CHAPTER 4
BRIDGE RIVER TERRANE
BRALORNE-PIONEER CAMP

INTRODUCTION

The Bralorne-Pioneer gold mine in southwest British Columbia (Figure 4.1) is historically the largest lode gold producer in the province. The Bridge River mining camp in which the Bralorne-Pioneer deposit is located, has enjoyed a long and profitable mining history starting in the mid-1800s with the discovery of placer gold on Cadwallader Creek and Bridge River. The first lode claims at Bralorne were located in 1896. Production soon followed and continued periodically throughout the 1900s until final closure in 1971 (Bellamy and Saleken, 1983). During this period the Bralorne-Pioneer mine produced over 113.4 tonnes (4,000,000 oz) of gold from 7 million tonnes of ore at an average recovered grade of close to 20 g/t (0.57 ounces per ton) (Leitch, 1990). Exploration has continued throughout the 1980s and 1990s to delineate additional gold-quartz veins. The area was visited during a 6-day period in 1991. Active underground drilling at that time by Levon Resources to delineate the subsurface extension of the Peter vein enabled underground access by way of the main portal on level #8 of the Bralorne mine (Photo 4.1). This provided a near continuous section through Bridge River sedimentary rocks into the southwest part of the Bralorne gabbro-diorite igneous complex and allowed direct observation and sampling of the vein system. We are grateful to Jim Miller-Tait for providing a review of the surface and underground geology at the Bralorne mine.

This chapter summarizes the lithotectonic setting of gold quartz veins in the Bralorne-Pioneer deposit with an emphasis on the ophiolitic character of the host rocks. It is the most significant gold producer in British Columbia and is a type example of the deposits under discussion. New Ar-Ar age data of hydrothermal vein micas associated with gold vein mineralization is reported and a revised terminology for host rocks of the Bralorne-Pioneer gold quartz veins is introduced.

PREVIOUS WORK

Studies of the Bralorne-Pioneer vein system were done either prior to 1950 when the mine was a major producer or during the gold rush of the 1980s when historically productive deposits such as this were afforded considerable exploration and research attention. McCann (1922), Dolmage (1934), Cairnes (1937) and Joubin (1948) published the classic works of the pre-1950 period. The most recent and comprehensive publications on the deposit have resulted primarily from doctoral research on the Bralorne-Pioneer mine by Craig Leitch (Leitch and Godwin, 1986, 1987, 1988; Leitch et al., 1989, 1991; Leitch, 1990). The geology of the Bridge River camp including detailed descriptions of the individual deposits have been part of studies by the British Columbia Ministry of Energy and Mines (Church, 1987a, b; Church and Pettipas, 1989; Church et al., 1988; Church, 1995; Sebert, 1987). A description of the geology of the Bralorne camp is given by Bellamy and Saleken (1983), with abbreviated summaries provided by Barr (1980) and Panteleyev (1992). Our current understanding of the regional geology as summarized below, is primarily from Schiarizza et al. (1997) and references therein.

REGIONAL GEOLOGICAL SETTING

The Bralorne-Pioneer mine is situated within the southeastern Coast Belt (Figure 4.1) (Monger, 1986; Journeay, 1990). This structurally complex belt is dominated by abyssal oceanic rocks with subordinate sedimentary and arc volcanic rocks and younger sedimentary basin fill sequences, all intruded by Late Cretaceous to Eocene felsic plutonic rocks (Schiarizza et al., 1997). Lithotectonic units and structures of the southeastern Coast Belt extend southward into the Cascade fold belt and form a strongly tectonized zone between the Intermontane Belt and a western zone that includes the western Coast Belt and Wrangelia Terrane (Monger et al., 1990).

The tectonic history of the region is complex, with recognition of earlier tectonic events complicated by structural disruption and intercalation of all the lithologies by Cretaceous and Tertiary faulting. It records a protracted and varied magmatic, depositional and deformational history extending from late Paleozoic to Middle Tertiary (Schiarizza et al., 1997).

Gold quartz vein deposits at the Bralorne-Pioneer mine are hosted within Late Permian (Leitch and Godwin, 1988; Leitch, 1990) ophiolitic basement rocks that occur as tec-
tonic fault bounded lenses within the Bridge River Terrane (Schiarizza et al., 1997; Figure 4.2). Like the Cache Creek Terrane, the Bridge River Terrane is dominated by a highly disrupted belt of Late Paleozoic to Early Mesozoic (Cordey and Schiarizza, 1993) chaotic chert-argillite deposits with lesser mafic volcanics, subordinate limestone, sandstone, conglomerate, serpentinite, gabbro, and minor Late Triassic blueschists, termed the Bridge River complex. Unlike the Cache Creek Terrane, however, the Bridge River Terrane is internally imbricated by Cretaceous and Tertiary faulting with Late Triassic to Early Jurassic volcanic arc sediments and lesser volcanic rocks of the Cadwallader arc-terranes (Rusmore, 1987; Rusmore et al., 1988; Schiarizza et al., 1997).

Terminology and lithotectonic subdivision of units throughout the Bralorne region have recently undergone fundamental changes. Ophiolitic assemblage and accretionary complex rocks were previously included in the Bridge River Terrane (Pottet, 1986; Monger, 1977a; Wright et al., 1982; Monger, 1984; Wheeler and McFeely, 1991). Subsequently the ophiolitic assemblage rocks were separated from the Bridge River Terrane and included in a distinct lithotectonic unit called the East Lisa Complex (Schiarizza et al., 1997). Based on regional correlations it has recently been suggested that sedimentary and volcanic 

**Cadwallader arc-terranes rocks are most likely stratigraphically tied to ophiolitic assemblage rocks.** Based on this relationship ophiolitic assemblage were included as part of the Cadwallader Terrane. In this view the Bridge River Terrane and Bridge River complex are considered one and the same Schiarizza et al. (1997). The Bridge River Terrane, however, contains mafic volcanic with lesser diabase and gabbro as isolated tectonic lenses and serpentinite as narrow bodies along fault zones (Schiarizza et al., 1997). Both the ophiolitic assemblage rocks and chert-argillite deposits are late Paleozoic in age and share a comparable abyssal oceanic origin. This provides a strong lithologic and temporal link between the ophiolitic and accretionary complex rocks. Differences between them are considered largely a function of scale, relating to varying degrees of tectonic disruption and attenuation of individual ophiolitic components. We maintain previous terrane terminology and include both the disrupted chert argillite succession of the Bridge River complex with ophiolitic assemblage rocks as part of the Bridge River Terrane. It cannot be ruled out, and is considered likely that the late Paleozoic abyssal basement rocks were already accreted along the North American continental margin prior to deposition of the Late Triassic volcanic arc rocks of the Cadwallader Terrane. We therefore view the Bridge River Terrane as
Figure 4.4

Paleogene volcanic rocks

Plutonic Rocks
* Eocene (48-43 Ma)
  - Mission Ridge pluton and Rexmount porphyry

Latest Cretaceous (69-67 Ma)
  - Bendor suite

Late Cretaceous (92 Ma)
  - Dickson McClure suite

Early and/or Late Cretaceous
  - Silverquick and Powell Creek formations: conglomerate, shale, volcanic breccia

Early Cretaceous
  - Taylor Creek Group: shale, conglomerate

Middle Jurassic - Early Cretaceous
  - Relay Mountain Group: sandstone, shale

Early Jurassic - Early Cretaceous
  - Methow Terrane/Basin: sandstone, shale

Late Triassic to Middle Jurassic
  - Cadwallader Terrane
    - basalt, sandstone, conglomerate

Bridge River Accretionary Complex
  - Mississippian - Middle Jurassic
    - Chert, greenstone, argillite

Ophiolitic Assemblages
  - Late Carboniferous - Early Permian
    - Bralorne-East Liza Complex (greenstone and gabbro)
    - Shulaps Ultramafic Complex (harzburgite, serpentinite mélangé)

Figure 4.2. Geological setting of the Bralorne-Pioneer deposit (after Schiarizza and Garver, 1995).
consisting of both ophiolitic assemblage rocks and chaotic chert-argillite deposits, with the younger Late Triassic volcanic arc rocks as a distinct and possibly overlapping lithotectonic element.

DEPOSIT GEOLOGY

Permian ophiolitic assemblage rocks hosting the Bralorne-Pioneer mine were termed the ‘Bralorne block’ by Leitch (1990) and Leitch et al. (1991) (Figure 4.4). The term “block” is preferable to previous usage of “Bralorne intrusions” as it more adequately characterizes the relative age and tectonic relationships between this structurally bounded plutonic-volcanic complex and its surrounding rocks. It eliminates misconceptions that these rocks are an igneous suite that intrudes the adjoining rocks of the Bridge River complex and Cadwallader Terrane, a prevailing view of most early descriptive works.

Contact and age relationships as well the chemical composition of the individual units (Leitch et al., 1991; Church et al., 1995; Dostal and Church, 1994) establish that the Bralorne block is a differentiated suite of oceanic crustal ultramafic and mafic to felsic plutonic and cogenetic basaltic volcanic rocks. It can be subdivided into: an extrusive component of volcanic rocks, a transitional component of hypabyssal medium to fine-grained dikes that contain plutonic screens, a variably differentiated, multiple mafic, mafic to felsic plutonic suite of gabbro, diorite and trondhjemite, and an ultramafic cumulate suite of dunite, peridotite and pyroxenite. Table 4.1 identifies the component parts of an oceanic crustal section with reference to the historical nomenclature for the various lithologies.

The ‘Bralorne ophiolite’, is a preferred term than ‘Bralorne block’ to describe this tectonically emplaced, recognizably dismembered segment of Early Permian ocean crust. In addition to highlighting the tectonic character this term properly characterizes the associated lithologies within the block and alludes to their origin within an oceanic spreading center.

Host rocks for the primary producing veins of the Bralorne-Pioneer mining camp are the mafic to felsic, gabro-diorite-trondhjemite crustal plutonic section of the Bralorne ophiolite. Veins within the ophiolitic rocks have been long recognized for their overall regularity, size and continuity (Cirkel, 1900). To a lesser, though significant degree, veins continue into competent massive metabasalt, the main Pioneer fissure vein being the most notable example. The massive, medium to fine-grained, granular texture typical of host rocks in the area of the Pioneer mine, combined with the fact that the unit has survived as a competent entity suggest that it is more likely hypabyssal rather than volcanic in origin. Notably the ultramafic portion of the Bralorne ophiolitic assemblage is recognized as the least favourable unit for quartz vein development. Cairnes (1937) writes;

“Probably the least favourable rock for quartz veins is serpentine. Fissures rarely persist in this rock for any appreciable distance and mostly feather out abruptly on reaching it. This feature is well shown in Pioneer and Bralorne mine workings and is in more ways than one of economic significance, for some of the richest ore and most extensive shoots in these mines end against the serpentinite bodies.”

VEIN MORPHOLOGY AND MINERALOGY

Subsidiary fault sets related to movement along the major faults bounding the Bralorne ophiolite control the morphology and distribution of mineralized veins (Leitch et al., 1991). The block is cut by sets of en-echelon, mineralized faults formed in compressional and tensional shears related to sinistral transpressional movement along the Fergusson thrust to the northeast and the Cadwallader fault to the southwest (Figure 4.3). Three types of shear veins are recognized within the Bralorne-Pioneer deposit and include fissure, tension and cross veins.

Fissure veins, including Veins 51, 55 and 77 at Bralorne (Figure 4.3) and the Main vein at the Pioneer mine, are the richest in the camp. They are also the widest and most continuous of the three vein types (Joubin, 1948). They have been traced continuously for up to 1500 metres along a strike of roughly 110° and to a depth of 1800 metres down their steep northerly dip (Joubin, 1948; Leitch 1990). The fissure veins are commonly ribboned. They have an average

### TABLE 4.1
COMPONENT PARTS OF THE BRALORNE OPHIOLITE AND ASSOCIATED HISTORICAL NOMENCLATURE

<table>
<thead>
<tr>
<th>Oceanic Crustal Rocks of the Bridge River Ophiolitic Assemblage in the Bralorne Block</th>
<th>Corresponding Units of the Bralorne Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper crustal, basaltic to andesitic extrusive igneous rocks</td>
<td>Pioneer volcanic rocks (greenstone)</td>
</tr>
<tr>
<td>Dike transition between extrusive and intrusive complexes</td>
<td>Hybrid greenstone - diorite</td>
</tr>
<tr>
<td>Mid-crustal, differentiated gabbroic to trondhjemitic, multiphase plutonic complex</td>
<td>Bralorne diorite / Bralorne soda granite / Sumner gabbro / related minor phases</td>
</tr>
<tr>
<td>Transition from mid-crustal mafic plutonic complex to lower crustal ultramafic plutonic suite</td>
<td>Hornblendenite</td>
</tr>
<tr>
<td>Ultramafic-cumulate plutonic suite</td>
<td>President ultramafics (cumulate phases only)</td>
</tr>
</tbody>
</table>
width of 1 to 1.5 metres but often pinch and swell, ranging from several centimetres to seven metres in width (Bellamy and Saleken, 1983; Leitch, 1990).

Tension veins are generally less continuous than the fissure veins at usually about 500 metre strike lengths with similar dip extensions. They are also usually not as rich as the shear veins (Joubin, 1948). They are hosted by fault sets that strike roughly 250° and dip about 75° northwest (Leitch 1990) and appear to form oblique splays off the fissure veins. Veins consist of massive white quartz with erratic high gold values. They are characterized by open-space filling textures commonly including pockets of drusy to cockscob quartz between widely spaced and slickensided septae (Joubin, 1948). Examples of this vein type include the 75 and 83 veins at Bralorne, and the 27 vein at Pioneer. Cross veins are subeconomic and are interpreted to be connecting structures between the fissure and tension veins.

Ore and alteration mineralogy of the Bralorne-Pioneer veins has been described by McCann (1922), Dolmage (1934), Cairnes (1937), Joubin (1948), Stevenson (1958), Church (1987, 1995) and Leitch (1990) and is summarized here. Quartz is the dominant gangue mineral along with minor calcite, ankerite, sericite, clay-altered mariposite and talc. Most of the gold-quartz veins have a low metal content with sulphide minerals restricted mainly to altered wallrock septa but sulphides can be highly concentrated locally. Sulphide assemblages consist primarily of pyrite and arsenopyrite with lesser marcasite, pyrrhotite, chalcopyrite, sphalerite, galena and rare tetrahedrite. Pyrite is the most abundant sulphide and occurs mainly as disseminated crystals in both veins and altered wall rocks. Arsenopyrite occurs as disseminated, well-formed, pyramidal crystals and as minute acicular grains, mainly in veins but also in altered wall rock. Sphalerite and to a lesser extent galena are locally conspicuous in the veins, whereas chalcopyrite is comparatively scarce but can be locally significant.

Ore shoots with mainly free gold occur in the most fractured and deformed parts of the veins, notably at the intersections or junctions of vein-bearing fissures (Cairnes, 1937). Well-ribboned quartz is characteristically better grade than adjoining massive quartz. Vein septa are relatively narrow dark films, streaks or bands composed of one or more of sulphide, sericite and chlorite minerals occurring over ribboned widths of 2 to 3 centimetres. Native gold occurs sparsely disseminated throughout the vein quartz or concentrated between ribbons in the quartz. Along the face of the ribbons native gold is commonly associated with minute, acicular crystals of arsenopyrite. Quartz breccias are also relatively rich, and bands of gouge and crushed vein matter may contain high grades. Native gold also occurs in massive, white quartz or coarsely crystalline calcite and rich pockets of such material are common in the western mine workings close to the serpentinite contact. In this area there is spectacular ore where native gold occurs together with masses of arsenopyrite. The richness of the ore shoots in the western mine workings compared to the remainder of the deposit is aptly described by Cairnes (1937, page 123) who writes:

“Altogether, four principal ore shoots are referred to by James, namely, a west-end shoot, a west shoot, and two easterly shoots. The west-end shoot rakes approximately with the intersection of the vein fissure and the serpentinite and extends back for several 100 feet from this intersection This is a high grade shoot and has provided exceptionally rich pockets. In a stope from 8-level, two tons alone produced $200 000 (9685 ounces) worth of gold. Another pocket yielded 400 pounds of gold from 900 pounds of ore.”

Wall rock alteration associated with vein mineralization is widespread and commonly intense. Alteration envelopes range from less than 0.1 to 10 metres in width, and in places coalesce into broad zones up to 50 metres wide. Although somewhat variable, there is a consistent zoning of alteration minerals from regionally metamorphosed wall rock into the vein core over average distances of 5 metres. The metamorphic assemblage of chlorite-epidote in the country rock reflects subgreenschist to greenschist facies typical of the regional metamorphic grade (Schiarizza et al., 1990, 1997). This grades through a buff-coloured, carbonate (calcite)-albite-sericite zone into an inner, cream-coloured,
Figure 4.4 Geology of the Bralorne-Pioneer mine area. Simplified after Leitch et al. (1991).
quartz-sericite-fucoxite-carbonate (ankerite) zone (Cairnes, 1937; Leitch, 1990). This alteration sequence is common in both the oceanic hostrocks of the deposit and in albite dikes which intrude structures hosting the gold-bearing veins (Leitch 1990). Fluid inclusion studies (Leitch et al., 1989) indicate that the Bralorne-Pioneer deposit is a mesothermal vein system formed at about 5 to 7 kilometres depth (1.25 to 1.75 kb) and 300° to 400° from low-salinity CO2-rich fluids.

AGE OF MINERALIZATION

The age of gold quartz vein mineralization at the Bralorne-Pioneer mine is currently constrained indirectly from the ages of felsic dikes that both predate and postdate the mineralizing event (Leitch, 1990; Leitch et al., 1991). Gold quartz veins are spatially and temporally related to intrusion of albite and hornblende porphyry dikes, coeval with the Early to Middle Cretaceous magmatic phases of the Coast Plutonic Complex. Pre to syn-mineralization albite dikes have a U-Pb zircon age of 91.4±1.4 Ma; syn to postmineral hornblende porphyry dikes have a K-Ar whole rock age of 85.7±3 Ma. Both the veins and co-structural dikes form en echelon sets subsidiary to the regional scale bounding shear and fault zones and appear to be related to movement along these faults.

In an attempt to directly determine the timing of hydrothermal activity, efforts were made to collect chrome-bearing micas associated with gold-quartz vein mineralization for Ar-Ar isotopic dating. A sample of carbonate altered and quartz veined massive metabasalt rock with visible mariposite was found in waste dumps along the west side of Cadwallader Creek directly across from the dilapidated Pioneer Mine (Photo 4.2). The contents of the mine dumps are relatively uniform and appear to be representative of the local vein host rocks. Rock types contained within the dumps consist on average of 50 to 60% medium to fine-grained, massive, equigranular grey-green basalt/diabase, 25 to 30% pink felsic dike rocks and 15 to 20% brown weathering carbonate-altered basalt (Photo 4.3a and b).

The spectrum (Figure 4.5) for this sample is unusual. The first step obtained at a laboratory extraction temperature of 650°C yielded 75% of the total gas release at an apparent age of 87 Ma. The subsequent steps have much lower ages, ranging from ~50-60 Ma. As discussed above, for a fine-grained impure sample such as this, redistribution of 39Ar by recoil may produce irregular spectral features. In this case, the total gas value, here 79 + 4 Ma, is the most reliable age estimate. This may be interpreted as a lower limit to the time of mineralization.

Several additional samples were collected from the North vein, both along the Main Adit Level No. 8 and also at surface roughly 1 km north of Bralorne where a shallow tunnel had been recently driven along the Cosmopolitan vein. Samples were taken from green, sheared and clay-altered zones marginal to pervasively hydrothermally altered felsic dikes along the mineralized quartz-vein structure. The material collected was dull green and amorphous, which on sampling was broken into 0.5 to 1.5 cm chips. A mineral which is indicated by Cairnes (1937, page 54) to be fairly prevalent throughout the vein system;

"most of the veins contain a conspicuous, light green, flaky to amorphous mineral referred to, in general as mariposite and presumed to be a chromium-bearing potash mica very similar in composition to the potassium-magnesium mica, alurgite."
Examination of this mineral by XRD analysis at The University of British Columbia by Mac Chandry with the BC Geological Survey determined it to be chrome-bearing illite.

Independently, Neil Church (personal communication, 1992) collected similar samples of fine-grained, green chrome-bearing illite from the area along the Level 8, Main Portal. These samples were processed by heavy liquids and provided separates, which he had isotopically dated by Ar-Ar at Dalhousie University (Appendix II). Results of these analyses are presented in Figure 4.5b. The two samples yielded spectra of similar shape, both with ages increasing from approximately 70 to 80 Ma over the gas released. These data suggest that the altered fault gouge zones from which the dated mineral was sampled underwent movement and accompanying hydrothermal activity at approximately 70 Ma. This is interpreted to be a post mineralization event producing alteration of preexisting mariposite.

**RELATIONSHIP TO TECTONISM**

Gold-quartz veins are hosted within a fault system related to a regional, mid to Late Cretaceous, east to west directed, contractional tectonic event. This tectonic activity internally imbricates and stacks late Paleozoic oceanic lithosphere with arc volcanic and sedimentary rocks (Cadwallader Terrane) as tectonic slices within and on top of late Paleozoic to mid Mesozoic transform-subduction accretionary complex rocks (Bridge River accretionary complex) and the overlying basin-fill sequence (Relay Mountain Group) (Schiarizza et al., 1997). Major orogenic activity at that time is recorded by a contractional event that is temporally constrained by the mid Cretaceous syn-orogenic flysch sedimentation in the Taylor Creek Group (Garver et al., 1989) suggesting uplift of ophiolitic rocks at that time (Garver et al., 1989; Calon et al., 1990; Macdonald, 1990; Schiarizza et al., 1997). In addition related structures are cross-cut by the 92 Ma Dickson McClure suite of intrusions.

Gold veins are both spatially and temporally related to felsic, albite and hornblende porphyry dikes (Leitch, 1990) which are coeval with early magmatic phases of the Coast Plutonic Complex (Parrish, 1992; Figure 4-3). These are associated with regional-scale, Cretaceous contractional tectonics related to emplacement of the Bridge River ophiolite assemblage (Schiarizza et al., 1989, 1997). These various geological and age constraints indicate that gold mineralization, dike intrusion and movement along the Bralorne fault zone was contemporaneous with mid to Late Cretaceous orogenesis.

**SUMMARY**

- The Bralorne-Pioneer mine is historically the largest lode gold producer in British Columbia. Gold-quartz veins hosted in the Bralorne ophiolite produced over 124 400 kilograms (4 million ounces) of gold at an average grade 18 grams per tonne (0.57 oz/ton) from a roughly 15 square kilometre area.
· The term ‘Bralorne ophiolite’ is introduced to designate the late Paleozoic oceanic crustal component that is host to gold-quartz veins at the Bralorne-Pioneer mine.

· Gold-quartz veins are hosted almost exclusively within the more competent mafic to felsic crustal plutonic and locally hyperbyssal portion of the ophiolitic assemblage. Notably, the veins are not well developed in altered ultramafic rocks but the richest and most spectacular gold ore is found where veins are adjacent to the ultramafic rocks.

· Gold-quartz veins are spatially associated with synmineral to postmineral albitite and hornblende porphyry dikes. Both the mineralizing event and dike intrusions are fault controlled. Mineralization is interpreted as syn-kinematic and structurally controlled by fault sets related to westerly directed transpressional movement along the Fergusson and Cadwallader faults bounding the Bralorne ophiolite. Felsic dike rocks display a consistent temporal and co-structural spatial association with gold quartz vein mineralization and suggests they may be genetically related.