Geochronological and Regional Metallogenic Investigations in the Bralorne – Bridge River Mining District (Parts of NTS 092D, J, I, O), Southwestern British Columbia: Project Rationale[1]

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INTRODUCTION

Orogenic gold deposits are characterized by structurally controlled, low-sulphide quartz veins that formed proximal to deep-crustal faults in greenschist-facies metamorphic terranes. These deposits, previously referred to as mesothermal, greenstone-hosted, shear-hosted and turbidite-hosted deposits, have a wide range of associated mineralization styles and associated metals that are dependent upon the depth (pressure) and temperature at which they formed in the crust, as well as the character of the hostrocks. Whereas the vertical extent of an orogenic lode gold deposit is known to span several kilometres at an individual mine, the range of possible formation depths for these deposits extends from the deep hypozonal (15–20 km) to the shallow epizonal (2–5 km) environments (Groves *et al.*, 1998). This recognition led to the development of the continuum model (Colvine, 1989; Groves, 1993; Groves *et al.*, 1998), whereby a diverse range of deposits is accommodated within a single deposit model, with features specific to their temperature and depth of formation. For example, a range of Alaskan orogenic gold deposits with variable mineralogical assemblages and structural styles (Goldfarb *et al.*, 1997, 2005) would include those of the hypozonal Alaska-Juneau deposit (15 km), mesothermal Chugach Terrane deposits (5–10 km) and epizonal Donlin Creek deposit (2–3 km), all of which are classified by the orogenic deposit model.

The Bralorne – Bridge River mineral district in southwestern British Columbia (Fig 1) hosts a variety of mineral deposit types and styles, with the Bralorne-Pioneer orogenic gold vein systems being historically the most significant in economic terms. These deposits generated more than 128 t (4.1 million oz) of gold from high-grade ores (19.9 g/t; 0.58 oz/T), between 1897 and 1971 (Church, 1996), making them the largest lode gold producers in BC. However, although orogenic gold deposits almost always occur in districts with numerous significant producers, only a very small amount of gold (approximately 715 kg; 23,000 oz) was produced from other deposits (Wayside, Congress, Minto) in the district, despite almost 60 known occurrences. Furthermore, many of the mineral occurrences in the district are characterized by antimony and mercury mineralization, which historically led to their consideration as less attractive gold exploration targets.

The distribution of gold-dominant, stibnite-dominant and mercury-dominant mineral occurrences in the Bralorne – Bridge River area has been recognized to form a general zonation from west to east (Pearson, 1975; Woodsworth *et al.*, 1977). Limited, and often imprecise, isotopic dating of the mineralization also indicates a younging trend from west to east (Schiarizza *et al.*, 1997, Fig 35). These data and observations have resulted in the development of contradictory regional metallogenic models that variably involve: a single protracted mineralizing event; three different mineralizing events; three different structural episodes; zoning influenced by distance away from the Coast Plutonic Complex; and mineralization directly related to specific magmatic events, such as emplacement of the Bendor plutonic suite or albitite dikes (e.g., McCann, 1922; Cairnes, 1937; Woodsworth *et al.*, 1977; Leitch *et al.*, 1991; Church, 1996; Schiarizza *et al.*, 1997; Church and Jones, 1999). Most significantly, vein systems in the district have at different times been classified according to different deposit models, such as mesothermal (orogenic), intrusion-related, ophiolite-related and epithermal (e.g., Cairnes, 1937; Woodsworth *et al.*, 1977; Leitch *et al.*, 1989; Ash, 2001).

We would argue that this ambiguity is largely the effect of 1) imprecise and inaccurate dating of mineralization at Bralorne and other occurrences within this important district; and 2) lack of recognition that shallower, mercury and antimony-rich epizonal ores may be the tops to important orogenic gold vein systems. This is supported by oxygen isotope data from Maheux (1989), which suggests metal precipitation from one main fluid type throughout the district rather than the presence of unrelated, shallow meteoric hydrothermal cells that may have been responsible for relatively young epithermal deposits. Without better age data, it is difficult to relate mineralization to any single specific magmatic, structural or tectonic event with confidence. Consequently, it prevents establishment of a district-scale metallogenic model, which is a key component for better exploration targeting. As a result, a Geoscience BC project was established to provide improved geochronological and metallogenic models upon which to base exploration programs. At this preliminary stage of the project, we present further justification for the project and anticipated outcomes from samples collected in the summer of 2006.

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LOCATION

The project area is the region north of Pemberton, mostly between the towns of Gold Bridge and Lillooet in the Bridge River and Yalakom River valleys in southwestern British Columbia (Fig 1). The project area is mostly in the Taseko Lakes and Pemberton map areas, which are covered by 1:50 000 NTS map sheets 092O/01, 02, 03; 092J/09, 10, 11, 14, 15, 16; 092I/12, 13; and 092D/04. Map areas 092O and 092I have been identified as a priority for Geoscience BC proposals because of the mountain pine beetle infestation.

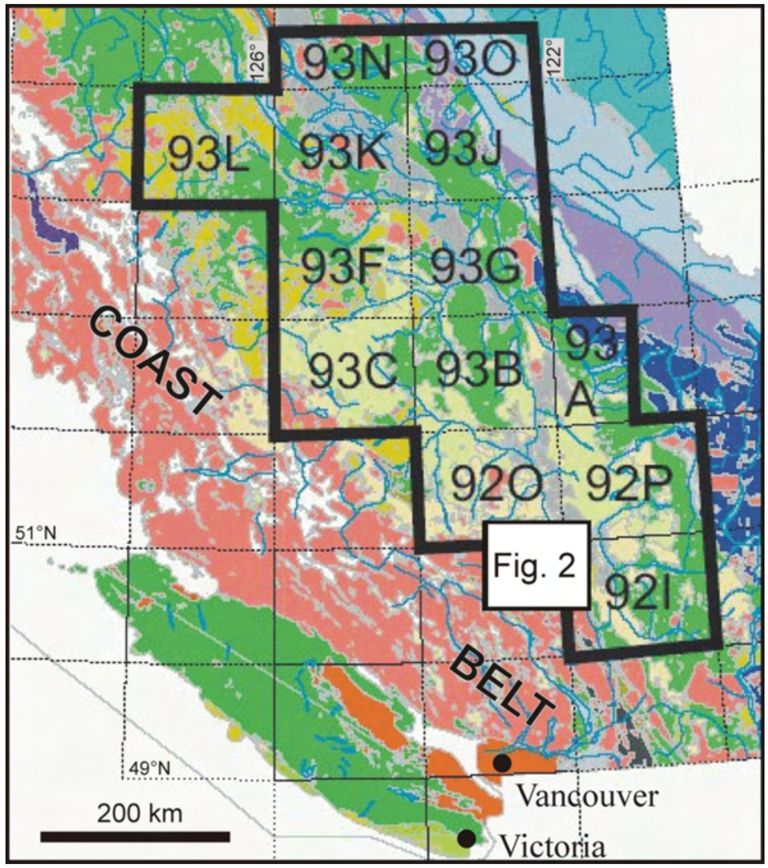

Figure 1. Location of project area (Fig 2) in southwestern British Columbia. Location of greatest infestation of mountain pine beetle outlined in black.

REGIONAL GEOLOGY

The project area is within the southeastern Coast Belt near its transition to the Intermontane Belt and is recognized as a region of structural complexity and intense deformation. Tectonically, the region is largely underlain by 1) the Mississippian to Middle Jurassic accretionary complexes of oceanic rock assemblages of the Bridge River Terrane in the west; 2) the intervening Late Triassic to Early Jurassic Cadwallader Terrane island arc volcanic rocks and mostly marine, clastic strata of a marginal basin; and 3) the Shulaps ultramafic complex in the east, which was obducted over rocks of the Cadwallader Terrane in the mid-Cretaceous (Schiarizza *et al.*, 1997). Together, these assemblages are variably overlain by clastic, mostly nonmarine successions belonging to the Jurassic-Cretaceous Tyaughton Basin.

The western margin of the area is defined by the eastern limit of the Coast Plutonic Complex, and its eastern limit by the Yalokom fault. Magmatically, the region has been intruded and overlain by a wide range of Cretaceous and Tertiary plutonic and volcanic rocks and their hypabyssal equivalents. Significant among these are the Late Cretaceous Bendor plutonic suite in the west and the Eocene Rexmount porphyry bodies in the east. Structurally, the region has been affected by the mid-Cretaceous contractional and oblique-sinistral Bralorne-Eldorado fault system and the westerly-directed Shulaps thrust belt (in the east). Early Late Cretaceous sinistral movements on the Eldorado fault and the Castle Pass fault system are likely coeval with deposition of most of the Bralorne ores (Schiarizza *et al.*, 1997). Younger, northwest-trending dextral displacements reactivated many of the older faults and were dominant in the east, particularly along the Marshall Creek and Yalakom faults, and are considered to have controlled mineralization that is located proximal to the faults in these areas.

PREVIOUS WORK

A considerable amount of excellent research has been completed in the region, providing a broad understanding of the relevant deposit geology and geochemistry. A solid geological foundation for the Bridge River area was provided by Schiarizza *et al.* (1997), building upon numerous studies in the region mentioned in the references. In addition to the numerous early studies on Bralorne-Pioneer and related mineral occurrences (McCann, 1922; Dolmage, 1934; Cairnes, 1937; Joubin, 1948), more recent broad-based contributions (Church, 1987, 1995; Church *et al.*, 1988; Church and Pettipas, 1989; Church and Jones, 1999) have been particularly important. Contemporary isotope geochemistry and geochronology studies, although solely specific to Bralorne-Pioneer deposit, have been completed by Leitch (1990), Leitch *et al.* (1989, 1991) and Ash (2001), and detailed fluid inclusion and stable isotope geochemistry studies were carried out on many mineral occurrences in the district by Maheux (1989).

METALLOGENIC MODELS

Throughout the Bralorne – Bridge River district, there is a variety of well-described mineral occurrence types (Fig 2). In addition to low-sulphide (orogenic) gold-quartz veins, there are numerous small stibnite, mercury, tungsten and polymetallic vein occurrences that have been mainly interpreted as being related to proximal intrusions or as being of epithermal origin. These mineral occurrences tend not to be the focus of aggressive exploration for associated gold resources. If gold enrichments exist in these various occurrences, such anomalies are typically small in magnitude and erratic in distribution, and overall gold deposition was likely related to boiling zones of limited vertical extent. This has discouraged aggressive gold exploration over much of the area, except for those veins proximal to the

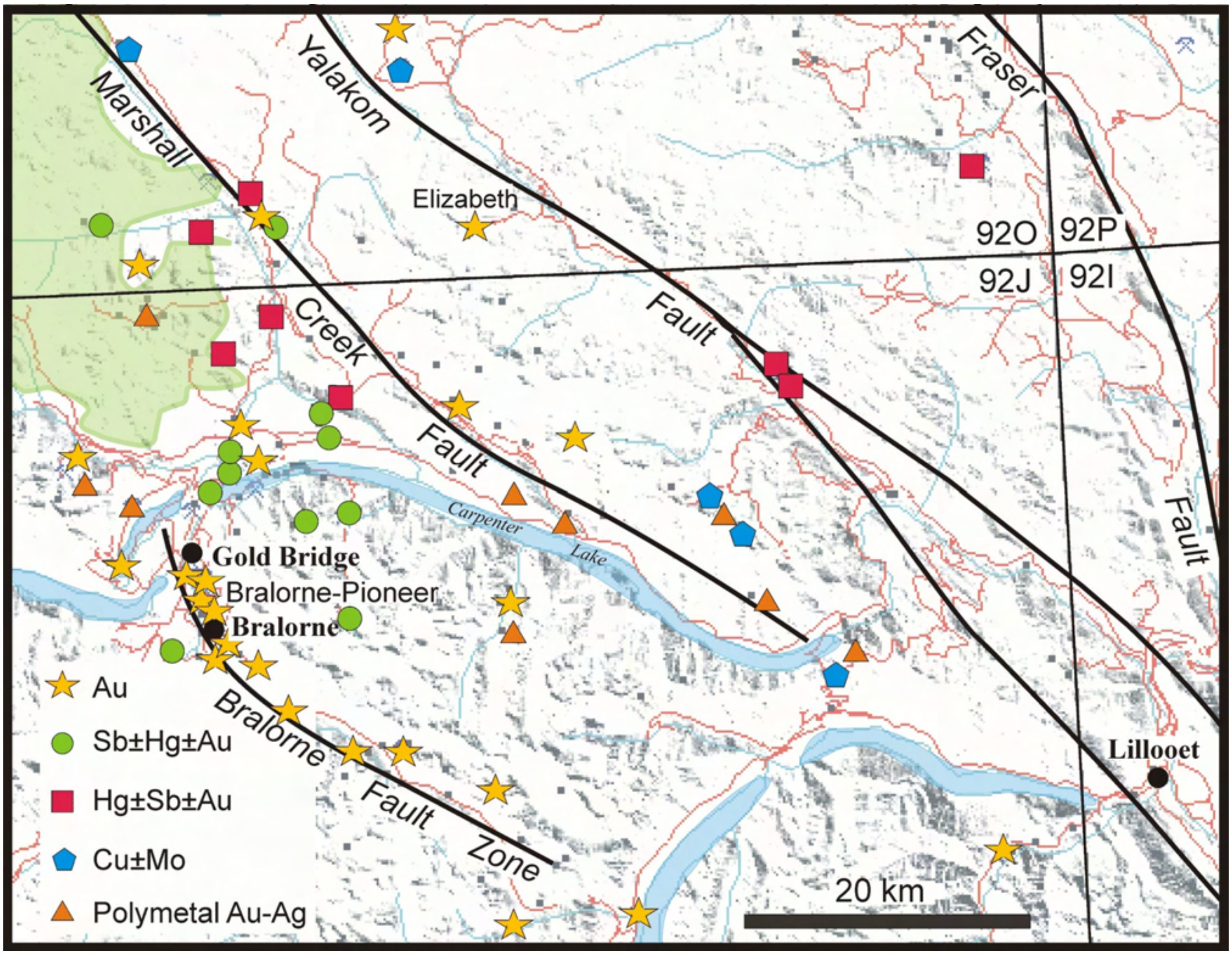

Figure 2. Study area, featuring the regional distribution of differing mineral deposit types in the Bralorne – Bridge River district and the major structural features. Shaded area in the northwest is the Spruce Lake Protected Area.

Bralorne-Pioneer gold system in the southern part of the district.

Building on the regional metal trends recognized by Pearson (1975), Woodsworth *et al.* (1977) emphasized a relationship between metal precipitation and the emplacement and cooling of the Coast Plutonic Complex (CPC). Similarly, an easterly decrease in K-Ar ages for mineral occurrences led Leitch *et al.* (1989) to suggest a model emphasizing the importance of proximity and cooling of *ca.* 80 to 59 Ma igneous rocks that form the eastern margin of the CPC. Further dating modified the model, whereby pulses of heat from the CPC resulted in several generations of mineralization, which decrease in age and formation P-T outward from the CPC (Leitch *et al.*, 1991). Additional work at Bralorne further emphasized a relationship with *ca.* 90 Ma albite porphyry dikes (Leitch *et al.*, 1991). In almost all cases, however, efforts have been toward partitioning the deposit types throughout the district into unrelated deposit groups or ore-forming events. For example, Schiarizza *et al.* (1997) recognized that each metal zone is associated with a different fault system; specifically, the gold deposits are associated with the Bralorne-Eldorado fault system, the stibnite mineralization is associated with the Castle Pass fault system, and the mercury mineralization is associated with the Marshall Creek and Yalakom – Relay Creek fault systems. Each of these three structural systems is considered to have been active at different times, thus further partitioning the district based on poorly defined geochronology.

Several intrusion-related models have been put forth to account for the generation of metallic mineralization in this district. Both the historic and some of the most recent models placed a large genetic emphasis on the role of magmatic rocks. Depending on the study, the CPC, the Bendor batholith, albitite dikes or the felsic porphyry bodies have been considered as potential causative mineralization agents.

Despite district-wide geochronology, Maheux (1989) was the one worker to suggest, based on oxygen and hydrogen isotope data, that all the different deposit types may be defined by a single model and that the classic epithermal model was not appropriate. He used the isotope data from numerous occurrences to develop a model that relied upon the deep circulation of a “unique meteoric” fluid as being responsible for the various ore systems throughout the entire district. He suggested that the variability of the ores in the Bridge River camp was suggestive of patterns seen in world-class ore camps in the Jiagnan orogen of southeastern China, the eastern Cordillera of South America, the Lachlan fold belt of southeastern Australia, and the Otago region of South Island, New Zealand.

GEOCHRONOLOGY

The timing of mineralization and the relationships with various magmatic units have often been based on age determinations of hosting and crosscutting rocks. The age of mineralization at Bralorne, for example, was constrained to between *ca.* 91 and 86 Ma by Leitch (1990), based on U-Pb and K-Ar dates on pre and postmineral dikes. This overlaps, within the range of analytical error, an 85 Ma K-Ar date on an altered intrusion near a mineralized vein on the Cosmopolitan property at the Bralorne deposit (Church, 1995). In contrast, Pearson (1977) reported a K-Ar white mica alteration age from Bralorne as *ca.* 64 Ma. Leitch *et al.* (1991) argued that it was likely a reset age due to the nearby CPC stocks.

Dikes at the Minto and Congress prospects yielded K-Ar dates of *ca.* 69 to 67 Ma (Harrop and Sinclair, 1986), which often are assumed to be the mineralization ages. This has, therefore, suggested to many workers that a series of mineralizing events over tens of millions of years may have characterized the Bridge River district. In the northern part to the district, Leitch *et al.* (1991) reported a K-Ar sericite date of *ca.* 58 Ma for the Lucky Gem deposit. A K-Ar date on hydrothermal fuchsite at Minto of *ca.* 45 Ma (Pearson, 1977) likely represents post-ore resetting.

In summary, most previous age determinations in the district were made using the K-Ar method. The reliability of this method cannot be independently assessed, but is often questioned because of the high susceptibility of a rock or mineral to argon loss at some time after crystallization. This is particularly likely for this part of BC, which has a complex thermal history. Utilization of the better Ar/Ar method would provide more interpretable data, if suitable samples for such a dating procedure can be found at many of the Bridge River mineral occurrences. Ash (2001) attempted to use this method for hydrothermal fuchsite in veined and altered diabase from the Pioneer mine dump. Unfortunately, problems associated with the evaluation of material that was too fine grained (*i.e.*, recoil) yielded a poor analysis and a result equivalent to a conventional K-Ar-type age at *ca.* 79 Ma. A couple of additional chrome-bearing illite samples from the Bralorne system gave Ar/Ar dates of *ca.* 80 to 70 Ma, but, as pointed out by Ash (2001), these dates may relate to thermal overprinting of an early fuchsite generation. Thus, this initial Ar/Ar attempt at dating Bralorne and Pioneer still emphasizes many problems in the geochronological picture and also conflicts with the constraints stressed by Leitch and co-workers. To the northwest, a *ca.* 70 ±5 Ma Ar/Ar age on the diorite that hosts the Elizabeth and Yalakom prospects (Schiarizza *et al.*, 1997) places a relatively young maximum age on these gold systems and yielded a large (10 m.y.) error window.

PROJECT RATIONALE

Previous metallogenic models for the region variably included 1) ore fluids sourced from different magmatic suites or from the CPC, 2) episodic pulses of heat from the CPC, or 3) different structural events. Without precise age determinations from the deposits and magmatic rocks, such assertions are impossible to make with confidence. Initial interpretations of generally similar stable isotopic data from veins throughout the district (Maheux, 1989), in combination with an understanding of the continuum model for orogenic gold deposits, potentially indicate that mineralization at Bralorne-Pioneer and throughout most of the district simply represents different structural levels of a single hydrothermal event. For example, although antimony and mercury deposits are often interpreted to be upper parts of small epithermal systems, hot spring deposits in California have fluid, isotopic and trace element chemistries similar to typical Mother Lode orogenic gold deposits, both consistent with a deep-crustal fluid source. In addition, the huge Donlin Creek gold deposit, originally a small stibnite prospect, is now recognized as an epizonal or shallow-crustal orogenic gold deposit (Goldfarb *et al.*, 2004), with heavy oxygen and light sulphur data indicating a fluid evolved through metamorphic devolatilization of the host flysch basin.

Within the diversity of mineralization in the Bridge River region, specific geological aspects, such as age, structural setting, crustal level and hydrothermal fluid types, can be used to assess prospectivity by associating appropriate deposit models, thus enabling more effective exploration targeting. In simple language, "Which occurrences are worthy of aggressive exploration efforts?" Although most indications of mineralization ages in the district are broadly Late Cretaceous, the existing age dataset is not sufficiently precise to allow district-wide comparisons between deposits, or with magmatism such as the Bendor plutonic suite. Additionally, most published dates are by the K-Ar method and are likely variably reset by younger thermal events; this is clearly evident from the abundance of contradictory age relationships in the literature on the district. The existing district geological data themselves are good: mapping is thorough, there is a wealth of deposit geological and mineralogical information, and adequate fluid and stable isotope data exist. To date, however, these data are not well compiled in a comprehensive manner, typically lacking appropriate interpretations and application to regional geology. This situation provides part of the justification for this project.

PROJECT OBJECTIVES

The main objective of this project is to comprehensively assess the nature and timing of mineralization in the Bralorne – Bridge River district, in order to construct a contemporary regional-scale exploration model.

The project will

1) obtain new and more precise geochronological control for both the world-class Bralorne-Pioneer deposits and many other gold, stibnite and mercury occurrences in the district;
2) determine the most appropriate deposit models for the varied deposit types of the district; and
3) provide a regional metallogenic model and suggestions for improved exploration targeting and success within the district.

METHODS

We plan to utilize two main methods for collection of new data to assess the regional metallogeny of the Bralorne – Bridge River mineral district: geochronology and ore-fluid geochemistry.

Three different geochronological dating methods will be variably employed on alteration, gangue minerals and, potentially, ore minerals, and these data will be combined with recognized crosscutting relationships. The Ar/Ar method will be most commonly used to date the timing of mineralization from different mineral occurrences across the region in order to assess their timing of formation. However, many of the lower temperature occurrences may not form minerals (*i.e.*, micas) that are appropriate or easily dated by this method. These will be constrained by dating hosting or crosscutting rock phases where possible, by both Ar/Ar and SHRIMP U-Pb. In addition, we will attempt to date the sulphide minerals themselves, particularly arsenopyrite, using the innovative Re-Os dating method with the participation of R. Creaser at the University of Alberta. This last method assumes that the host minerals contain enough Re, which is critical when dating such young events.

Ore geochemistry is an effective method of indicating the nature of the ore-forming fluids, their chemistry, origin and the processes involved in generating ore deposits. Most deposits from the region have a reasonable amount of existing geochemical data, such as fluid inclusion P-T-X measurements, and stable and lead isotope analyses. However, except for those from Bralorne (Leitch *et al.*, 1991), much of the other data remain unpublished. We intend to compile the salient published and unpublished data, and collect new data that will be assessed and interpreted. From this, we will provide a modern interpretation of the regional metallogeny upon which to base exploration models. Preliminary work indicates that quartz from the lower temperature stibnite veins precipitated from fluids with oxygen isotopic values similar to those of higher temperature gold-only veins at Bralorne-Pioneer. This observation alone is critical, as it means that the low-temperature veins are likely the upper parts of orogenic lode gold systems, and that they were not formed from shallow meteoric fluids associated with unrelated epithermal deposit types.

ANTICIPATED OUTCOMES

As the result of this project we will

1) determine the timing of mineralization at Bralorne and other deposits and occurrences across the entire district;
2) determine the timing of magmatic events, such as the Bendor plutons;
3) assess the nature of the fluids that formed deposits throughout the district; and
4) re-evaluate and determine the most appropriate ore deposit models for the region's MINFILE (2006) occurrences.

Fieldwork has been completed, samples and observations have been obtained from approximately 12 significant occurrences and deposits, and materials have been submitted for geochronology, fluid inclusion and stable isotope study.

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