Age of Mineralization and 'Mine Dykes' at Copper Mountain Alkaline Copper-Gold-Silver Porphyry Deposit (NTS 092H/07), South-Central British Columbia

by M.G. Mihalynuk, J. Logan, R.M. Friedman[1] and V.A. Preto[2]

KEYWORDS: Copper Mountain, alkalic porphyry, Cu-Au-Ag deposit, mineralization, alteration, geochronology, isotopic age, U-Pb zircon, U-Pb titanite, $^{40}Ar/^{39}Ar$, Quesnel Arc

INTRODUCTION

Underground mass mining techniques have enabled profitable extraction of the deep portions of porphyry deposits at minesites worldwide. Often considered a relatively new innovation, block caving was originally developed for copper mining in Utah in 1906 (Barger and Schurr, 1944). Examples of block cave mining of copper porphyry deposits include the recently decommissioned San Manuel Cu mine in Arizona, and the currently active alkalic Cu-Au-Ag Ridgeway deposit in New South Wales, Australia. Profitable underground mining of large tonnage, low-grade deposits combined with the recent strength in metal commodity prices has prompted deep exploration of porphyry deposits in British Columbia, especially within the prolific Quesnel terrane (Figure 1). For example, in the Iron Mask batholith near Kamloops, New Gold Inc. has outlined 44.4 million tonnes at a grade of 0.98% Cu, 0.72 g/t Au and 2.27 g/t Ag (New Gold Inc., 2007) beneath the former Afton pit and has started development. Copper Mountain Mining Corporation has similarly demonstrated the potential for subsurface extensions to mineralization that was extracted from open pits at Copper Mountain, about 15 km south of Princeton, in south-central BC (Figure 2).

In 2009, the company reported a resource of 470.8 million tonnes grading 0.311% Cu (0.15% Cu cut-off; O'Rourke, 2008) adjacent to, and beneath, the proposed 'super pit' (Figure 3; Holbek, 2009). Current plans are to extract 211.2 million tonnes at 0.361% Cu from the super pit (Chance et al., 2009). This resource of more than 1 billion kilograms Cu adds significantly to historical production between 1908 and 1996 of ~650 million kilograms of Cu, nearly 16 million grams Au and over 648 million grams Ag (BC Geological Survey, 2009; MINFILE 092HSE001). In addition, largely untested magnetotelluric targets extend 1000 m below the lowest planned super pit levels (Holbek, 2007, 2009).

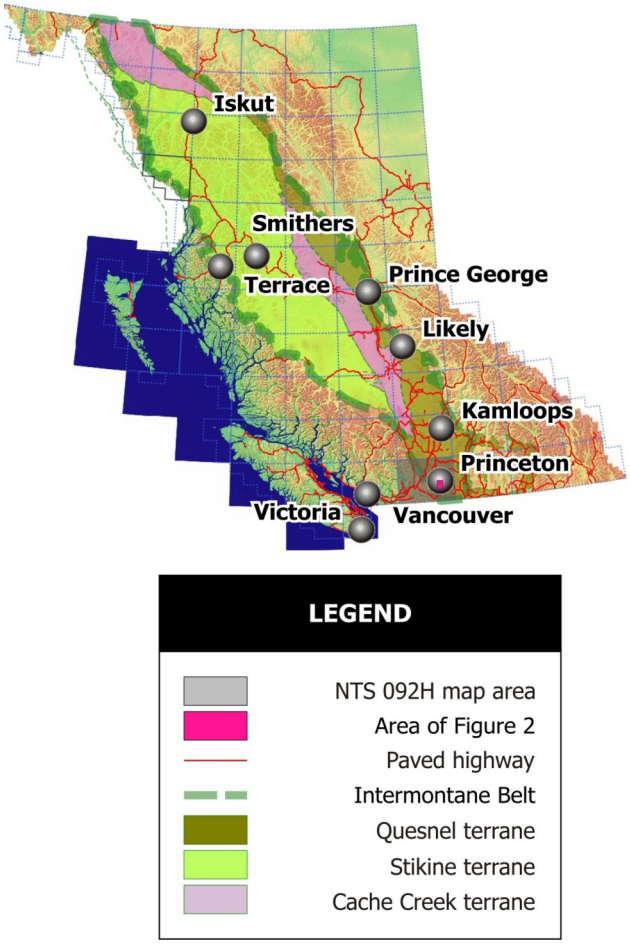

Figure 1. Location of the Copper Mountain area south of Princeton, south-central British Columbia. The area covered by Figure 2 is shown on top of the southern part of the Princeton town symbol.

Large capital expenditures are required for deep exploration and development, so a clear and accurate exploration model is particularly desirable. To this end, we initiated a geochronological investigation of the mineralizing system at Copper Mountain in 2006. Our principal objective was to test the assertion that mineralization at Copper Mountain was coeval with the emplacement of the Lost Horse Intrusions of the Copper Mountain intrusive suite (e.g., Figure 4; Preto, 1972). However, existing geochronometric determinations place the age of mineralization in the Early Jurassic

[1]*Pacific Centre for Isotopic and Geochemical Research, The University of British Columbia, Vancouver, BC*

[2]*Preto Geological Inc., Sooke, BC*

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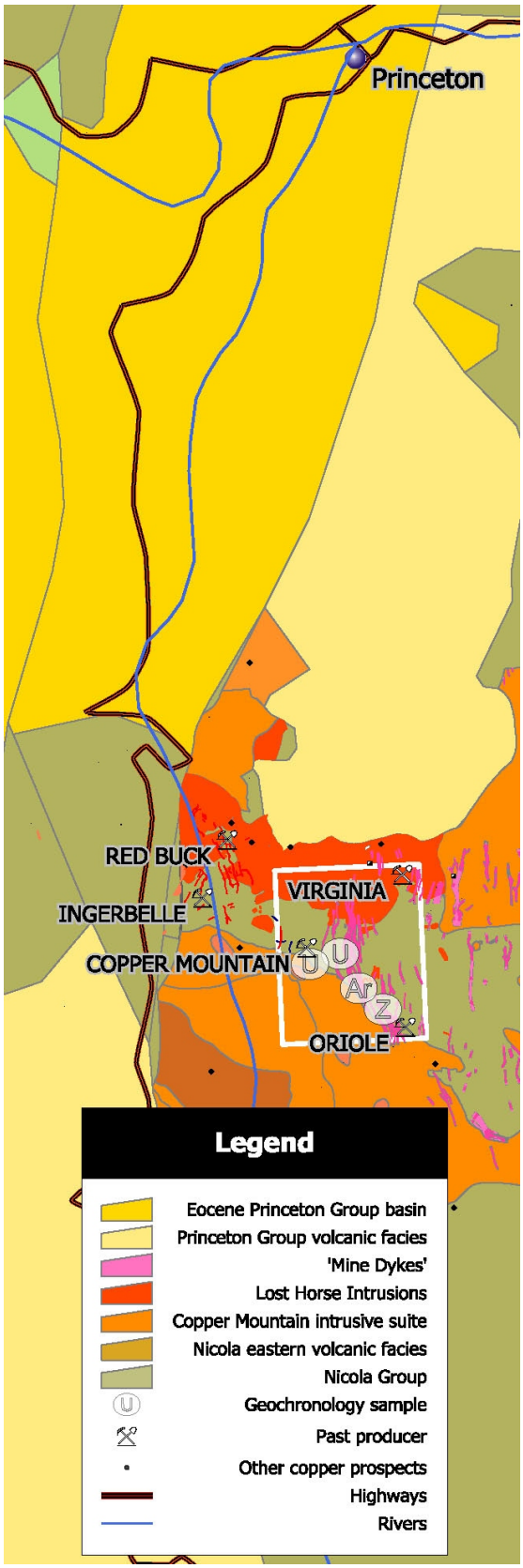


Figure 2. Regional geological map of the Copper Mountain area, south-central British Columbia, incorporating mapping by Preto (1972) and compilations by Preto et al. (2004) and Massey et al. (2005).

(192 ±16 Ma and 198 ±14 Ma; Breitsprecher and Mortensen, 2004; recalculated from Preto, 1972 and Farquharson and Stipp, 1969, respectively), while the best crystallization age data on phases of the mineralized Copper Mountain suite intrusive rocks place them in the Late Triassic (Figure 4; Mortensen et al., 1995; 202.7 +4.4/–0.5 Ma, 200.3 ±2.1 Ma and 204 ±6 Ma). Based on these data, and in consideration of their full error limits, between –14 and 33 m.y. (median, 7 m.y.) elapsed between intrusion and mineralization of the Copper Mountain stock. Even without considering error envelopes, the means of these datasets suggest that 7 m.y. elapsed, which is far greater than is typical for the main mineralizing event in porphyry deposits (McInnis et al., 2005) and raises the question of a separate, younger mineralizing intrusion.

Geochronometric data from various workers have been combined together with new data as part of an investigation of Mesozoic copper porphyry deposits in BC under the direction of J. Logan (Logan and Mihalynuk, 2005a, b; Logan and Bath, 2006; Logan et al., 2007). This work has shown that increased geochronometric precision on intrusive and mineralizing events reveals them to be coeval, within the resolution of the geochronometric technique applied. Additionally, the new data show that, with a few notable exceptions, all alkalic copper porphyry deposits in the Canadian Cordillera are part of a metallogenic epoch in the latest Triassic (together with numerous calcalkalic deposits, such as Highland Valley; e.g., Ash et al., 2007). Herein we affirm both the addition of the Copper Mountain alkalic porphyry to this epoch and the original assertion of Preto (1972), that intrusion and mineralizing events are essentially synchronous at Copper Mountain.

LOCATION AND GEOLOGICAL SETTING

Copper Mountain is located within the Quesnel Arc (Figure 1), a crustal terrane that accreted to ancestral North America (ANA) or a crustal ribbon that lay adjacent to ANA in Early Jurassic time (ca. 186 Ma; Nixon et al., 1993). 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., Brown et al., 1996; Mihalynuk, 1999; Logan and Koyanagi, 2000). Arc growth continued sporadically with a significant pulse in the Late Triassic. Near the end of this magmatic pulse, a prolific metallogenic event is manifest as a chain of alkalic Cu–Au±Ag–Mo porphyry deposits along the arc axes. Intrusions allied with mineralization at Copper Mountain were recognized by Preto (1972, 1979) as part of this well-endowed magmatic suite.

Mineralization at Copper Mountain is mainly focused at the margins and between the polyphase Copper Mountain stock (to the south) and the Lost Horse Intrusions (to the north). Intervening country rocks that host the bulk of the mineralization locally display protolith textures of andesitic to basaltic lapilli tuff and breccia belonging to the Late Triassic Nicola Group. Intense hydrothermal alteration of these rocks generally displays the following petrogenesis:

1) biotite flooding

2) extensive albite-epidote metasomatism

3) K-feldspar and scapolite veining

SAMPLES FOR AGE DETERMINATION

Four samples were selected for isotopic age determination. Two samples from mineralized veins that contain medium-grained crystals of titanite were collected for U-Pb determination. Because of the relatively high closure temperature for lead diffusion in titanite at 660–700°C (Scott and St-Onge, 1995), relatively straightforward isotopic age determinations were anticipated from the mineralization in these two vein samples. In addition, coarse-grained euhedral biotite was extracted from an archival specimen of museum-quality massive bornite-chalcopyrite-biotite from the Big Lead to provide a $^{40}Ar/^{39}Ar$ cooling age on mineralization from a spectacular 'glory hole' (now mined out).

The fourth sample, a relatively unaltered representative sample of the 'Mine Dyke' swarm (Figures 3, 5), was collected to date the late, cross-cutting intrusions. We are not aware of any published crystallization age for the 'Mine Dyke' swarm; existing ages are cooling ages, mainly K-Ar and fission-track determinations.

Titanite-Bearing Veins

Titanite occurs in dominantly south-trending, planar sets of K-feldspar veins. Vein mineralogy includes coarse, chloritized biotite, malachite-stained bornite and chalcopyrite, epidote and titanite (Figure 6). White alteration envelopes are interpreted as albite; no bladed scapolite was observed.

These veins were sampled at the margin of the Copper Mountain stock (MMI06-32-5) along the haul road south of Pit 1 (Figure 3) and midway between the Copper Mountain stock and the main body of Lost Horse Intrusions, on the north rim of Pit 2 (MMI06-32-3). They probably belong to the 'ore fractures' reported by Preto (1972). Where the veins of pegmatitic biotite–K-feldspar–copper sulphides, called 'ore fractures', thickened to 30 cm or more, they were historically exploited by miners from glory holes. One especially rich glory hole, known as the Big Lead, was located in what is now the central part of Pit 3.

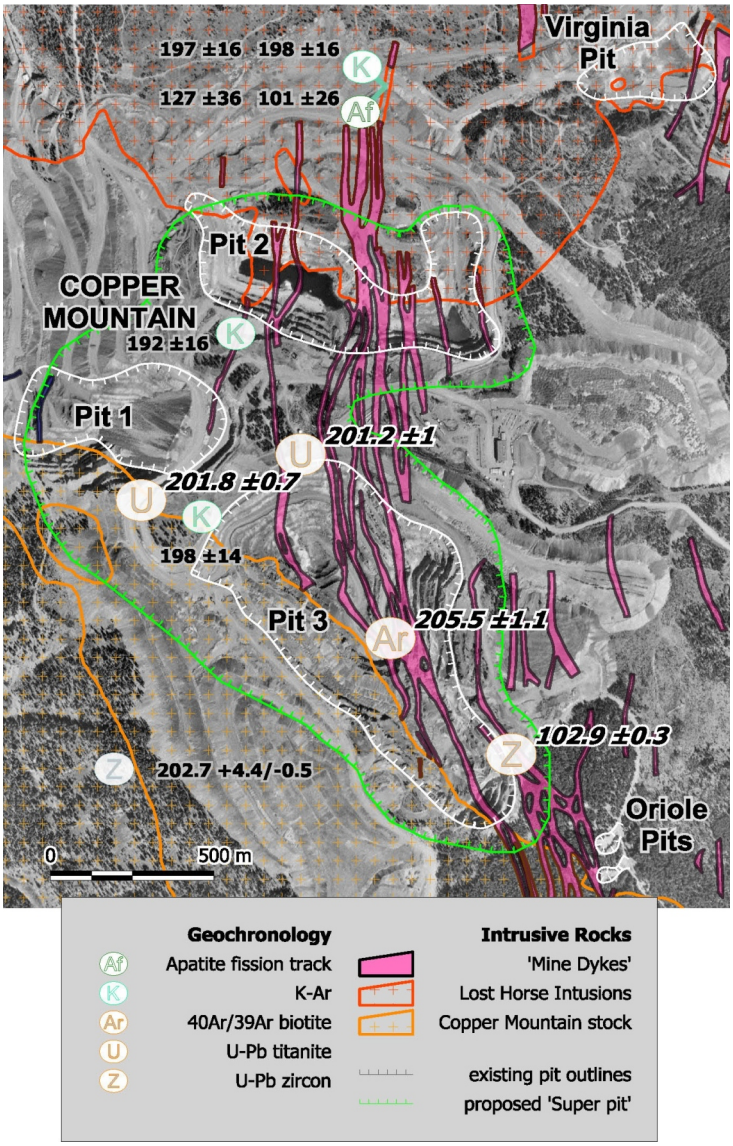


Figure 3. Locations of geochronological samples collected as part of this study (large symbols) and those collected previously by other authors (smaller symbols) as reported in the database compiled by Breitsprecher and Mortensen (2004), Copper Mountain area, south-central British Columbia. Geological contacts and underlying imagery are adapted from Preto et al. (2004). The proposed 'super pit' outline is from Chance et al. (2009). Values on the map are in Ma.

Big Lead Massive Bornite-Biotite

Massive bornite–chalcopyrite–biotite±K-feldspar of the Big Lead was sampled by V.A. Preto in 1969. The sample was taken from the subsidence area over shallow stopes and glory holes, which was located near what is now the middle of Pit 3 (see Plate XIII in Preto [1972] for a historical perspective). This archival sample contains beautiful, euhedral booklets of coarse, vitreous biotite within massive copper sulphide. Such textural equilibrium suggests simultaneous growth of the idiomorphic biotite crystals and chalcopyrite from a magmatic-hydrothermal fluid. Idiomorphic biotite enclosed in bornite is reported at other high-grade porphyry deposits such as Grasberg, where they are interpreted as coarse-grained replacements of mafic phenocrysts (Pollard et al., 2005).

'Mine Dyke' Swarm

The 'Mine Dykes' are white to yellow-orange weathering, blocky to flaggy and relatively recessive (Figure 5). They dip steeply and anastomose, generally conforming to a strong north-northeast trend with a few orthogonal exceptions (Figures 2, 3. 5). Preto (1972) reported their compositional range as trachyte to rhyolite. Medium-grained, grey quartz eyes are conspicuous (7%), and coarse-grained probable K-feldspar relicts are replaced by greasy green clay. Matrix material is a bleached, fine-grained aplite with ~1% magnetite and traces of pyrite. In general, the dikes are strongly clay- and carbonate-altered and only ghosts of former feldspar phenocrysts remain.

U-PB 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.

Titanite was handpicked from samples MMI06-32-3 and 32-5. Picked samples were microscopically evaluated to ensure purity (Figure 7). Pink, brown and greenish grain fragments of moderate clarity were selected for analysis. Titanite sample aliquots analyzed are shown in Figure 7. Uranium-lead isotopic age determinations were obtained by thermal ionization mass spectroscopy (U-Pb ID-TIMS) with results listed in Table 1 and plotted in Figure 8.

Zircon was separated from the 'Mine Dyke' sample MMI06-32-4 using standard mineral separation techniques (crushing, grinding, Wilfley wet shaker table, heavy liquids and magnetic separation), followed by hand picking. Air-abraded single zircon grains were analyzed (Figure 7). Uranium-lead isotopic age determinations were obtained by U-Pb ID-TIMS with results listed in Table 2 and plotted in Figure 9. Details of both the mineral separation and analytical techniques are presented in Logan et al. (2007).

U-PB GEOCHRONOLOGY RESULTS

All data overlap concordia at the 2 confidence level and quoted ages are based on Ludwig concordia interpretations (Figures 8, 9) for all three samples (Tables 1, 2). The two mineralized vein samples that contain titanite were analyzed in three (MMI06-32-3) or four (MMI06-32-5) fractions. Analytical results from the fractions can be interpreted in two ways. If the data from the two widely separated copper sulphide–epidote–K-feldspar-titanite veins are part of the same mineralizing event, then the data may be considered collectively, in which case a pooled concordia age for the two dated titanite samples yields 201.6 ±0.6 Ma (mean square of weighted deviates [MSWD] = 1.16, probability = 0.28). However, we prefer the more conservative approach, and consider the age of the mineralizing event as some time(s) between the 2 error envelopes of 200.2–202.5 Ma.

Four single zircon fractions were analyzed from the 'Mine Dyke' sample. Error envelopes for the individual analyses mutually overlap on concordia. Together they providing a tight age determination of 102.85 ±0.25 Ma, with a MSWD of 1.8 and probability of concordance of 0.18 (Figure 9). We recommend using a slightly more conservative best age of 103 ±0.3 Ma.

$^{40}AR/^{39}AR$ COOLING AGE

The $^{40}Ar/^{39}Ar$ isotopic age determinations were obtained by the laser-induced step-heating technique. Details of the analytical techniques are presented in Logan et al. (2007). Gas measurements obtained during each of the heating steps are presented in Table 3. Consideration of the entire release spectrum produces a total release integrated age of 192.98 ±0.95 Ma (Table 3), which is not geologically meaningful. Low-temperature steps should be rejected (Figure 10) because loosely bound argon has been partially lost. A resultant, robust plateau produced by the higher-temperature steps 8 through 14 represents 71.8% of the

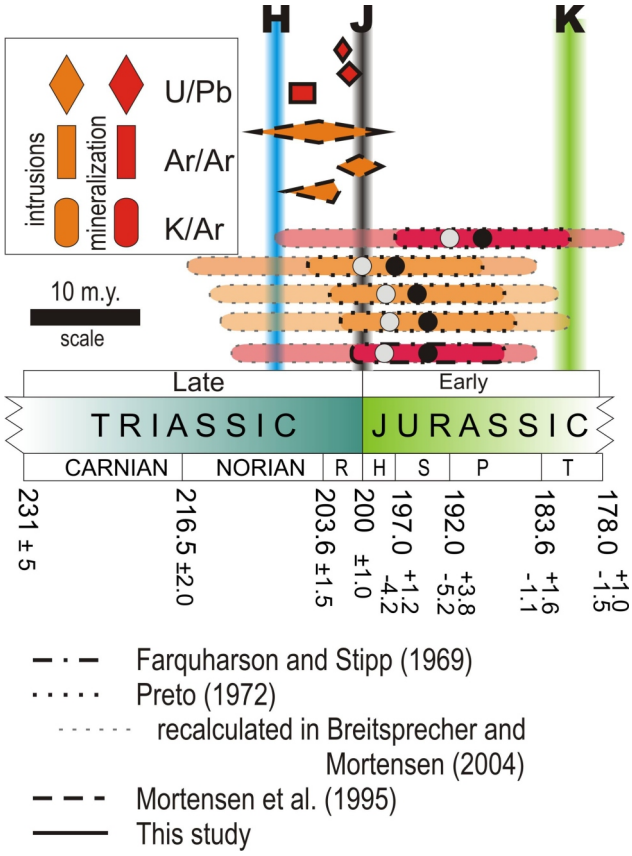


Figure 4. Geological timeline showing age determinations from the mineralizing system at Copper Mountain, south-central British Columbia. Triassic-Jurassic boundaries from time scales discussed in the text are H = Harland et al. (1982), J = Pálfy et al. (2000) and K = Kulp (1961). Abbreviations: H, Hettangian; P, Pliensbachian; R, Rhaetian; S, Sinemurian; T, Toarcian. Time scale is from Okulitch (2002), which incorporates the Jurassic time scale of Pálfy et al. (2000).

^{39}Ar released. This plateau provides the best interpreted age of 205.5 ±1.1 Ma (1 , including J-error of 0.5%). The MSWD for this determination is 0.29, with a probability of 0.94. Initial $^{40}Ar/^{36}Ar$ is 277.6, lower than the atmospheric value of 295.5.

DISCUSSION OF AGE DETERMINATIONS

Extensive intrusion of the Copper Mountain area by the swarm of 'Mine Dykes' has reset the isotopic systems with low closure temperatures. For example, fission-track cooling ages for the Lost Horse Intrusions and dikes are reported by Christopher (1973) as ranging from 100 to 127 Ma (with uncertainties on the order of ±25 Ma—see Figure 3 for specific examples). These dates reflect the annealing of apatite within the Late Triassic intrusions where they are intersected by the dike swarm. The U-Pb age reported herein, 102.9 ± 0.3 Ma, is the first crystallization age from the 'Mine Dyke' swarm, and is concordant with the fission track ages. It is identical, within error, to the age of the Verde Creek quartz monzonite, which is dated by K-Ar biotite as 100 ±8 Ma and 102 ±8 Ma (Breitsprecher and Mortensen, 2004; recalculated from Preto, 1972 as 98

±4 Ma and 101 ±4 Ma).The 'Mine Dykes', however, are observed to cut the Verde Creek pluton (Preto, 1972) and must, at least locally, be younger. Interestingly, the northerly trending dike swarm parallels the straight western margin of the 20 km long Verde Creek pluton, which is located immediately east of the area outlined by the southern half of Figure 2.

Isotopic age determination of mineralization at Copper Mountain has relied largely upon cooling ages or imprecise fission track techniques (Figures 3, 4). Although a robust U-Pb zircon age from the Copper Mountain stock yielded 202.7 +4.4/–0.5 Ma, 200.3 ±2.1 Ma and 204 ±6 Ma (Figure 4; Mortensen et al., 1995), age determinations from mineralization have historically been by techniques susceptible to isotopic disturbance. This is particularly problematic in the mine area where extensive intrusion by the younger 'Mine Dykes' heated the surrounding country rocks. Such cooling ages include K-Ar biotite determinations on the Copper Mountain stock and mineralized veins that yielded a mean age of 193 ±7 Ma (Sinclair and White, 1968), and those on the pegmatitic sulphide veins and Lost Horse and other intrusions that yielded a "mean age of 193.5 ±8 Ma" (Preto, 1972). Consistency of these two datasets and the time scale calibration of the day (Kulp, 1961) placed the intrusions and mineralization within the

Figure 5. Light-coloured 'Mine Dykes' cutting dark, hydrothermally altered Nicola Group volcanic strata within Pit 3, Copper Mountain, south-central British Columbia. View is to the southeast. The location of sample MMI06-32-4 is just visible on the far pit wall (red arrow).

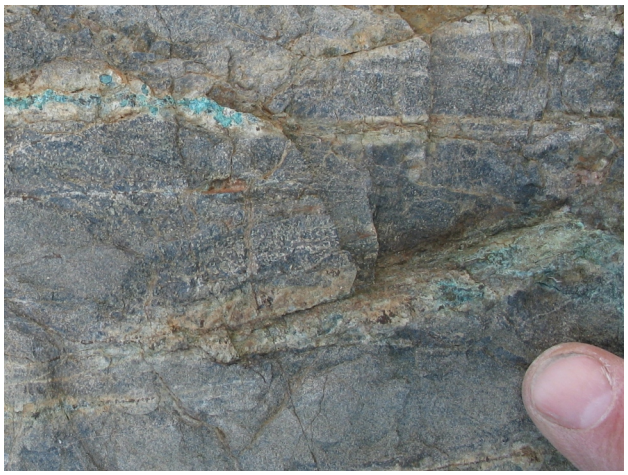


Figure 6. Pegmatitic mineralized K-feldspar veins containing copper carbonate–stained biotite–chalcopyrite–bornite–epidote–titanite, Copper Mountain, south-central British Columbia. The light-coloured halo is probably due to albite alteration.

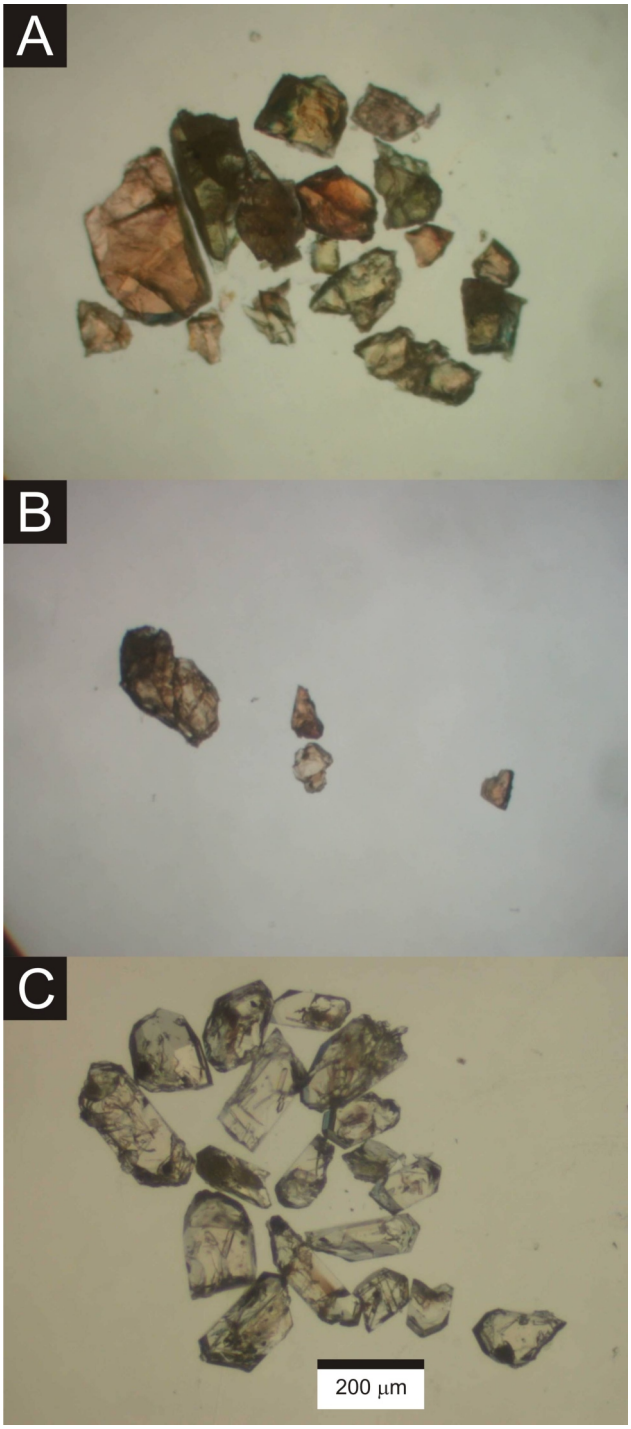


Figure 7. Titanite grains analyzed from samples from Copper Mountain, south-central British Columbia: **A)** titanite from sample MMI06-32-3; field of view is ~2 mm; **B)** titanite from sample MMI06-32-5; field of view is ~2 mm; **C)** zircon separate from sample MMI06-32-4 prior to abrasion (200 m scale bar).

Table 1. U-Pb thermal ionization mass spectrometry analytical data for titanite from mineralized veins in samples MMI06-32-3 and MMI06-32-5, Copper Mountain, south-central British Columbia.

Fraction[1]	Wt	U[2]	Pb*[3]	$^{206}Pb/^{204}Pb$[4]	Pb*/Pb$_c$[5]	Pb[6]	Th/U[7]	Isotopic ratios ±1σ,%[8]			r[9]	% discordant[10]	Apparent ages ±2σ,Ma[8]		
	(mg)	(ppm)	(ppm)			(pg)		$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$			$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
MMI06-32-3															
T1	19	139.4	5.5	319.2	5.90	17.3	1.183	0.031843 ±0.20	0.221415 ±1.09	0.05043 ±1.01	0.4880	6.1	202.07 ±0.8	203.09 ±4.0	214.9 ±46.1/47.4
T2	26	58.4	2.3	234.1	4.24	13.7	1.196	0.031564 ±0.20	0.213294 ±1.75	0.049009 ±1.65	0.5322	-35.6	200.33 ±0.8	196.31 ±6.2	148.3 ±75.5/79.2
T3	13	75.7	3.1	189.7	3.48	11.2	1.341	0.0317 ±0.26	0.223142 ±2.54	0.051053 ±2.41	0.5546	17.6	201.18 ±1.0	204.52 ±9.4	243.2 ±107.4/115
MM06-32-5															
T1	66	80.6	7.6	137.7	5.58	88.3	7.449	0.03209 ±0.436	0.226608 ±1.50	0.051215 ±1.25	0.6762	19.0	203.62 ±1.8	207.39 ±5.6	250.5 ±56.4/58.4
T2	52	114.9	10.5	266.3	11.35	47.4	7.130	0.031856 ±0.176	0.217481 ±1.68	0.049514 ±1.60	0.5363	-17.6	202.15 ±0.7	199.81 ±6.1	172.3 ±72.9/76.3
T3	68	165.8	12.0	779.3	27.41	29.0	4.967	0.031746 ±0.092	0.220232 ±0.34	0.050314 ±0.29	0.6308	3.9	201.47 ±0.4	202.1 ±1.2	209.5 ±13.4/13.5
T4	84	60.0	5.7	201.3	8.52	54.3	7.450	0.031939 ±0.284	0.220755 ±1.10	0.050129 ±0.94	0.6451	-0.8	202.67 ±1.1	202.54 ±4.0	201 ±43.1/44.3

[1]Fraction ID: T1,T2, etc. All analysed titanites were fragments taken from veins.

[2]U blank correction of 0.2 pg ± 20%; U fractionation corrections were measured for each run with a double $^{233-235}U$ spike.

[3]Radiogenic Pb; all raw Pb data corrected for fractionation of 0.23%/amu ±20% determined by repeated analysis of NBS-982 reference material.

[4]Measured ratio corrected for spike and Pb fractionation.

[5]Radiogenic Pb/common Pb, including ^{208}Pb.

[6]Total common Pb in analysis based on blank isotopic composition: $^{206}Pb/^{204}Pb$ = 18.5 ±3%, $^{207}Pb/^{204}Pb$ = 15.5 ±3%, $^{208}Pb/^{204}Pb$ = 36.4 ±0.5%.

[7]Model Th/U derived from radiogenic ^{208}Pb and the $^{207}Pb/^{206}Pb$ age of fraction.

[8]Corrected for fractionation, blank (5 pg, based on procedural blanks) and common Pb, the latter with a composition based on Stacey-Kramers model Pb at 200 Ma (Stacey and Kramers, 1975).

[9]Correlation coefficient.

[10]Discordance in % to origin.

Table 2. U-Pb thermal ionization mass spectrometry analytical data for zircon from the 'Mine Dyke' sample MMI06-32-4, Copper Mountain, south-central British Columbia.

Fraction[1]	Wt	U[2]	Pb*[3]	$^{206}Pb/^{204}Pb$[4]	Pb*/Pbc[5]	Pb[6]	Th/U[7]	Isotopic ratios ±1σ, %[8]			r[9]	% discordant[10]	Apparent ages ±2σ,Ma[8]		
	(mg)	(ppm)	(ppm)			(pg)		$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$			$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
MMI06-32-4															
A	16	217.46	3.6	832.6	13.4	4.2	0.467	0.016087 ±0.15	0.107795 ±0.61	0.0486 ±0.57	0.39466	20.1	102.88 ±0.3	103.95 ±1.2	128.6 ±26.6/27
B	14	126.93	2.1	541.5	8.6	3.4	0.447	0.016129 ±0.5	0.108037 ±1.2	0.04858 ±1.1	0.487005	19.3	103.15 ±1	104.17 ±2.4	127.6 ±49.3/50.9
C	5	386.9	6.5	261.2	4.1	7.9	0.552	0.01604 ±0.28	0.105135 ±1.4	0.047537 ±1.2	0.492711	-34.7	102.58 ±1	101.5 ±2.6	76.3 ±58.2/60.4
D	4	669.44	11.0	380.4	5.8	7.4	0.424	0.016103 ±0.2	0.10663 ±0.9	0.048024 ±0.8	0.448427	-2.5	102.98 ±0.5	102.88 ±1.8	100.5 ±39.1/40

[1]All grains air abraded; all single grains processed and analysed, except where noted by number of grains after fraction ID.

[2]U blank correction of 0.2 pg ±20%; U fractionation corrections were measured for each run with a double $^{233-235}U$ spike.

[3]Radiogenic Pb; all raw Pb data corrected for fractionation of 0.23%/amu ±20% determined by repeated analysis of NBS-982 reference material.

[4]Measured ratio corrected for spike and Pb fractionation.

[5]Radiogenic Pb/common Pb, including ^{208}Pb.

[6]Total common Pb in analysis based on blank isotopic composition: $^{206}Pb/^{204}Pb$ = 18.5 ±3%, $^{207}Pb/^{204}Pb$ = 15.5 ±3%, $^{208}Pb/^{204}Pb$ = 36.4 ±0.5%.

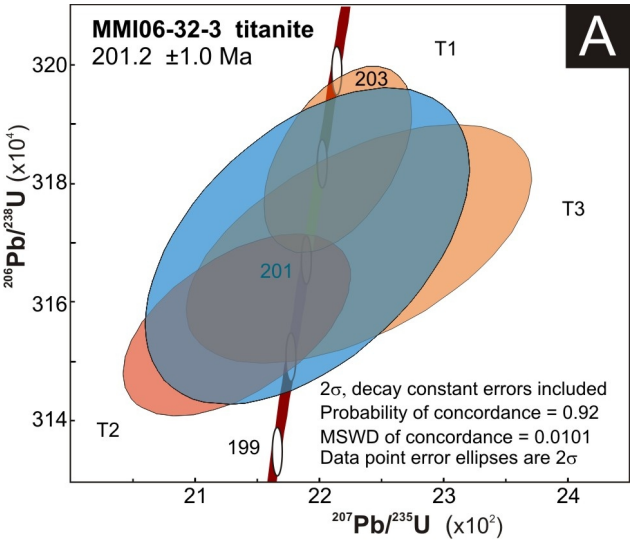
[7]Model Th/U derived from radiogenic ^{208}Pb and the $^{207}Pb/^{206}Pb$ age of fraction.

[8]Fractionation, blank and common Pb corrected; Pb procedural blanks were ~2.0 pg and U <0.2 pg. Common Pb compositions are based on Stacey-Kramers model (Stacey and Kramers, 1975) Pb at the interpreted age of the rock: MMI06-32-4 – 103 Ma.

[9]Correlation coefficient.

[10]Discordance in % to origin.

Late Triassic period, which extended to 181 Ma (K on Figure 4). Both the mineralized veins and intrusions cut rocks that contain meagre but significant fossil collections yielding Late Triassic ages. Penecontemporaneous country rocks and intrusions seemed consistent with evidence for a near-surface intrusive environment Such evidence includes porphyritic textures and breccia bodies indicative of low confining pressures (Preto, 1972). However, a time scale revision in 1982 (Harland et al., 1982; H on Figure 4) pushed the Triassic-Jurassic boundary back to 208 Ma, providing for a ~15 m.y. lag between deposition of arc strata and intrusion. A subsequent revision of the Jurassic time scale for the Canadian Cordillera (Pálfy et al., 2000; J on Figure 4), moderated the 1982 Triassic-Jurassic boundary revision, placing the new boundary at 200 ±1.0 Ma. Following the time scale revision in 2000, the Copper Mountain story was: intrusion around 202 Ma, in the Late Triassic, followed by mineralization around 193 Ma, in the Early Jurassic. In light of typical durations for hypogene ore formation, which range from 0.01 to 0.1 m.y. for Cu±Mo±Au porphyry deposits worldwide (McInnis et al., 2005) the lag time of nearly 10 m.y. seemed unreasonable, and most



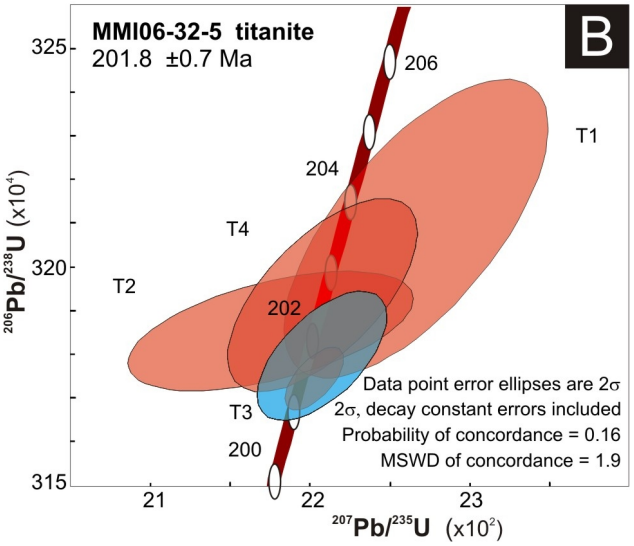


Figure 8. Concordia plots for U-Pb thermal ionization mass spectrometry data for samples from Copper Mountain, south-central British Columbia: **A)** sample MMI06-32-3; **B)** sample MMI06-32-5. 2 error ellipses for individual analytical fractions are red. Blue ellipses represent the best estimate concordia age of the sample. Concordia bands include 2 errors on U decay constants.

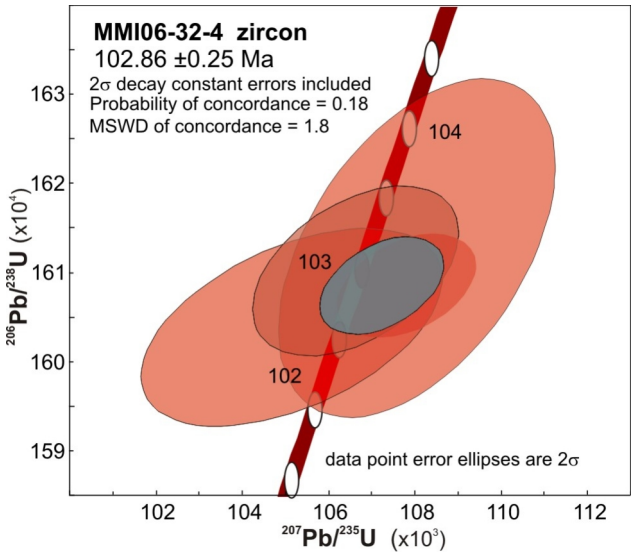


Figure 9. Concordia plot for U-Pb thermal ionization mass spectrometry data for the 'Mine Dyke' sample, MMI06-32-4, Copper Mountain, south-central British Columbia. 2 error ellipses for individual analytical fractions are in red. The blue ellipse represents the best estimate concordia age of the sample. Concordia bands include 2 errors on U decay constants.

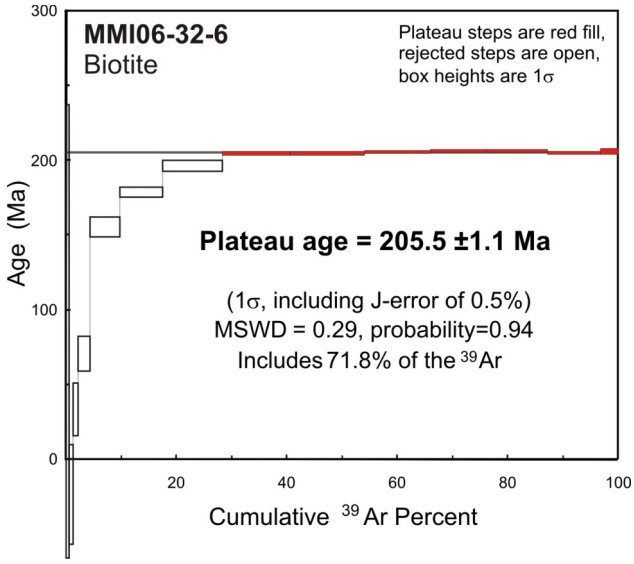


Figure 10. Step-heating Ar gas release spectra for euhedral biotite from sample MMI06-32-6, Big Lead, bornite-biotite ore, Copper Mountain, south-central British Columbia. Plateau steps are filled; rejected steps are open. Box heights at each step are 1 . Rising low-temperature steps to the robust plateau at 205.5 ±1.1 Ma indicate a deficit of loosely bound Ar.

Table 3. $^{40}Ar/^{39}Ar$ step heating gas release data from sample MMI06-32-6, a centimetre-thick slice of a sample of the Big Lead glory hole biotite-bornite mineralization, Copper Mountain, south-central British Columbia.

MMI06-32-6 Laser Power (%)	Biotite Isotope Ratios $^{40}Ar/^{39}Ar$	$^{38}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	Ca/K	Cl/K	$\%^{40}Ar$ atm	f ^{39}Ar	$^{40}Ar^*/^{39}ArK$	Age (in Ma)
2	363.182±0.012	0.344±0.046	0.085 ±0.076	1.308 ±0.022	0.961	0.018	103.47	0.2	-12.772 ±7.318	-255.28 ±157.12
2.2	100.783± 0.008	0.224 0.026	0.065 ±0.059	0.354 ±0.019	1.58	0.033	101.28	0.92	-1.319 ±1.822	-24.76 ±34.42
2.4	41.627 ±0.008	0.131 0.030	0.164 ±0.018	0.147 ±0.023	4.343	0.02	95.47	0.71	1.835 ±0.958	33.88 ±17.52
2.73	40.243 ±0.005	0.115 0.018	0.027 ±0.053	0.127 ±0.018	0.623	0.018	90.23	2.1	3.880 ±0.664	70.91 ±11.90
3.2	30.272 ±0.004	0.078 0.015	0.013 ±0.035	0.074 ±0.018	0.307	0.011	70.93	5.5	8.736 ±0.398	155.89 ±6.80
3.4	21.238 ±0.004	0.059 0.015	0.007 ±0.044	0.039 ±0.017	0.176	0.009	52.04	7.67	10.114 ±0.201	179.29 ±3.39
3.6	16.366 ±0.012	0.048 0.022	0.004 ±0.045	0.018 ±0.023	0.086	0.007	31.42	11.06	11.149 ±0.195	196.67 ±3.25
3.8	13.820 ±0.004	0.041 0.013	0.002 ±0.058	0.008 ±0.026	0.044	0.006	15.33	12.27	11.622± 0.079	204.57 ±1.32
3.9	13.110 ±0.006	0.038 0.013	0.002 ±0.054	0.005 ±0.025	0.033	0.005	10.64	13.46	11.637 ±0.078	204.81 ±1.30
4	12.476 ±0.004	0.036 0.019	0.001 ±0.069	0.003 ±0.038	0.016	0.005	5.73	11.83	11.677 ±0.061	205.48 ±1.01
4.1	12.338 ±0.004	0.036 0.023	0.002 ±0.087	0.003 ±0.046	0.017	0.005	4.32	10.07	11.713 ±0.065	206.08 ±1.08
4.2	12.291 ±0.004	0.035 0.021	0.002 ±0.076	0.003 ±0.036	0.016	0.005	4.01	11.16	11.712 ±0.060	206.06 ±0.99
4.2	12.233 ±0.004	0.035 0.017	0.002 ±0.060	0.003 ±0.048	0.01	0.005	4.02	9.56	11.648 ±0.063	204.99 ±1.05
4.4	12.445 ±0.005	0.037 0.029	0.004 ±0.079	0.005 ±0.068	0.03	0.005	4.54	3.49	11.712 ±0.110	206.07 ±1.83
Total/Average	16.998 ±0.001	0.046±0.003	0.064 ±0.001	0.020 ±0.003	0.117	0.011		100	11.669 ±0.028	

J-error = 0.010331 ±0.000010

Volume ^{39}ArK = 1157.55

Integrated Date = 192.98 ±0.95

Volumes are $1\times10^{-13}cm^3$ 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($^{37}ArCa/^{39}ArK$).

likely attributable to the large errors of the age determinations from mineralization (Figure 4).

Our sampling of mineralization includes titanite-biotite–bearing veins in the margin of the Copper Mountain stock and those equidistant between the Copper Mountain stock and the body of Lost Horse Intrusions (Figure 3). In addition to this spatial variability, we have used two different techniques: U-Pb titanite and $^{40}Ar/^{39}Ar$ biotite dating with closure temperatures of 660–700°C (Scott and St-Onge, 1995) and 300–450°C (McDougall and Harrison, 1999), respectively. These techniques are more robust than the K-Ar biotite technique used in the past. Our results for the titanite-bearing veins, 201.2 ±1.0 Ma and 201.8 ±0.7 Ma, are identical, within error, to the crystallization ages reported by Mortensen et al. (1995). 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 of alkalic porphyry deposits (e.g., Iron Mask and Mt. Polley; Logan et al., 2007), and results from other porphyry systems globally (McInnis et al., 2005). Our new data provide a tight integration of the Copper Mountain deposit with the ca. 205–200 Ma alkalic Cu-Au porphyry event that stretches the length of the Canadian Cordillera.

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