 2000; Schiarizza *et al.*, 2009a). Cu-Mo±Au mineralization is hosted within the intrusion (Southeast zone) and Cu-Au±Mo mineralized quartz stockwork and breccias (Megabuck, Deerhorn, Spellbound and Takom zones) are hosted in the volcanic and volcaniclastic country rock up to 1.5 km west of the north-trending contact with the batholith (Logan *et al.*, 2007).

Mineralization at Megabuck crosscuts upper volcaniclastic units of the Nicola Group and consists of an early quartz-magnetite-chalcopyrite±gold stockwork system overprinted by carbonate±chalcopyrite-pyrite veinlets. A pyritic halo surrounds the mineralized stockwork. Analogy with the alkalic porphyry mineralization at Mount Polley mine has been suggested, but the alkaline Cu-Au porphyries are typically quartz undersaturated. In addition, the alkalic porphyries are not characterized by quartz stockwork, and they are Late Triassic in age (Logan and Bath, 2006).

The Southeast zone is a blind deposit that was discovered in 2007 by drilling a well-defined (>1500 m wide), overburden-covered IP chargeability anomaly. Three widely spaced vertical diamond-drill holes completed during the 2007 program were mineralized from top to bottom (each hole reaching ~300 m depth). The best grades came from hole WJ-07-79, which intersected 203.55 m grading 0.34% Cu and 0.014% Mo (Fjordland Exploration Inc., 2008). Follow-up drilling to date totals 18 holes and indicates that the pyrite, chalcopyrite and molybdenite mineralization is vertically zoned from copper-gold mineralization (1.01% Cu, 0.44 g/t Au over 200.8 m) to copper- molybdenum (0.24% Cu, 0.014% Mo over 60.0 m) mineralization with increasing depth (Peters, 2009; Fjordland website). Mineralization in the Southeast zone consists of pyrite, chalcopyrite, molybdenite and trace bornite, which occur along fractures, in quartz veinlets and as disseminations (Figure 5). It is hosted entirely in quartz monzonite and granodiorite of the Takomkane batholith.

PREVIOUS AGE DATING

Isotopic age determinations for mineralized rock assemblages sampled in the vicinity of the Brenda deposit have been reported by various authors (Figures 2, 6). Parrish and Monger (1992) reported U/Pb dates for zircons and titanite separates. White *et al.* (1968) and Oriel (1972) report a number of K-Ar dates from whole rock, hornblende and biotite samples. A sample collected 13 km north of the Brenda pit returned an Early Jurassic U-Pb crystallization age from zircon, and a sample collected 13 km southwest of the pit yielded cooling ages between 150 and 140 Ma for titanite (Parrish and Monger, 1992). The titanite corroborates similar age brackets for K/Ar, biotite cooling ages at Brenda mine. The historical K/Ar data from biotite and hornblende separates for the Brenda mine suggested a ~176 Ma age for primary (?) hornblende and a ~146 Ma age for secondary, hydrothermal (?) biotite, with an interpretation that the pluton that hosts the deposit is older and not the causative phase assuming that the secondary biotite is dating the mineralizing event (Soregaroli and Whitford, 1976). To test this hypothesis we collected three samples from the vicinity of Brenda pit; one for U-Pb analyses, one for Ar-Ar and a mineralized vein sample for Re-Os age modelling.

Age dating in the vicinity of the Woodjam Property includes U-Pb, zircon constraints on the crystallization age of a number of phases of the Takomkane batholith and cooling ages established by Ar-Ar step heating of hornblende and feldspar mineral separates (Logan *et al.*, 2007; Schiarizza *et al.*, 2009a&b). Schiarizza (personal communication) has provided unpublished zircon ages of 196.84 ±0.22 Ma for the Woodjam Creek phase of the Takomkane batholith and a rough age estimate of *ca.* 204 Ma for an unnamed coarse plagioclase porphyry stock; both are shown on Figure 4. In addition a drill core sample (WJ04-37) of quartz-feldspar-biotite porphyry dike that cuts mineralization in the Megabuck Cu-Au zone returned an undisturbed biotite cooling age of 163.67 ±0.83 Ma, providing an upper age limit for the Cu-Au±Mo mineralization (Logan *et al.*, 2007).

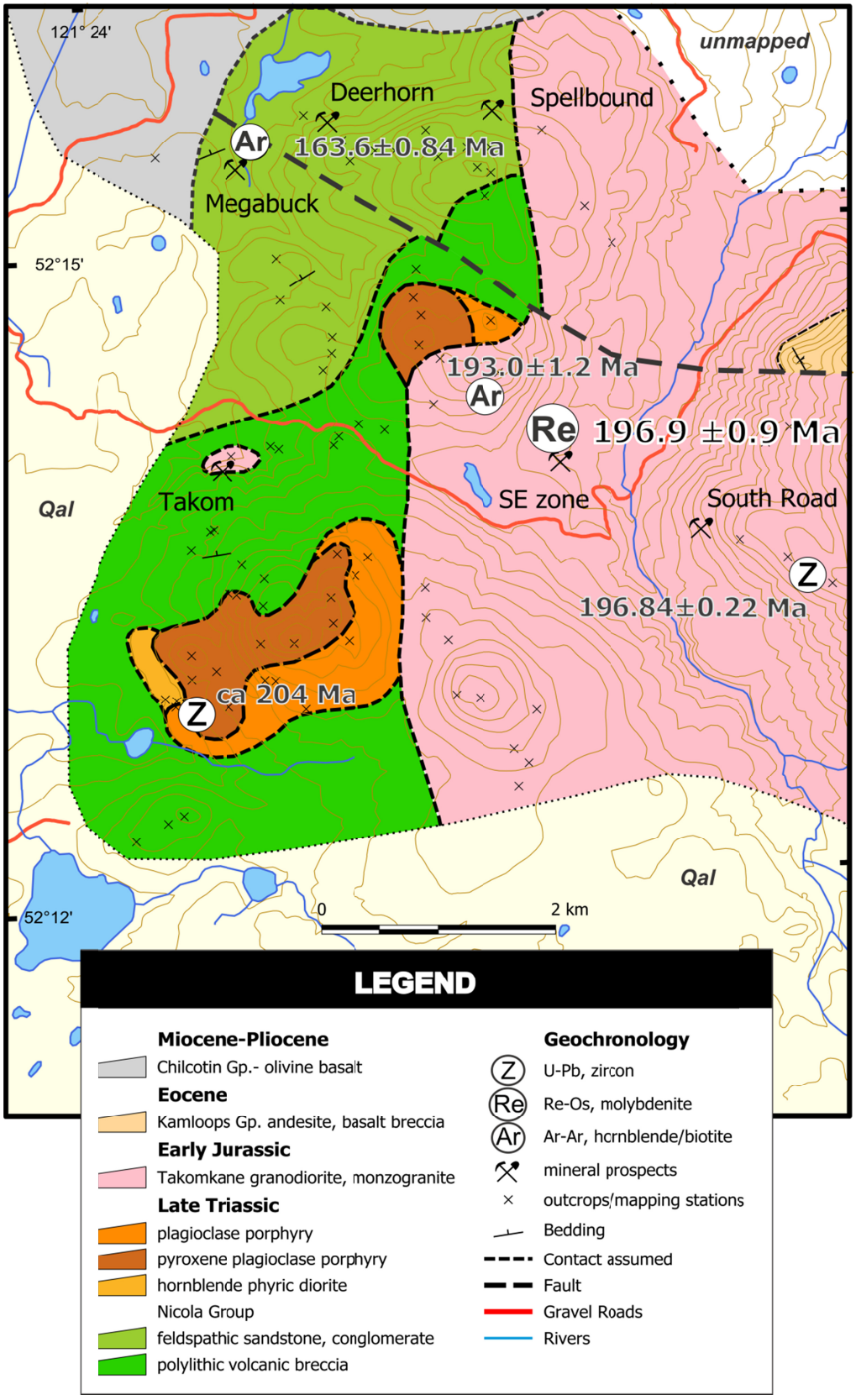

Figure 4. Local geology of the Woodjam property showing location of geochronological sample collected as part of this study (large symbol) and those collected previously by other authors (smaller symbols) as reported by Logan *et al.* (2007) and Schiarizza (personal communication, 2010). Geological contacts from Schiarizza *et al.* (2009b).

Figure 5. High-grade molybdenite (Mo) – chalcopyrite (Cpy) mineralized fracture cutting weakly altered hornblende quartz granodiorite of Takomkane batholith. Drill core from Southeast zone, drillhole WJ07-79.

SAMPLES FOR AGE DETERMINATION

To better understand the temporal relationships between the magmatic, hydrothermal and cooling history of the Brenda stock; U-Pb, Re-Os and Ar-Ar dating techniques were employed on zircon, molybdenite, and hornblende and biotite mineral separates respectively (Figure 2). Three samples were selected for isotopic age determination. Two samples of the weakly altered and mineralized hornblende-biotite-quartz diorite were collected and submitted to the Pacific Centre for Isotopic and Geochemical Research (PCIGR) at the Department of Earth and Ocean Sciences, The University of British Columbia. A third sample of mineralized quartz vein that contained medium-grained pyrite, chalcopyrite and coarse platelets of molybdenite was collected and analysed at the Radiogenic Isotope Facility at the University of Alberta.

Brenda

Hornblende±biotite granodiorite

A 20 kg sample (07JLO32-225) of hornblende-biotite granodiorite was collected from an upper bench outcropping at the southeast end of the pit (Zn 10, UTM 715234E, 5529257N). The granodiorite, a mesocratic, medium grained intrusive is comprised of equigranular intergrowths of plagioclase (40%) and potassium feldspar (25%), sub-rounded quartz (20%), chloritic hornblende and vitreous euhedral biotite (5-15%, total mafics) with sparse poikilitic potassium feldspar megacrysts. Accessory titanite, apatite and variable amounts of interstitial magnetite comprise noticeable but minor disseminated grains.

Zircon, hornblende and biotite were separated from the granodiorite and analysed separately to constrain the cooling history of the pluton, and its alteration and mineralizing system.

Chalcopyrite-molybdenum-pyrite bearing quartz veins

The molybdenite sample (07JLO32-226) submitted

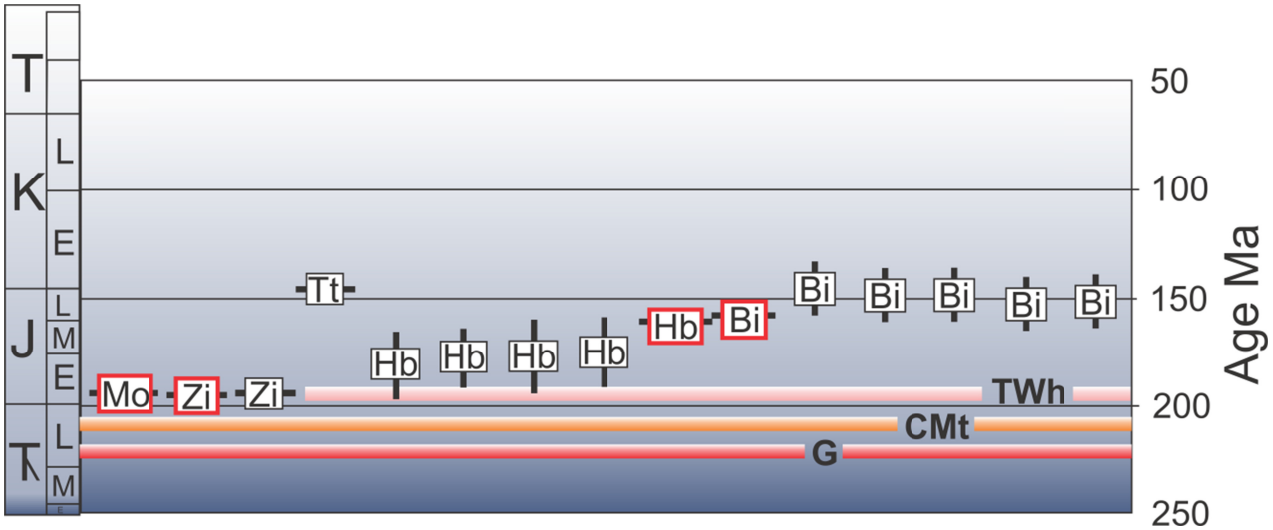

Figure 6. Age's plot of Re/Os (Mo), U/Pb (Zi & Tt), K/Ar (Hb), Ar/Ar (Hb & Bi) and K/Ar (Bi) analyses of samples from the area around the Brenda mine. Red squares are samples from this study, black squares compiled from White, Harakal and Carter (1968), Oriel (1972) and Parrish and Monger (1992). The zircon and molybdenite dates are interpreted to be crystallization and mineralization ages, titanite, hornblende and biotite show consistently younger ages that reflect a complicated cooling and/or resetting history that is evident with both K/Ar and Ar/Ar analyses. 2 σ error bars for each analysis are shown. Age spans for the Guichon (G), Copper Mountain (CMt) and Takomkane-Wildhorse (TWh) plutonic suites also shown.

for Re-Os dating was collected from the northeast corner of the Brenda pit (Zone 10, UTM 715279E, 5529449N) from a 35 cm wide, steeply dipping northeast trending bullish quartz vein mineralized with chalcopyrite, disseminated pyrite and fracture-filling molybdenite (Figure 7). The mineralogy, orientation and its' crosscutting relationship with pegmatitic feldspar-quartz veins suggest that the molybdenite sampled comes from a Stage 3 vein (Soregaroli and Whitford, 1976).

Woodjam - Southeast zone

Hornblende±biotite quartz monzonite

A well-mineralized interval of Takomkane batholith quartz monzonite containing molybdenum was sampled from an 8 cm long sample of split drillcore (provided by B. Laird, of Mincord Exploration Consultants Ltd.) from 317 m below the collar of diamond-drill hole WJ07-79 (Zn 10, 613104E, 5788240N). Molybdenite and chalcopyrite occupy millimetre-wide quartz veins and fractures cutting weak potassium-altered and silicified medium-grained hornblende quartz monzonite. Molybdenite was separated from the quartz monzonite and analysed to obtain a model age for mineralization.

U-PB AND ^{40}AR/^{39}AR GEOCHRONOLOGY METHODS

Sample preparation and analytical work for both the U-Pb and the ^{40}Ar/^{39}Ar isotopic ages presented herein was conducted at the Pacific Centre for Isotopic and Geochemical Research (PCIGR) at the Department of Earth and Ocean Sciences, The University of British Columbia.

Zircon was separated from the "Brenda stock" sample JLO07-32-225 using standard mineral separation techniques (crushing, grinding, Wilfley (wet shaker) table, heavy liquids and magnetic separation), followed by hand picking. Details of the separation techniques can be found in Logan *et al.* (2007). Air abraded single zircon grains were analysed with results listed in Table 1 and plotted in Figure 8a. U-Pb isotopic age determinations were obtained by Thermal Ionization Mass Spectroscopy (U-Pb ID-TIMS). Details of the both the mineral separation and analytical techniques are presented in (Logan *et al.*, 2007).

^{40}Ar/^{39}Ar isotopic age determinations were obtained by the laser-induced step-heating technique. Details of the analytical techniques are presented in (Logan *et al.*, 2007). Hornblende and biotite were separated from a granodiorite phase of the Brenda stock and analysed separately to constrain its cooling history.

U-Pb geochronology results

U-Pb analyses of five zircon grains separated from the Brenda granodiorite were determined by thermal ionization mass spectrometry (TIMS) technique.

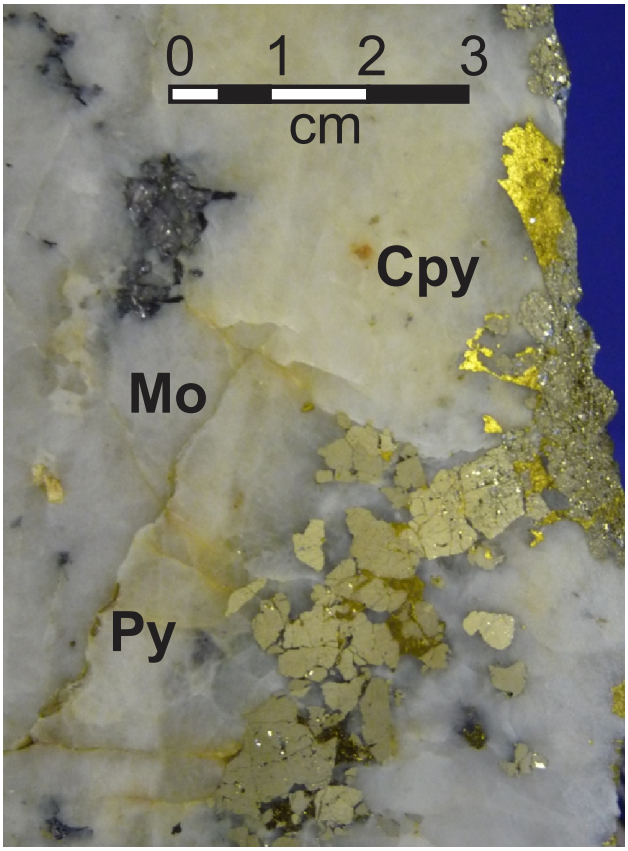

Figure 7. Stage 3 quartz vein mineralized with disseminated pyrite (Py), coarse blebby chalcopyrite (Cpy) and fracture-filling molybdenite (Mo). Re/Os sample JLO07-226.

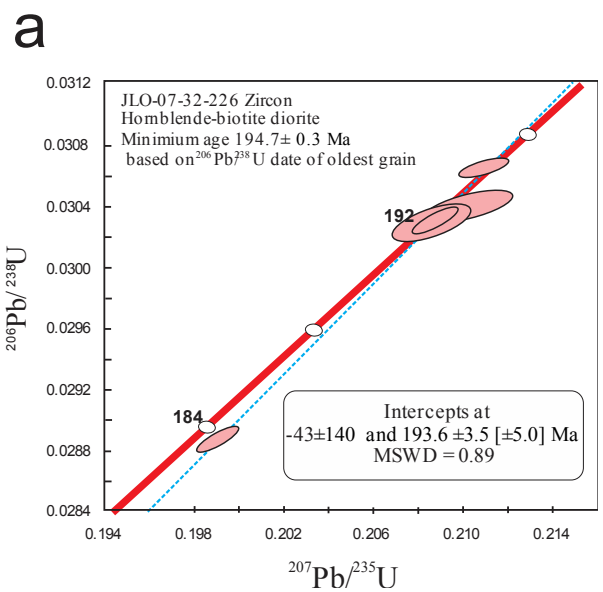

Figure 8a. Concordia plot for U/Pb TIMS data for sample JLO07-32-226. 2 σ error ellipses for individual analytical fractions are red. Minimum age 194.7 ±0.3 Ma based on ^{206}Pb/^{238}U date of oldest grain. Concordia bands include 2 σ errors on U decay constants.

Analysed mineral fractions and results are presented in Table 1, and the data are illustrated in Figure 8a.

Of the five grains dated, four overlap Concordia at the 2 σ confidence level between about 192-195 Ma and

Table1. U-Pb Thermal Ionization Mass Spectrometry analytical data for zircon from hornblende, biotite quartz diorite of the Brenda stock, sample JLO07-32-225.

		Compositional Parameters							Radiogenic Isotope Ratios										Isotopic Ages						
Sample	Wt. mg	U ppm	Th/U	Pb ppm	$^{206}Pb^*$ x10^{-13} mol	mol % $^{206}Pb^*$	Pb^*/Pb_c	Pb_c (pg)	$^{206}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	% err	$^{207}Pb/^{235}U$	% err	$^{206}Pb/^{238}U$	% err	corr. coef.	$^{207}Pb/^{206}Pb$	±	$^{207}Pb/^{235}U$	±	$^{206}Pb/^{238}U$	±	% disc
	(a)	(b)	(c)	(d)	(c)	(e)	(e)	(e)	(e)	(f)	(g)	(g)	(h)	(g)	(h)	(g)	(h)		(i)	(h)	(i)	(h)	(i)	(h)	
JLO-07-32-225																									
A	0.013	202	0.351	6.2	3.3605	99.55%	65	1.24	4142	0.112	0.050188	0.590	0.210449	0.690	0.030412	0.264	0.545	203.69	13.68	193.93	1.22	193.13	0.50	5.19
B	0.009	251	0.376	7.8	2.9461	99.58%	70	1.01	4452	0.120	0.049979	0.239	0.208895	0.367	0.030314	0.229	0.773	194.00	5.56	192.62	0.64	192.51	0.43	0.77
C	0.008	368	0.375	10.9	3.3267	99.56%	67	1.21	4212	0.120	0.050012	0.239	0.199138	0.372	0.028879	0.240	0.778	195.53	5.56	184.40	0.63	183.53	0.43	6.14
D	0.007	448	0.376	13.8	3.6796	99.76%	122	0.73	7699	0.120	0.049945	0.553	0.208626	0.683	0.030295	0.328	0.598	192.42	12.87	192.40	1.20	192.40	0.62	0.01
E	0.006	113	0.357	3.6	0.9137	99.28%	40	0.54	2586	0.113	0.049906	0.340	0.210936	0.422	0.030655	0.169	0.637	190.60	7.92	194.34	0.75	194.65	0.32	-2.12

(a) A, B etc. are labels for abraded single zircon grains.
(b) Fraction masses determined on Sartorious SE2 ultramicrobalance to +/- 1 microgram.
(c) Nominal U and total Pb concentrations subject to uncertainty in fraction masses.
(d) Model Th/U ratio calculated from radiogenic 208Pb/206Pb ratio and 207Pb/235U age.
(e) Pb* and Pbc represent radiogenic and common Pb, respectively; mol % $^{206}Pb^*$ with respect to radiogenic, blank and initial common Pb.
(f) Measured ratio corrected for spike and fractionation only. Mass discrimination of 0.23% +/- 0.05%/amu +/- 1s, absolute, based on analysis of NBS-982; all Daly analyses.
(g) Corrected for fractionation, spike, and common Pb; up to 1 pg of common Pb was assumed to be procedural blank: 206Pb/204Pb = 18.50 ± 1.0%; 207Pb/204Pb = 15.50 ± 1.0%; 208Pb/204Pb = 38.40 ± 1.0% (all uncertainties 1-sigma). Excess over blank was assigned to initial common Pb with Stacey and Kramers (1975) model Pb composition at 195 Ma.
(h) Errors are 2-sigma, propagated using the algorithms of Schmitz and Schoene (2007) and Crowley et al. (2007).
(i) Isotopic dates are calculated using the decay constants l238=1.55125E-10 and l235=9.8485E-10 (Jaffey et al., 1971). 206Pb/238U and 207Pb/206Pb ages corrected for initial disequilibrium in 230Th/238U using Th/U [magma] = 3.
(j) Corrected for fractionation, spike, and blank Pb only.

one is normally discordant, lying slightly off Concordia at about 184 Ma. This data array is likely the result of Pb loss from at least four of the five analysed grains (Figure 8a, Table 1). The $^{206}Pb/^{238}U$ date for the oldest grain, at 194.7 Ma, is taken as a minimum age of crystallization for the rock, which assumes that none of the analysed grains contain older inherited zircon.

$^{40}Ar/^{39}Ar$ cooling age

Hornblende separated from the Brenda stock yields a complicated argon release spectra with older apparent ages in the low-temperature steps (1-5) indicating probable excess argon. The five-step plateau age of 160.7 ±0.9 Ma is calculated from the final 40.8% of the total ^{39}Ar (Figure 8b). Gas measurements obtained during each of the heating steps are presented in Table 2.

Biotite from the same sample Brenda stock granodiorite gave a well-defined plateau age of 158.22 ±0.82 Ma, represented by 83.7% of the total ^{39}Ar released (Figure 8c). Gas measurements obtained during each of the heating steps are presented in Table 3. The inverse isochron results in 11 points which define a poor quality isochron with an age of 158.7 ±1.1 Ma, an initial $^{40}Ar/^{36}Ar$ of 211 ±160 Ma, and a MSWD of 1.07.

RE-OS GEOCHRONOLOGY METHODS

Molybdenite was separated from the rock samples by metal-free crushing and milling, and concentrated using gravity and magnetic methods following Selby and Creaser (2004). The Re content was established for each molybdenite separate, to determine optimal spiking for the subsequent measurement of Re and Os by isotope dilution using a mixed double spike solution containing isotopically enriched ^{185}Re and isotopically enriched ^{188}Os and ^{190}Os.

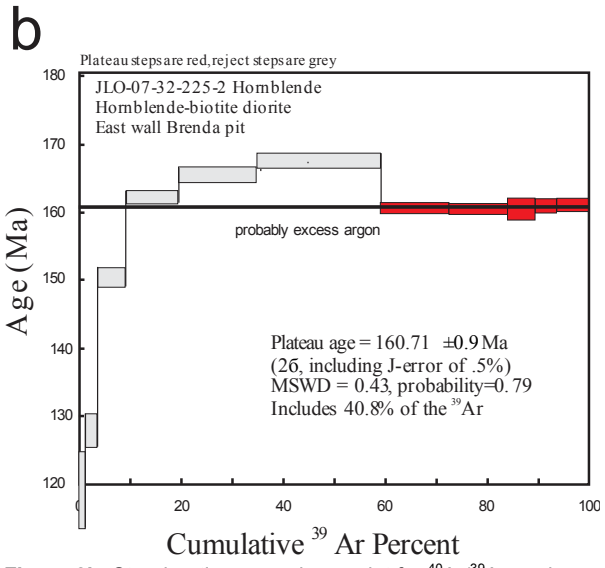

Figure 8b. Step-heating gas release plot for $^{40}Ar/^{39}Ar$ analyses for hornblende sample JLO07-32-225-2 hornblende.

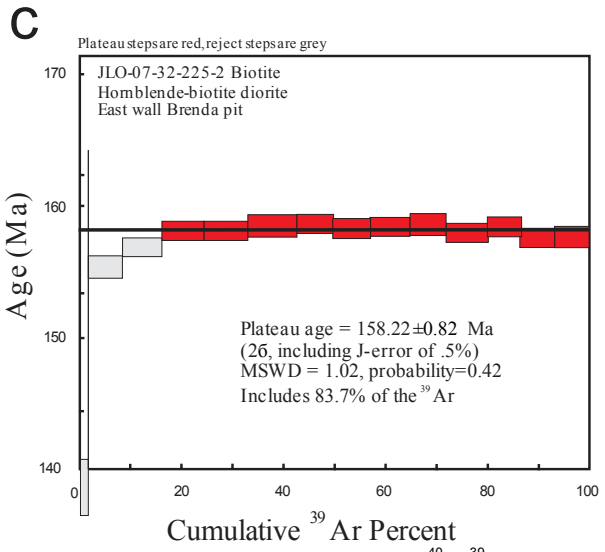

Figure 8c. Step-heating gas release plot for $^{40}Ar/^{39}Ar$ analyses for biotite sample JLO07-32-225-2.

Table 2. $^{40}Ar/^{39}Ar$ step heating gas release data from sample JLO07-32-225-2 hornblende.

07JLO32-225-2	Hornblende									
Laser	Isotope Ratios									
Power(%)	$^{40}Ar/^{39}Ar$	$^{38}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	Ca/K	Cl/K	$\%^{40}Ar$ atm	f ^{39}Ar	$^{40}Ar^*/^{39}ArK$	Age
2	195.8500±0.0417	0.4150±0.0670	-0.1166±18.0450	0.5249±0.0583	0	0.073	79.32	0.08	38.143±7.094	327.07±55.63
2.3	42.6956 0.0149	0.0992 0.0827	0.1174 1.5399	0.0994 0.0257	0.461	0.016	68.72	1.25	13.071 0.662	118.88 5.83
2.6	20.6180 0.0096	0.0360 0.1174	0.0945 0.9724	0.0218 0.0404	0.371	0.004	30.16	2.34	14.070 0.291	127.65 2.55
2.9	19.5351 0.0060	0.0374 0.0371	0.2265 0.2086	0.0095 0.0440	0.888	0.005	13.6	5.6	16.689 0.160	150.44 1.39
3.2	19.1815 0.0054	0.0962 0.0197	0.7585 0.0195	0.0041 0.0559	2.974	0.019	5.27	10.34	18.055 0.121	162.22 1.04
3.5	19.3676 0.0067	0.1537 0.0176	1.1309 0.0233	0.0037 0.0396	4.436	0.032	4.41	15.4	18.438 0.134	165.50 1.15
3.8	19.4876 0.0067	0.1589 0.0159	1.7967 0.0159	0.0038 0.0217	7.055	0.033	4.01	24.23	18.670 0.130	167.50 1.12
4.1	18.3525 0.0046	0.0745 0.0187	0.5371 0.0386	0.0018 0.0499	2.105	0.014	2.03	13.31	17.876 0.088	160.68 0.75
4.3	18.1525 0.0042	0.0709 0.0260	0.5589 0.0422	0.0012 0.0934	2.191	0.013	1.05	11.66	17.848 0.084	160.44 0.72
4.5	18.2846 0.0076	0.0573 0.0786	0.4295 0.1939	0.0015 0.2607	1.684	0.01	1.16	5.15	17.851 0.179	160.47 1.54
4.8	18.3992 0.0058	0.0636 0.0563	0.5870 0.0847	0.0018 0.1195	2.301	0.011	1.37	4.46	17.902 0.124	160.91 1.07
5.4	18.3739 0.0053	0.0691 0.0469	0.6906 0.0970	0.0017 0.0886	2.708	0.013	1.42	6.19	17.930 0.107	161.15 0.92
Total/Average	19.2832±0.0011	0.1050±0.0042	1.9943±0.0031	0.0050±0.0067	3.655	0.02		100	17.974±0.025	

J-error = 0.005211±0.000008

Volume ^{39}ArK = 385.12

Integrated Date = 161.53±0.49

Volumes are $1x10^{-13}$ cm^3 NPT

Neutron flux monitors: 28.02 Ma FCs (Renne et al., 1998)

Isotope production ratios: ($^{40}Ar/^{39}Ar$)K=0.0302±0.00006, ($^{37}Ar/^{39}Ar$)Ca=1416.4±0.5, ($^{36}Ar/^{39}Ar$)Ca=0.3952±0.0004, Ca/K=1.83±0.01($^{37}ArCa/^{39}ArK$).

Table 3. $^{40}Ar/^{39}Ar$ step heating gas release data from sample JLO07-32-225-2 biotite.

07JLO32-225-2	Biotite									
Laser	Isotope Ratios									
Power(%)	$^{40}Ar/^{39}Ar$	$^{38}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	Ca/K	Cl/K	$\%^{40}Ar$ atm	f ^{39}Ar	$^{40}Ar^*/^{39}ArK$	Age
2	123.5134±0.0287	0.1456±0.1915	0.2985±0.0827	0.3857±0.0491	1.168	0.016	93.21	0.04	7.862±4.704	72.34±42.42
2.3	31.9991 0.0076	0.0549 0.1191	0.1600 0.0343	0.0745 0.0372	0.621	0.006	68.65	0.46	9.776 0.811	89.52 7.25
2.6	19.1244 0.0045	0.0334 0.0473	0.0606 0.0411	0.0182 0.0427	0.235	0.004	27.4	1.21	13.648 0.240	123.79 2.10
2.9	19.4652 0.0043	0.0322 0.0154	0.0258 0.0282	0.0072 0.0286	0.1	0.004	10.77	6.75	17.280 0.098	155.35 0.85
3.1	18.6313 0.0044	0.0320 0.0250	0.0179 0.0572	0.0038 0.0209	0.069	0.004	5.85	7.8	17.456 0.082	156.86 0.70
3.3	17.9873 0.0044	0.0307 0.0211	0.0200 0.0375	0.0011 0.0619	0.078	0.004	1.67	8.35	17.602 0.081	158.12 0.70
3.5	17.8601 0.0043	0.0314 0.0353	0.0194 0.0238	0.0007 0.0881	0.075	0.004	0.97	8.5	17.602 0.080	158.12 0.69
3.7	17.8887 0.0051	0.0312 0.0381	0.0278 0.0272	0.0007 0.0609	0.108	0.004	0.9	9.56	17.648 0.093	158.51 0.80
3.8	17.9001 0.0045	0.0314 0.0240	0.0218 0.0351	0.0006 0.1005	0.084	0.004	0.78	6.98	17.669 0.083	158.69 0.71
4	17.8708 0.0049	0.0340 0.0403	0.0580 0.0244	0.0007 0.0854	0.223	0.005	0.88	7.36	17.625 0.089	158.32 0.77
4.2	17.8661 0.0044	0.0313 0.0206	0.0367 0.0297	0.0006 0.0865	0.141	0.004	0.77	7.79	17.642 0.081	158.47 0.69
4.4	17.9249 0.0048	0.0318 0.0451	0.0406 0.0221	0.0007 0.1042	0.156	0.004	0.96	7.27	17.663 0.089	158.64 0.77
4.6	17.8118 0.0045	0.0315 0.0207	0.0448 0.0265	0.0006 0.0916	0.172	0.004	0.81	7.99	17.582 0.082	157.95 0.71
4.8	17.9181 0.0046	0.0322 0.0244	0.0488 0.0290	0.0008 0.0685	0.187	0.004	1.06	6.5	17.634 0.085	158.40 0.73
5	17.8185 0.0046	0.0317 0.0181	0.0783 0.0235	0.0008 0.0954	0.301	0.004	1.05	6.54	17.538 0.086	157.57 0.74
5.3	17.8425 0.0047	0.0318 0.0274	0.1172 0.0152	0.0009 0.0434	0.45	0.004	1.13	6.88	17.552 0.085	157.69 0.73
Total/Average	18.1053±0.0006	0.0320±0.0041	0.0890±0.0018	0.0020±0.0068	0.163	0.005		100	17.491±0.014	

J-error = 0.005204±0.000008

Volume ^{39}ArK = 1149.1

Integrated Date = 157.17±0.34

Volumes are $1x10^{-13}$ cm^3 NPT

Neutron flux monitors: 28.02 Ma FCs (Renne et al., 1998)

Isotope production ratios: ($^{40}Ar/^{39}Ar$)K=0.0302±0.00006, ($^{37}Ar/^{39}Ar$)Ca=1416.4±0.5, ($^{36}Ar/^{39}Ar$)Ca=0.3952±0.0004, Ca/K=1.83±0.01($^{37}ArCa/^{39}ArK$).

The Carius-tube method was used in this study for the dissolution of molybdenite and equilibration of sample and tracer Re and Os. Molybdenite samples were dissolved and equilibrated with a known amount of tracer in reverse aqua regia (2:1 16 N HNO_3 and 12N HCl, 3 ml) at 240°C for 24 h then cooled and refrigerated prior to Os and Re separation. Extraction of OsO_4 from the acid-sample mix was achieved using modified solvent extraction and microdistillation techniques. Mo was removed by solvent extraction from the acid-sample mixture after Os separation. Rhenium was then purified by HNO_3 + HCl-based anion exchange chromatography using standard techniques. Total procedural blanks for Re and Os are less than 2 picograms and 0.5 picograms, respectively. These procedural blanks are insignificant in comparison to the Re and Os concentrations in the molybdenite analysed here. The purified Re and Os was analysed by Negative Thermal Ion Mass Spectrometry (N-TIMS), and abundances of ^{187}Re and ^{187}Os calculated.

Typically, 20 mg of molybdenite was used for the full Re-Os analysis, and all data are presented in Table 4. An overview of the Re-Os method of dating molybdenite can be found in Stein *et al.* (2001).

Model ages are calculated from the simplified isotope equation: $t = \ln(^{187}Os/^{187}Re + 1)/\lambda$, where λ is the ^{187}Re decay constant ($1.666 \pm 0.005 \times 10^{-11}$ a-1; Smoliar *et al.*, 1996), which contains a ±0.31% uncertainty in the value of λ (Selby *et al.*, 2007) and assumes that molybdenite crystallizes with only Re and no Os. The 2σ age uncertainty quoted above (Table 4) reflects all known sources of analytical error, fully propagated to arrive at the quoted age uncertainty.

Re-Os Geochronology Results

The Re-Os model ages for molybdenite from the Brenda mine and Southeast zone of the Woodjam South property are early Jurassic, 193.9 ±0.9 Ma and 196.9 ±0.9 Ma respectively (Table 4). These are considered good quality data that accurately reflect the age of molybdenite crystallization.

DISCUSSION OF AGE DETERMINATIONS

Typical porphyry systems are characterized by multiple intrusive and hydrothermal phases that overprint and reset metal and alteration zonations and isotopic-signatures (Gustafson and Hunt, 1975). So too has copper-molybdenum mineralization at the Brenda deposit formed during multiple stages, as evidenced by crosscutting mineralized vein assemblages. To unravel the relationships between the magmatic (*i.e.* crystallization age) and mineralization and later cooling history of the Brenda stock; we utilized three different techniques: U-Pb zircon for magmatic crystallization, Re-Os isotope system for hydrothermal mineralization, and $^{40}Ar/^{39}Ar$ dating of two mineral systems for the age and rate of cooling. Zircon closure temperatures are generally taken to be > 900°C in a magmatic environment (Mezger, 1990).The Re-Os geochronometer is remarkably resilient to both hydrothermal metamorphism (Selby and Creaser, 2001) and granulite-facies metamorphism (Bingen and Stein, 2002) and should reliably date crystallization of molybdenite, not later disturbance events. Hornblende and biotite have Ar retention closure temperatures of 570-465°C and 360-280°C (Reiners and Brandon, 2006) respectively. The $^{40}Ar/^{39}Ar$ dating techniques is more robust than the K-Ar biotite technique used in the past and provides more information about the rate of cooling.

Brenda

Historical potassium-argon dates of samples from the Brenda mine area produced a mean age (n=4) for hornblende of 178.5 ±15.5 Ma and a mean age of 148 ±9.2 Ma (n=5) for apparent co-existing biotite (Figure 6). Interpretation of these results suggested that the Brenda stock crystallized about *ca.* 178 Ma and the148 Ma biotite date from the pit area was interpreted to be the age of mineralization (White *et al.*, 1968). In addition, it was postulated that the Cu and Mo could have been emplaced at different times due in part to their independent concentration within separate structural trends. Copper is distributed along northeast-trends and the molybdenite on northwest-trending structures. To test this scenario the molybedenite mineralization dated was collected from one of the younger vein sets (Stage 3 vein). However, it has an Early Jurassic Re-Os model age identical, within error, to the crystallization age of the batholith.

Our $^{40}Ar/^{39}Ar$ results for hornblende indicate excessive radiogenic argon and a plateau age defined by only 40% of ^{39}Ar and a biotite cooling age that is identical, within error, to the hornblende data ca 159 Ma. This age is intermediate to the historic K/Ar clusters for

Table 4. Re/Os isotopic results and age determinations of molybdenite for samples JLO07-226 and WJ-07-79.

Sample	Re (ppm)	^{187}Re (ppm)	^{187}Os (ppb)	Common Os (pg)	Age ± 2σ (Ma)
WJ07-79	403.2 ± 1.3	253.4 ± 0.8	832.6 ± 0.6	1.6	196.9 ± 0.9
JLO07-32-226	68.45 ± 0.23	43.02 ± 0.14	139.2 ± 0.2	<0.5	193.9 ± 0.9

ppm = parts per million by weight, ppb = parts per billion by weight, pg = picograms (10^{-12} g)

hornblende and biotite (Figure 6) and has no clear cause inherent to the Brenda stock. However, a ~167 Ma titanite cooling age (Parrish and Monger, 1992; Figure 6) is reported for a sample of the Pennask batholith collected ~2 km north of its southern contact with the Osprey Lake batholith (166 ±1 Ma) and less than a kilometre away from a suite of north-trending Early Tertiary (62 ±2 Ma) potassium feldspar porphyry dikes and plugs (Parrish and Monger, 1992). In addition, historic K/Ar, Ar/Ar and Rb/Sr dates from around the mine range down to 135 Ma (Figure 6; Breitsprecher and Mortensen, 2004) and probably reflect partial re-setting of original cooling ages by younger magmatic suites in the area including; Middle Jurassic (Osprey Lake batholith), mid-Cretaceous (Okanagan batholith) and Early Tertiary (Nicola batholith) granitic bodies.

Our U/Pb results for zircon separated from the granodiorite hosting mineralization at the mine: ~194.7 ±0.3 Ma is identical, within error, to the 194 ±1Ma crystallization age reported for Pennask batholith biotite granodiorite by Parrish and Monger (1992). The Re-Os model age for molybdenite mineralization is 193.9 ±0.9 Ma also synchronous within error (Figure 6).

Woodjam - Southeast zone

The Re/Os model age for Southeast zone molybdenite mineralization at ~196.9 ±0.9 Ma is identical to the U/Pb, zircon crystallization ages (196.84 ±0.22 Ma, P. Schiarizza, personal communication, 2010) and is compatible with the Ar/Ar, biotite and feldspar cooling ages (193.0 ±1.2 Ma and 192.2 ±1.1 Ma, Logan *et al.*, 2007) for the Woodjam Creek phase of the Takomkane batholith (Schiarizza *et al.*, 2009b). The ore mineralogy, style and age indicate that Southeast zone formed in response to Early Jurassic calcalkaline magmatism. It is *ca.* 10 to 15 Ma younger than mineralization at Gibraltar (Oliver *et al.*, 2009) and *ca.* 8 Ma younger than mineralization associated with alkaline magmatism at Mount Polley.

If there is any systematic difference in the ages of intrusion and mineralization, its measurement is beyond the resolution of the geochronometers available to us. This contemporaneity of intrusion and hypogene mineralization is consistent with the results of similarly robust datasets elsewhere within the Cordilleran belt for alkalic porphyry deposits (*e.g.* Iron Mask and Mt. Polley (Logan *et al.*, 2007), and results from other porphyry systems globally (McInnes *et al.*, 2005). Our new data provide a tight integration with the ~195 Ma calcalkaline Cu-Mo±Au porphyry event that is exposed along the length of Quesnellia and may have implications for similar aged Cu-Au-Mo metallogenic systems in Stikinia (*i.e.* Kerr, Sulphurets and Premier (?)) and northern Cordillera.

MESOZOIC QUESNEL

Spatial and temporal relationships between magmatic cycles in arcs and porphyry copper formation has long been recognized (Sillitoe, 1972; Clark *et al.*, 1976; Sillitoe and Perrelló, 2005) and is well displayed in southern Quesnel terrane, where three subparallel, linear, Cu-Mo, Cu-Au and Cu-Mo±Au porphyry belts occur within the 20 Ma epoch considered here (Figure 9). In southern Quesnellia, migration of Late Triassic to Early Jurassic magmatism across southern British Columbia is indicated by linear belts of temporal plutons reflecting 50 Ma of arc evolution above an east-dipping subduction zone (Mortimer, 1987; Parrish and Monger 1992; Ghosh, 1995). Quesnel arc magmatism and associated porphyry mineralization migrated eastward with time, beginning in the west, *ca.* 210-215 Ma with emplacement of plutons and development of calcalkaline Cu-Mo±Au deposits at Highland Valley and Gibraltar. New data suggests multiple stages of mineralization at Highland Valley; that post-dates intrusion of the Guichon batholith by up to 4 Ma (Ash *et al.*, 2007). In the central axis of the arc are slightly younger alkaline intrusions and 205 Ma, Cu-Au mineralization at Mount Polley (Logan *et al.*, 2007) and Copper Mountain (Mihalynuk *et al.*, 2008), part of the chain of similar deposits that extends the length of the Intermontane Belt (Barr *et al.*, 1976; Figure 1).

Early Jurassic calcalkaline magmatism and Cu-Mo±Au mineralization was initiated following an approximate 3-5 Ma hiatus. In southern QN the roots of this arc are defined by a 375 km long arcuate belt of 197-193 Ma granodiorite plutons (Takomkane/Wildhorse suite) and in the north by the Hogem batholith. In central QN, it is under represented, probably because of the thick glacial cover in this region. Late Early Jurassic alkaline magmatism and porphyry Cu-Au formation at Mt Milligan closely followed emplacement of the Quesnel arc onto Ancestral North American (ANA) margin at ~186 Ma (Nixon *et al.*, 1993). A second pulse of alkaline magmatism at ~178 Ma in northern QN at Lorraine (Logan and Mihalynuk, in review) and >156 Ma in southern QN at Sappho (Nixon and Laflamme, 2002) are probable post-subduction partial melts of subduction-modified arc-lithosphere (Richards, 2009).

CONCLUSIONS

Copper-molybdenum±gold mineralization at the Brenda deposit formed during several stages, as evidenced by mineralogically different and crosscutting vein assemblages. Our isotopic age dating results show that the time span between magma crystallization and the final stages of mineralization is too small to be measured by the geochronometers employed. It is most likely less than a million years. It formed from the same evolving magmatic/mineralizing episode responsible for emplacement and crystallization of the Early Jurassic Pennask batholith. The same relationship between mineralization and magmatism is evident on the

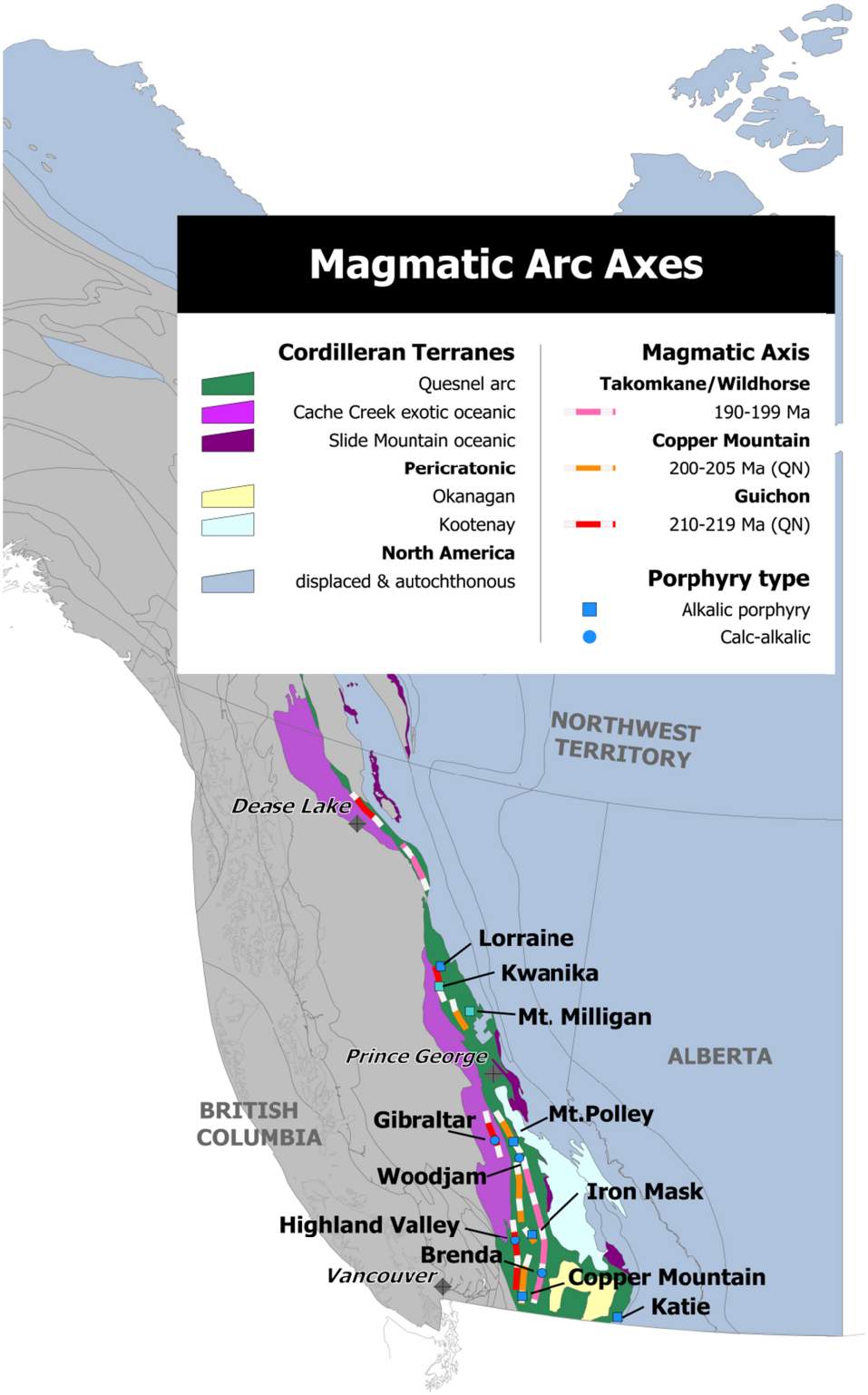

Figure 9. Linear traces of Late Triassic and Early Jurassic arc plutons define discrete north trending, eastward progressing axis of magmatism along the length of Quesnel.

Woodjam property 280 km to the north, where molybdenum from the Southeast zone has a Re-Os model age for mineralization that overlaps the Early Jurassic crystallization age of the host Takomkane batholith.

Early Jurassic mineralization at Brenda and Woodjam-Southeast is hosted in large, medium to coarse-grained, equigranular calcalkaline intrusives. In both cases Cu-Mo±Au mineralization occurs very close to the margins of these upper crustal batholith-sized intrusions. These are important exploration criteria that incorporate the type of porphyry deposit and degree of uplift and erosion affecting these parts of the porphyry belt. In contrast, the Late Triassic Cu-Au±Ag alkalic systems are small, high level complex intrusions which intrude coeval and cogenetic? volcanic rocks. Mineral and alteration assemblages are unique to each type of porphyry deposit (Sillitoe, 2002; McMillan, 2005). As a result, geochemical and geophysical responses dictate different techniques to delineate alkaline (eTh/K lows located on flanks of magnetic highs; Shives *et al.*, 1997) *vs.* calcalkaline (conductive I.P. geophysical response related to sulphide halo) porphyry deposits. It follows then, to ensure successful exploration along the Quesnel arc it is critical to understand where and in which magmatic/metallogenic belt you are and which potential targets you should expect.

It is anticipated from the exploration successes at Woodjam property by Fjordland Exploration Inc, Cariboo Rose Resources and Gold Fields Horsefly Exploration Corp., that the recognition of this Early Jurassic Cu-Mo±Au porphyry belt will help to focus more exploration on this 375 km long prospective belt of calcalkaline intrusions in south-central British Columbia. If so, new discoveries are certain to be realized.

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REFERENCES

Ash, C.H., Reynolds, P.H., Creaser, R.A. and Mihalynuk, M.G. (2007): ^{40}Ar-^{39}Ar and Re-O isotopic ages for hydrothermal alteration and related mineralization in the Highland Valley Cu-Mo deposit, SW BC; in Geological Fieldwork 2006, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2007-1, pages 19-24.

Barr, D.A., Fox, P.E., Northcote, K.E. and Preto, V.A. (1976): The Alkaline Suite Porphyry Deposits: A Summary; in Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 359-367.

Beatty, T. W., Orchard, M. J., and Mustard, P. S. (2006): Geology and tectonic history of the Quesnel terrane in the area of Kamloops, British Columbia; Colpron, M., and Nelson, J., Editors, *in* Paleozoic evolution of pericratonic terranes at the ancient pacific margin of North America, Canadian and Alaskan Cordillera, Special Paper 45, *Geological Association of Canada*, pages 483-504.

Bingen, B. and Stein, H.J. (2002): Molybdenite Re-Os dating of biotite dehydration melting: the Rogaland granulites, S Norway; 12th Annual V.M. Goldschimdt conference Davos, Switzerland, A78.

Breitsprecher, K. and Mortensen, J.K. (2004): BC Age 2004A-1: A database of isotopic age determinations for rock units from British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resource*, Open File 2004-03.

Breitsprecher, K., Weis, D., Scoates, J.S. and Anderson, R.G. (2010): Targeting mineralized Late Triassic to Early Jurassic plutons in the Nicola arc, southern Quesnel terrane, Canadian Cordillera; *in* Geological Association of Canada, Targeted Geoscience Initiative 3 Workshop, Vancouver, URL accessed November, 2010, http://www.gac-cs.ca/workshops/TGI3/abstracts/13_GAC_TGI3_Breitsprecher_mineralizd_plutons.pdf

Carr, J.M., (1967): Geology of the Brenda Lake Area; *British Columbia Minister of Mines and Petroleum Resources*, Annual Report, 1967, pages 183-212.

Clark, A. H., Farrar, E., Caelles, J. C., Haynes, S. J., Lortie, R. B., McBride, S. L., Quirt, G. S., Robertson, R. C. R., and Zentilli, M. (1976): Longitudinal variations in the metallogenetic evolution of the Central Andes: A progress report; *Geological Association of Canada,* 14, pages 23-58.

Cooke, D. R., Hollings, P., and Walshe, J. L. (2005): Giant Porphyry Deposits: Characteristics, Distribution, and Tectonic Controls; *Economic Geology and the Bulletin of the Society of Economic Geologists*, v. 100, pages 801-818.

Crowley, J.L., Schoene, B. and Bowring, S.A., (2007): U-Pb dating of zircon in the Bishop Tuff at the millennial scale; *Geology*, vol. 35, no. 12, pages 1123-1126.

Dawson, G.L. and Ray, G.E., (1988): Geology of the Pennask Mountain Area, 92H/16, *B.C. Ministry of Energy, Mines & Petroleum Resources* Open File Map 1988-7, scale 1:25 000.

Fjordland Exploration Inc. (2008a): Woodjam's Southeast zone returns 0.40% copper and 0.014% molybdenum over 113.8 metres; Fjordland Exploration Inc., news release, January 18, 2008.

Ghosh, D. K., (1995): Nd-Sr isotopic constraints on the interactions of the Intermontane Superterrane with the western edge of North America in the southern Canadian Cordillera, *Canadian Journal of Earth Sciences*, vol 32, pages 1740-1758.

Gustafson, L.B. and Hunt, J.P. (1975): The Porphyry copper deposit at El Salvador, Chile: *Economic Geology and the Bulletin of the Society of Economic Geologists*, v. 70, pages 857-912.

Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C., Essling, A.M., (1971): Precision measurement of half-lives and specific activities of ^{235}U and ^{238}U, Phys. Rev. C4, pages 1889–1906.

Logan, J.M. and Bath, A.B. (2006): Geochemistry of Nicola Group Basalt from the Central Quesnel Trough at the

Latitude of Mount Polley (NTS 093A/5, 6, 11, 12), Central British Columbia; *in* Geological Fieldwork 2005, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2006-1, pages 83-98.

Logan, J.M. and Mihalynuk, M.G. (in review): Tectonic controls on Early Mesozoic paired alkaline porphyry deposit belts (Cu-Au ±Ag-Pt-Pd-Mo) within the Canadian Cordillera, Economic Geology.

Logan, J.M., Mihalynuk, M.G., Ullrich, T. and Friedman, R.M. (2007): U-Pb ages of intrusive rocks and 40Ar/39Ar plateau ages of copper-gold-silver mineralization associated with alkaline intrusive centres at Mount Polley and the Iron Mask batholith, southern and central British Columbia; *in* Geological Fieldwork 2006, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2007-1, pages 93-116.

Massey, N.W.D., MacIntyre, D.G., Desjardins, P.J. and Cooney, R.T. (2005): Digital geology map of British Columbia: whole province; *BC Ministry of Energy, Mines and Petroleum Resources*, Geofile 2005-1, scale 1:250 000, URL <http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/GeoFiles/Pages/2005-1.aspx> [December 2010].

McInnes, B.I.A., Evans, N.J., Fu, F.Q. and Garwin, S. (2005): Application of thermochronology to hydrothermal ore deposits; *Reviews in Mineralogy and Geochemistry*, v. 58, pages 467-498.

McMillan, W.J. (2005): Porphyry Cu-Mo Deposits of the Highland Valley District, Guichon Creek batholith, British Columbia, Canada; Porter, T.M. Editor, in Super Porphyry Copper & Gold Deposits: A Global Perspective; PGC Publishing, Adelaide, v. 1, pages 259-274.

Mezger, K. (1990): Geochronology in granulites, in Granulites and Crustal Evolution, D. Vielzeuf and Ph. Vidal, eds. pp. 45 l-470, Kluwer, Dordrecht, The Netherlands.

Mihalynuk, M.G., Logan, J.M., Friedman R.M. and Preto V.A. (2010): Age of Mineralization and 'Mine Dykes' at Copper Mountain Alkaline Copper-Gold-Silver Porphyry Deposit (NTS 092H/07), South-Central British Columbia; *in* Geological Fieldwork 2009, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2010-1, pages 163-172.

Minfile Number 92HNE047, Brenda Mine, *BC Ministry of Energy, Mines and Petroleum Resources*, online document, <http://minfile.gov.bc.ca/Summary.aspx?minfilno=092HNE047 >[December 2010].

Mortensen, J.K., Ghosh, D.K. and Ferri, F. (1995): U-Pb geochronology of intrusive rocks associated with copper-gold porphyry deposits in the Canadian Cordillera; in Porphyry deposits of the Northwestern Cordillera of North America, *Canadian Institute of Mining and Metallurgy,* Special Volume 46, pages 142-158.

Mortimer, N. (1987): The Nicola Group: Late Triassic and Early Jurassic Subduction-related Volcanism in British Columbia; Canadian Journal of Earth Sciences, Volume 24, pages 2521-2536.

Mortimer, N., Van, d. H. P., Armstrong, R. L., and Harakal, J., (1990): U-Pb and K-Ar dates related to the timing of magmatism and deformation in the Cache Creek terrane and Quesnellia, southern British Columbia: *Canadian Journal of Earth Science*, v. 27, pages 117-123.

Nixon, G.T., Archibald, D.A. and Heaman, L.M. (1993): 40Ar-39Ar and U-Pb geochronometry of the Polaris Alaskan-type complex, British Columbia; precise timing of Quesnellia-North America interaction, *in* Geological Association of Canada; Mineralogical Association of Canada; annual meeting; program with abstracts, Joint Annual Meeting: Waterloo, ON, Canada, Geological Association of Canada, page 76.

Nixon, G.T. and Laflamme, J.H.G. (2002): Cu-PGE mineralization in alkaline plutonic complexes, *BC Ministry of Energy, Mines and Petroleum Resources*, GeoFile 2002-2.

Oliver, J. L., Crozier, J., Kamionko, M., and Fleming, J. (2009): The Gibraltar Mine, British Columbia. A billion tonne deep copper-molybdenum porphyry system: structural style, patterns of mineralization and rock alteration; Roundup 2009 Program with abstracts: Vancouver, BC, *Association for Mineral Exploration British Columbia*, pages 35-36.

Oriel, W.M., (1972): Detailed bedrock geology of the Brenda copper-molybdenum mine, Peachland, British Columbia, *Unpublished* M.Sc. thesis, *University of British Columbia*, Vancouver, BC, 94 pages.

Palfy, J., Smith, P.L. and Mortensen, J.K. (2000): A U-Pb and 40Ar-39Ar time scale for the Jurassic; *Canadian Journal of Earth Sciences*, volume 37, pages 923–944.

Parrish, R., Roddick, J.C., Loveridge, W.D., and Sullivan, R.W. (1987): Uranium lead analytical techniques at the geochronology laboratory, Geological Survey of Canada; in Radiogenic Age and Isotopic Studies, Report 1, *Geological Survey of Canada*, Paper 87-2, pages 3-7.

Parrish, R. R., and Monger, J. W. H. (1992): New U-Pb dates from southwestern British Columbia, Radiogenic age and isotopic studies, Report 5, *Geological Survey of Canada*, pages 87-108.

Peters, L.J. (2005): Summary technical report on the Woodjam claims, Cariboo Mining District; unpublished report, Fjordland Exploration Inc., 115 pages.

Reiners, P.W and Brandon, M.T. (2006): Using thermochronology to understand orogenic erosion; Annual Review Earth and Planetary Science, volume 34, pages 410-466.

Renne, P.R., C.Swisher, C.C., III, Deino, A.L., Karner, D.B., Owens, T. and DePaolo, D.J., (1998): Intercalibration of standards, absolute ages and uncertainties in 40Ar/39Ar dating; Chemical Geolology, Volume 145(1-2), pages 117-152.

Richards, J.P. (2003): Tectono-magmatic precursors for porphyry Cu-(Mo-Au) deposit formation: *Economic Geology and the Bulletin of the Society of Economic Geologists*, v. 98, pages 1515-1533.

Richards, J.P. (2009): Postsubduction porphyry Cu-Au and epithermal Au deposits: Products of remelting of subduction-modified lithosphere; *Geology*, v. 37, pages 247-250.

Schiarizza, P., Bell, K., and Bayliss, S. (2009a): Geology and mineral occurrences of the Murphy Lake area, south-central British Columbia (93A/03); *in* Geological Fieldwork 2008, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 2009-1, pages 169-188.

Schiarizza, P., Bell, K., and Bayliss, S. (2009b): Geology of the Murphy Lake area, NTS 93A/03; *BC Ministry of Energy,*

Mines and Petroleum Resources, Open File 2009-03, 1:50 000 scale.

Selby, D. and Creaser, R.A. (2001): Re-Os geochronology and systematics in molybdenite from the Endako porphyry molybdenum deposit, British Columbia, Canada. ; *Economic Geology*, Volume 96, pages 197-204.

Schmitz, M. D., and Schoene, B., (2007): Derivation of isotope ratios, errors, and error correlations for U-Pb geochronology using ^{205}Pb-^{235}U-(^{233}U)-spiked isotope dilution thermal ionization mass spectrometric data; Geochem. Geophys. Geosyst., v.8, 20 pages.

Selby, D., and Creaser, R.A., (2004): Macroscale NTIMS and microscale LA-MC-ICP-MS Re-Os isotopic analysis of molybdenite: Testing spatial restrictions for reliable Re-Os age determinations, and implications for the decoupling of Re and Os within molybdenite; Geochimica et Cosmochimica Acta, 68, pages 3897-3908.

Selby, D., Creaser, R.A., Stein, H.J., Markey R.J., and Hannah, J.L., (2007): Assessment of the ^{187}Re decay constant by cross calibration of the ^{187}Re-^{187}Os molybdenite and U-Pb zircon chronometers; Geochimica *et* Cosmochimica Acta, 71, pages 1999-2013.

Shives, R.B.K., Charbonneau, B.W., and Ford, K.L. (1997): The detection of potassic alteration by gamma ray spectrometry - recognition of alteration related to mineralization; *in* "Geophysics and Geochemistry at the Millenium", Proceedings of the Fourth Decennial International Conference on Mineral Exploration (Exploration 97), 1100 pages, Toronto, Ontario, Canada, September 1997.

Sillitoe, R. H. (1972): Relation of metal provinces in western Americas to subduction of oceanic lithosphere; *Geological Society of America*, Bulletin, v. 83, pages 813–818.

Sillitoe, R. H. (2002): Some metallogenic features of gold and copper deposits related to alkaline rocks and consequences for exploration; *Mineraliun Deposita*, 37, pages 4-13.

Sillitoe, R.H. and Perrelló, J. (2005): Andean copper province: Tectonomagmatic settings, deposit types, metallogeny, exploration and discovery; *Economic Geology,* 100th Anniversary Volume, pages 845-890.

Soregaroli, A.E. (1968): preliminary report on geological studies at the Brenda Mine; unpublished report for Noranda Exploration Company, Limited.

Soregaroli, A.E. and Whitford, D.F., (1976): Brenda; Sutherland Brown, A., Editor, *in* Porphyry Deposits of the Canadian Cordillera, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 186-194.

Smoliar, M.I., Walker, R.J. and Morgan, J.W. (1996): Re-Os ages of Group IIA, IIIA, IVA, and IVB iron meteorites. *Science* 271, pages 1099-1102.

Stacey, J.S. and Kramer, J.D., (1975): Approximation of terrestrial lead isotope evolution by a two-stage model: Earth and Planetary Science Letters, v. 26, pages 207-221.

Stein, H.J., Markey, R.J., Morgan, J.W., Hannah, J.W., and Schersten, A. (2001): The remarkable Re-Os chronometer in molybdenite: how and why it works. Terra Nova, 13, pages 479-486.

Weeks, R.M., Bradburn, R.G., Flintoff, B.C., Harris, G.R., and Malcolm, G. (1995): The Brenda mine: The life of a low-cost porphyry copper-molybdenum producer (1970-1990), southern British Columbia, Schroeter, T., Editor, *in* Porphyry deposits of the Northwestern Cordillera of North America, *Canadian Institute of Mining and Metallurgy,* Special Volume 46, pages 192-200.

Wetherup, S. (2000): Diamond drilling report on the Woodjam Property; *BC Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 26242, 40 pages.

Wheeler, J. O., and McFeely, P. (1991): Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America, "A" series Map, *Geological Survey of Canada*, p. 1 sheet.

White, W.H., Harakal, J.E. and Carter, N.C. (1968): Potassium argon ages of some ore deposits in British Columbia; Canadian Institute of Mining and Metallurgy Bulletin, Volume 61, pages 1326–1334.

Woodsworth, G.J., Anderson, R.G. and Armstrong, R.L. (1991): Plutonic Regimes; Chapter 15, in Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C.J., Editors, *Geological Association of Canada*, Geology of Canada, Volume 4, pages 491-531.