PLUTONIC-RELATED GOLD-QUARTZ VEINS AND THEIR POTENTIAL IN BRITISH COLUMBIA

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Abstract

Extending westerly across the Yukon Territory and into Alaska for more than 1000 km is a mid-Cretaceous magmatic belt and associated Au mineralization. This belt of rocks, called the Tintina Gold Belt, hosts plutonic-related Au deposits, such as Fort Knox, Dublin Gulch, Brewery Creek, and Pogo. The intrusions belong to the Tombstone–Tungsten belt in Yukon, and to the Fairbanks intrusions in Alaska. British Columbia, Yukon, and Alaska share a common geological and metallogenic history, and therefore contain similar potential to host plutonic-related Au deposits. Geology, mineral occurrence, and regional geochemical databases have been used to identify prospective areas and 43 'possible' plutonic-related Au-quartz veins in British Columbia. These are located primarily in the Omineca and Foreland belts, and are associated with the mid-Cretaceous, peraluminous to metaluminous intrusions of the Cassiar and Bayonne plutonic suite. Tungsten, Bi, and Te are useful pathfinders; W for identifying prospective regions (*i.e.*, W-Sn magmatic province), and together with Bi, for identifying individual occurrences. Field studies were started in the Shuswap and Kootenay Lake areas in southern British Columbia because these areas share with the Tintina Gold Belt a number of similarities, among which are mid-Cretaceous granitic intrusions, the occurrence of solitary, stockwork, and sheeted quartz veins with Au-W-Bi signatures, and the presence of regional geochemical anomalies for pathfinder elements. The Shuswap study focused on the Baldy batholith west of Adams Lake in the Kootenay terrane, where Teck Corporation is evaluating the Cam-Gloria property. Gold mineralization at Cam-Gloria is associated with Bi, As, W, and Cu-bearing assemblages in multiple vein structures enclosed by wide pervasive zones of sericitic alteration. Field work near Kootenay Lake concentrated on the Sanca Creek stock, an apophysis of the Mount Skelly pluton, located north of Creston in North America rocks. Limited past production of Au and W from quartz-filled sheeted veins at the Valparaiso and Government deposits, and the distribution of low-grade mineralization throughout the Sanca Creek stock, indicate that this is a good British Columbia example of a Fort Knox-type of Au-quartz vein deposit. The distribution of low-grade Au mineralization warrants assessment for potential bulk-tonnage resources. Exploration programs for plutonic-related Au deposits in British Columbia should focus inboard of the accreted terranes in marginal basin rocks of the pericratonic terranes or North America platformal rocks, particularly in and around highly differentiated granitic intrusions. As in Alaska and Yukon, the best targets are mid-Cretaceous plutons and batholiths in structural settings that expose or juxtapose deposits formed at different crustal levels. The discovery of the high-grade Pogo Au deposit within amphibolite-grade gneisses in Alaska indicates potential in equivalent high-grade metamorphic rocks of the Omineca belt in the Canadian Cordillera.

Introduction

Gold-quartz veins associated with granitic intrusions are attracting considerable exploration interest in Alaska and Yukon. The shift to exploration for bulk-mineable, low-grade Au targets in the 1980s resulted in a number of discoveries, including the Fort Knox mine and the Dublin Gulch deposit. The recent discovery of the high-grade, auriferous quartz zones on the Pogo property in Alaska (161.7 tonnes Au, or 5.2 M oz; Smith *et al.* 1999b and this volume) has revitalized interest in exploration for high-grade Au-bearing lodes in the Cordillera (Fig. 1).

These auriferous quartz veins have been called

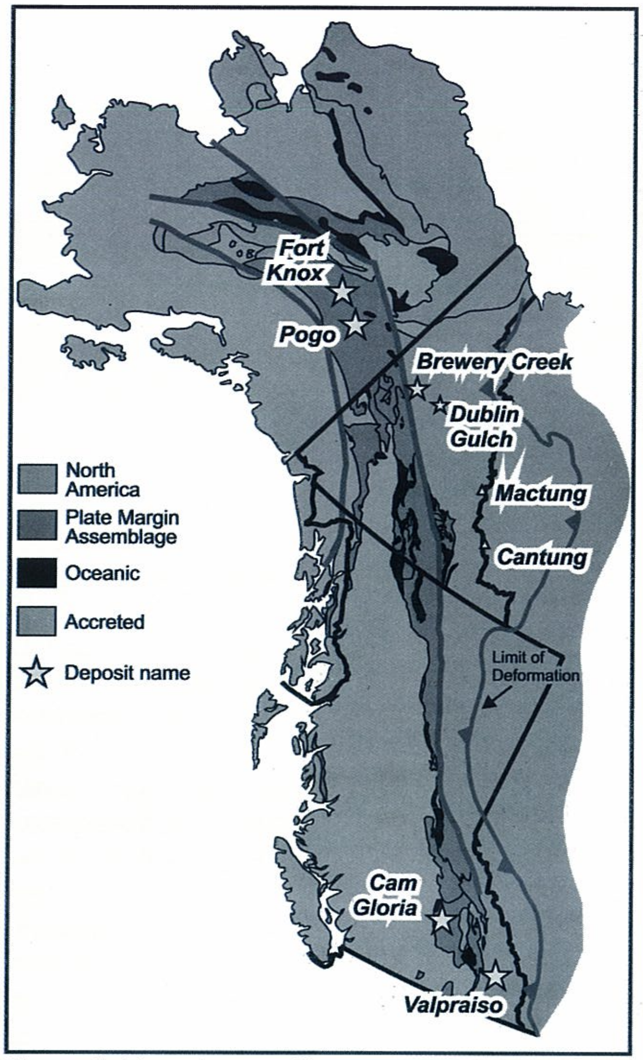


Figure 1. Tectonic assemblage map, after Wheeler and McFeely (1991), showing the distribution of North America, plate margin, oceanic, and accreted rocks of the Canadian and Alaskan Cordillera, the location of the Tintina Gold Belt, and selected deposits.

plutonic-related gold deposits (McCoy *et al.* 1997), intrusion-related gold deposits with Bi, W, and As (Thompson *et al.* 1999), plutonic porphyry gold (Hollister 1992), and Au lithophile-element deposits (J.R. Lang, personal comm. 1998). As these deposits are not porphyry deposits and can contain chalcophile elements, we favor using the term plutonic-related gold-quartz veins. This name has the added connotation that these deposits generally form at greater depths than many other deposits of Au (McCoy *et al.* 1997).

The successful discovery of gold near Cretaceous intrusions in Alaska and Yukon leads the prospector to ask where else might plutonic-related gold-quartz veins be found. British Columbia has similar intrusions in similar tectonic settings with associated placer and lode gold, W-bearing veins and skarns, and pegmatites and highly differentiated granitoid rocks (Lefebure and Cathro 1999). This article identifies key exploration criteria for plutonic-related Au-quartz veins, identifies some prospective areas to explore for them in British Columbia, and reports preliminary results of studies from the Shuswap and Kootenay arc areas in the southern part of the province.

Plutonic-related Au-Quartz Deposits

The principal features of plutonic-related deposits of Au are reviewed in articles in this volume, as well as in a number of recent publications. Among the latter are overview articles by Baker *et al.* (in press), McCoy *et al.* (1997), Poulsen *et al.* (1997), and Thompson *et al.* (1999), and descriptions of individual deposits (*e.g.*, Bakke 1995; Bakke *et al.* 1998; Hitchins and Orssich 1995; Marsh *et al.* 1999; Morávek 1996; Smith *et al.* 1998a,b, 1999a,b). The major occurrences in Yukon and Alaska are the sheeted and stockwork veins at Fort Knox, Dublin Gulch, and Clear Creek, and the high-grade quartz veins and bodies at the Pogo claims (Liese zone). The Au deposits in Alaska and Yukon are spatially associated with the Fairbanks intrusions of central Alaska and the correlative Yukon Tombstone suite (Poulsen *et al.* 1997; Baker *et al.* in press). Gold mineralization is generally within or proximal (<3 km) to the intrusions (Fig. 2). The Au occurs in skarn, disseminated replacement and vein deposits, as well as in the plutonic-related quartz veins.

This article focuses on two distinct styles of plutonic-related Au mineralization: intrusion-hosted, low-grade, large-tonnage, sheeted and stockwork low-sulfide vein systems (Fort Knox, Dublin Gulch, and Moksrko), and high-grade quartz veins and bodies that occur proximal to granitoid intrusions (Liese zone, Pogo claims; possibly Kasperské Hory).

Plutonic-related Sheeted and Stockwork Au-Quartz Veins (Fort Knox Type)

The bulk-mineable, low-grade Au-quartz vein systems, like Fort Knox, consist of numerous veinlets that range in width from hairline fractures to more than 10 cm, and of fewer veins that can be more than

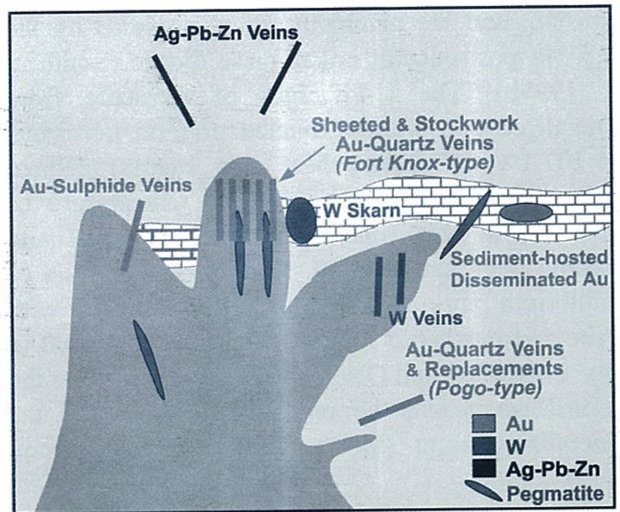


Figure 2. Schematic model of plutonic-related mineral deposits, showing different styles and metal assemblages of intermediate to felsic plutons intruded into continental margin setting.

a meter wide. Although there may be small areas of stockwork, the veinlets and veins typically are sheeted (*i.e.*, trend in the same direction). There can be several ages of vein sets with various orientations, such as are described for the Fairbanks district by McCoy *et al.* (1997), and for Dublin Gulch by Hitchins and Orssich (1995). Whereas it may occur in more than one generation of veinlets, commonly the Au is economically significant only in a particular vein set. Typically, the Au-bearing veins have remarkably little wallrock alteration.

The best known example of a sheeted Au-quartz vein-type deposit in North America is the Fort Knox mine, approximately 30 km northeast of Fairbanks, Alaska. The following description is from Bakke (1995) and Bakke *et al.* (1998). Reserves as of September 1998 were 143.5 Mt grading 0.82 g/t Au with a cutoff of 0.39 g/t, which includes a low-grade stockpile containing 8.5 Mt of 0.51 g/t Au. The deposit is hosted by a multiphase, granitic pluton that is approximately 600 × 1000 m. The pluton consists of an early biotite-rich, fine-grained granite that was intruded by a medium-grained, porphyritic granite, and later by coarse-grained, seriate, porphyritic granite. The granites cut muscovite-quartz schist and micaceous quartzite of the Fairbanks Schist, part of the Cleary Sequence.

The Au occurs in NW-trending quartz veins and veinlets, fractures, pegmatite veins, and shear zones. In general, pneumatolytic pegmatite veins, of clear to grey quartz, large K-feldspar megacrysts, and micaceous clots grade upward into grey quartz pegmatites with euhedral albite megacrysts, and these in turn grade into grey quartz veins (McCoy *et al.* 1997). Second-stage, grey veins of quartz and white mica with minor ankerite and sericite selvages, as well as some zones in shears, contain Au (McCoy *et al.* 1997). The veins vary in width from microscopic to 15 cm. The shear zones are up to 1.5 m wide, parallel the veins, are typically filled with granulated white quartz, and have mixed phyllic and argillic alteration with abundant iron oxide and clay gouge along the margins. In the vicinity of shear zones, vein abundance increases and vein orientations predominantly parallel the shear plane.

Gold occurs with Bi and Te minerals and is associated with pyrite and arsenopyrite mineralization that occurs on the vein margins of the pegmatite and grey veins, is erratically distributed in the milky white quartz veins, and is uniformly distributed as "micron-size" grains in shear zones. The sulfide content in the veins is <1.0% and includes trace to minor amounts of molybdenite and scheelite. Native gold occurs apart from sulfides or on sulfide grain boundaries, and is more than 80% recoverable by using standard cyanide-leach techniques for both the oxide and sulfide ores (McCoy *et al.* 1997). The orebody is oxidized beyond the depths of drilling.

Plutonic-related Au-Quartz Veins (Pogo Type)

Current exploration interest for plutonic-related deposits of Au is focused on searching for high-grade quartz lodes such as occur at the Liese zone on the Pogo property in Alaska. The property is underlain by Proterozoic to early Paleozoic paragneiss and minor orthogneiss of the Lake George subterrane of the Yukon–Tanana terrane. Strata consist of a sequence of gneisses interpreted to represent a metamorphosed siliciclastic and calcareous sedimentary succession intercalated with mafic volcanic and intrusive rocks (Smith *et al.* 1999b). These highly deformed, amphibolite (sillimanite)-grade rocks are intruded by granite, granodiorite, and pegmatite dykes interpreted to represent marginal phases of the mid-Cretaceous Goodpaster batholith, and by diorite and basalt dykes.

The Liese zone consists of two sub-parallel, gently dipping tabular quartz bodies (L1 and L2) and a third (L3) as yet poorly defined zone at depth. The quartz zones are hosted predominantly by gneisses and cut the dominant foliation. The quartz bodies vary from 1 to 21 m in thickness, and dip from 25 to 30°. The largest, L1 (formerly called the Main zone), extends at least 1300 m along strike. Envelopes of biotitic alteration up to 0.5 m wide occur adjacent to the veins and are overprinted by later, widespread quartz-sericite stockwork and sericite-dolomite alteration.

The quartz bodies vary in character, color, and mineralogy, and have textures of both vein and replacement-style mineralization. White and grey quartz varieties are reported to be present; the former has associated pyrrhotite and löllingite and is interpreted to be early, whereas the latter has arsenopyrite and pyrite. A third type of quartz displays a saccharoidal or polygonal texture which led some of the initial workers to identify the L1 zone as a "quartzite" unit. Petrographic studies have shown that the polygonal quartz occurs as inclusions within optically continuous microcline crystals (Smith *et al.* 1999b), suggesting either an igneous replacement or metamorphic origin for this texture. All three varieties of quartz are Au-bearing. Sulfide content in the quartz lodes is approximately 3% and includes arsenopyrite, pyrite, pyrrhotite, löllingite, chalcopyrite, bismuthinite, various Ag-Pb-Bi ± S minerals, maldonite, native bismuth, galena, and tetradymite. The native gold is typically 1-25 μm in diameter, but can be as large as 100 μm. The gold is commonly rimmed by native bismuth. The mineralization grades to more than 75 g/t Au over widths of several meters and is associated with elevated values of Bi, Te, Ag, As, Sb, Cu, and Mo.

The geological resource as of 1998 for the L1 body is 6.57 Mt grading 18.17 g/t Au, and the L2 body contains 2.48 Mt grading 17.14 g/t Au at a cutoff grade of 3.43 g/t (Smith *et al.* 1999b). Grades of Au correlate well with those of Bi, and also with As and Ag. The median grade for Ag in the mineralized zones is 2 ppm. One drillhole followed steep shears and veins of quartz with 8.6 g/t Au for >75 m; this is interpreted as a possible feeder zone.

The age of mineralization at Pogo is broadly bracketed by recent U-Pb and Ar-Ar studies of intrusive rocks and alteration (Smith *et al.* 1999b). The maximum is a U-Pb age of ~128 Ma for zircon from a ductile-deformed, quartz-sulfide-mineralized intrusion, and the minimum age is provided by the 94.5-Ma post-mineralization Liese diorite (Smith *et al.* 1999b). The U-Pb ages of monazite from mineralized and weakly foliated granitic intrusions are 107.1 to 107.9 Ma; these ages suggest ambient temperatures of 600 °C (blocking temperature of monazite) at this time, and date a thermal and possible deformation event. Microprobe analysis of equilibrium pairs of arsenopyrite and löllingite with pyrite and pyrrhotite suggest temperatures of 500 to 640 °C (McCoy and Olson 1997), suggesting that the thermal event may be one and the same as the mineralizing event (Moira Smith, personal comm. 1999).

The Liese zone shares a number of characteristics with plutonic-related quartz veins in the Fairbanks district and Yukon, including geological setting, close association with Cretaceous intrusions, low sulfide content, identical geochemical signature, and similar fluid compositions. The mineralization probably represents a deeper, higher temperature part of a plutonic-related Au system (Moira Smith, personal comm. 1999). The initial results suggest that the Liese zone is slightly older than the 91-92 Ma deposits that are associated with the Tombstone suite and correlative Fairbanks intrusions.

Associated Styles of Mineralization

Many plutonic-related deposits of Au are associated with a variety of other types of mineralization (Fig. 2). For example, peripheral to the sheeted Au-quartz veins in the Eagle Creek zone of the Dublin Gulch property are placers of gold and W, solitary quartz veins with Au and sulfides, and a W-rich skarn (Hitchins and Orssich 1995). The W skarn and the sulfide-Au quartz veins are spatially and genetically related to the Dublin Gulch stock (Baker *et al.* in press). Farther away from the stock are Ag-Pb-Zn veins which Baker *et al.* have interpreted to be distal mineralization related to the intrusion. Similar veins 2 to 5 km from the source intrusion for other Fort Knox-type deposits were noted by Thompson *et al.* (1999). Additional styles of mineralization related to granitoid intrusions in Alaska and Yukon are shear-hosted lode Au, Au-bearing skarn, Sb-Au and base-metal vein, vein Hg, and sediment-hosted deposits with disseminated Au.

These associated styles of mineralization provide one of the best methods for identifying areas to prospect for plutonic-related deposits of Au. As the shear-hosted and sulfide-quartz veins, the Sb-Au and base-metal veins, and the sediment-hosted deposits with disseminated Au can form some distance above or away from the parent intrusion, they can be used to identify areas prospective for covered or buried intrusions.

A number of Au-bearing deposits in south-western Alaska are related to Late Cretaceous granitic intrusions. The deposits contain Hg, As, and Sb minerals, and many are associated with extensive zones of alteration by carbonate. The mineral assemblages and fluid inclusions suggest that the deposits formed from fluids similar to those of the plutonic-related Au-quartz deposits, but at shallower depths (McCoy *et al.* 1997). Perhaps the best example is the Donlin Creek deposit, which consists of quartz-stibnite veins in granite porphyry and silicified sandstone, quartz-Au replacements, and wide zones of disseminated sulfides in quartz veins along shears and in stockwork (Bundtzen and Miller 1997; Ebert *et al.* this volume). The ore minerals include auriferous pyrite, stibnite, cinnabar, arsenopyrite, and sulfosalts. Placer Dome reported that the deposit contained a geological resource of 44 Mt grading 2.5 g/t Au at a 1 g/t cutoff in 1998, and the company's 1999 annual report gives a resource of 11.5 M oz.

Key Exploration Parameters

The key exploration guide for plutonic-related deposits of Au is to explore in, and around, highly differentiated granitic intrusions, specifically those intruded in continental marginal settings, which is a setting shared by Sn and W magmatic provinces (Thompson *et al.* 1999). The Fort Knox-style of mineralization typically occurs near the apex of the stock or batholith; therefore, the intrusions generally have limited surface exposures. McCoy *et al.* (1997) pointed out that Cretaceous intrusions with surface areas >4 km^2 do not host large Au deposits in the Fairbanks district, even though creeks draining these exposures contain large placers of gold. The mineralizing intrusions commonly occur in belts or clusters; therefore, there may be unmapped, small stocks nearby or along the trend. Gold-quartz veins may also occur in country rock overlying buried intrusions where the only signs of the stock may be granite, pegmatite, or aplite dykes, hornfelsic metasediments, or the more distal styles of plutonic-related mineralization.

The known prospective areas are underlain by Proterozoic–Paleozoic miogeoclinal rocks of ancestral North America, and by the pericratonic Yukon–Tanana and Kootenay terranes. The rocks were deposited along the margin of the North American craton, in shelf and marginal basin environments. Accretion of Quesnellia in Jurassic time led to the deformation, metamorphism, and ultimate translation of these rocks along thrust faults onto the craton. The rocks vary from sub-greenschist to amphibolite-grade facies. The Liese zone is hosted by gneisses, and it is possible that the Pogo-style mineralization is more likely to occur in higher grade metamorphic rocks than typically host other types of Au-quartz lodes.

Other exploration criteria for plutonic-related Au-quartz vein deposits are:

(1) leucocratic granitic rocks with evidence for a volatile-rich fluid phase or extreme different-tiation, such as miarolitic cavities, pegmatite and aplite dykes, or possibly specific minerals such as tourmaline;
(2) associated styles of mineralization, such as Au and W placers, W skarns and veins, Au-quartz veins, Sb-Au- base-metal veins, and possibly distal Ag-Pb-Zn veins and sediment-hosted disseminated Au;
(3) anomalous values of Au, W, As, Bi, Te, Sn, and Mo in silts, soils, and rocks; heavy-mineral concentrates appear to be particularly useful;
(4) anomalous aeromagnetic and ground-magnetic data used to identify low-magnetite, reduced intrusions and their magnetic, hornfelsic contact-metamorphic aureoles;
(5) Au mineralization is controlled at hand-sample, outcrop, and possibly regional scales by structures, both tensional and shear;
(6) low sulfide contents (1-5%), typically arseno-pyrite, pyrrhotite, and native bismuth; and
(7) limited wallrock alteration, typically as selvages of K-feldspar, albite, biotite, sericite, and quartz.

Cordilleran Geology

The Canadian Cordillera consists of five distinct morphogeological belts (Fig. 3; Gabrielse *et al.* 1991). In British Columbia, the Foreland belt is

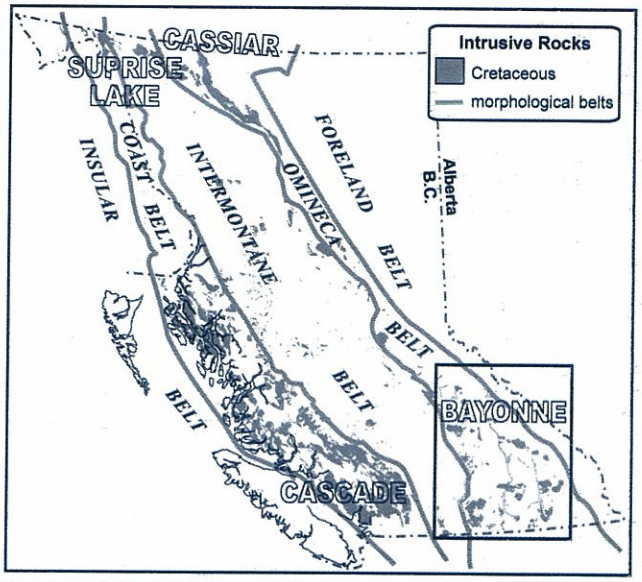


Figure 3. Distribution of Cretaceous plutonic rocks in the Cordillera of British Columbia, showing relationship to the morphogeological belts. Data for the Cassiar, Surprise Lake, Cascade, and Bayonne suites are from Woodsworth *et al.* (1991).

characterized by Proterozoic to Upper Jurassic platformal and miogeoclinal strata that were deposited on the rifted western margin of ancestral North America and then translated northeastward by thin-skinned thrusts and folds to form the Rocky Mountain fold-and-thrust belt. Palinspastic reconstructions indicate at least 200 km of post-middle Cretaceous shortening in the southern foreland belt (Bally *et al.* 1966; Price and Mountjoy 1970), and eastward displacement in the north is estimated to be 50 km (Gabrielse *et al.* 1991). The Omineca belt is the exhumed metamorphic–plutonic hinterland to the foreland belt. In southern British Columbia, the Omineca belt consists of the Kootenay terrane and the Barkerville subterrane, which consist of metamorphic rocks probably equivalent to, or deposited in proximity to, North America miogeoclinal strata (Gabrielse *et al.* 1991). West of the Omineca belt are the Intermontane, Coast, and Insular belts, consisting primarily of Paleozoic to Early Jurassic oceanic and island-arc terranes. Amalgamation of these terranes and accretion to the western margin of North America occurred in the Middle Jurassic and Early Cretaceous (Monger *et al.* 1982; Gabrielse and Yorath 1991). Ratios for initial Sr in the Omineca and Foreland belts are commonly greater than 0.705, and those in the western belts are commonly less than 0.705 (Armstrong 1988). The transition between the Omineca and Intermontane belts roughly coincides with the western margin of old radiogenic continental crust and the eastern limit of allochthonous volcanic terranes.

Plutonic rocks make up a substantial proportion of the Canadian Cordillera, particularly in the Coast and Omineca belts (Fig. 3). The mid-Cretaceous plutons of these two belts are markedly different. Plutons in the Coast belt are primarily *I*-type, commonly contain hornblende in addition to biotite, and are poor in large-ion lithophile elements (Woodsworth *et al.* 1991). Plutons in the eastern belt (Bayonne and Selwyn suites) are *S*-type, felsic, rich in large-ion lithophile elements, and have initial $^{87}Sr/^{86}Sr$ between 0.710 and 0.740 (Anderson 1988; Armstrong 1988; Woodsworth *et al.* 1991). The eastern belt of plutonic rocks intrudes North America and marginal assemblage rocks comprising the pericratonic terranes of the northern Cordillera (Fig. 1). Deposits of Mo, W, and Sn in the northern Canadian Cordillera are related primarily to the mid-Cretaceous (at 110 and 90 Ma) intrusive episodes of the eastern suite (Sinclair 1995). These include skarn-W deposits, such as Cantung and Mactung, and porphyry W-Mo deposits at Ray Gulch and Logtung. This W-Sn±Mo province extends more than 1000 km across Yukon and into Alaska after restoration of the dextral motion on the Tintina fault. The province also follows the Omineca belt southward 1600 km, to Salmo near the Canada–US border. Extensive U-Pb dating of Cretaceous intrusive rocks from throughout Yukon has led to the recognition of three temporally distinct NW-trending plutonic suites, which in general young from southwest to northeast (Mortensen *et al.* 1995). From oldest they are the Whitehorse – Coffee Creek and Anvil – Cassiar plutonic suites (110-100 Ma), the Tay River plutonic suite (98-96 Ma), and the Tombstone and Tungsten plutonic suite (95-90 Ma). The Tombstone–Tungsten suite of intrusions from this belt in Yukon and Alaska has been shown to host or be directly related to many of the Au deposits in the Tintina Gold Belt (McCoy *et al.* 1997; Baker *et al.* in press).

The Tombstone–Tungsten belt (TTB) extends from the western Northwest Territories near Macmillan Pass (Selwyn plutonic suite of Anderson 1983, 1988) to Dawson City, Yukon, where it is truncated by the Tintina fault (Murphy 1997). The belt reappears more than 400 km to the northwest in eastern Alaska, and continues westward into and beyond the Fairbanks mining district (McCoy *et al.* 1997). Along its length from east to west, the TTB intrudes brittle-deformed, but relatively unmetamorphosed, miogeoclinal Neoproterozoic to Paleozoic pelites and calcareous rocks of the Selwyn basin and Mackenzie platform in Yukon; in Alaska, the intrusions cut metamorphosed and ductile-deformed sedimentary and volcanic rocks of the Yukon–Tanana terrane. Individual intrusions are unfoliated, cross-cut the country-rock foliations, and are surrounded by low-pressure (*i.e.*, high-level intrusion) contact-metamorphic aureoles of hornfels and calc-silicate rocks. Typically, gossanous metamorphic aureoles envelope two or three small plutons or cupolas.

In Yukon, the TTB comprises a western Tombstone suite of metaluminous intrusions, and an eastern suite of the peraluminous Tungsten intrusions. The Tombstone suite consists of medium- to coarse-grained biotite ± hornblende monzogranite, whereas the Tungsten suite is primarily of biotite and biotite-muscovite granodiorite, quartz monzonite, and granite (Gordey and Anderson 1993). The western end of the Tombstone plutonic suite gives U-Pb dates of 91.5 ± 2.0 Ma (Murphy 1997; Baker *et al.* in press). Most K-Ar, Rb-Sr, and U-Pb dates from the eastern end of the belt give a similar range of ages, although some of the Tungsten-suite intrusions are older (98-96 Ma; Mortensen *et al.* 1997).

West of the Tintina fault in Alaska, the TTB is characterized by 93-86 Ma, subalkaline and alkalic intrusions hosted in high-grade, polydeformed quartzite and quartz muscovite schists of the Fairbanks Schist unit (Newberry and Bundtzen 1996; McCoy *et al.* 1997). This assemblage is interpreted to be part of the Yukon–Tanana terrane (Dusel-Bacon *et al.* 1993), but Baker *et al.* (in press) recognize striking similarities between the Fairbanks Schist and metamorphosed parts of the Hyland Group (Selwyn basin).

The tectonic setting of the TTB is uncertain. The radiogenic nature of Pb and Sr isotopes, and the inherited Pb in zircon indicate that the magma was derived from the melting of continental crust. The eastward change from metaluminous to more peraluminous compositions might reflect differences in the thickness and character of crust beneath the Selwyn basin and Mackenzie platform, respectively (Murphy 1997). Alternatively, Mortensen *et al.* (1997) suggested the TPS to be likely of mantle derivation, but strongly contaminated with crustal material. Using trace-element geochemistry and discriminant plots, McCoy *et al.* (1997) and McCoy (1999) proposed a continental magmatic arc setting for the generation of the mid-Cretaceous Au-related plutons.

Bayonne Plutonic Suite of Southeastern British Columbia

In the southeastern Canadian Cordillera, mid-Cretaceous plutons of the Bayonne suite intrude a wide area extending from North America west across the Omineca and Intermontane belts (Fig. 4). Most of the plutons are post-metamorphic and discordant with the country rocks. The plutons form an arcuate belt of batholiths and stocks, generally composite bodies, comprising several distinct phases, which follow the eastern edge of the Kootenay arc and beyond as far northwest as Quesnel Lakes. These intrude miogeoclinal rocks of North America affinity. West of the Kootenay arc, batholiths and large stocks intrude rocks of the Kootenay and Barkerville terranes. North of 51° latitude, the batholiths and plutons, such as Baldy and Goldstream, are elongate easterly.

The mid-Cretaceous suite consists of medium to coarse-grained, biotite-hornblende monzogranite to granodiorite, and biotite and biotite-muscovite granites. Many of the intrusions are composite bodies consisting of one or more of these granitoid types, and the available geochemical data show no simple change from metaluminous to peraluminous along the belt as observed in the Tombstone–Tungsten suite in Yukon. The Bayonne suite is metaluminous to weakly peraluminous hornblende-biotite granite and strongly peraluminous two-mica granite, aplite, and pegmatite. Isotopes of initial Sr and Pb suggest an extensive interaction with continental crust. Trace elements (discrimination diagrams of Pearce *et al.* 1984) are indicative of within-plate tectonic settings for the intrusions that cut North America rocks (Brandon and Lambert 1993, and this study), but also display volcanic-arc signatures for some of the others (*e.g.*, Goldstream, Honeymoon Bay, Baldy).

At the southern end of the Omineca belt, the

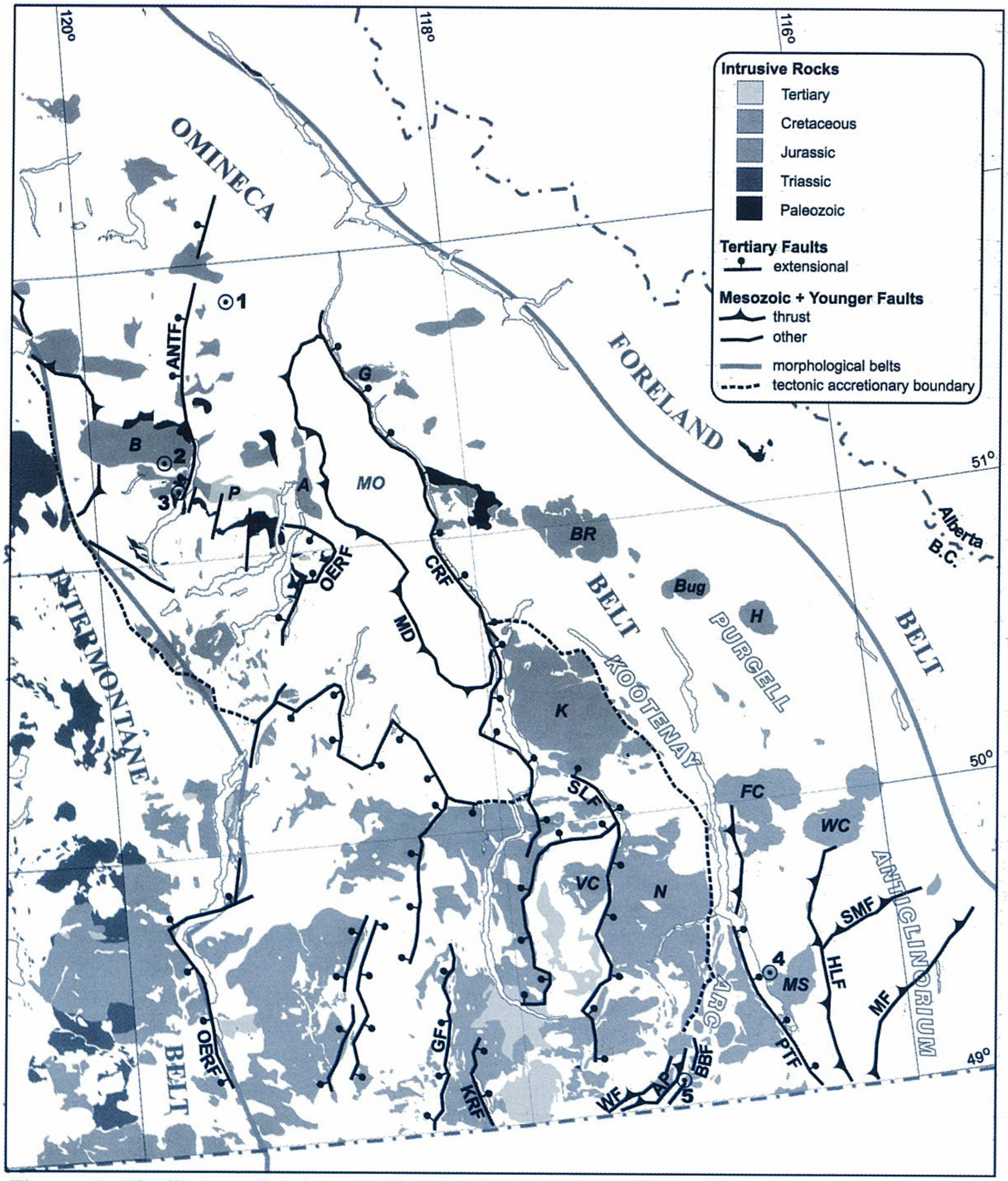


Figure 4. Distribution of Paleozoic, Triassic, Jurassic, Cretaceous, and Tertiary plutonic rocks in southeastern British Columbia; also shown are the morphogeological belts and tectonic accretionary boundary. Eocene normal faults (Parrish *et al.* 1988; Johnson 1994) bound higher metamorphic grade Shuswap-complex rocks; barb is on hangingwall side. **ANTF** Adams–North Thompson fault; **OERF** Okanagan–Eagle River fault; **MD** Monashee décollement; **MO** Monashee complex; **CRF** Columbia River fault; **SLF** Slocan Lake fault; **VC** Valhalla complex; **GF** Granby fault; **KRF** Kettle River fault; **WF** Wanetta fault; **AF** Argillite fault; **BBF** Black Bluff fault; **PTF** Purcell thrust fault; **HLF** Hall Lake fault; **MF** Moyie fault; **SMF** St. Mary's fault. Plutonic rocks are **B** Baldy; **P** Pukeshun; **A** Anstey; **G** Goldstream; **BR** Battle Range; **Bug** Bugaboo; **H** Horsethief Creek; **K** Kuskanax; **FC** Fry Creek; **WC** White Creek; **N** Nelson; **MS** Mount Skelly. Numbers correspond to mineral occurrences: **1** Bizar; **2** San; **3** Cam-Gloria; **4** Valparaiso; **5** Emerald Tungsten.

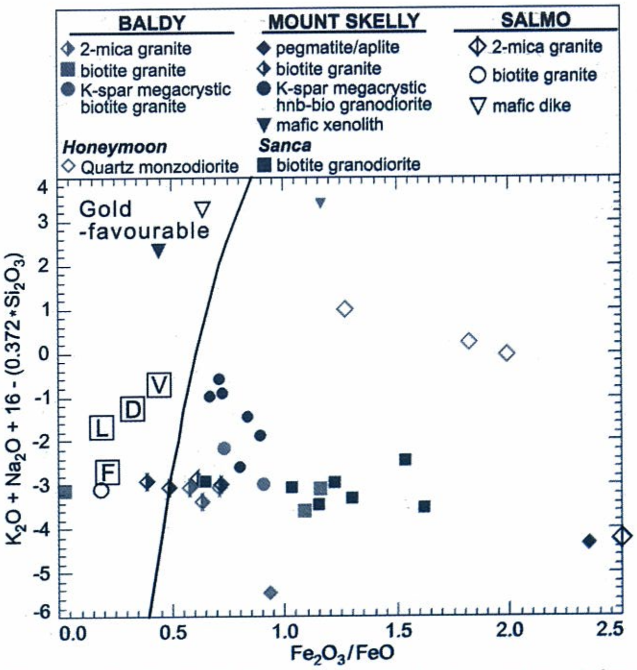


Figure 5. Fe_2O_3/FeO versus alkalinity index (after Mutschler *et al.* 1985) for intrusions from the mid-Cretaceous Bayonne suite: Baldy, Honeymoon Bay, Mount Skelly, Sanca Creek, Emerald. The Au-favorable field of low-oxidation-state, Au-related intrusions of Leveille *et al.* (1988) is shown together with selected plutons associated with Au systems in interior and southwestern Alaska. **D** Democrat; **F** Fort Knox; **L** Liberty Bell; **V** Vinasale Mountain (from McCoy *et al.* 1997).

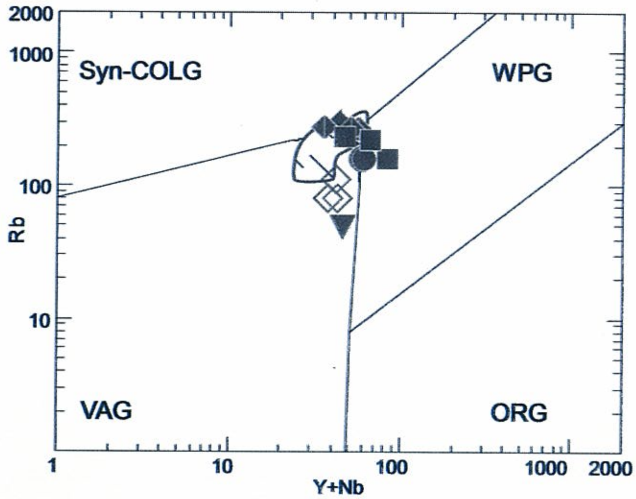
intrusions of the Bayonne suite have Sr, Nd, and Pb isotopic compositions and REE patterns that can be derived entirely from partial melting of local crustal lithologies (Brandon and Lambert 1993; Brandon and Smith 1994). Therefore, these mid-Cretaceous intrusions are likely the result of crustal melting without a mantle-derived mafic precursor, and they were probably generated in response to crustal thickening initiated by thrusting during collapse and obduction of the marginal basin.

Chemistry of the Bayonne Plutonic Suite

All initial $^{87}Sr/^{86}Sr$ values for the Baldy, Bugaboo, Fry Creek, Horsethief Creek, and Sanca Creek intrusions are well above 0.705 (Armstrong 1988) and show a large upper crustal or evolved component, suggesting that Precambrian basement underlay their source regions. Initial $^{87}Sr/^{86}Sr$ for Baldy is 0.7054 (Jung 1986). Brandon and Lambert (1993) reported initial ratios ranging from 0.70715 to 0.70806 for biotite granite, and up to 0.71780 for aplite from the Bugaboo; 0.70774 for biotite granite, and 0.7169 to 0.73754 for two-mica granites of Fry Creek; and initial ratios from 0.70794 to 0.71019 for biotite granite, and up to 0.71321 for aplite from Horsethief Creek. For the Sanca Creek stock, the initial ratios range from 0.70646 to 0.70782 (Ghosh 1995).

The relationship between Au-associated plutons and oxidation state was defined by Leveille *et al.* (1988). Interior Alaskan W-related intrusions have low oxidization states, which plot below 0.6% Fe_2O_3/FeO, in the Au-favorable field (McCoy *et al.* 1997). Using these parameters, the Au-favorability of the mid-Cretaceous Bayonne suite was tested. Unaltered samples of the Baldy batholith, Honeymoon Bay stock, Mount Skelly pluton, Sanca Creek stock, and the Emerald stock are plotted on the Fe_2O_3/FeO ratio versus alkalinity index (Fig. 5). Selected plutons from interior Alaska (McCoy *et al.* 1997) are also shown. A single sample of equigranular biotite-muscovite granite from the eastern end of the Baldy batholith, a fine-grained biotite granite from the interior, youngest phase of the Mount Skelly pluton, an equigranular biotite granodiorite from the Emerald stock (Emerald-Tungsten, Salmo), a sample of mafic zenolith from the main phase of the Mount Skelly pluton, and a biotite-olivine lamprophyre dyke from the Sheep Creek gold camp, Salmo, all plot in the Au-favorable field.

Low Rb and Nb abundances have been cited by McCoy (1999) as characteristics of Au-mineralizing intrusions of the plutonic-related deposit type. These low abundances are also characteristic of granites formed in volcanic arc settings (Pearce *et al.* 1984). Data for the Bayonne suite from the southern Canadian Cordillera are shown in Figure 6, along with the field for the Tombstone suite (Murphy 1997). The Honeymoon Bay stock plots in the volcanic-arc field, whereas the phases of the Baldy batholith straddle the triple junction of the fields for VAG – syn-COLG and WPG (Fig. 6a). The same distribution is shown for the intrusive phases of the Mount Skelly and Sanca Creek bodies (Fig. 6b). Unpublished data for the Goldstream pluton show biotite granite which overlaps the Tombstone field, and hornblende-bearing quartz diorites which plot in



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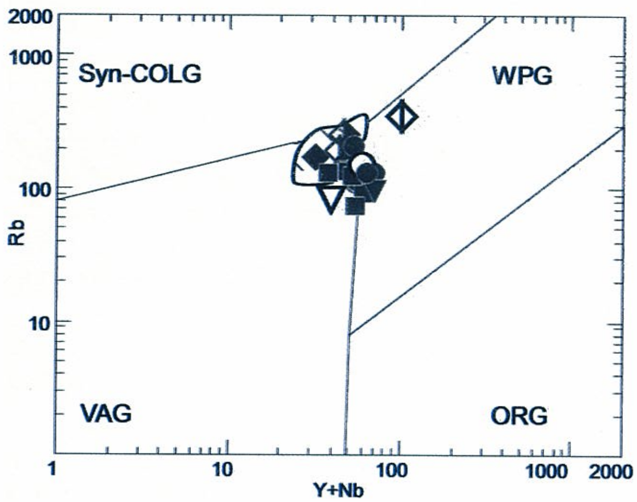

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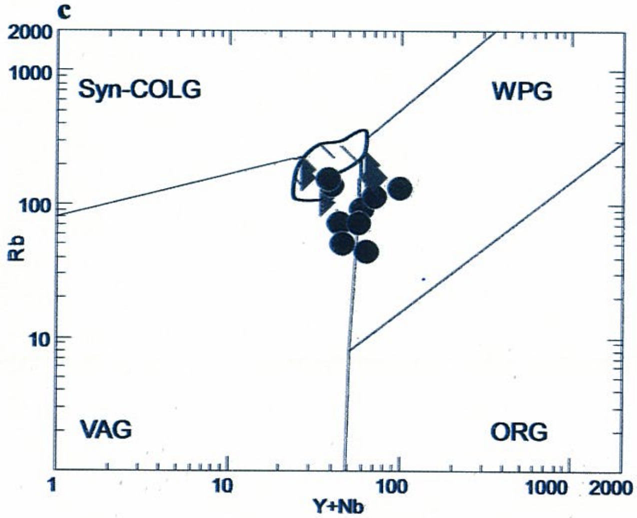

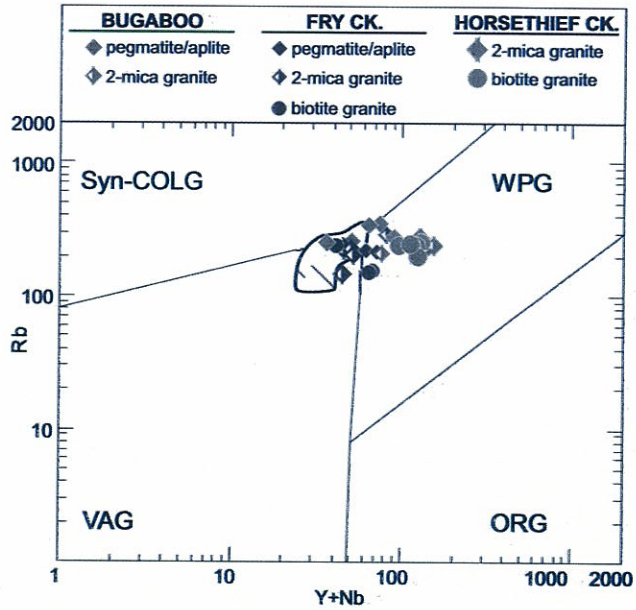

Figure 6. Rubidium versus Y + Nb values for unaltered Cretaceous plutonic rocks of southern British Columbia. Tectonic setting boundaries are from Pearce *et al.* (1984). The field for metaluminous plutons and dykes of the Tombstone–Tungsten suite is from Murphy (1997). (**a**) Baldy samples; (**b**) Kootenay samples; (**c**) Goldstream samples; (**d**) Bugaboo, Fry Creek, and Horsethief Creek data, from Brandon and Lambert (1993), with symbols as in Figure 5 for 6a and 6b. Symbols for the Goldstream pluton are: solid circle = hornblende diorite, diamonds = biotite granite.

the WPG field (Fig. 6c); for the Bugaboo, Fry Creek, and Horsethief Creek plutons, data from Brandon and Lambert (1993) have substantially higher Nb values and plot in the WPG field (Fig. 6d).

Prospective Areas for Plutonic-related Au Veins in B.C.

British Columbia shares many of the geological features found in Alaska and Yukon. Among these features are granitic intrusions and pegmatites that are the same age and of compositions similar to those of the Tombstone suite, and numerous mineral occurrences of the types that occur associated with plutonic-related Au deposits in Alaska, including placer and lode-Au veins, W-bearing veins and skarns, and Au-bearing skarns and mantos. Despite the obvious potential, there has been only limited exploration in the province for plutonic-related Au deposits. In the last few years, several companies and prospectors have recognized this opportunity and have started grassroots exploration programs. Geology, mineral occurrence, and regional geochemical databases have been used to identify prospective areas for plutonic-related Au-quartz veins in British Columbia (Lefebure and Cathro 1999; Table 1). As these databases are incomplete, other areas with equal potential likely remain to be identified. The following sections highlight some of the features that stand out at the provincial scale.

Quartz Veins with Au-W-Bi

British Columbia has a number of Au-quartz veins, with anomalous amounts of W and Bi, which may be related to granitoid intrusions. Many are candidates to be plutonic-related deposits of Au. A total of 43 occurrences and deposits was identified as 'possible' plutonic-related quartz-Au veins by searching the provincial mineral-occurrence database, MINFILE, and selected assessment reports (Table 2 and Fig. 7). Among the criteria used to distinguish plutonic-related veins from other types of Au-bearing quartz veins are association with W, Bi, or Sn minerals and permissive geology. Many of the higher grade Au veins were found by prospectors and have been known for many years. Only four low-grade Au vein systems (possible analogues to the Fort Knox type) were identified, which undoubtedly reflects the relatively recent recognition of their economic potential. We are convinced that a more intensive investigation of the database would lead to the identification of more 'possible' occurrences of plutonic-related quartz-Au veins.

Bismuth and Te are useful pathfinders for plutonic-related Au deposits (McCoy 1997; Thompson *et al.* 1999; Baker *et al.* in press). Many of the plutonic-related deposits of Au show a strong positive correlation between Bi and Au (McCoy 1999), which is consistent with the close association of Bi minerals with native gold in the mineralization. However, as Bi is known to be concentrated in many styles of proximal intrusion-related mineralization (Sillitoe 1991), it cannot be used on its own. There are 148 mineral occurrences in British Columbia's MINFILE database which have Bi or Te as a commodity, within a mineral, or as a geochemically anomalous analysis. Many of these occurrences belong to a variety of deposit types, including skarns, porphyries, polymetallic veins, and Au-quartz veins, which may be intrusion-related. As Bi alone does not serve to distinguish different types of intrusion-related mineralization, and as Bi, until recently, commonly has not been included in analyses of mineralization, other deposit-type characteristics, such as the strong geochemical association with W, proved more useful at the provincial scale for identifying prospective regions and occurrences.

Tungsten, typically as scheelite, is reported as a major commodity in 118 vein, 57 skarn and 9 porphyry occurrences (Lefebure and Cathro 1999). Many of these occurrences have not been explored recently and may warrant re-sampling to identify possible associated plutonic-related Au deposits. Although much less common than scheelite, wolframite occurs in number of areas. As W-bearing vein systems can exhibit a vertical zoning from predominantly scheelite at depth to wolframite at shallower levels (Li Yidou 1993; Liu and Ma 1993), it is possible that the intrusions related to the wolframite veins were emplaced at shallower depths. Numerous wolframite-quartz veins in the Atlin region are related to the Surprise Lake suite, much of which has associated molybdenite, and some of which has galena, chalcopyrite, and cassiterite (*e.g.*, Thor, Hobo, Pereye Tungsten, and Weir Mountain). The Black Prince and Garnet occurrences are similar and contain Au. The Creston area is the only other region in the province with reported quartz-wolframite veins, such as the Valparaiso and Sarah 2 occurrences with base metals and Au (see below). Wolframite is reported from several porphyry deposits, most notably the Glacier Gulch molybdenum deposit and the Logtung tungsten deposit. Some scheelite-quartz vein occurrences also have minor wolframite. In general, the wolframite-quartz veins have higher base metals and Ag contents, and possibly lower Au contents, than the scheelite-quartz veins.

These occurrences, together with regional geochemical survey data, define three major W-rich provinces (Lefebure *et al.* 1999). The largest W-bearing province extends from Cassiar to Salmo. It is west of the Rocky Mountain Trench and coincides with mid-Cretaceous intrusions (Cassiar and Bayonne suites) of the Omineca belt. The second W-bearing province extends northeast from Terrace to the edge of the Bowser basin and is associated with

Table 1. Prospective areas for plutonic-related Au-quartz deposits in British Columbia

Area	Major Intrusions	Mineral Occurrences	RGS Data	Comments
		MID-CRETACEOUS INTRUSIONS		
Logtung–Cassiar	Cassiar and Thudaka batholiths	W veins and skarns, W-Mo porphyry (Logtung), beryl, placer Au, Au-quartz veins	*no Au, Bi, Sn for 104 O and P, no data for 094L*; abundant W anomalies; very weak W+Au response on 104I	beryl and W occurrences in Horseranch Range area, Boya Hill W and Au placers
Germansen Landing	Mesilinka pluton; Osilinka stock; Germansen batholith	placer Au and Au-W, Au-quartz veins, pegmatite and beryl localities, a few W vein occurrences away from larger intrusions	*no Sn data*; numerous Au+W and W anomalies	placer Au and pegmatites near Williston Lake may be related
Prince George (south)	Naver pluton	placer Au and Au-W, Au-quartz veins, W vein, Au-W±Bi veins, W veins	*no Au or Bi, Sn only for 93G,H*; numerous W anomalies	includes mesothermal quartz veins in Barkerville gold camp; no directly associated intrusions
Valemont–Revelstoke–Kimberley	Battle Range, Bugaboo, Horsethief, Fry Creek, and White Creek batholiths	Au-W±Bi veins, polymetallic veins, numerous Au-quartz and W veins and skarns, minor placer Au, pegmatite and beryl occurrences	*Bi only for 82G and J; no Sn for 82M and N*; numerous Au+W, Sn+Au, W, and a few Au+W+Sn anomalies	some W vein occurrences do not appear to have been sampled for Au
Creston area (southeast of Nelson)	Bayonne and Rykert (Kaniksu) batholiths	Au-W veins, Au occurrences, Sn veins, W porphyry, W veins, Sn porphyry, beryl	*no Bi for 82F*; a few Au+W anomalies, low Sn values may reflect analytical technique	to the east find W veins, Au placers and, polymetallic veins
Salmo Camp (east of Trail)	Lost Creek pluton; Wallace Creek and Hidden Creek stocks	W skarns and veins, Au-quartz veins, Au-W-Bi veins, minor placer Au	*no Bi for 82F*; a number of Au+W anomalies, low Sn values may reflect analytical technique	
		LATE CRETACEOUS INTRUSIONS		
Atlin–Cassiar	Surprise Lake, Dawson Peaks, Klinkit and Glundebery batholiths	placer Au and Au-W, Au-quartz veins, W veins, beryl, Au-W-Bi quartz veins	*no Au or Bi data; no Sn data for 104O and P*; numerous W+ Sn and W anomalies	most strongly anomalous area for Sn and W in the province
Hazelton	Bulkley intrusions (Rocher Deboule)	placer Au, Au veins, polymetallic veins, W veins	*no Bi; no Sn for 093E or 093N*; numerous Au+W and W anomalies extending north from Hazelton	
Terrace		numerous Au-quartz veins, placer Au, W veins	*no Sn or Bi for 103I*; a number of Au+W and numerous W anomalies	
Bridge River Camp (west of Lillooet)	Bendor pluton	numerous Au-quartz veins, Au-W veins, W veins	*no Sn or Bi data for 092J and 092O*; a number of Au + W and W anomalies	Bridge River mining camp, includes Bralorne

Table 2. Possible plutonic-related Au-W-Bi quartz veins in British Columbia

Minfile Number	Name	Status	Commodities					
104N 053	South (Garnet)	Prospect	WO	AU	MO	CU	PB	SN
104J 014	Mack	Prospect	MO	CU	AU	WO		
104A 062	Little Pat	Showing	WO	AU	AG	CU	MO	PB
103I 047	Gold Dome	Showing	AU	AG	CU	PB	ZN	WO
093L 073	Whitewater	Showing	WO	AU	ZN	PB	AG	
093E 019	Lindquist (Deerhorn)	Developed Prospect	AU	AG	WO	ZN	PB	CU
093H 023	Hardscrabble	Past Producer	WO	AU	PB	ZN		
093H 010	Mosquito Creek	Past Producer	AU	AG	PB	ZN	WO	
093H 019	Cariboo Gold Quartz	Past Producer	AU	AG	WO	BI	PB	ZN
093A 091	Cariboo Thompson	Past Producer	AU	AG	PB	ZN	WO	
093A 071	Cariboo Hudson	Past Producer	AU	AG	PB	ZN	WO	
093A 038	Holmes Ledge	Showing	AG	AU	PB	WO	ZN	CU
092O 018	Tungsten Queen	Past Producer	WO	SB	HG	AU		
092JNE034	Rex mountain	Prospect	AU	AG	CU	BI	WO	
092JNE024	Arizona	Developed Prospect	AU	AG	WO	PB	ZN	CU
092JNE071	Bristol	Prospect	WO	AU	AG	ZN	CU	PB
082M 267	Bizar	Showing	AU	BI	CU	AG		
082M 080	Stanmack	Showing	AU	AG	WO	MI		
082M 167	Orphan Bay	Showing	AU	WO				
082M 266	Cam-Gloria	Showing	AU	AG	PB	CU		
082KNW032	Ophir Lade	Past Producer	AU					
082LSW042	White Elephant	Past Producer	AU	AG	BI	TE	WO	
082KSW184	Oro	Showing	AU	WO				
082FNW127	Alpine Gold	Past Producer	AU	AG	PB	ZN	MO	WO
082FSW087	Venango	Past Producer	AU	AG	PB	ZN	WO	
082FSW086	Kenville (Granite-Poorman)	Past Producer	AG	AU	PB	ZN	CU	CD
082FSW168	Athabasca	Past Producer	AU	AG	PB	ZN	CU	WO
082FSW088	Royal Canadian	Past Producer	AU	AG	ZN	PB	WO	
082FSW179	Rozan (Ridge Zone)	Prospect	AU	PB	ZN	AG	CU	
082FSE008	Storm King	Prospect	AG	PB	SN	CU	AU	WO
082FSE038	Valparaiso	Past Producer	ZN	PB	WO	AU	AG	CU
082FSE055	Sarah 2nd	Past Producer	AG	AU	PB	WO	CU	ZN
082FSE039	Gold Basin	Prospect	PB	CU	WO	AU	AG	
082FSW046	Kootenay Belle	Past Producer	AU	AG	PB	ZN	WO	
082FSW010	Emerald Tungsten (Bismuth Zone)	Prospect	WO	MO	BI	AU		
082FSW011	Dodger (Gold Quartz Veins)	Prospect	WO	MO	AU			
082FSW002	Bunker hill	Past Producer	AU	AG	WO	MO		
082ESW084	Gypo	Past Producer	SI	FL	MI	AU	AG	CU
082ESW090	Susie	Past Producer	AG	AU	PB	ZN	CU	SI
092HSE101	Granite Scheelite	Developed Prospect	AU	AG	CU	ZN	PB	WO
092HNW054	Monument	Prospect	AU	WO	CU	PB		
092HNW053	Rodd B	Showing	AU	WO				
092GNW013	Ashlu	Past Producer	AU	AG	CU	ZN	WO	

the Late Cretaceous Bulkley intrusions. The third one has numerous occurrences of Sn, and follows the Late Cretaceous Surprise Lake suite easterly from Atlin.

In contrast to occurrences of W, British Columbia has relatively few of Sn. Most are associated with the Surprise Lake suite near the Yukon border, or with the Rocher Deboule stock near Hazelton. These occurrences can be used to identify regions of interest for Au-quartz veins (Thompson *et al.* 1999) or for auriferous quartz-stibnite veins such as those of Donlin Creek.

Placer Gold and W

British Colombia has 355 deposits of placer gold recorded in the MINFILE database, and many more occurrences are not documented. The deposits are widely distributed throughout the province. Production of placer gold in some areas has seemed disproportionately large compared to the size of

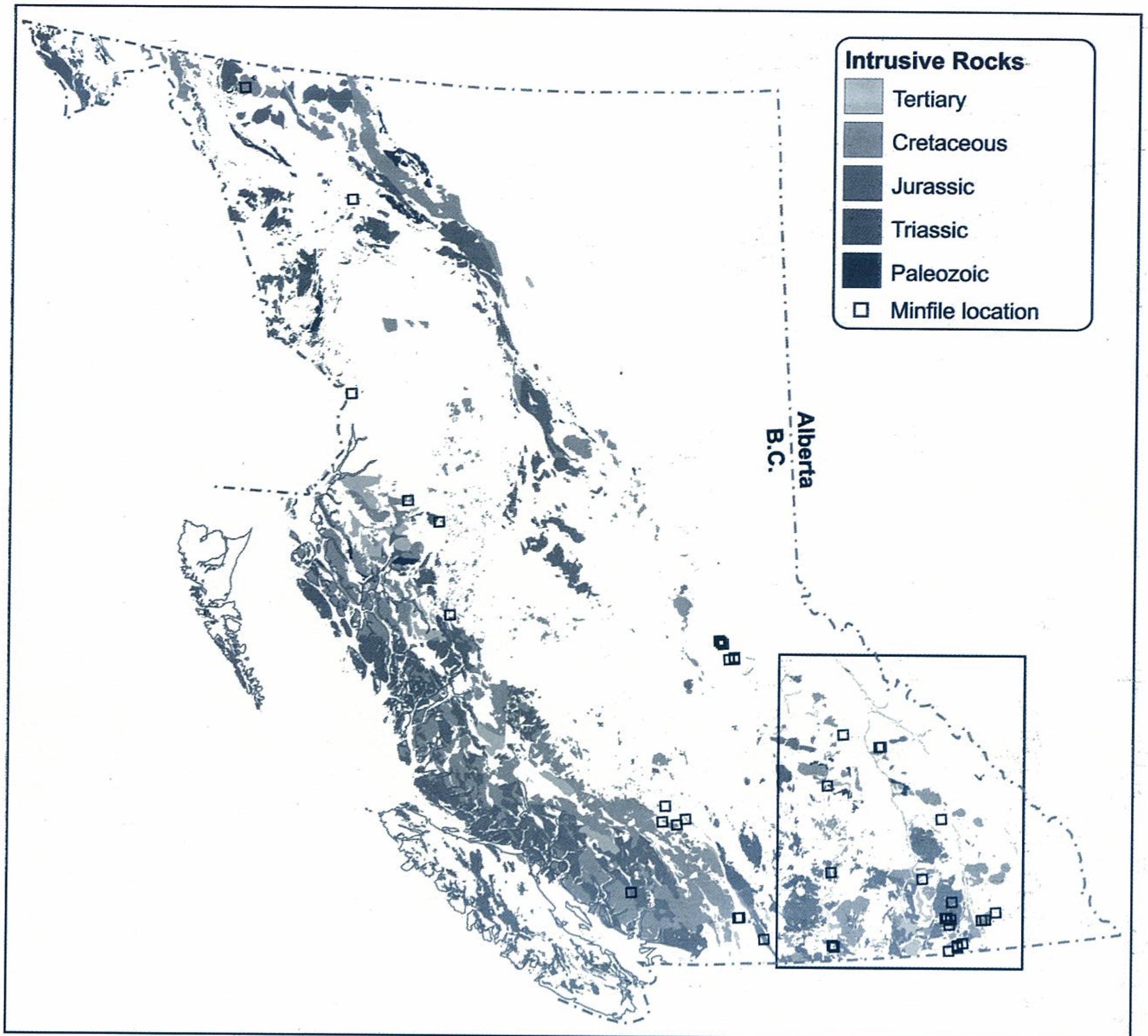

Figure 7. Distribution of possible plutonic-related Au-Bi-W-quartz veins in British Columbia.

known Au lodes, which may indicate potential for discovery of more hard-rock deposits. In other locations, no source of lode-Au has been identified. Areas with placer gold that may warrant investigation for possible plutonic-related Au-W quartz veins are north of Revelstoke, near Cranbrook, east of Williston Lake, and along the Liard River.

There has not been a recorded production of W from placer deposits in British Columbia, although scheelite is reported by Stevenson (1943) from clean-up concentrates from several creeks in the Cariboo (*e.g.*, Hardscrabble Creek, Red Gulch, Lowhee Creek, Stevens Creek, California Gulch, Nugget Gulch). The Boulder Creek placer-gold occurrences in the Atlin area contain placer wolframite downstream from several wolframite lode showings (from MINFILE).

Regional Geochemical Anomalies

For plutonic-related Au deposits, among the important pathfinder elements in rock, soil, and stream sediments are As, Bi, W, Sn, Mo, Te, and Sb. British Columbia has a large Regional Geochemical Survey (RGS) database collected mainly from samples of stream silt. Unfortunately, not all regions of the province have been sampled, and not all surveys were analyzed for the same suite of elements. The latter point is particularly significant for identifying prospective drainage basins for plutonic-related Au deposits because analyses of samples for Au are available for only half of the province, and sample coverage for Bi and Sn extends over a much smaller area. In a first-pass evaluation of the RGS database, only values for Au, W, and Sn equal to, or exceeding the 95 percentile were used by Lefebure *et al.* (1999) to identify strongly anomalous samples. Numerous samples with coincident anomalous values of Au and W were found even at these high thresholds, and several areas with anomalous values of W in stream sediments and associated mineral occurrences were identified. The most numerous anomalies of W are associated with the Surprise Lake suite of intrusions, and in the Barkerville terrane east of Williams Lake.

Preliminary Field Results from Southeastern British Columbia

Given the exploration interest in Pogo-type mineralization and the prospective nature of the province, the British Columbia Geological Survey initiated a field project to provide more information about plutonic-related Au deposits. The Shuswap and Kootenay areas (Fig. 7), which contain intrusions of the mid-Cretaceous Bayonne suite, were selected for initial study from the Lefebure *et al.* (1999) data set. The Shuswap study focused on the Baldy batholith west of Adams Lake in the Kootenay terrane, where Teck Corporation is evaluating the Cam-Gloria property. The Kootenay field work concentrated on the Mount Skelly pluton, located north of Creston in North America rocks. These areas were selected because they have mid-Cretaceous granitic intrusions, Au-quartz veins, sheeted veins or stockwork, Au-W-Bi signatures, and RGS anomalies of pathfinder elements. The areas were mapped and sampled on a reconnaissance basis to test their potential for Fort Knox and Pogo-style deposits. In addition, Lett and Jackaman (2000) carried out multi-media stream-sediment sampling to study the geochemical signature of the plutonic-related Au mineralization in these areas.

Regional Geology of Southeastern British Columbia

The present geological architecture of south-eastern British Columbia reflects the cumulative effects of Mesozoic accretion of Quesnellia to North America and, immediately post-dating compression, substantial extension and exhumation in the Tertiary. Obduction of Quesnellia in the southern Canadian Cordillera began in the earliest Middle Jurassic in response to collision and thrusting of the Intermontane superterrane over the western margin of North America (Monger *et al.* 1982; Brown *et al.* 1986; Murphy *et al.* 1995). Archibald *et al.* (1983) documented Barrovian metamorphism and major deformation circa 165-175 Ma in the Kootenay arc, followed by exhumation and rapid cooling to <300 °C prior to the end of the Jurassic. The same Middle Jurassic event occurred in the northern Monashee and Cariboo mountains (Rees 1987; Murphy 1987) and is preserved in the hangingwall rocks of Eocene extension faults (Johnson 1994; Parrish 1995). Easterly vergent thrust faults detached the supra-crustal rocks from the North America basement, and translated the rocks along a major sole thrust correlative with the Monashee décollement (Brown *et al.* 1992). Northeast-directed motion along the Monashee décollement continued during Cretaceous time, but whether deformation was continuous or episodic is unclear. Contraction caused tectonic wedging that thickened the crust and caused structurally lower rocks to be metamorphosed, and produced anatectic peraluminous melts in the Cretaceous and Paleocene. In the northern Shuswap, Parrish (1995) evoked a foreland-propagating fold–thrust belt to explain both the Late Cretaceous to Eocene deformation and metamorphism within the Monashee complex (structurally below the Monashee décollement) and the more varied and long-lived middle Jurassic to Eocene tectonic history of the overlying Selkirk allochthon. This scenario involved westward thrusting of the Monashee complex (basement and sedimentary cover) beneath the hot allochthon in Latest Cretaceous to Paleocene. In the allochthon, progressively higher structural levels cross older thrust faults that bound supracrustal rocks with consistently older ages of peak thermal metamorphism. For the southern Kootenay arc, dates provided by Leclair *et al.* (1993) from U-Pb in zircon, titanite, and allanite constrain penetrative deformation and regional metamorphism to the mid-Cretaceous in amphibolite-facies footwall rocks of the Purcell thrust fault, west of Kootenay Lake (Fig. 4). Contraction seems to have continued until the latest Paleocene (Parrish *et al.* 1988; Carr 1992), at which time southern Omineca underwent extension. The wide zone of high-grade metamorphic rocks in the southern Omineca belt reflects the substantial amount of extension the area has undergone.

The Kootenay terrane of the Adams Lake region comprises Proterozoic and Lower Paleozoic sedimentary, volcanic, and plutonic rocks and their metamorphic equivalents. Schiarizza and Preto (1987) subdivided the stratigraphy into a lower sequence correlative with Neoproterozoic and Lower Paleozoic ancestral North American miogeoclinal strata and a stratigraphically higher package of Late Paleozoic volcanic arc-related rocks. West of Adams Lake, in the hangingwall of the Eocene Adams – North Thompson fault (Fig. 4), the rocks are chiefly lower greenschist facies, with chlorite and biotite assemblages, but to the east, footwall rocks are higher grade amphibolite-facies sillimanite-bearing rocks of the Shuswap metamorphic complex (Read *et al.* 1991). The Shuswap metamorphic complex is a large, northerly-trending metamorphic core complex (Armstrong 1982). It is bound on its west side by the west-side-down Okanagan Valley system (Parkinson 1985; Johnson 1994) and to the east by the east-side-down Columbia River – Slocan Lake system (Read and Brown 1981; Parrish 1984), both outwardly dipping Eocene normal faults. Adopting the nomenclature of Brown and Carr (1990), the Shuswap complex includes only the high-grade rocks in the footwall of these Eocene extension faults.

Shuswap Area –Kootenay Terrane

The Baldy batholith is a west-trending, mid- to Late Cretaceous post-accretionary intrusion (Schiarizza and Preto 1987; Calderwood *et al.* 1990). It intrudes Proterozoic to mid-Paleozoic metasedimentary and metavolcanic rocks of the Kootenay terrane and post-dates most of the penetrative deformation in the area; however, emplacement coincided with some of the latest folding, and late faults offset its northern contact (Schiarizza and Preto 1987). The country rocks host a variety of mineral deposits (mafic VMS, bimodal felsic VMS, disseminated Cu-Mo, and stratabound Ag-Pb-Zn) which pre-date intrusion of the batholith, and a wide variety of mineral deposits may be related to its intrusion (polymetallic base metal veins, porphyry Mo, Au-pyrrhotite veins, Au-quartz veins, and W-bearing veins).

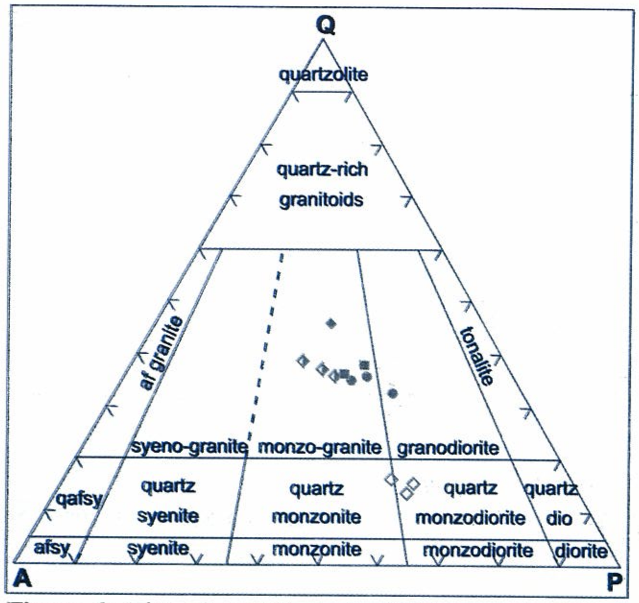

Figure 8. Plot of modal quartz–K-feldspar–plagioclase for the Baldy batholith and Honeymoon stock. Fields are from LeMaitre (1989), and symbols are as for Figure 5.

The Baldy batholith is a multiphase granite intrusion which covers approximately 650 km^2. The western two-thirds of the batholith consists of two compositionally similar, but texturally distinct, granite phases: a K-feldspar megacrystic biotite-hornblende granite to granodiorite, and an equigranular biotite monzogranite (Fig. 8). The eastern third of the batholith is predominantly a leucocratic biotite-muscovite granite in which muscovite occurs as euhedral and ragged grains associated with biotite. Coarse-grained biotite-muscovite pegmatite and fine-grained feldspar-quartz aplite dykes cut all of these phases.

The aeromagnetic survey map for the Adams Lake area shows a weaker magnetic signature for the two-mica granite comprising the eastern end of the batholith, thereby distinguishing this granite from the two western phases. A ground survey of magnetic susceptibilities of the batholith using a hand-held Exploranium KT-9 Kappameter shows the same variation, but distinct ranges and average values allow all three phases to be distinguished (Logan and Mann 2000a).

The K-Ar dates for biotite from the Baldy batholith include the early work by Wanless *et al.* (1966), Kirkland (1971), and Jung (1986), who reported ages of 99 ± 5 Ma; 101 ± 5 Ma and 106 ± 5 Ma; and 104 ± 3 Ma, respectively. These samples

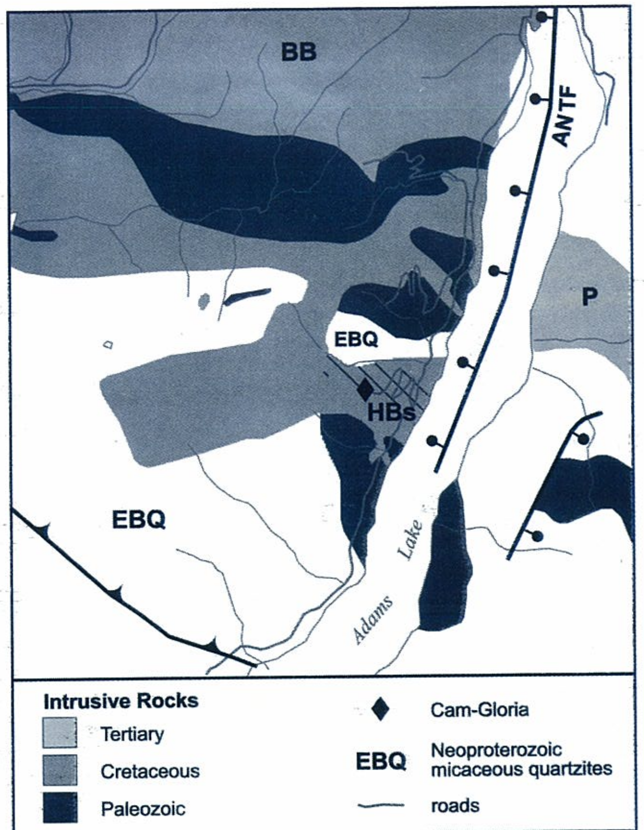

Figure 9. Geology of the southeastern Baldy batholith (BB), showing the location of the Honeymoon stock (HBs) and mineralization at Cam-Gloria. P = Pukeshun granite.

provide ages for the northern and westernmost biotite ± hornblende granite portion of the Baldy batholith. A single U-Pb date for zircon from this area gave an emplacement age of 115.9 ± 4.6 Ma for the Baldy batholith (Calderwood *et al.* 1990); K-Ar dates of biotite from gneiss and orthogneisses located south of Baldy batholith and west of Adams Lake gave ages of 129 ± 4 Ma and 99.7 ± 4 Ma (Belik 1973), and a small quartz monzonite body also from this area (Fig. 9), gave a biotite-derived age of 82 ± 6 Ma (Wanless *et al.* 1966). Schiarizza and Preto (1987) correlated the granitic rocks located south of the main body (*i.e.*, Honeymoon stock) with the Baldy batholith.

South of the Baldy batholith, between East Barriere and Adams lakes (Fig. 9), an irregular east-trending granite body interfingers with Devono – Mississippian orthogneiss and Neoproterozoic to Paleozoic micaceous quartzites of EBQ (Schiarizza and Preto 1987). The contacts are irregular and more complex than the steep, clearly cross-cutting relationships between the Baldy batholith and its country rock. Intrusive rocks include hornblende-porphyritic monzodiorite, biotite-hornblende-epidote quartz monzodiorite, and biotite granite. These may represent smaller individual intrusions which, at the present scale of mapping, could not be separated. Coarse-grained gneissic units containing sillimanite-staurolite-biotite-hornblende assemblages, calc-silicate gneisses (Schiarizza and Preto 1987), and rusty-weathering migmatites with felsic leucosomes, pegmatites, and sugary-texture aplite dykes host the intrusions in this area. It is not known whether these metamorphic mineral assemblages represent contact or burial metamorphism.

The southeasternmost apophysis, here called the Honeymoon stock (shaded area in Fig. 9), hosts the Cam-Gloria Au-quartz vein. The quartz monzodiorite is typically coarsely crystalline and equigranular (Fig. 10). Megacrysts of K-feldspar occur randomly throughout and form as much as 5% of the rock, but few megacrysts are visible in outcrops. Major minerals include plagioclase (An_{70-50}), K-feldspar, hornblende, biotite, quartz, and epidote. Among the accessory minerals are apatite, titanite, magnetite, and zircon. Euhedral grains of epidote, some in amoeboidal intergrowths with plagioclase, are intimately intergrown with hornblende and biotite (Fig. 11). The epidote is interpreted to be primary magmatic. The mineral assemblage quartz,

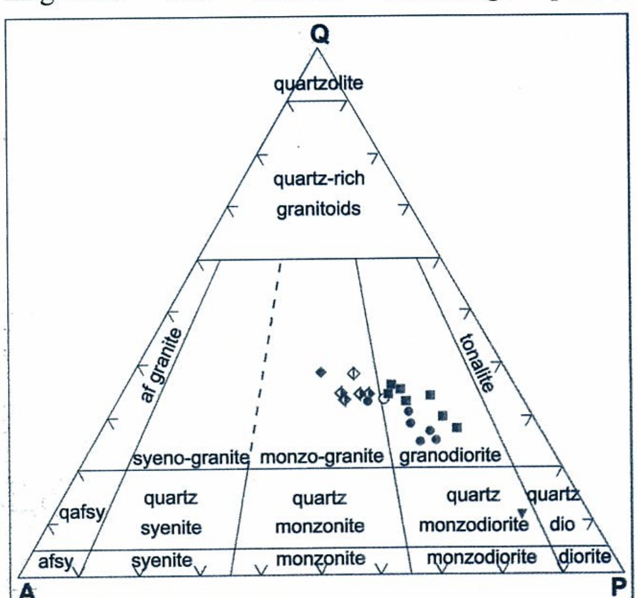

Figure 10. Plot of modal quartz–K-feldspar–plagioclase feldspar for Mount Skelly pluton, Sanca Creek stock, and environs. Fields are from LeMaitre (1989), and symbols are as for Figure 5.

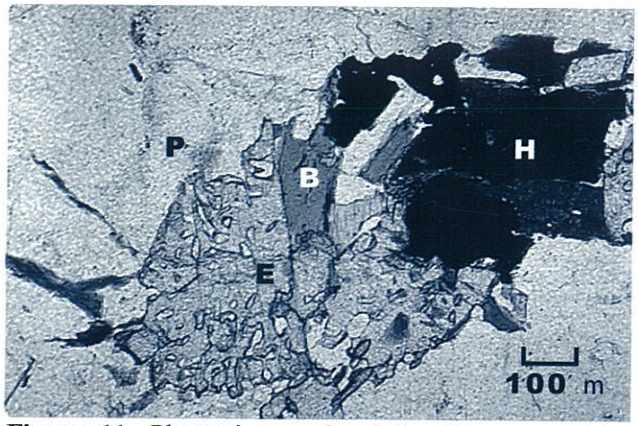

Figure 11. Photomicrograph of the Honeymoon Bay quartz monzodiorite, showing the typical texture of epidote (E), its euhedral contact with biotite (B), and wormy intergrowth with plagioclase (P).

Figure 12. The Cam-Gloria Au prospect near Adams Lake, showing a surface exposure of the Main quartz vein.

plagioclase, K-feldspar, hornblende, epidote, biotite, titanite, and magnetite suggests equilibrium pressures of at least 8 kbar (Zen 1989) and conditions of formation corresponding to greater crustal depths, under fairly oxidizing conditions (Zen and Hammerstrom 1984). Other intrusions reported to contain magmatic epidote in southeastern British Columbia are the middle Jurassic Nelson batholith (Ghent *et al.* 1991) and the Raft and Mount Toby plutons (Brandon and Smith 1994).

Cam-Gloria

The Cam-Gloria Au prospect (MINFILE 82M 266) is 3 km west of Honeymoon Bay, Adams Lake (Fig. 9). The property was staked by prospector Camille Berubé in 1997 following the release of a till geochemical survey (Bobrowsky *et al.* 1997) which showed two anomalous sample sites (215 and 43 ppb Au) in the area. The main auriferous quartz vein was discovered on an existing logging road (Fig. 12; Cathro 1998; Lett *et. al* 1998). The property was optioned to Teck Corporation in early 1999, and surface mapping started during the summer. Initial excavator trenching and diamond drilling were conducted in September-October, 1999.

The Main vein occupies a zone, 35 to 40 m wide and 700 m long, of variable alteration, shears, and quartz veins in quartz monzodiorite of the Honeymoon Bay stock. The alteration zone strikes 025° to 045°, dips 45 to 70° NW, and appears to pinch and swell along strike. At the Discovery zone, drilling indicated the Main vein to be up to 7.3 m thick. Drilling has intersected two and, in places, three additional (>1 m wide) veins within the broad alteration zone. Sub-parallel (sheeted) veins up to 10 cm wide were encountered over a width of about 20 m in one drillhole. A second, parallel alteration zone has been discovered by trenching about 100 m northwest of the main zone. The alteration zones have been affected by moderate to pervasive sericite and clay alteration of feldspars and mafic minerals, and some veins have narrow (2-5 cm) selvages of biotite and K-feldspar. This alteration assemblage overprints a low-grade, regional chloritic alteration.

The veins contain an average of 1-5% coarse-grained sulfides, mainly pyrite and pyrrhotite, with traces of galena, chalcopyrite, sphalerite, and arsenopyrite. Gold values are variable but seem to be associated with galena, fine-grained bluish grey sulfides, and local discordant gouge or brecciated zones. Pegmatitic textures, consisting of coarse-grained quartz and plagioclase crystals, were noted in the Main vein in one of the deeper intersections.

Surface sampling of the Main vein returned anomalous values of Ag, Bi, Cu, and Pb, and weakly anomalous values of As, Mo, Sb, Te, and W (Table 3). The highest values of Au come from the footwall and hangingwall margins of the vein (samples 10-148, -153 and -150, Table 3). At the southwestern end of the Main vein, sericite-altered quartz monzodiorite and vein quartz are exposed in an 8 m-trench (sample 10-147). Adjacent to the veins (2 to 8 cm wide), pervasive sericite and coarse muscovite replaced feldspars and mafic minerals in the

Table 3. Selected geochemical analyses, Main vein, Cam-Gloria property

Au	Ag	As	Bi	Cu	Mo	Pb	Sb	W	Zn	Sample Description
20	1.9	5.9	7.7	27	0	53	0.2	1	4	grab silicified-sericite altered monzonite
1570	6.6	12	18	32	1	27	0.4	0.4	2	3.3 m chip sample starting from the FW
902	9.6	31	9.5	49	1	169	0.4	1.6	2	3.3 m chip from HW side of vein
67	13	24	31	116	1	271	0.6	0.3	6	grab, disseminated po, py, trace cpy, gn
1540	3.2	51	31	163	2	43	1.5	0.6	30	1.5 m chip, southwestern end of main vein
18300	16	23	196	381	3	354	2.5	7.8	378	chip, altered footwall-monzonite, brecciated vein
73	11	21	72	251	4	277	2.3	2	526	1.5 m chip, coarse- and fine-grained pyrite
892	61	193	240	203	11	1165	1.7	<0.1	576	grab, fracture fill blebs of po, py, gn

Au in ppb, all others in ppm; Au, As and Sb by INA; other elements by total digestion/ICP

1112	8.6	27	55	113	12	420	3.7	n/a	27	grab, mineralized vein material
3746	61	87	56	17	<2	191	<5	8	18	grab, mineralized vein material
10*	1.2	31	123	794	33	60	1.8	86**	20	grab, mineralized vein material

Au in ppb, all others in ppm; Au by INA, other elements by total digestion/ICP
*Au by fire assay/ICP; **W by total digestion/ICP, other elements by ICP

monzodiorite. The footwall part of the Main vein consists of a zone, 0.2 to 0.5 m thick, of brecciated vein flooded by dark grey silica and fine-grained sulfides. This zone is underlain by a variably mineralized, dark grey fault-gouge zone which passes abruptly into altered quartz monzodiorite.

Pale green fluorite occurs in the footwall of the Main vein and in several narrow quartz-sulfide veins exposed in road cuts some 100 to 200 m to the east. The latter are apparently Au-poor, but do contain locally anomalous Bi, Cu, and W values. In addition, float boulders of garnet-pyroxene skarn with traces of pyrrhotite and weakly anomalous Cu and W values have been located on the road about 750 m northeast of the Main vein.

East of Cam-Gloria, in the higher grade metamorphic rocks of the Shuswap complex, prospecting since 1997 has discovered stockwork and sheeted-vein, shear zone, manto, and skarn showings containing Au, Bi, W, Cu, and other metals within and adjacent to mid Cretaceous (or younger?) intrusions. The new showings, although generally poorly explored, indicate the potential for plutonic-related deposits of Au in the region. Two other new Au prospects with anomalous Bi, Cu, W, and Te have been discovered in amphibolite-grade quartzite and schist of the Shuswap complex. The Goldstrike (Bizar) and GQ occurrences are at an early stage of exploration, but work by Cathro and Lefebure (in prep.) suggests that they have some characteristics of plutonic-related Au systems, including anomalous Bi and Te contents and, for GQ, a nearby mid-Cretaceous pluton (92-94 Ma; Parrish 1995). The setting in amphibolite-grade pericratonic rocks with pegmatites is similar to that of the Pogo deposit in Alaska.

The Goldstrike (Bizar) property (MINFILE 82M 267) is 16 km northeast of the village of Avola (Fig. 4). Mineralization consists of semi-concordant, stockwork, and sheeted quartz-sulfide veinlets hosted by amphibolite-grade micaceous quartzite and quartz-muscovite-biotite-garnet schist of the Shuswap complex. A semi-concordant layer of auriferous massive pyrrhotite and minor chalcopyrite, up to 20 cm wide, occupies the western end of the Discovery showing. The layer is concordant with dominant synmetamorphic foliation and has been deformed, together with the schists, into southerly plunging crenulation folds. Tight fractures and narrow centimeter-wide veins of grey quartz with limonite selvages trend northerly and dip steeply, cross-cutting the micaceous quartzite and schists. Locally, as many as five veinlets per meter are present, ranging from <1 to 10 cm in width. Some high-grade assays and anomalous values for Au have been reported for grab samples from the concordant

Table 4. Selected geochemical analyses, Goldstrike (Bizar) property

Au	Ag	As	Bi	Cu	Mo	Pb	Sb	W	Zn	Sample Description
63	0.05	0.8	77.2	19	76	16.5	-0	0.5	2	20 cm cross-cutting qtz vein, trace py
41400	3.6	5.9	4200	2120	1	6	0.3	<10.	28	grab, concordant sulfide layer
23400	1.8	3.3	2460	1230	<1.0	12	0.1	<10.	56	grab, 20 cm massive po+qtz layer
50	0.2	0.7	9.69	383	0.6	0.5	-0	0.1	4	cross-cutting qtz-plag-andalusite vein
<.2	0.3	2	0.9	21	<0.2	16.5	-0	0.5	40	cross-cutting qtz veins, 1-3 cm
5	1.7	15.2	1.22	393	1.2	24	0.1	4.7	18	grab, py+chlorite in rusty qtz vein
73	0.35	1.2	3.68	39	0.2	14	-0	10	12	sericite-altered, silicifed biotite schist

Au in ppb, all others in ppm; Au, As and Sb by INA, other elements by total of digestion/ICP

massive pyrrhotite layers and quartz veins, respectively. Bismuth is particularly enriched, and values correlate directly with Au values (1:1). In addition, anomalous Cu, Ni, Se, Te, and W values are present (Table 4). Drilling in October 1999 intersected narrow zones of sulfide-bearing quartz.

Kootenay Lake Area – North America

The southern Kootenay arc coincides with the western margin of the Purcell anticlinorium, a broad, northerly plunging structural culmination of sedimentary rocks of the Middle Proterozoic Purcell Supergroup. The lower strata consist of deep-water turbidites of the Aldridge Formation, and extensive Moyie gabbroic intrusions. Overlying the Aldridge, but beneath the basal unconformity that separates the Purcell and Windermere supergroups, are the fine-grained grey and green clastic quartz-rich rocks of the Creston Formation and the fine-grained calcareous rocks of the Kitchener and Dutch Creek formations which underlie the study area. Conglomerates of the Toby Formation, the basal Windermere, unconformably overlie this succession northwest of Sanca stock and define a west-facing succession of North America strata. West of the Purcell thrust fault are penetratively deformed and metamorphosed Neoproterozoic and Paleozoic rocks of the Kootenay arc (Fig. 4).

The Mount Skelly Pluton (MSP) is a middle to late Cretaceous post-accretionary intrusion (Archibald *et al.* 1984; D. Archibald, personal comm.) that belongs to the Bayonne plutonic suite (Woodsworth *et al.* 1991; Reesor 1996). The pluton, located 30 km north of Creston on the east side of Kootenay Lake (Fig. 10), trends northeasterly across the structural fabric of Proterozoic Purcell and Windermere supergroup rocks. The pluton consists of three intrusive phases differentiated on the basis of mineralogy, texture, grain size, and magnetic signature (Logan and Mann 2000b). From oldest to youngest, these phases are K-feldspar megacrystic hornblende-biotite granodiorite, coarse- or fine-grained biotite granodiorite, and a biotite-plagioclase-porphyritic leucogranite (Fig. 10). Fine- to medium-grained quartz-feldspar-garnet aplite and hornblende-biotite-plagioclase-phyric dykes, quartz veins, and less commonly, coarse-grained pegmatite dykes occur within the plutons, commonly near the margins of the intrusive phases. Biotite porphyry (lamprophyre) dykes occur locally within and adjacent to mineralized structures. Veins of Au-bearing quartz, W-bearing veins, and molybdiferous greisen veins are hosted within the multiphase intrusion, and polymetallic base-metal veins occur in the surrounding country rocks. Past production of gold is recorded from the Government and Valparaiso crown grants, whose workings are within a satellite body of coarse-grained, biotite monzogranite located between Sanca and Akokli creeks, 2 km east of Kootenay Lake (Fig. 13).

K-Ar data for biotite and muscovite from the Mount Skelly pluton and the Sanca Creek stock of the Bayonne batholith yield conventional dates between 69 and 99 Ma (Archibald *et al.* 1984; D. Archibald, personal comm. 1999). The age of the K-feldspar megacrystic hornblende granodiorite phase of the MSP is approximately 99 Ma, and its southern tail of leucocratic biotite granite averages 70 Ma. Biotite granodiorite of the Sanca Creek stock is approximately 80 Ma. The $^{40}Ar/^{39}Ar$ data yield plateau-shaped age spectra which do not record evidence of a reheating event (Archibald *et al.* 1984).

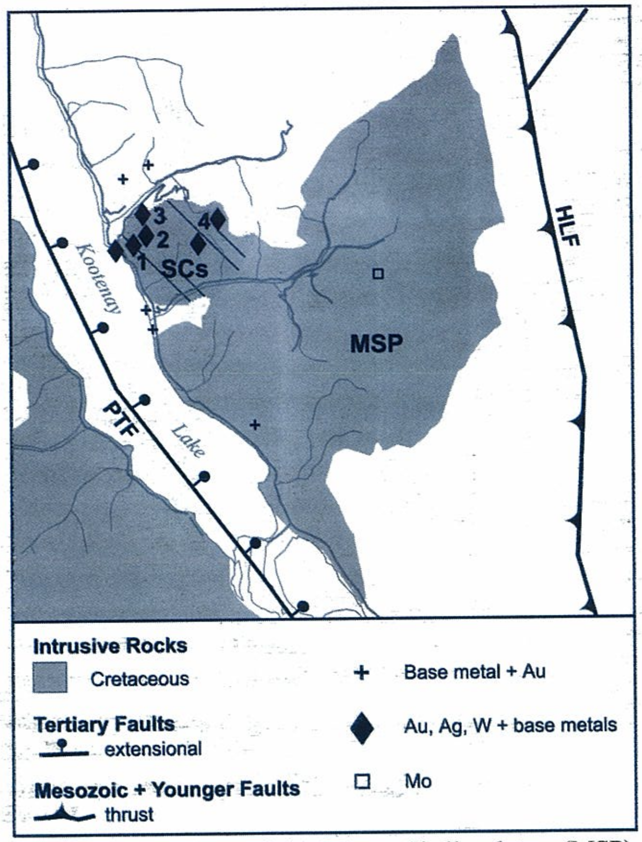

Figure 13. Geology of the Mount Skelly pluton (MSP), intrusive phases, and mineralization related to the Sanca Creek stock (SCs). Mineral occurrences include Au-W deposits: **1** Valparaiso–Government; **2** Sarah; **3** Lost Mine; **4** German Basin, Mo and base metal + Au veins.

The Mount Skelly pluton intruded the Creston Formation and developed a low-pressure contact-metamorphic aureole. Andalusite and cordierite porphyroblasts overgrow the penetrative fabric in country rock within 1 km of the northern contact. The presence of andalusite suggests emplacement pressures of less than about 4 kbar. Retrograde garnet-biotite-sericite-cordierite schists are locally present but, for the most part, characteristic pelite-derived mineral assemblages are poorly developed because of the quartzose composition of the Creston Formation. A rusty-weathering, muscovite-biotite, sillimanite-bearing zone of migmatite occupies the innermost zone adjacent to the pluton. The zone is about 100 m wide and comprises ductile-deformed, amoeboid-shaped, micaceous, quartzose, and calc-silicate country rocks. The zone is cut by tourmaline-muscovite pegmatites and quartz veins. The contact with the intrusion is steep and sharp. The monzonite is neither foliated nor chilled near its margin. The occurrence of sillimanite without kyanite suggests that the pressure did not exceed about 6 kbar (at 600 °C).

The majority of the MSP consists of a coarse-grained, biotite-hornblende granodiorite which is characterized by abundant euhedral K-feldspar megacrysts and rounded mafic xenoliths. Titanite is commonly visible in hand samples of coarse-grained varieties, as are trace amounts of magnetite and epidote. The mafic xenoliths are lenticular to round, monzodiorite to quartz diorite in composition, and consist mainly of biotite, plagioclase, quartz, and titanite. Close to the northwestern margin of the pluton, the inclusions and K-feldspar megacrysts define a north-trending, east-dipping foliation which parallels the contact. This is the oldest phase in the pluton and has a stronger magnetic signature than the other phases of the MSP.

Fine- to medium-grained, generally equigranular, biotite granite crops out between Mount Skelly and Jackson Peak in the eastern portion of the pluton and immediately south of Mount Sherman in the west-central portion of the pluton. This phase cuts the main hornblende-biotite megacrystic phase. The granite, which is leucocratic because of the low amount of biotite (~5%), is fine- to medium-grained, equigranular to locally porphyritic, and rarely contains sparse feldspar megacrysts.

The Sanca Creek stock is northwest of the Mount Skelly pluton and is separated from the main body by septa of metamorphosed country rock. The stock stands out as a separate, low- to moderate-strength magnetic anomaly on the aeromagnetic survey map, thus suggesting that the stock is a separate body. It consists of a medium- to coarse-grained, biotite ± hornblende granodiorite with large (to 1.5 cm), round, violet to pale grey, aggregates or anhedral crystals of quartz. Sparse feldspar megacrysts occur locally throughout.

Mineralization is hosted in all intrusive phases of the Mount Skelly pluton. Shear zones with Au-As-bearing quartz have been discovered in the oldest phase, and sheeted veins with Mo mineralization are known from the younger biotite granite, but the majority of Au-W mineralization is contained within the Sanca Creek stock. The stock hosts the Valparaiso, Government, Sarah, Lost Mine, and German Basin past-producing Au mines (Fig. 13). The mineral occurrences are hosted in sub-parallel


Figure 14. Sheeted fractures and quartz veinlets in biotite granodiorite of the Sanca Creek stock.

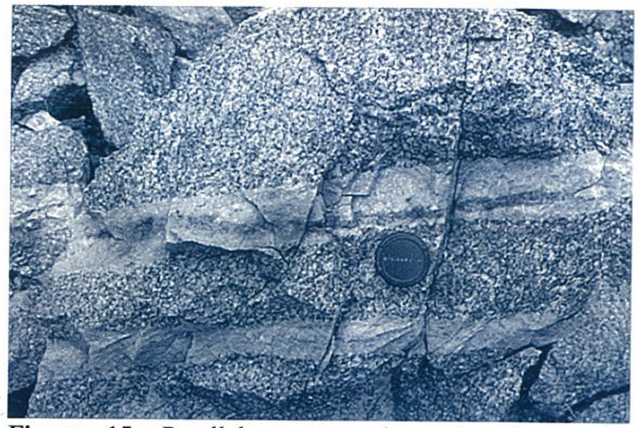
Figure 15. Parallel quartz vein, mineralized with pyrrhotite, and an aplite dyke, hosted by coarse-grained biotite granodiorite of the Sanca Creek stock.

quartz ± pyrite, sphalerite, galena, scheelite, wolframite, Au veins which fill prominent north-trending joint and fault structures (Figs. 14, 15).

The Valparaiso – Government vein was discovered in the early 1900s and has received the most exploration and development to date. Shipments of ore are reported for 1900, 1901, and 1933, and W concentrate was produced in 1955. The vein, a well-defined quartz-filled fissure in biotite granodiorite of the Sanca Creek stock, is exposed over a strike length of 800 m in various open cuts. It was developed underground by 160 m of drifts in the Government workings, and by 200 m of drifts in the Valparaiso workings at its north end. The main vein structure strikes northerly, dips 40° E, and averages between 1.6 and 2 m in width. Surface samples of the main and distal parallel veins returned anomalous Au, As, W, Bi, Cu, Pb, and Zn. Centimeter- to meter-wide, parallel, quartz-filled sheeted fractures are hosted in hangingwall and footwall sections of the main vein-fault. Two footwall veins are exposed underground in the Valparaiso workings: a 0.12-m scheelite-bearing vein and a 0.45-m sulfide-rich vein of ribbon quartz. These underlie the main vein-fault, a 1.1-m oxidized zone consisting of six, 1-3 cm quartz veinlets that are hosted by sheared hematite- and limonite-stained granodiorite. The granodiorite contains discrete, centimeter-wide, clay-altered shear planes. Sampling indicates Au is associated with the higher sulfide content (Table 5). Mineralization consists of pyrite, arsenopyrite, wolframite, galena, sphalerite, and rare chalcopyrite which occur as streaks, blebs, and disseminations irregularly distributed along the vein, but seem to be concentrated along the vein walls. Values of Au and Ag are proportional to the amount of sulfides in the vein. At the Government property, a biotite lamprophyre dyke occupies the footwall to the vein and crosses the vein at numerous places.

East of, and 200 m above the Government shaft, the Imperial – Sarah workings (Fig. 13) explore a parallel-mineralized quartz vein. Surface cuts expose narrow, north-trending quartz veins hosted by sericite-altered biotite granodiorite. A 0.5-m quartz vein with biotite lamprophyre hangingwall is exposed in a trench north of the caved adit. Mineralization consists of pyrite, arsenopyrite, wolframite, sparse sphalerite and galena, and traces of chalcopyrite.

The northern extension of the Valparaiso vein was explored by 40 m of drift in the Lost Mine workings located approximately 1000 m north of the Valparaiso tunnel (Fig. 13). Here the structure consists of two fractured quartz veins, 0.4 and 0.6 m thick, and a narrow footwall gouge zone containing oxidized pyrite.

The German Basin showing is 3.6 km east of the Vaparaiso–Government properties, high on the ridge between Sanca and Akokli creeks (Fig. 13). The vein strikes north, dips west, and is traceable on surface for 100 m. The vein is developed by two adits, a shaft, and numerous open cuts and several raises to surface from the adits. The vein pinches and swells, from 2 m at the portal to a minimum width of 0.15 m (Greene 1981). Adjacent to mineralized structures, the granodiorite is altered; biotite is replaced by chlorite and sericite, and feldspars are replaced by sericite. The quartz contains sparse pockets and disseminations of pyrite, sphalerite, galena, and

Table 5. Selected geochemical analyses, Valparaiso–Government property

Au	Ag	As	Bi	Cu	Mo	Pb	Sb	W	Zn	Sample Description
371	8	10600	8	544	2	1160	2.2	10	730	0.9 m chip, altered-sheared HW
2690	23.6	26200	22	615	5	492	2.2	1150	162	0.50 m chip sample of qtz vein
10	1.2	9600	<2.00	2820	3	210	2.5	40	4050	lamprophyre dyke footwall to vein
14400	>100.0	126000	140	8140	<1.0	234	5.2	3160	80	grab, high-grade sulfide in HW
95	3	1110	9.57	124	1.4	1065	3.1	41.7	2520	1.1 m chip granite + qtz veinlets
55	6.6	643	2	140	6	4680	4.1	1810	486	12 cm scheelite-bearing qtz vein
5310	71.8	41400	72	542	11	6350	7.8	7100	354	0.45 m sulfide-rich ribboned vein
1040	12.4	89.3	<2.00	285	4	1630	2.3	2130	16	scheelite, py 3-4 cm qtz vein
2330	24	12.8	0.45	144	12	8420	4	51	568	qtz vein, sericite alteration selvage
28	0.25	9.5	2.29	6	19	60.5	0.3	9.4	28	grab, 3 veins and alteration selvage
157	3.4	9.3	2.93	21	0.2	113.5	0.2	5.4	18	grab, altered granite + qtz veins

Au in ppb, all others in ppm; Au, As and Sb by INA, other elements by total digestion/ICP

rare, orange-colored scheelite.

Surface drilling to assess the extent of mineralization in the Government showing has been hampered by broken ground conditions which prevented completion of a 1981 diamond-drill program. Percussion drilling was attempted in 1988 to complete the objectives of the 1981 program, but ground conditions again proved insurmountable. The intersection of numerous centimeter- to meter-wide parallel mineralized and altered fractures, however, is encouraging and indicates that mineralization is not restricted to the main zone (Valparaiso fault), but occupies sheeted fractures over a wide vertical range in the intrusion (Greene 1981). The low-grade, bulk-tonnage potential for the showings has not been fully tested.

Conclusions

British Columbia, Yukon, and Alaska share a similar geological and metallogenic history. In the context of a model for plutonic-related Au deposits, salient features common to this part of the North American Cordillera include:

- an extensive continental margin-parallel W-Sn magmatic province,
- metallogenically distinct plutonic episodes favorable for Au mineralization,
- the relative timing of the prospective plutons (*i.e.*, post-date initial accretionary tectonism, but precede subsequent shortening), and
- structural settings which expose or juxtapose deposits formed at different crustal levels (*i.e.*, Eocene extension or transpression).

Unfortunately, the age and chemistry of some of the intrusive rocks in British Columbia are not as well known as for Yukon and Alaska. More work, together with regional geological mapping, is needed to understand better the tectonic setting and magmatic evolution of this part of the Cordillera.

The discovery of the high-grade Pogo Au deposit within amphibolite-grade gneisses in Alaska has pointed out the exciting potential in equivalent high-grade metamorphic rocks of the Omineca belt in the Canadian Cordillera. Limited prospecting during the last two years in the Shuswap complex of south-central British Columbia has discovered occurrences of auriferous veins with anomalous Bi, W, and Te values in high-grade metamorphic rocks possibly associated with mid-Cretaceous intrusions.

Mineralization at Cam-Gloria has characteristic metal assemblages, including Bi, As, W, and Cu, and multiple sheeted vein structures. The wide zone of pervasive sericitic alteration accompanying quartz veins and mineralization is not a well-developed characteristic of plutonic-related deposits. Metal assemblages, association with felsic mid-Cretaceous granitic intrusions, and the quartz-filled veins and fractures indicate that the Valparaiso–Government deposit is a good British Columbia example of a Fort Knox-type of intrusion-hosted, Au-quartz vein deposit. The distribution of low-grade mineralization throughout the Sanca Creek stock warrants assessment in the context of this deposit model.

We anticipate that Au-quartz veins related to granitoid rocks will be found in other parts of British Columbia that have been little explored in recent years. Exploration programs should focus inboard of the accreted terranes in marginal basin rocks of the pericratonic terranes or North America platformal rocks, particularly in areas intruded by mid-Cretaceous felsic intrusions.

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