Investigations of Orogenic Gold Deposits in the Cariboo Gold District, East-Central British Columbia (Parts of NTS 093A, H): Final Report

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Introduction

The Cariboo gold district (CGD) in east-central British Columbia (BC; Figure 1) is one of BC's most productive placer-gold camps, having yielded an estimated 80 to 96 tonnes (2.5 to 3 million ounces) of placer-gold (roughly half of BC's total historical placer-gold production) since its discovery in the mid-1800s (e.g., Levson and Giles, 1993). Gold-bearing quartz vein systems and pyritic replacement deposits in metamorphic rocks of the Barkerville terrane, in the Wells-Barkerville area (Figure 1), were located soon after the discovery of placer-gold in the area, and have produced approximately 38.3 tonnes (1.2 million ounces) of gold since that time. At present, lode-gold exploration in the CGD focuses on both the Wells-Barkerville area and the structurally higher rock units of the Quesnel terrane, located farther to the south and west where the Spanish Mountain and Frasergold deposits occur (Figure 1).

Gold-bearing veins and replacement deposits in the CGD are classed as orogenic systems (Goldfarb et al., 2005), because there is evidence for strong structural control and the mineralization does not appear to be spatially or temporally related to intrusive rocks. A study of lode-gold mineralization and potential of the CGD (Figure 1) was initiated by the authors in 2008, aimed at providing constraints on the age(s) and structural controls on mineralization in different parts of the CGD. The study included a synthesis of previous work in the region together with focused structural, geochronological and Pb-isotopic studies of some of the main lode-gold occurrences in the belt. The main goals of this work were to better understand the geology and gold metallogeny of the CGD, to provide guidelines for future exploration of the district, and to enable comparisons to other similar gold districts globally. A detailed discussion of the structural setting and controls on gold mineralization in the CGD, based largely on this new work, was presented by Rhys et al. (2009). A preliminary discussion of dating and Pb-isotopic studies of gold deposits and occurrences in the CGD was also included in that contribution. In this paper, the authors report new $^{40}Ar/^{39}Ar$ dating results and discuss the implications for the timing of orogenic gold systems in the region. Discussions also include the age and petrochemistry of intrusive rocks in the vicinity of gold mineralization in the Spanish Mountain area, and the use of Pb-isotopic constraints to identify possible sources of the gold and other metals in deposits and occurrences throughout the CGD.

Keywords: orogenic gold, Cariboo gold district, vein, gold-rich replacement

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Regional Geological Framework

The regional geological setting of the CGD is discussed in detail in Rhys et al. (2009) and is only briefly summarized here. The CGD is underlain by parts of four main terranes (Figure 1). Bedrock in most of the northern and eastern parts of the area includes polydeformed, medium grade metamorphic rocks of the Barkerville terrane and the structurally overlying Cariboo terrane, which are separated by the northeast-dipping Pleasant Valley thrust fault (Struik, 1987, 1988; Figure 1). Structurally overlying both the Barkerville and Cariboo terranes in the northern part of the area are mafic volcanic rocks and associated sedimentary units of the Slide Mountain terrane. The southwestern margin of the Barkerville terrane is structurally overlain along the Eureka thrust by much less deformed and less metamorphosed rock units of the Quesnel terrane. In this area, the Quesnel terrane mainly consists of a package of weakly deformed, variably phyllitic, carbonaceous siliciclastic rocks (locally termed the 'black phyllite' by Rees, 1987; equivalent to the 'black pelite succession' of Logan, 2008), with minor mafic volcanic and volcaniclastic interlayers. This lower, dominantly meta-clastic package is overlain along the Spanish thrust (Struik, 1988; Logan, 2008) by mafic to intermediate volcanic rocks assigned to the Late Triassic Nicola Group. The sedimentary package has yielded Middle and Late Triassic fossil ages (Bloodgood, 1992; Panteleyev et al., 1996). The Crooked Amphibolite (Figure 1) occurs as a discontinuous, strongly deformed and metamorphosed lens of mafic metavolcanic rocks and minor serpentinite, along the Eureka thrust between the Quesnel terrane and the underlying Barkerville terrane.

Several suites and ages of intrusive rocks are present in the Wells-Barkerville camp and adjoining portions of the Barkerville terrane. Strongly deformed granitic to granodioritic orthogneiss bodies of Early Mississippian age occur in several localities, particularly in the vicinity of Quesnel Lake and the Eureka Peak syncline (Figure 1). Variably foliated metadiorite units, some of which have yielded Early Permian U-Pb zircon ages, occur as small, widespread but volumetrically minor sills, dikes and irregular bodies within the Snowshoe Group of the Barkerville terrane (Struik, 1988; Schiarizza and Ferri, 2003). In the Wells-Barkerville area, several small, strongly altered, and foliated felsic bodies, termed the Proserpine intrusions, have been documented and appear to have been emplaced prior to the D_2 folding (Struik, 1988; Schiarizza and Ferri, 2003). Younger, rare, locally quartz-phyric rhyolite dikes and relatively fresh lamprophyre dikes, both of which appear to be

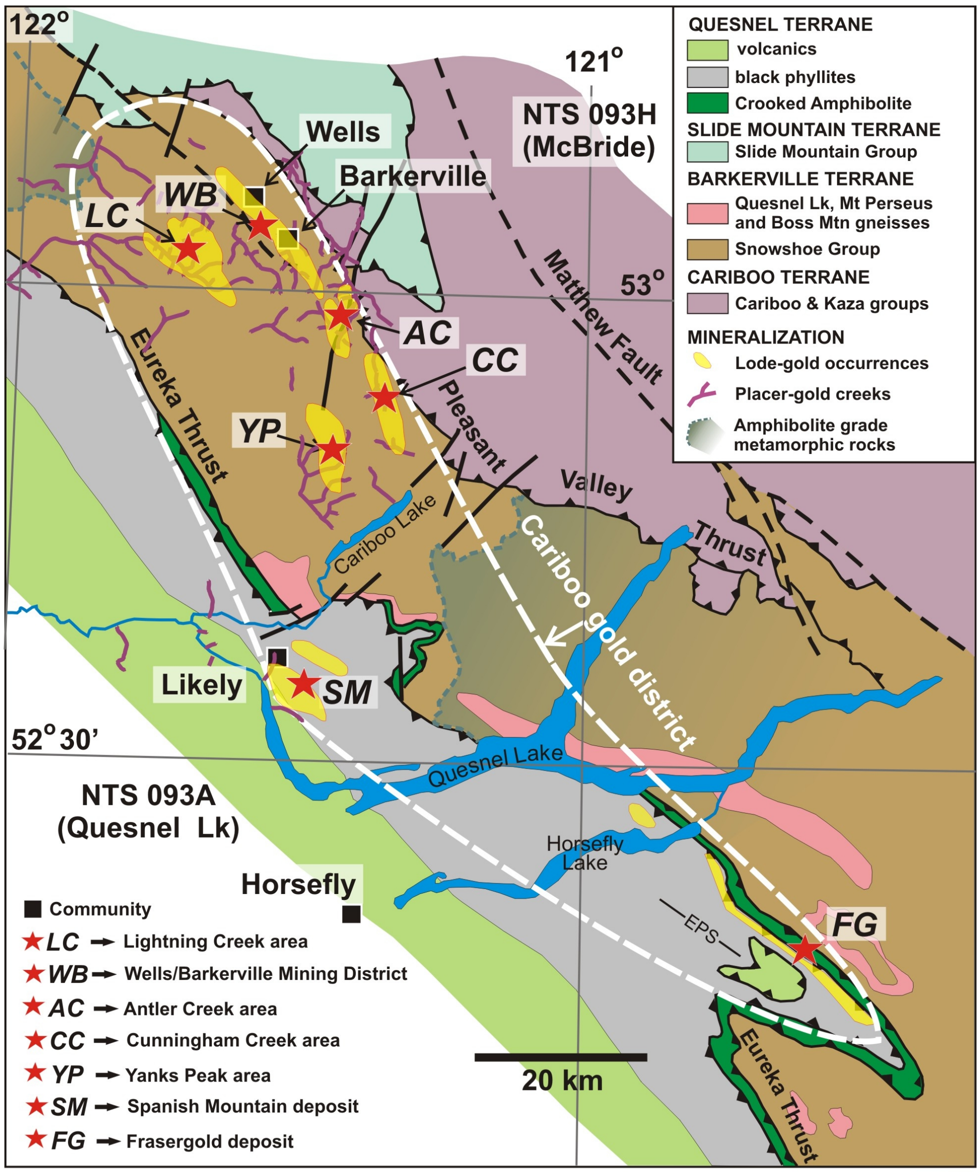

Figure 1: Regional geological setting of the Cariboo gold district, east-central British Columbia, showing principal terranes and major lithological packages. Areas of known lode-gold occurrences are shaded in yellow, and placer-gold producing creeks are indicated by thick purple lines. Principal known gold-producing areas in the Barkerville terrane are in areas of greenschist-grade metamorphism, and do not extend into amphibolite-grade domains. Abbreviation: EPS, Eureka Peak syncline.

post-tectonic, are also present in several localities in the eastern Barkerville terrane area (Holland, 1954; Struik, 1988; Termuende, 1990).

Several small intrusions occur in the vicinity of gold mineralization in the Spanish Mountain area southwest of Quesnel Lake; these occur within the black phyllite succession of the Quesnel terrane and range from diorite to monzonite and syenite in composition. Rhys et al. (2009) reported Early Jurassic U-Pb zircon ages for several of these bodies.

Metamorphic rocks in the CGD have been affected by two dominant syn- to post-accretionary phases of deformation (D_1 and D_2), which affect rocks in both the Quesnel and Barkerville terranes. D_1 structures include a penetrative slaty to phyllitic cleavage (S_1) that is axial planar to generally east- to northeast verging tight to isoclinal, generally northwest-trending F_1 folds and shear zones. The D_1 event is interpreted to be associated with emplacement of the Quesnel terrane onto the Barkerville terrane along the Eureka thrust (Rees, 1987; Bloodgood, 1987, 1992; Panteleyev et al., 1996; Ferri and Schiarizza, 2006). D_1 was accompanied and locally outlasted by peak regional metamorphism. D_2 structures regionally include the Eureka Peak syncline (Figure 1), which openly refolds both the earlier S_1 foliation and associated folds and the D_1 Eureka thrust (Bloodgood, 1987, 1992). D_2 structures include a secondary, locally dominant crenulation cleavage (S_2), which is axial planar to the Eureka Syncline and other D_2 folds (F_2; Bloodgood, 1987, 1992). An intense, shallow northwest-plunging composite intersection and elongation lineation (L_2) occurs at the intersection of S_2 and older S_1 foliation, and is parallel to F_2 fold axes. The long axes of many gold-bearing zones in the area are parallel to L_2, and extensional veins related to many gold deposits in the area are approximately orthogonal to L_2. Locally developed, late, north- to northeast-trending crenulation cleavage and kink bands reflect late, retrograde, low-strain events.

Structurally late northerly to north-northeasterly trending, right-lateral (dextral) faults occur throughout the CGD, extending across and offsetting lithological contacts, including major thrust surfaces associated with terrane boundaries. These faults have a protracted structural history, locally displaying early semi-brittle fabrics, with widespread later brittle displacements along clay gouge seams. These structures are commonly spatially associated with late gold-bearing quartz veins that are widespread throughout the district.

Lode Gold Deposits in the Barkerville Terrane

Most historical gold exploration and placer and lode-gold production in the CGD has been from localities within the Barkerville terrane. Known lode-gold occurrences are most abundant over an approximately 50 km strike length from Cariboo Lake in the southeast to several kilometres northwest of Wells (Figure 1). Most placer-gold deposits in the area are spatially associated with portions of the Barkerville terrane that are known to contain lode-gold occurrences, suggesting that much of the placer gold is locally sourced (this is discussed in more detail by Mortensen and Chapman, 2010, and Chapman and Mortensen, 2011). Known lode-gold mineralization appears to be confined to rocks of sub-biotite grade (Figure 1), suggesting that the associated vein systems may be preferentially localized in lower greenschist-grade rocks (Struik, 1988).

Wells-Barkerville camp

The Wells-Barkerville camp (Figure 1) was the source of nearly all historical lode-gold production and much of the placer production from the CGD (Hall, 1999). An estimated 38.3 tonnes (1.2 million ounces) of gold in the camp came from the Cariboo Gold Quartz (MINFILE 093H 019, BC Geological Survey, 2010), Island Mountain (MINFILE 093H 019) and Mosquito Creek (MINFILE 093H 025) mines in the Wells-Barkerville camp. Gold mineralization in the area includes both pyritic replacement bodies and veins. The nature and structural controls on gold mineralization in the Wells-Barkerville camp are discussed in detail by Rhys et al. (2009).

Approximately one-third of the lode-gold production from the Wells-Barkerville camp was from replacement mineralization (Ray et al., 2001), which occurs as multiple small (500–40 000 tonnes), manto-like, folded, northwest-plunging, rod-shaped bodies of massive, fine-grained pyrite > (Fe-carbonate + quartz) that replace limestone bands. Replacement style ore shoots in the Island Mountain and Mosquito Creek mines are spatially associated with hinge zones of mesoscopic D_2 folds. Mineralization is commonly banded, with alternating pyrite- and carbonate-dominant bands. Highest Au grades are associated with fine-grained pyrite within which Au occurs as grains along crystal boundaries and fractures. Replacement mineralization also occurs in the Bonanza Ledge Zone south of Wells (MINFILE 093H 140; Figure 1), where it replaces thinly bedded meta-clastic rocks rather than limestone.

At least two stages of quartz veining occur in the Wells-Barkerville camp, including early poorly mineralized and deformed veins, which are cut by later gold-bearing, late tectonic quartz-carbonate-pyrite veins. The early veins contain only background or low (<2 g/t) gold concentrations. The younger, main-stage quartz veins, associated with gold mineralization, are structurally late and post-date all D_1 and much or all D_2 strain in the region. They have been the source of approximately two-thirds of the lode-gold production in the Wells-Barkerville camp (Hall, 1999). The auriferous veins form complex vein arrays at two or more orientations (Sutherland-Brown, 1957; Skerl, 1948). Veins consist of white quartz+pyrite with Fe-carbonate±muscovite selvages. Scheelite and fuchsite are local accessory minerals, and native gold occurs in association with pyrite, and locally cosalite and bismuthinite (Skerl, 1948). Where the quartz veins occur together with replacement style mineralization, the veins typically cut across it.

The relationship between the replacement and vein styles of mineralization in the Wells-Barkerville area has long been a topic of debate (e.g., Benedict, 1945; Robert and Taylor, 1989, Ray et al., 2001). The close spatial association of the two styles of mineralization in a single, northwest-plunging mineralizing system could be interpreted in three different ways: 1) a genetic link, representing different products of a single, long-lived, syn-metamorphic and syn- deformational mineralizing event; 2) vein mineralization being remobilized from older Au-enriched replacement ores; or 3) two unrelated mineralizing events with common structural controls. Insufficient evidence is available to resolve this debate; however, dating results discussed below demonstrate that the two styles of mineralization formed over a relatively short time interval, and thus could be related.

Cunningham Creek Area

Southeast of the Wells-Barkerville camp, vein showings extend discontinuously over a 40 km strike length to Cariboo Lake (Figure 1), and are associated with significant placer-gold producing drainages such as Cunningham, Keithley, Antler and Grouse creeks (Schiarizza, 2004).

Lode-gold mineralization along Cunningham Creek (Figure 1) occurs mainly in sets of structurally late quartz-sulphide veins that are similar in style to those in the Wells-Barkerville camp. Auriferous quartz veins commonly include coarse-grained pyrite-arsenopyrite and minor galena and sphalerite fill. Farther to the south, prospects including Skarn (Silver Mine), Penny Creek, and Cariboo Hudson (MINFILE 093A 071) occur as northerly to north-northwesterly trending, discordant and steeply dipping fault-fill veins (Delancey, 1988; Termuende, 1990). These veins contain abundant galena, sphalerite, pyrite, tetrahedrite and arsenopyrite. The veins in this area are much more Ag-rich than those to the northwest. The Cunningham Creek area veins display similar timing relationships to regional fabrics as main-stage gold-bearing quartz veins in the Wells-Barkerville camp. The veins post-date all D_1 and most or all D_2 strain, and are associated with northerly trending, dextral faults.

Geological Setting and Gold Mineralization in Quesnel Terrane Metasedimentary Units

The Spanish Mountain deposit (MINFILE 093A 043), held by Skygold Ventures Ltd., and the Frasergold deposit (MINFILE 093A 150), currently held by Eureka Resources Inc., are two significant gold deposits that have been discovered within lower greenschist-grade metasedimentary units in the lower part of the Quesnel terrane (Figure 1).

Spanish Mountain

The Spanish Mountain deposit (MINFILE 093A 043) is hosted by the black phyllite package of the Quesnel terrane, including interbedded slaty to phyllitic, dark grey to black siltstone, carbonaceous mudstone, greywacke, and minor conglomerate. The main host for gold mineralization is carbonaceous phyllite and argillite. The sedimentary units at Spanish Mountain are intruded by plagioclase±quartz± hornblende sills and locally dikes, which range in thickness from a few tens of centimetres to as much as 100 m thick. These sills are affected by all phases of folding, alteration and quartz vein mineralization, and have given Early Jurassic U-Pb zircon ages (Rhys et al., 2009).

The Spanish Mountain deposit is a bulk tonnage gold system that also includes local higher grade gold-bearing quartz veins (Peatfield et al., 2009). The most economically significant gold mineralization (>1 g/t Au) occurs in wide zones (10–135 m), hosted mainly within the black argillite unit as a set of stacked, roughly lensoid bodies. The largest zone identified thus far is the 'Main Zone', which has been traced by drilling over a strike length of approximately 1.3 km, and width of 500 m (Peatfield et al., 2009). At least two periods of mineralization are recognized within these mineralized zones at Spanish Mountain; an earlier phase of disseminated pyrite and pyrite-quartz veinlets, and a later phase of fault-related quartz veining. These later veins and vein-faults resemble the dominant, late vein-related gold mineralization style in the Barkerville terrane. They cut the folded early quartz-pyrite veins and may contain minor pyrite, galena, sphalerite and tetrahedrite. The highest gold grades in the Spanish Mountain deposit are typically associated with quartz veins, particularly in association with mineralized faults. The association of steeply dipping, northeast-trending extension veins with the faults in the Spanish Mountain area, and the structurally late timing of veining (late to post-D_2), is similar to that observed in the Barkerville terrane, suggesting a possible structural and temporal link between gold mineralization in the two areas (Rhys et al., 2009).

Frasergold

The Frasergold property (MINFILE 093A 150) is located approximately 60 km southeast of Spanish Mountain and covers an ~10 km long, northwest-trending area of mineralized prospects along the northeast limb of the Eureka Peak syncline (Figure 1). Anomalous gold zones on the property were defined by drilling and soil sampling. Mineralization at Frasergold is hosted by the same general sequence of Middle to Late Triassic metasedimentary rocks that occur at Spanish Mountain, consisting of a fine-grained turbidite sequence that is dominated by black carbonaceous phyllite with local thin interbeds of metasiltstone, and more rarely, fine-grained metasandstone. Unlike Spanish Mountain, however, intrusive rocks appear to be absent from the section at Frasergold.

Gold mineralization at Frasergold occurs within, or is spatially associated with, stratabound sets of white quartz veins containing lesser amounts of Fe-carbonate+muscovite+pyrite that are developed within ‘knotted’, Fe-carbonate porphyroblastic, carbonaceous phyllite. The veins form complex sets that are developed in concentrated zones several metres to tens of metres wide, which collectively dip to the southwest and form a bulk tonnage low-grade gold deposit. An inferred historical resource (non NI 43-101 compliant) of 6.6 million tonnes grading 1.6 g/t (0.055 oz/t) gold to depths of 100 m and over a 3 km strike length has been reported (Goodall and Campbell, 2007).

Unlike gold-bearing quartz veins in the Barkerville terrane and at Spanish Mountain, those within mineralized zones at Frasergold formed structurally early in the tectonic evolution of the area. The veins have been affected by both D_1 and D_2 strain, and are commonly transposed and boudinaged, locally with the development of internal S_1-parallel sericite stylolites. The veins are affected by F_2 folds. Fe-carbonate typically occurs as clots, bands and selvages on veins, which contain disseminated pyrite±pyrrhotite with locally trace amounts of chalcopyrite, sphalerite and galena. Structurally late quartz extension veins and shear veins, as seen in the Barkerville lode-gold deposits and at Spanish Mountain, have not been observed at Frasergold.

Several other gold occurrences that are similar in style to that at Frasergold, including the Kusk occurrence (MINFILE 093A 061; Belik, 1988) and the Forks occurrence (MINFILE 093A 092; Howard, 1989), occur approximately 4 km along strike to the southeast and 20 km northwest of the Frasergold deposit, within the same belt of Triassic phyllite. Collectively, these occurrences and the Frasergold deposit define a mineralized corridor that is nearly 35 km long.

New Analytical Results and Interpretation

$^{40}Ar/^{39}Ar$ Geochronology

A total of 13 $^{40}Ar/^{39}Ar$ ages were reported by Rhys et al. (2009) for metamorphic and hydrothermal white mica from the Wells-Barkerville area. In Table 1 below the authors present an additional 14 $^{40}Ar/^{39}Ar$ ages from the study area, including more results from gold occurrences in the Barkerville terrane together with ages from the Spanish Mountain and Frasergold deposits. The results are compiled along with the previous results in Figure 2.

The $^{40}Ar/^{39}Ar$ ages obtained for metamorphic and hydrothermal micas from the CGD during this project (Figure 2) range from Late Jurassic to Early Cretaceous. Rhys et al. (2009) argued that since the temperatures of regional metamorphism indicated by metamorphic mineral assemblages in the mineralized portions of the Barkerville terrane are relatively low, muscovite ages from the syn- to mainly post-metamorphic gold lodes probably reflect the age of formation of the veins rather than post-metamorphic cooling ages. Two early (pre-mineral), deformed quartz-pyrite veins in the Wells-Barkerville camp give consistent ages of 156–153 Ma. Micas in replacement-type ore and in late, gold-bearing extensional veins in the Wells-Barkerville camp, and elsewhere in the Barkerville terrane, range in age from 148–135 Ma, with no obvious correlation between age geographic location, or style or composition of mineralization. The ages generally overlap with ages for metamorphic micas in the Wells-Barkerville camp, although it is uncertain which of these metamorphic samples, if any, may have been affected and potentially disturbed by hydrothermal activity related to the gold mineralization. Taken at face value the data suggest that the mineralizing event in the Barkerville terrane was protracted, lasting at least 13 m.y.

Micas from various gold-bearing quartz veins in the Spanish Mountain area are substantially older than those from within the Barkerville terrane, ranging from 160–152 Ma. Rhys et al. (2009) had speculated, based on structural arguments, that structurally late gold-bearing extensional veins at Spanish Mountain were the same age as similar veins in the Barkerville terrane; however, the $^{40}Ar/^{39}Ar$ dating results indicate that this is not the case.

The age of formation of gold-bearing veins at the Frasergold deposit is still uncertain. Micas from four samples of gold-bearing vein material at Frasergold were dated using $^{40}Ar/^{39}Ar$ methods. One sample yielded ages of 147 and 143 Ma (analyzed in duplicate), whereas three other samples gave considerably younger ages ranging from 129 to 122 Ma (Figure 2). The micas were all from veins that were strongly deformed and boudinaged, therefore, it is likely that the $^{40}Ar/^{39}Ar$ systematics would have been disturbed and possibly completely reset during that deformation. It is unlikely, therefore, that the ages reflect the actual time of formation of the gold-bearing veins. It is probable that even the oldest ages obtained from Frasergold (147–143 Ma) reflect the timing of superimposed deformation of pre-existing veins rather than the age of vein formation.

Muscovite from a sulphide-bearing quartz vein (not known to contain gold) from within the Eureka thrust zone, east of the Frasergold deposit, gave the youngest age in the entire study, at 110.8 ±1.2 Ma. This vein was undeformed, and thus the age may give the actual timing of vein formation. There is insufficient information on the timing of deformation in this area to be able to relate this veining event to specific phases of regional tectonism.

Table 1. Summary of new $^{40}Ar/^{39}Ar$ dating results from Cariboo gold district, east-central British Columbia.

Sample no.	Rock type and location	Interpreted $^{40}Ar/^{39}Ar$ age
Spanish Mountain		
SP-50-b	Muscovite in barren qtz vein above Imperial Pit	151.4 ± 1.7 Ma (good plateau); 155.2 ± 1.8 Ma (good plateau)
SP-109	Muscovite in vein in Ropes of Gold area	159.9 ± 1.8 Ma (good plateau)
SP-116	Muscovite in vein in Ropes of Gold area	153.7 ± 0.9 Ma (good plateau)
07-688-209m	Fuchsite as alteration in porphyry sill	155.2 ± 1.0 Ma (excellent plateau)
07-635-235m	Muscovite in quartz vein	156.4 ± 1.7 Ma (good plateau)
ROG08-02-29.4m	Muscovite in quartz vein	159.4 ± 1.7 Ma (excellent plateau)
Frasergold		
FG-01-c	Muscovite in quartz vein along Eureka thrust	110.8 ± 1.2 Ma (excellent plateau)
FG-02-a	Muscovite in deformed quartz vein underground at Frasergold	146.9 ± 1.6 Ma (good plateau); 143.4 ± 1.5 Ma (isochron age; no plateau)
FG-03-b	Muscovite in deformed quartz vein underground at Frasergold	126.9 ± 1.5 Ma (good plateau)
FR-04-a	Muscovite in deformed quartz vein on road above Frasergold adit	123.0 ± 3.8 Ma (isochron age; no plateau)
FG07-308-16.7 m	Muscovite in deformed quartz vein in drill core at Frasergold	129.0 ± 1.3 Ma (isochron age; no plateau)
Barkerville terrane		
WB-09	Muscovite in vein in Hibernia occurrence trench	137.4 ± 1.6 Ma (good plateau)
WB-11-b	Muscovite in vein in Jewelry Box occurrence trench	141.0 ± 1.6 Ma (excellent plateau)
PSP05-02-30m	Muscovite in vein in Proserpine occurrence drillcore	136.8 ± 1.5 Ma (excellent plateau)
PSP05-01-240m	Muscovite in vein in Proserpine occurrence drillcore	135.0 ± 1.5 Ma; 136.5 ± 1.2 Ma (isochron ages; no plateaux)

Pb-Isotopic Studies

A total of 74 Pb-isotopic analyses are available from gold-bearing replacements and veins in the CGD, including 57 analyses that were done as part of this study. These data are shown in $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{206}Pb$ versus $^{208}Pb/^{206}Pb$ diagrams in Figure 3. Also shown for reference is the 'shale curve' of Godwin and Sinclair (1982), which models the average growth of Pb-isotopic compositions in the North American miogeocline and associated pericratonic terranes (including the Barkerville terrane) of the northern Cordillera (Mortensen et al., 2006).

Lead analyses from the Barkerville terrane samples lie on or above the shale curve in $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ space (Figure 3A), suggesting that the Pb (and presumably Au) in these occurrences was extracted from rocks of North American affinity, or more likely from the Barkerville terrane itself. Lead in sulphides in the Frasergold deposit, which is hosted in the black phyllite of the Quesnel terrane, is substantially less radiogenic, which is consistent with the Pb having been derived at least in part from a somewhat more juvenile source such as Quesnel terrane igneous rocks (as indicated by the field of igneous lead compositions from the Nicola arc from Breitsprecher et al., 2008). Lead analyses from the Spanish Mountain deposit, also hosted in the black phyllite unit, form an array that extends from the Frasergold cluster to significantly more radiogenic values, overlapping in part with analyses from the Barkerville terrane. This suggests a mixed source for the contained Pb. The Quesnel terrane is interpreted to be a continental-margin arc that was probably built on a thinned and extended western margin of the Barkerville terrane. Thus, a component of Pb in Spanish Mountain veins could be derived from Barkerville terrane units that structurally underlie the Quesnel terrane in this area (beneath the Eureka thrust). Ferri and Friedman (pers. comm., 2009), however, have obtained abundant Precambrian detrital zircons from a sample of conglomerate within the black phyllite unit, suggesting that this sedimentary unit was derived from erosion of continental rocks (probably the Barkerville terrane). Thus Pb derived from the black phyllite unit itself would be expected to have a mixed signature, including more radiogenic components from the Barkerville terrane and possibly a less radiogenic component related to the arc magmas (Figure 3B).

Results of the Pb-isotopic study are interpreted to indicate that most of the Pb and other contained metals in gold-bearing deposits and occurrences in the CGD were derived either from the immediate host rocks for the occurrences or from rock units that immediately underlie them. A relatively local source for the metals in the CGD deposits differs from models that have been proposed for other large orogenic gold systems (e.g., the Otago schist belt in South Island, New Zealand; Mortensen et al., 2010), in which metals are interpreted to have been derived from very large volumes of rock during prograde greenschist- to amphibolite-facies metamorphism.

Igneous Geochemistry of Intrusive Rocks

The nature and origin of the intrusive sills and dikes in the Spanish Mountain area are interesting, in view of their close spatial relationship with gold mineralization. Rhys et al. (2009) reported Early Jurassic U-Pb zircon crystallization ages for three of these bodies ranging from 185.6 ±1.5 to 187 ±0.8 Ma. These intrusions are typically fine- to medium-grained and equigranular to sparsely plagioclase-phyric, and have been strongly overprinted by hydrothermal alteration. An unusual feature of many of the bodies is the presence of locally abundant chromite grains of presumably xenocrystic origin, as well as small rounded mafic to ultramafic xenoliths. Both the chromite grains and mafic/ultramafic xenoliths are typically rimmed by Cr-mica (fuchsite), the presence of which was initially interpreted to indicate a mafic or possibly ultramafic composition for the sills. Major, trace and rare earth element analyses have been carried out on six samples of intrusions from throughout the Spanish Mountain area, and the data are plotted on discriminant plots in Figure 4. The results show that most of the samples are intermediate in composition (diorite, monzonite and monzodiorite; Figure 4A) except for one analysis, which yields a much more mafic composition, possibly due to the presence of abundant mafic xenolithic and xenocrystic material. All of the sample compositions fall in the volcanic arc field in Figure 4B.

The Spanish Mountain sills and dikes are the only Early Jurassic bodies that have been recognized thus far intruding the black phyllite unit of the Quesnel terrane. Rhys et al.

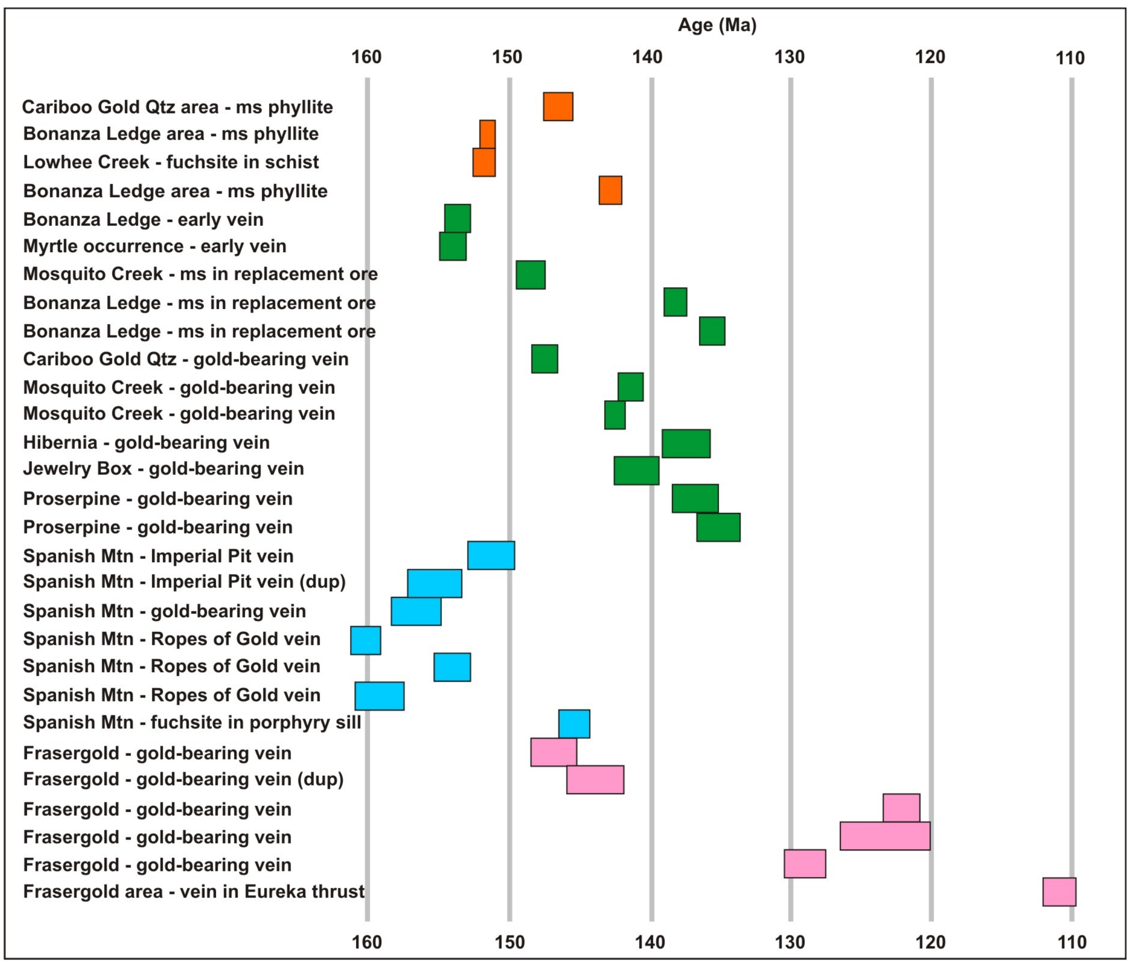

Figure 2. Compilation of all $^{40}Ar/^{39}Ar$ dating results from the Cariboo gold district, east-central British Columbia. Abbreviation: ms, muscovite.

(2009) suggested that the locally irregular contacts of these sills, and brecciation on their finer-grained margins that may represent peperitic textures, indicate that the intrusions were emplaced into wet, unconsolidated sediments. If correct, this would require that the protolith of the black phyllite in the Spanish Mountain area is actually Early Jurassic in age, rather than Middle or Late Triassic as has previously been proposed (e.g., Panteleyev et al., 1996). There are no fossil ages from the black phyllite package in the Spanish Mountain area, and it is in structural contact with the overlying Late Triassic volcanic sequence; hence, the depositional age of the black phyllite in this area is presently unconstrained.

The significance, if any, of the Early Jurassic intrusions at Spanish Mountain and apparent spatial association with gold mineralization is uncertain. Although Early Mesozoic intrusions are relatively widespread in this part of the cen-

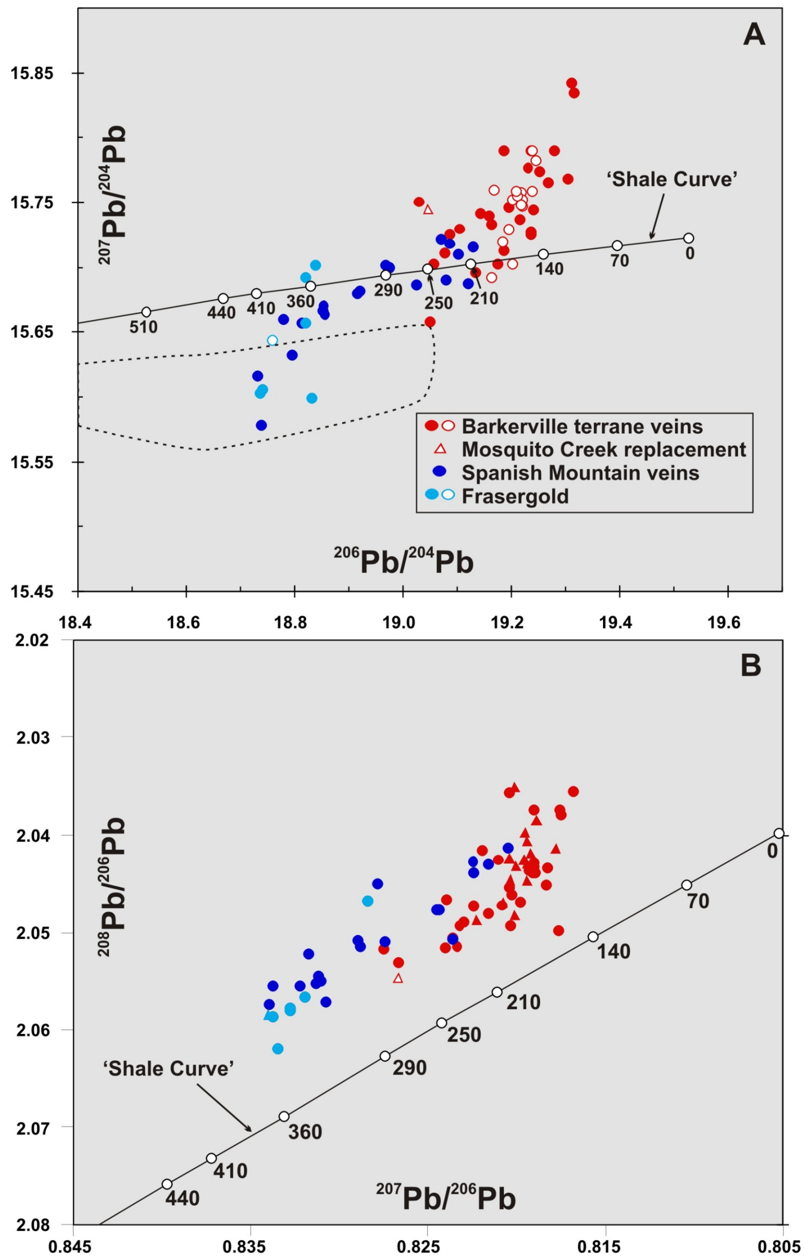

Figure 3. Lead isotopic compositions of gold-bearing veins and replacements from the Cariboo gold district, east-central British Columbia. The 'shale curve' of Godwin and Sinclair (1982) is shown for reference. The dashed outline in **A)** shows the field for Pb-isotopic compositions of Nicola arc intrusive and volcanic rocks from Breitsprecher et al. (2008). Solid symbols represent analyses done as part of this study and open symbols are analyses from Godwin et al. (1988).

tral Quesnel terrane (e.g., Logan et al., 2007), no other intrusions of this particular age range have been recognized thus far. The $^{40}Ar/^{39}Ar$ dating results for the Spanish Mountain veins indicate that the mineralization is at least 35 m.y. younger than the intrusions; hence, there can be no direct genetic relationship between the intrusions and mineralization.

Discussion and Ongoing Work

Results of structural analysis carried out during this study have established the main structural controls on orogenic gold mineralization in the Wells-Barkerville and Cunningham Creek areas in the Barkerville terrane, and the Spanish Mountain and Frasergold areas in the Quesnel terrane. The structural study suggested that the mineralization in the Barkerville terrane and at Spanish Mountain were of roughly the same age (late- and post-D_2), and that Frasergold was somewhat older (pre-D_1). This interpretation was based on the assumption that D_1 and D_2 deformation occurred at approximately the same time at different structural levels in the CGD. Our new $^{40}Ar/^{39}Ar$ age data, however, indicate this assumption is incorrect. Gold mineralization at Frasergold is presently only constrained to be >148 Ma, and therefore may be the oldest mineralization in the belt. However, vein-style mineralization in the structurally deeper Barkerville terrane is mostly younger than that in structurally higher rock units at Spanish Mountain (148–135 Ma in the Barkerville terrane compared to 161–150 Ma at Spanish Mountain).

Lead isotopic studies of gold mineralization in the CGD indicate that metals in the various gold deposits and occurrences were mostly derived from local host rocks, and were probably not brought in during an influx of mineralizing fluids generated at great depth, as has been suggested for many other orogenic gold systems in the world (e.g., Goldfarb et al., 2005; Mortensen et al., 2010). In the Barkerville terrane, gold-bearing veins and replacement occur in lower greenschist-facies host rocks, and appear to be absent within higher metamorphic-grade (amphibolite facies) rock units (Figure 1). It is therefore possible that the metals and fluids were mobilized from Barkerville terrane assemblages at relatively shallow depths below the gold-bearing portion of the terrane during prograde greenschist- to amphibolite-facies metamorphism. The source of fluids and metals that generated gold-bearing veins in the black phyllite unit of the Quesnel terrane is more problematical, since Pb isotopes suggest that the metals (and presumably fluids) were derived from the phyllite unit, but this unit nowhere experienced metamorphism above middle greenschist facies, at least at the present level of exposure. Thus prograde dehydration reactions do not appear to be a viable mechanism for mobilizing fluid (and metals) from the black phyllite units. Similarly, despite the apparent spatial association between the Early Jurassic intrusions and gold mineralization in the Spanish Mountain area, the intrusive rocks cannot be genetically related to the mineralization because, 1) the gold mineralization formed ca. 25–30 m.y. after the intrusions were emplaced, and 2) there are no intrusions known in the vicinity of the Frasergold deposit or other similar gold occurrences in the Quesnel terrane. The reason for the localization of gold mineralization in particular areas within the Quesnel terrane, therefore, remains uncertain.

The authors are continuing work on two main lines of investigation within the CGD. First, attempts are being made to identify mineral phases such as monazite or xenotime that formed during hydrothermal activity in the various gold zones and are amenable to dating using U-Pb methods, but have substantially higher closure temperatures than that of the $^{40}Ar/^{39}Ar$ system in muscovite (~350°C). Such

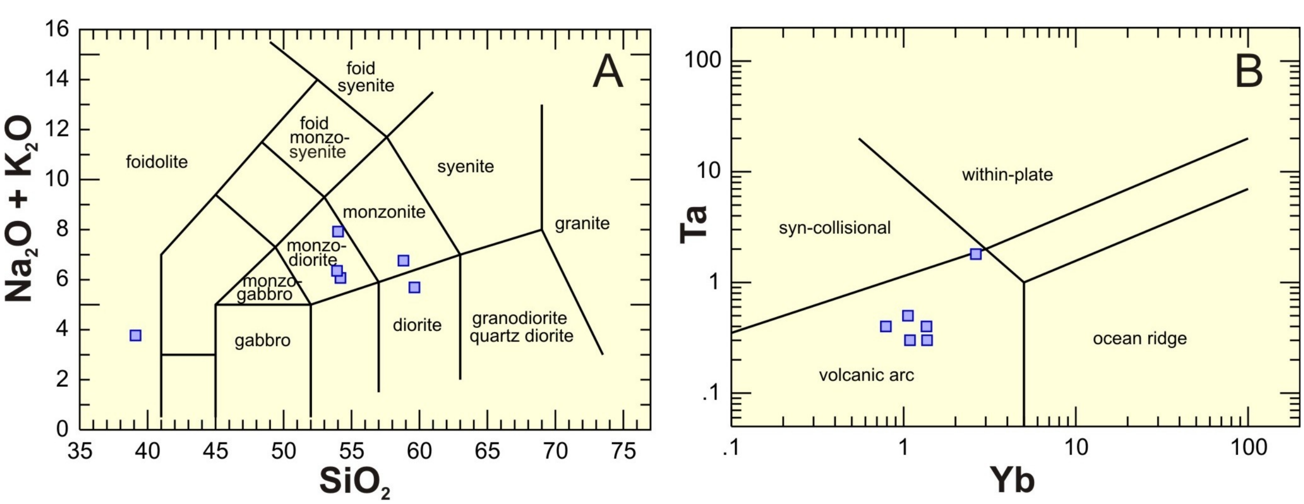

Figure 4. Compositions of Early Jurassic intrusions in the Spanish Mountain area, east-central British Columbia. Fields in **A**) are from Le Bas et al. (1986) and those in **B)** are from Pearce et al. (1984).

phases, if present, should record the age of the hydrothermal activity with no possibility of later thermal overprinting and resetting. Second, a fluid chemistry study of gold-bearing veins from throughout the CGD, will be conducted using an extensive suite of samples that were collected for this purpose during the 2008 field season.

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