Intrusion-Related Gold Mineral Occurrences of the Bayonne Magmatic Belt

By James M. Logan

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INTRODUCTION

Intrusion-related gold deposits, as described by Thompson *et al.* (1999), are a new and economically important class of deposits that occur within felsic magmatic provinces known to host tungsten and/or tin mineralization. Traditionally these magmatic provinces were not believed to host significant gold mineralization and as a consequence are under explored for this type of deposit. Examples of intrusion-related gold deposits occur worldwide (Thompson *et al.*, 1999, Lang and Baker, 2001), but those most applicable to exploration in British Columbia are the well-studied Alaska and Yukon deposits of the Tintina Gold Belt (Newberry *et al.*, 1995; McCoy *et al.*, 1997; Baker *et al.*, 1996). Major deposits include Fort Knox (~210 t Au), Dublin Gulch (~36 t Au), Brewery Creek (~29 t Au) and Pogo (~161 t Au).

The British Columbia Geological Survey initiated a field-based project in 1999 to identify the potential for intrusion-related gold deposits in the province. Southeastern British Columbia (Fig. 1) was selected because it has similarities with the Tintina Gold Belt; including mid-Cretaceous granitic intrusions, intrusion-hosted and peripheral quartz veins with Au-W-Bi metal signatures, and regional geochemical anomalies of pathfinder elements for intrusion-related gold deposits (Lefebure *et al.,* 1999).

In response to encouraging results from the 1999 and 2000 field studies (Logan, 2000; 2001; Cathro and Lefebure, 2000), a regional compilation map of the study area was completed (Logan, 2002). In addition, ongoing research includes; Ar-Ar analysis of alteration and intrusive phases (Douglas Archibald, Queen's University), fluid inclusion studies of selected mineral occurrences and intrusive phases (Kathryn Dunne) and galena and feldspar Pb-isotope studies (Janet Gabites, The University of British Columbia). Preliminary results from these studies are presented below, the final results and interpretations will appear in a separate publication. The compilation map (Geoscience Map 2002-1) shows the distribution, geochemistry and physical characteristics of the intrusions and intrusion-related mineral occurrences that comprise the Bayonne magmatic belt and provides an up-to-date framework in which to assess the applicability of the "intrusion-related gold system model" in southeast British Columbia. Early in the compilation process it was obvious that geological data, and in particular recent geochronological studies, in southeast British Columbia are limited in comparison to data available for the Tombstone-Tungsten magmatic suite (Mortensen, 1999; Mortensen *et al.*, 2000). In contrast to the metaluminous, subalkalic, reduced I-type Tombstone Suite, the Bayonne suite consists of mostly peraluminous, subalkalic hornblende-biotite granodiorite and highly fractionated 2-mica granites, aplites and pegmatites. Some of these intrusions have associated Au-W-Bi-As quartz vein occurrences analogous with intrusion-related deposits in the Tintina Gold Belt. In addition, the metal association and mineral zonation developed around specific Bayonne suite intrusions is most easily explained by depth of emplacement, and can be used to direct exploration into areas of higher potential for undiscovered intrusion-related gold deposits.

INTRUSION-RELATED GOLD SYSTEMS

Intrusion-related gold systems (Lang and Baker, 2001), like many other magmatic-hydrothermal systems, form ore deposits that are characterized by, diverse styles of mineralization, a wide range of mineral and metal assemblages, and spatial association with their related intrusive centers (Fig. 1). Distinctive features of intrusion-related systems are reviewed in recent publications by McCoy *et al.* (1997), Poulsen *et al.* (1997), Thompson *et al.* (1999), Hart *et al.*

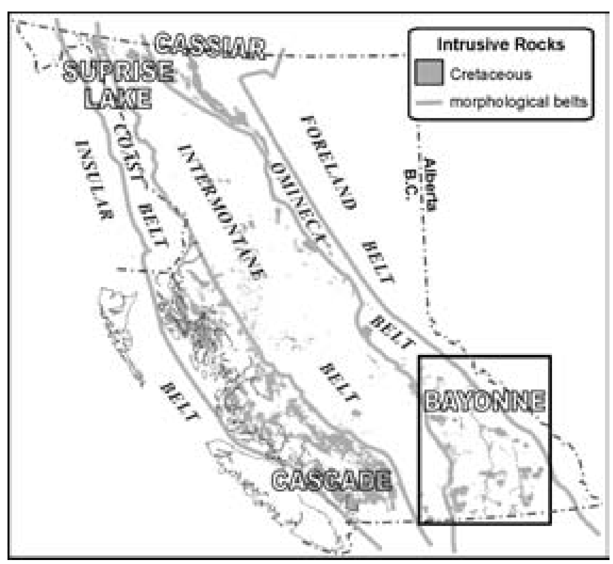

Figure 1. Location map Bayonne magmatic belt.

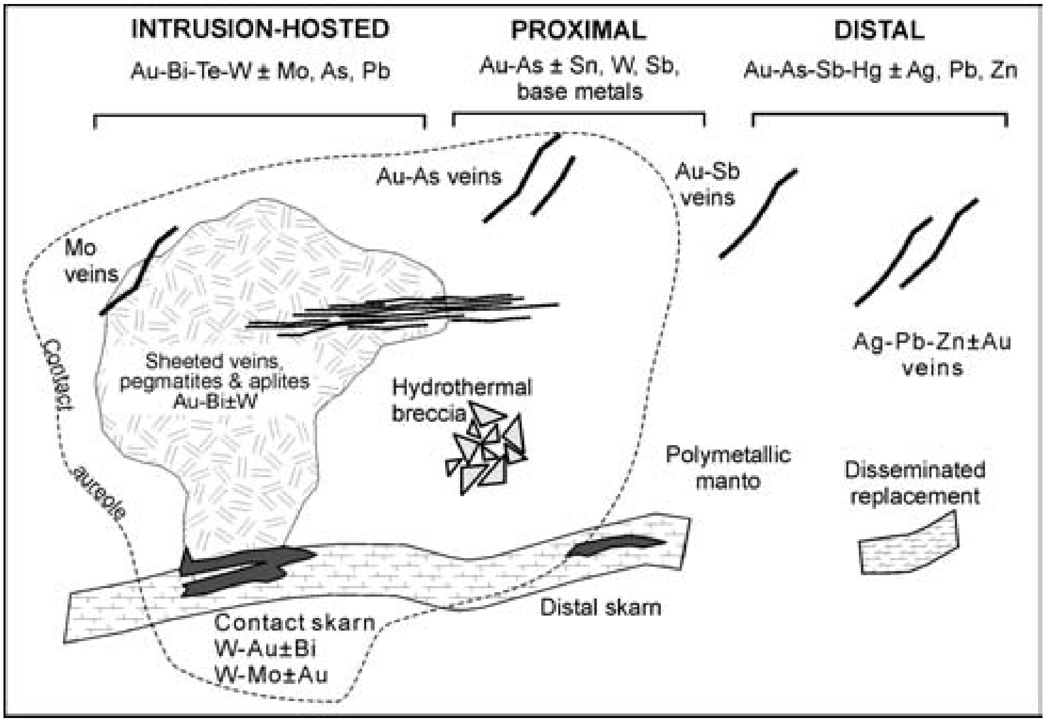

Figure 2. Schematic geological model for intrusion-related gold deposits, showing variations in styles from intrusion-hosted to proximal and distal deposits (Lang and Baker, 2001; adapted from Hart *et al.*, 2000).

(2000) and Newberry (2000). Common features (summarized from Lang and Baker, 2001) include: (1) association with relatively reduced, metaluminous, subalkalic intrusions of intermediate to felsic compositions; (2) location within a continental magmatic arc known for tungsten and/or tin mineralization and characterized by coeval intrusions of alkalic, metaluminous calcalkalic and peraluminous compositions; (3) carbonic hydrothermal fluids; (4) an auriferous metal assemblage containing elevated Bi, W, As, Mo, Te and/or Sb with low concentrations of base metals; (5) a low sulphide mineral content of <5%; and (6) an areally restricted, commonly weak hydrothermal alteration.

Hart *et al.* (2000) separated Yukon deposits into three categories based on their spatial relationship to intrusions (Fig. 2). Intrusion-hosted deposits comprise low grade, large tonnage sheeted and stockwork, low sulphide, auriferous vein systems characterized by metal assemblages containing Au-Bi±Te±Mo±W. For example, at Fort Knox gold mineralization occurs in pegmatites, aplites and quartz veins (Bakke, 1995), while it is found in miarolitic cavities within the Emerald Lake Pluton (Duncan, 1999). Proximal deposits are located in the host rocks adjacent to the intrusion generally within the contact metamorphic aureole. Deposits of this group include contact skarn assemblages of W-Au±Bi and W-Mo±Au±Cu (Dublin Gulch property), disseminated carbonate replacements, tin and copper-rich breccias and vein-deposits. Distal deposits are located beyond the limits of the contact aureole. They include auriferous vein-fault zones (True North), breccias, Ag±Au rich base metal veins and disseminated replacement of carbonaceous and calcareous rocks (Brewery Creek, Poulsen, 1996; Diment and Craig, 1998). Metal assemblages for distal deposits are characterized by a Au-As-Sb±Hg signature.

Similar, *intrusion-hosted* Mo and Au-quartz-As-W vein occurrences (*i.e.* Valparaiso and Rosan), *proximal* W-Cu-Au skarns (*i.e.* Lucky Bear) and Au-Ag-Bi-Cu-Pb fault-veins (*i.e.* Cam-Gloria) and *distal* Pb-Zn-Au-As-Sb ±W quartz-carbonate veins (*i.e.* Ruth Vermont, McMurdo) are located in southern British Columbia associated with the mid-Cretaceous Bayonne Suite (Logan, 2002). The southern end of the Omenica belt that corresponds to the Bayonne Magmatic belt contains extensive magmatic-hydrothermal mineral deposits (Fyles and Hewlett, 1959; Höy, *in press*). Many contain primarily base metals with only minor precious metal but are still important exploration tools that may be used to direct exploration to an intrusion-related gold center. The metal assemblages and metal ratios associated with distal *vs* proximal *vs* intrusion-hosted are also important to establish the position of the causative intrusion.

MESOZOIC INTRUSIONS OF THE CANADIAN CORDILLERAN

Mesozoic granitoid plutons comprise a substantial proportion of the Canadian Cordillera, particularly in the Coast and Omineca belts (Woodsworth *et al.*, 1991; Fig. 1). The plutons of these two belts are markedly different. The granodiorite to tonalite batholiths of the Coast belt were emplaced within large subduction-related magmatic arc complexes that developed along the continental margin (Barker and Arth, 1990; Brandon and Smith, 1994). The volumetrically smaller granodiorite and high-K_2O granites of the Omineca belt were emplaced inboard of the main magmatic arc in continental margin rocks. The mechanisms responsible for magma production in the Cordilleran interior are controversial but likely require a combination of factors involving heat and magma transfer from the mantle to the crust (Hyndman and Foster, 1988; Hoisch and Hamilton, 1990) and crustal thickening (Patiño Douce *et al.,* 1990) which together resulted in crustal anatexis (Brandon and Smith, 1994).

Cretaceous plutons of the Omineca belt extend for more than 1600 km along the Canadian Cordilleran interior from the Yukon to the Canada-US border and comprise six suites that include from north to south Tombstone, Tungsten, Tay River, Anvil, Cassiar and Bayonne (Mortensen *et al.*, 1997; Mortensen, 1999; Woodsworth *et al.*, 1991). A Mo-W±Sn metallogenic province is associated with this Cretaceous magmatic belt. The Tombstone and some of the Tungsten suite plutons are known to host intrusion-related gold deposits (*i.e.* Tintina Gold Belt), but to date only small auriferous vein and skarn occurrences of this particular deposit type and possibly some placer gold deposits are known to be associated with Bayonne suite plutons.

BAYONNE MAGMATIC BELT

The Bayonne magmatic belt is a 50 to 75 km wide arcuate belt extending from the Canadian-USA border northwest to Quesnel Lake (Figure 3). It lies inboard (east) of the terrane accretionary boundary and is bound on the east by the Rocky Mountain Trench. The plutons intrude miogeoclinal rocks of North American affinity. Northwest of the Kootenay Arc, batholiths and large stocks intrude rocks of the Kootenay and Barkerville terranes. Mid-Cretaceous plutons of the Bayonne suite comprise the majority of these magmatic rocks, but volumetrically smaller and fewer Middle Jurassic Nelson suite plutons are present also (Brown *et al.,* 1992), and north of 51° latitude Devonian, Late Cretaceous and Tertiary suites are known (Parrish, 1992; Logan and Friedman, 1997).

The Middle Jurassic suite comprises syn- to late-tectonic plutons that were emplaced during the collapse of the outer margin and accretion of Quesnellia (Monger *et al.*, 1982; Archibald *et al.*, 1984; Price, 1986; Murphy *et al.*, 1995). The younger, mid Cretaceous plutons are discordant with regional structures formed during the early Middle Jurassic accretionary event, and for the most part are undeformed. Assigning syn-, late or post-tectonic categories to plutonic suites can be misleading and oversimplifies younger Cretaceous and Tertiary deformation. For example, in the Shuswap region, the Anstey Pluton (92-94 Ma; Parrish, 1992) was sheared and metamorphosed after ca. 90 Ma at sillimanite stable conditions (5-8 kbar). In the southern Kootenay Arc the *late-synkinematic* Baldy Pluton (117+4/-1 Ma, Leclair *et al.*, 1993) was emplaced during penetrative deformation at crustal levels of 3.5 to 5.5 kbars, while the *postkinematic* Midge Creek Stock (111±1 Ma, Leclair *et al.*, 1993) was emplaced between 4 and 11 Ma later at crustal levels of 2.5 to 3.5 kbars. The Kaniksu/Ryker Batholith (93.8±1 Ma, Brown *et al*., in prep) was intruded at levels of ~5.5 kbars, deeper than most Cretaceous plutons in the area south of Salmo and also during prograde metamorphism and tectonism. Those examples illustrate how depth of emplacement varies dramatically along the length of the magmatic belt with plutons intruded at structural levels that span both brittle and ductile regimes.

DEPTH OF EMPLACEMENT

In the Cretaceous, between 115 to 90 Ma (Archibald *et al.*, 1984) composite plutons and batholiths were emplaced at mid-crustal levels along the length of the Bayonne belt (Table 1). Contact metamorphic mineral assemblages from the contact aureoles of the mid-Cretaceous plutons in the western Purcell anticlinorium indicate that the plutons intruded into bathozone 2 or 3, at pressures of 2.5 - 4.3 kbar (Archibald *et al.*, 1983, 1984; Warren, 1997). Mineral assemblages from the contact aureoles of the Battle Range batholith and Albert stock indicate pressures of ~3.5 kbar (Sears, 1979) and for Goldstream and Long Creek plutons pressures <3.8 kbar (Logan and Colpron, 1995). At the southern end of the Kootenay Arc pressure data from pelitic assemblages in the contact aureole of the Summit Creek stock and Sheep Creek stock indicate that these plutons were intruded into bathozone 1 or 2, at pressures of ~2.5 kbar (Archibald *et al.,* 1983; Mathews, 1953). At the northern end of the magmatic belt contact metamorphic mineral assemblages from the contact aureole of the Baldy Batholith indicate bathozone 1 or 2, and pressures of ~ 2.5 kbar.

In general the intrusions at the north and southern ends of the belt have contact metamorphic mineral assemblages that indicate pressures of <2.5 kbars. At the center of the arc contact metamorphic mineral assemblages for the Battle Range, Bugaboo, Horsethief, White Creek and Fry Creek batholiths indicate pressures of 3.5 kbars or higher. Higher-pressure mineral assemblages are present adjacent to Big Mouth pluton, located on the western flank of the Windy Range metamorphic culmination and also adjacent to the Shore Line Stock and Corn Creek Gneiss indicating deeper structural levels. The different emplacement depths along the length of the belt are most likely a manifestation of the deeper levels of exhumation at its center, where the shallower plutons (<2.5 kb) have been removed by erosion.

The Middle Jurassic, syn- to late tectonic plutons, on the other hand were intruded at greater depths in the Kootenay Arc and Purcell Mountains (4.3 - 5.6 kbar; Archibald *et al.*, 1984; Warren, 1997) and the Adams Plateau (~3.5 kbar, Logan, 2002) at the north end of the belt.

INTRUSION-RELATED METAL ZONING

The Bayonne suite is the southern component of a 1600 km long W-Sn±Mo province extending from the Yukon territory south to Salmo.

The Bayonne magmatic belt has a well-defined Mo-W±Sn metal association. It is enriched in large-ion lithophile elements, such as uranium, rare earth elements, lead and silver, and is relatively depleted in copper and zinc.

TABLE 1
CHARACTERISTICS OF CRETACEOUS PLUTONS IN THE BAYONNE MAGMATIC BELT, SOUTHEASTERN BRITISH COLUMBIA (AFTER LOGAN, 2002)

PLUTON (area)	COMPOSITION OF PHASES	ASSOCIATED MINERALIZATION	EMPLACEMENT PRESSURE	DEPTH (1 kbar=3.5 km)
Baldy 558 km^2	hb-bi GRNT bi-mu GRNT	Mo, Cu-Mo, W±Au, Au-Cu±Co, Pb-Ag-Zn±Au	BATH 1 (qtz-mu-an-cor) <2.5 kbar	<9 km
Downie 5 km^2	QMDT	Cu	<BATH 2 (qtz-bi-ga-an) <3.5 kbar	<12 km
Goldstream 103 km^2	QMZD, GRNT	Mo, W-Mo, Pb-Ag-Zn±Au	BATH 3 (qtz-mu-an) <3.8 kbar	<13 km
Long Creek 35 km^2	QMNZ, GRNT	W-Mo	<BATH 2 (qtz-bi-ga-an) <3.5 kbar	<12 km
Albert 36 km^2	bi-GRNT GNDT	W-Mo	BATH 2 - 3 (si-an-st-mu) ~3.5 kbar	~12 km
Battle Range 519 km^2	GRNT GRDT	Sn, Mo, W-Mo, Pb-Ag-Zn±Au	BATH 2 - 3 (si-an-st-mu) ~3.5 kbar	~12 km
Bugaboo 151 km^2	leuco-QMNZ	U, Pb-Ag-Zn±Au	BATH 2 and 3 (qtz-mu-an-st) 2.5-3.8 kbar	9-13 km
Horsethief Creek 132 km^2	bi-QMNZ	Mo, U, W-Mo, Pb-Ag-Zn±Au	<4.3 kbar	<15 km
Shoreline 23 km^2	bi-mu GRNT	Ag-Pb-Zn±Au	BATH 5 (ga-bi-ky-si) 5-6 kbar	17-21 km
Fry Creek 611 km^2	leuco- QMNZ	Mo, Au, W-Sn, Ag-Pb-Zn±Au	BATH 2 and 3 (qtz-mu-ga-an-st and qtz-mu-si) 2.5-3.8 kbar	9-13 km
White Creek 435 km^2	leuco- QMNZ porph-QMNZ hb-biGRDT	Be, W, W-Mo, Pb-Ag-Zn±Au	>BATH 3 (qtz-mu-si-st) >3.8 kbar	>13 km
Mount Skelly 302 km^2	bi-GRNT bi-hb GRDT	Mo-W±Cu, As-Pb-Ag-Au, W	BATH 2 and 3 (qtz-mu-an-st) ~3.5 kbar	~12 km
Baldy 35 km^2	leuco-GRDT		(ga-si-bi-mu-qtz-pl) 3.5-5.5 kbar	12-20 km
Midge Creek 17 km^2	bi-GRDT, TNLT	Pb	(an-si) 2.5-3.5 kbar	9-12 km
Lost Creek 24 km^2	leuco- QMNZ	Mo, W-Mo, U	BATH 1 (an, w/ no si) <2.5 kbar	<9 km
Summit 5 km^2	QMNZ, bi-GRNT	Mo, W-Mo, U	BATH 1-2 (qtz-bi-mu-an) ~2.5 kbar	~9 km
Sheep Ck 3 km^2	GRNT	Mo, Au,:Ag-Pb-Zn±Au	BATH 1-2 (qtz-bi-an±ga) ~2.5 kbar	~9 km
Corn Creek Gneiss 3 km^2	bi-mu GRNT	Mo, W	BATH 4 (qtz-mu-ky-si; w/ no an, ga) <5.5 kbar	<20 km
Rykert/Kanisku 27 km^2	bi-GRDT, bi-mu GRNT		BATH 4 (qtz-mu-ky-si; w/ no an, ga) <5.5 kbar	<20 km

Associated Mineralization:
Ag=silver, As=arsenic, Au=gold, Be=beryl, Co=cobalt, Cu=copper, Mo=molybdenum, Pb=lead, Sn=tin, U=uranium, W=Tungsten, Zn=zinc
Emplacement pressures:
BATH=bathozones, kbars=kilobars, an=andalusite, cor=cordierite, gnt=ganet, ky=kyanite, pl=plagioclase, qtz=quartz, si=sillimanite, st=-staurolite.
Composition of Phases:
APLT=aplite, DORT=diorite, GBBR=gabbro, GRDT=granodiorte, GRNT=granite, MNZT=monzonite, QMNZ= quartz monzonite, QMZD=quartz monzodiorite, SYNT=syenite, TNLT=tonalite

In these environments, metal zonation generally reflects depth of emplacement and distance from causative intrusive patterns (Flanigan *et al*., 2000; Hart *et al*., 2000; Lang and Baker, 2001). Assemblages change from U, Sn, W, W-Mo and Ag-Pb-Zn-Au from deeper to shallower levels and from intrusion/pegmatite hosted to distal structurally controlled veins or replacements. The distribution of known mineral occurrences around the Baldy Batholith defines a simple elliptical pattern extending outward from the western, hornblende-biotite granite phase of the intrusion. At the center are porphyry occurrences containing Mo±Cu±Au, near the margin and beyond are Au-Cu-Bi peripheral veins and W-Cu±Au±Bi skarns, and beyond these are distal veins with low gold values and metal assemblages containing Ag-Pb-Zn±Au and Ag-Pb-Zn±As±Au. No mineral occurrences are known to be associated with the peraluminous, muscovite-biotite granite phase that comprises the eastern portion of the batholith.

Relating intrusion-hosted, sheeted gold-quartz vein mineralization and even peripheral gold-tungsten-bismuth skarn and manto mineralization to late stage magmatic fluids from an intrusion can be straightforward, but understanding the genesis of mineralization that is distal to the causative intrusive or hosted in older intrusive rocks (*i.e.* Cam-Gloria) becomes more difficult. This study collected samples to evaluate the relationships between intrusion and deposits in the areas surrounding the Baldy Batholith, Battle Range and Mount Skelly Pluton and local areas in the Northern Selkirk Mountains and the southern Kootenay Arc.

The focus of this report is on the Baldy Batholith. In the area of the Baldy Batholith there are three separate intrusion-related vein deposits associated with this mid-Creta-

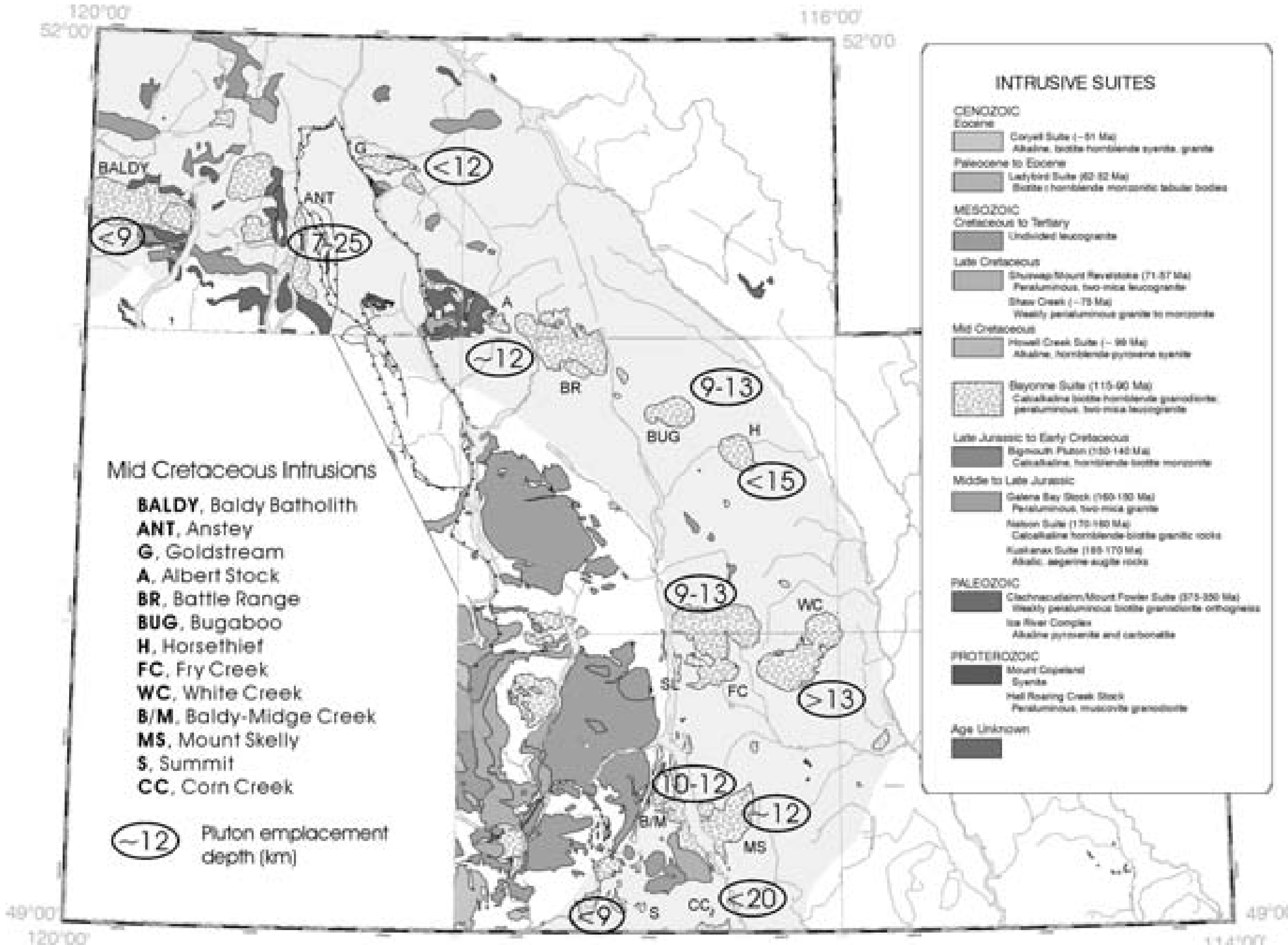

Figure 3. Distribution of plutonic rocks in southeastern British Columbia, illustrates the inboard location of the Bayonne Magmatic belt. Numbers are the mid Cretaceous emplacement depths calculated from contact metamorphic mineral assemblages using pressure limits defined for bathozones (Carmichael, 1978).

ceous felsic body. The San (MINFILE 82M 135), Windpass, Sweet Home (MINFILE 92P 39, 40), and Cam Gloria (MINFILE 82M 266) are quartz fissure veins hosted by a variety of intrusive rocks (Logan, 2000, 2001; and references within). Only the San is hosted in the causative mid-Cretaceous Baldy Batholith; the others are located variable distances from its margins, but are related to its associated Cretaceous hydrothermal activity. The Windpass/Sweet Home veins are hosted in a Permian or older gabbro of the Fennell Formation, approximately 1.5 km west of the Baldy, and the Cam Gloria veins occupy a Middle Jurassic monzodiorite, located approximately 8 km from the southern contact of the Baldy. At the Windpass/Sweet Home deposits the gabbro provided the competent host with open structures. At Cam Gloria the relationship between mineralization and the age of the host monzodiorite is not readily apparent in the field and geochronological (personal communication, D. Archibald, 2000; personal communication, Mortensen, 1999) and geochemical studies were necessary to establish the Cretaceous age of mineralization.

The metal ratios and zonation of these vein systems with respect to the Baldy Batholith generally follows the classic intrusion-related patterns (Figure 1), (Flanigan *et al.*, 2000; Hart *et al.,* 2000; Lang and Baker, 2001). On the other hand the San is a Ag-rich, Pb-Zn-As-Bi±Au quartz vein enveloped by a moderate to strong alteration zone of sericite and iron-carbonate. It does not have the typically low base metal content and high Bi:Au ratios common to intrusion-hosted deposits. The proximal Au-Ag-Cu-Bi quartz veins of the Windpass and Sweet Home mines possess high Bi:Au ratios (Logan, 2001) and the distal auriferous Pb-Ag-Bi±As quartz veins at Cam-Gloria have moderate Bi:Au ratios. ^{40}Ar-^{39}Ar cooling ages from alteration sericite at the San give 93 Ma that correspond with mid Cretaceous biotite and muscovite cooling ages for the batholith (Wanless *et al.*, 1966; Kirkland, 1971; personal communication, D. Archibald, 2000). Galena Pb-isotope compositions from all three cluster together with feldspar leads from the batholith around Cretaceous model ages (personal communication, J. Gabites, 2001).

TABLE 2
CHARACTERISTICS OF ALASKA AND YUKON INTRUSION-RELATED DEPOSITS
(FLANIGAN *ET AL.*, 2000)

Deposit	Size (Au)	Mineralization*	Characteristics	Temp*	Pressure	Depth*
True North	1.3 M oz	S-hosted	distal, intermediate depth		~0.5 kb	0.5 km
Ryan Lode	2.4 M oz	I-hosted	proximal, intermediate depth		0.5-.75 kb	<3 km
Dolphin	1.5 M oz	I-hosted	intermediate depth		1 kb	3 km
Cleary Hill		S-hosted	intermediate depth	~300°C	0.9 kb	3 km
Brewery Creek	0.6 M oz	I&S-hosted	shallow level		<1 kb	<3.5 km
Clear Creek		I-hosted	low pressure metam assemblages: and, sill, cor, pyrr, bio, grnt			
Fort Knox	7.2 M oz	I-hosted	deep-level	305±25°C	1.25-1.5 kb	4-5 km
Dublin Gulch	1.5 M oz	I-hosted	bi-qtz-an	200-350°C	>1.5 kb	>5.25 km
Pogo	5.2 M oz	S-hosted	proximal, deep-level	310-640°C	1.75-2.0 kb	6-7 km
Scheelite Dome		I&S-hosted	brittle	240-350°C	up to 2.5 kb	< 8 km
Mactung*		sheeted veins			>2.3 kb	
		W-skarn			2-2.5 kb	8.5 km
Donlin Creek	10.1 M oz	I-hosted	shallow level	<550°C	<0.5 kb	< 2 km
Nixon Fork	0.1 M oz	Skarn	intermediate level		<1 kb	<3.5 km
Shotgun	1.0 M oz	I-hosted	proximal	450-600°C	low pressure	

Mactung data (Atkinson and Baker, 1986)

Mineralization: S-hosted = sediment hosted, I-hosted = intrusion hosted.

Temperature: from fluid inclusion thermometry/barometry and/or sulphide pair thermometry

Depth: conversion from pressure data uses 1 kb = 3.5 km.

IMPLICATIONS FOR EXPLORATION

Contact metamorphic mineral assemblages from country rocks adjacent to the plutons and batholiths of the Bayonne Magmatic belt indicate varying pressures from <2.5 kbars to ~5 kbar (using pressure limits defined for bathozones; Carmichael, 1978). These pressure ranges correspond to emplacement depths of ~8 km to as much as 18 km (assuming 1 kbar = 3.5 km). In comparison, the intrusive-related mineral deposits in Alaska and the Yukon are inferred to have formed at generally shallower levels (Table 2), with several notable exceptions: Pogo and Scheelite Dome. The schematic geological and exploration model of Lang and Baker (2001) show a vertical range from the surface to 7 km depth and a lateral range of 2 km for intrusion-related gold systems. This level of the crust is generally attributed to the brittle regime, and with the exception of the Pogo deposit, the majority of Alaska and Yukon deposits formed under pressure, temperature, fluid content and strain rates associated with brittle deformation. The mid-Cretaceous intrusions of the Bayonne magmatic belt were intruded at structural levels that span both brittle and ductile regimes.

Using the intrusion-related model of Lang and Baker (2001) the explorationist would be focused to areas at the northern and southern ends of the belt where shallower level (<2.5 kbar) mid Cretaceous intusions and related mineralization are preserved. Gold-bismuth quartz veins (Windpass, Sweet Home) at the west end of the Baldy Batholith have mid-1900s production records totaling more than 1.0 M g of Au (Taylor, 1989) and recent discoveries along its southeastern margin at the Cam-Gloria (Evans, 1999). At the south end of the belt near Salmo, tungsten skarn, molybdenum mineralization and bismuth-gold mantos are developed in Paleozoic calcareous sediments adjacent to, and more distal from Cretaceous intrusions on the Emerald Tungsten property (Cathro and Lefebure, 2000). The gold-silver vein deposits of the Sheep Creek camp, located 6 km to the northeast are also Cretaceous or younger (Höy, i*n press*). Biotite granite intrusions with molybdenum occupy the lower levels at the Kootenay Belle gold mine (Mathews, 1953) and infer a spatial relationship to the Au-Ag veins. Mineralization formed at deeper structural levels (~3.5 kbar) is exposed east of Kootenay Lake. Here, there has been limited past production of gold and tungsten from quartz-filled sheeted veins hosted by the Mount Skelly stock at the Valparaiso mine near Creston. There are also low-grade, auriferous, sheeted veins throughout the stock. The characteristics of the Valparaiso veins indicate this is a British Columbia example of a Fort Knox-type deposit (intrusion-hosted) that has formed at substantially deeper levels than its Alaskan counterpart.

ONGOING RESEARCH

Geochronological, fluid inclusion and Pb-isotope investigations of mineral occurrences associated with the Bayonne Suite are ongoing. The ability to establish relationships between mineralization and the intrusive host is paramount to understand the potential of the intrusion and for directing exploration to additional mineralization in the belt.

Age constraints for the plutons are complicated by the composite nature of the larger bodies, discordant U-Pb systematics related to inheritance (xenocrystic zircons), high-grade metamorphism and lead loss. The limited database consists primarily of old K-Ar, Rb-Sr and more recent Ar-Ar ages all which represent relative cooling ages specific to the blocking temperature of the minerals dated. The few uranium-lead zircon age dating studies have focused on the Tertiary extension history of southeastern British Columbia (Parrish *et al*., 1988; Parrish 1995; and references within; Carr, 1992). Preliminary uranium-lead dating studies have been completed on the Battle Range Batholith and identify a 100Ma honblende granodiorite phase, and an approximately 87 Ma, 2-mica granite (personal communication, W. McClelland, 2001). Doug Archibald (Queen's University) has completed $^{40}Ar/^{39}Ar$ step-heating analyses of a substantial number of alteration assemblages associated with Cretaceous intrusion-related mineralization throughout the belt. For the most part, cooling ages of plutons, alteration and mineralization are mid-Cretaceous, but disturbed $^{40}Ar/^{39}Ar$ spectrum indicate some Late Cretaceous and Eocene thermal events for both the Baldy Batholith (north end of the belt) and Mount Skelly Pluton (south end of the belt), respectively.

Pb-isotope analyses of potassium feldspars from intrusions and sulphides from mineralization are currently underway at The University of British Columbia under the direction of Janet Gabites. The study was undertaken to determine the Pb isotope characteristics of a variety of intrusion-related mineral occurrences and selected mid-Cretaceous intrusions that comprise the Bayonne Magmatic belt. These data, in conjunction with the extensive deposit database of southeast British Columbia, will characterize intrusion-hosted, proximal and distal deposits, and permit an assessment of the potential for additional unrecognized intrusive-related mineral deposits. Other studies have utilized initial Pb isotope ratios of plutons to characterize source regions for granitoid rocks (Ayuso, 1986; Bevier, 1987). Isotopic studies of intrusion-related gold systems in the Yukon and Alaska show that Pb-isotope values of potassium feldspars from plutons and galenas from veins and skarns show a similar range in values (McCoy *et al*., 1997, Mortensen *et al*., 1996). Assuming the vein deposits are intrusion-related (magmatic Pb) their galena Pb-isotope compositions should be similar to the initial Pb-isotope compositions of the plutons, which in the case of the mid-Cretaceous suite were derived from anatexis of Precambrian crust in response to crustal thickening.

Fluid inclusion work was carried out by Kathyrn Dunne to characterize the fluids associated with late-stage plutonic phases and pegmatites of the mid Cretaceous suite and to compare them with fluids associated with gold mineralization. The Baldy and Battle Range Batholith areas were selected for fluid inclusion study and microthermometric analyses because they contain late-stage phases as well as intrusion-hosted, proximal and distal styles of mineralization. It was hoped that composition and temperature results could be interpreted with respect to the spatial relationship these categories infer. The preliminary results of the Bayonne study indicate that the fluids are rich in CO_2 and that all of the fluid inclusions homogenize between 150 and 350^o C.

Intrusion-related gold deposits are characterized by low to moderate (0-12%) saline fluids rich in CO_2 (McCoy *et al.*, 1997, Baker and Lang, 1999, 2001). Fluid inclusions from these systems comprise vapour-rich and vapour-poor inclusions that consistently indicate H_20-CO_2 immiscibility occurred during gold deposition (Metz, 1991, McCoy *et al.*, 1997).

In an earlier study Hardy (1993) indicated that the Sheep Creek gold veins formed from $H_2O-CO_2 \pm CH_4$, low to moderately saline fluids at temperatures of 300 ± 500^oC under conditions of variable pressures between 1-2 kbars. These too have similar characteristics and conditions of formation to those described by McCoy *et al.* (1997) and Baker and Lang (1999) for intrusion-related gold deposits in Alaska and the Yukon.

CONCLUSIONS

The Bayonne magmatic suite comprises the southern extension of an extensive mid Cretaceous W±Sn±Mo metallogenic province that follows the Omineca belt north from the Canadian-US border to Alaska. Gold mineralization is associated with the Tombstone and Tungsten suite intrusions at the north end of the belt. The Tombstone intrusions are primarily metaluminous, subalkalic, reduced I-type suite, and are associated with Au-Bi-W-As-Sb mineralization, and while the Tungsten suite also contain sheeted auriferous quartz veins ±Bi-Te similar to Fort Knox style mineralization they comprise a suite of strongly peraluminous 2-mica granites more commonly associated with W skarn deposits. The Bayonne suite intrusions of southern British Columbia are mostly peraluminous, subalkalic granodiorite and highly fractionated 2-mica granites, aplites and pegmatites that have more similarities with the Tungsten than Tombstone suite. In general the intrusions in the Bayonne magmatic belt were emplaced at greater depths (under greater pressures) than either of the Tombstone or Tungsten suites. Many of the Bayonne plutons contain Mo mineralization that reflect the greater depth of emplacement.

The northern and southern ends of the Bayonne Magmatic belt contain structural levels that preserve the shallowest intrusions (<9 km). Intrusion-related mineral assemblages (Au-Bi-W-Te) are concentrated around these intrusions and the potential to discover new occurrences is highest in these areas.

Ongoing research will shed more light on the similarities the Bayonne mineral occurrences share with the Yukon and Alaska deposits but will also recognize those characteristics and exploration criteria unique to the gold mineralization associated with the mid Cretaceous intrusions of southern British Columbia.

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