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TABLE I. Reserves in some alkalic porphyry Cu-Au deposits.

		Age (Ma)	Million Tonnes	Cu %	Au ppm	Ag ppm	Reserve Type	Source	
1512	Mount Milligan	183	299	0.22	0.450		mineable	Sketchley and others (in press)	x
1202	BP-Chuchi	185(est)	50	0.21-0.40	0.21-0.44		geologic	Nelson and others (1991)	✓
1261	Lorraine	185(est)	10	0.70	0.343		geologic	Kennecott Corp (pers. comm.)	✓
1201	Copper Mtn Camp	205	167.7	0.46	0.127	1.72	production	Holbeck and others (in press)	✓
1200	Afton	206	30.8	0.77	0.580	4.2	mineable/prod	Kwong (1987)	✓
1211	Ajax	206	20.7	0.45	0.340		mineable/prod	Ross and others (in press)	✓
1630	Pothook	206	3.26	0.35	0.770		production	L. Bond (pers. comm.)	✓
1257	Big Onion	206						not available	
1617	DM	206	2.685	0.38	0.270		geologic	L. Bond (pers. comm.)	X ✓
1616	Crescent	206	1.448	0.44	0.180		production	L. Bond (pers. comm.)	✓
	Katie	185(est)	small	0.04-1	low 0.X			Cathro and others (1993)	X no R/P figure
1516	Galore Creek	211	125	1.06	0.400	7.7	proven	Enns and others (in press); Sinclair and others (1982)	x
1513	Mount Polley	203	48	0.44	0.583	4.5	mineable	Nicic and others (in press); Sinclair and others (1982)	X

Much of this information, however, remains unpublished or in press. Brief summaries of the geology, alteration, and mineralization of several of the better known deposits are therefore presented here as a prelude to a generalized description.

Galore Creek

The host rocks to the intrusive complex at Galore Creek are mafic to intermediate alkalic volcanic rocks of the Carnian to Norian Stuhini Group (fig. 3; Enns and others, in press). Stuhini volcanic rocks are dominantly augite and plagioclase phyric basalt and andesite flows and fragmental rocks with subordinate interbedded clastic sedimentary rocks; less abundant silica-undersaturated units with pseudoleucite phenocrysts (a mixture of nepheline-orthoclase-analcime pseudomorphic after trapezohedral leucite crystals) overlie the silica-saturated units (Logan and Panteleyev, 1991). The Stuhini Group formed in a partially subareal volcanic arc environment (Logan and Koyansilveri, 1989). At Galore Creek the Stuhini Group has been intruded in a five by two kilometer area by up to 14 phases of syenite dikes, sills, and stocks (Allen and others, 1976; Stanley, 1992; Enns and others, in press). The syenite intrusions range from fine to coarse grained and typically contain large orthoclase phenocrysts which locally reach 25 centimeters in length. Some early syenites which include those temporally and spatially related to formation of the copper-gold mineralization contain pseudoleucite phenocrysts. One dike type contains euhedral phenocrysts of melanite garnet (andradite with high TiO_2). As a group the intrusions contain variable proportions of phenocrysts of orthoclase, plagioclase, pseudoleucite, melanite, clinopyroxene, biotite, and hornblende in a matrix of pilotaxitic potassium feldspar, disseminated magnetite, and accessory apatite and titanite. Clinopyroxene phenocrysts are ubiquitous, and biotite, apatite, and magnetite are almost always present both as phenocryst and groundmass minerals. Plagioclase is present in some intrusions but absent from many, and aluminous hornblende is only present in one late dike set.

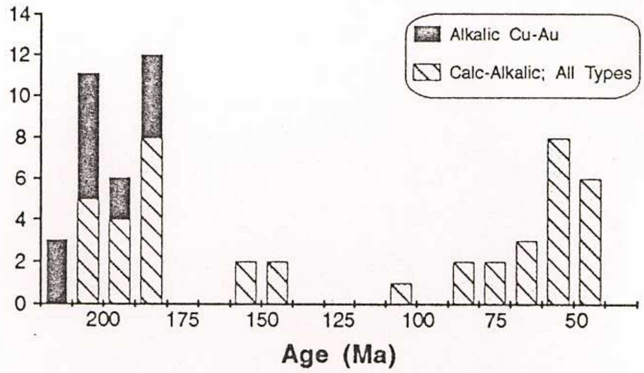

Figure 2. Radiometric ages of porphyry systems in British Columbia.

Copper-gold mineralization is developed in 12 zones at Galore Creek, but the following description emphasizes relationships in the Central Zone which hosts most of the reserves. In general, alteration is intense and obliterates original textures. Early alteration comprises a potassium-calc-silicate assemblage of andradite garnet-potassium feldspar-biotite-anhydrite-apatite ± magnetite ± diopside in the core of the zone. This early alteration assemblage at the core grades laterally to a potassic assemblage of potassium feldspar-biotite-anhydrite-magnetite-minor pyrite. Garnet-bearing alteration largely preceded but locally overlapped sulfide deposition and chalcopyrite and bornite began to precipitate as garnet alteration waned and as potassic alteration became dominant. Late stage alteration produced pyrite, carbonate, anhydrite, minor sphalerite, and trace galena, and sodalite, fluorite, and allanite have been identified in trace amounts, particularly in the potassium-calc-silicate alteration. Locally albite-epidote veins cut potassium-calc-silicate and potassic alteration, and all alteration types are locally overprinted by sericite ± anhydrite ± carbonate ± pyrite ± hematite alteration. Copper sulfide mineralization occurs both in altered

DISTRIBUTION, AGE, AND PRODUCTION HISTORIES OF DEPOSITS

Porphyry deposits are broadly distributed in western Canada (fig. 1; Dawson and others, 1991). All known deposits of the alkalic suite, however, are located in rock sequences which formed predominantly in an intraoceanic island arc environment in the Quesnellia and northern Stikinia tectonostratigraphic terranes (Souther, 1991; Gabrielse and others, 1991). The general geologic environment of most alkalic deposits is similar and includes an intrusive complex cutting volcanic host rocks that share temporal and compositional similarities with the plutons. The volcanic host rocks occur in belts that can be correlated along the Cordillera and comprise the Nicola Group in southern Quesnellia, the Takla Group in central Quesnellia, and the Stuhini Group in northern Stikinia; each volcanic belt contains both calc-alkalic sequences and alkalic suites that range to shoshonitic compositions (Mortimer, 1987).

Nine deposits with reserves in excess of 10 million tonnes and several smaller deposits and prospects may be considered alkalic copper-gold porphyry deposits (fig. 1; table 1). The Iron Mask Batholith contains at least 10 individual deposits and prospects (Kwong, 1987); the past-producers, Afton and Ajax, are the largest. In central British Columbia the Hogem Batholith (Garnett, 1978) and satellite intrusions which are probably related to it have many associated deposits and prospects; the most significant are Mount Milligan (Sketchley and others, in press), Lorraine (Wilkinson and others, 1976; Bishop and others, in press), and Chuchi (Nelson and others, 1992; Barrie, 1993), but none have been exploited. The largest production has come from the Copper Mountain camp, which includes the Ingerbelle deposit and several zones in the adjacent Copper Mountain area (Holbeck and others, in press). The Mount Polley and Galore Creek Deposits have substantial reserves and grades higher than average for the suite but have not been mined. Katie is small and is the only deposit in the Jurassic Rossland Group (Cathro and others, 1993). Assignment of the Kerr (Bridge, 1993; Ditson and others, in press) and Red Chris (Newell and Pietfield, in press) deposits to the alkalic suite continues to be debated, and they are not discussed here.

Porphyry deposits in the Canadian Cordillera formed from Latest Triassic to Eocene time (fig. 2). Alkalic deposits in the same region, however, formed only between 212 and 183 Ma (fig. 2; Godwin and Mortensen, in press).

DESCRIPTIONS OF INDIVIDUAL DEPOSITS AND DISTRICTS

In recent years interest in alkalic porphyry deposits as exploration targets has resulted in voluminous new geologic data.

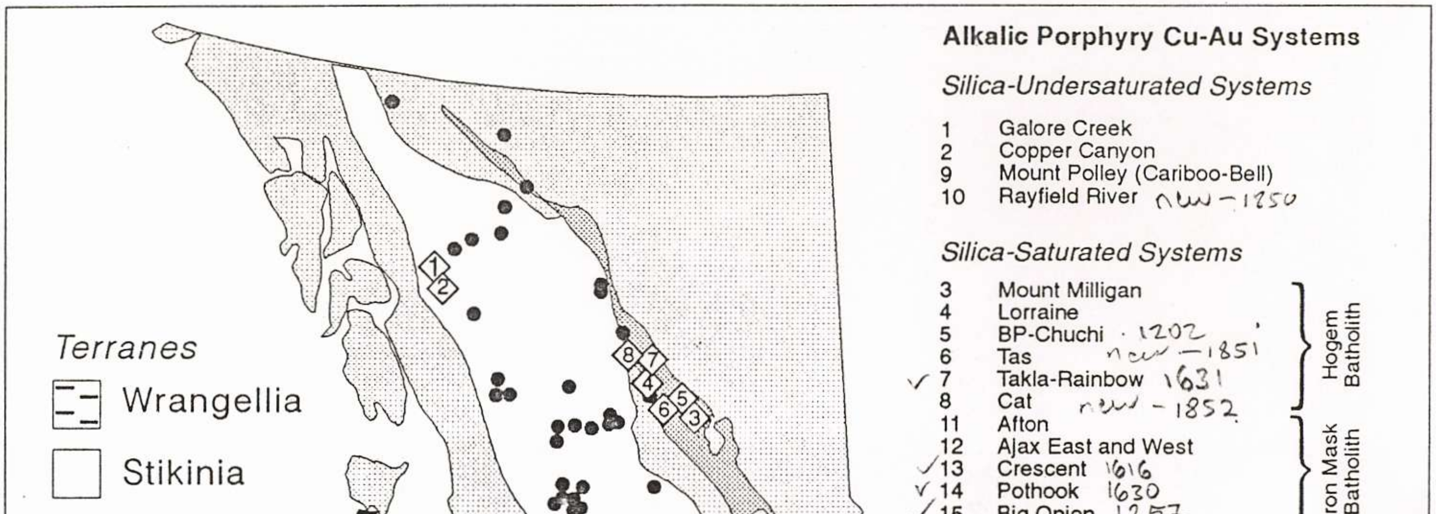

Figure 1. Location of porphyry base and precious metal deposits in the tectonostratigraphic terranes of British Columbia. The distinction between silica-saturated and silica-undersaturated deposits is discussed in the text.

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Porphyry Copper-Gold Deposits Related to Alkalic Igneous Rocks in the Triassic-Jurassic Arc Terranes of British Columbia

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IN/ Porphyry Deps of Am Cord. Ariz. Geol. Soc. Dig. 20 (1995)

ABSTRACT

The Triassic-Jurassic arc terranes of Quesnellia and northern Stikinia in British Columbia host numerous copper-gold-silver porphyry deposits which are associated with alkalic igneous rocks. The alkalic suite porphyry deposits may be further subdivided into a group associated with silica-saturated alkalic intrusive complexes and a second group associated with feldspathoid-bearing, silica-undersaturated alkalic igneous rocks. Many characteristics of alteration, mineralization, and timing of hydrothermal events differ between these two subtypes, and both alkalic subtypes have many characteristics which also distinguish them from the more common copper-molybdenum-silver calc-alkalic deposits. These characteristics include (1) the common presence of albitic (sodic) and potassium-calc-silicate alteration; (2) weaker relationships to relatively more differentiated intrusions in a given district; (3) a near absence of quartz as an alteration mineral but the presence of abundant carbonate; (4) absence or only weak development of peripheral mineralization such as skarns or mesothermal veins; (5) paucity of sericitic (phyllic), clay-dominated (argillic), and aluminosilicate-rich (advanced argillic) alteration assemblages; (6) abundant hydrothermal magnetite associated with mineralization and high concentrations of primary igneous magnetite in associated intrusions; (7) weaker association of alteration and mineralization to stockwork zones of dilatant fractures; and (8) absence of significant molybdenum concentrations.

The alkalic deposits, however, also share many similarities with calc-alkalic deposits. These similarities include (1) formation in volcanic arc environments, (2) association of mineralization with specific stages in multiphase intrusive complexes, (3) cores of potassic alteration surrounded and locally overprinted by propylitic alteration, (4) early pervasive or microfracture-controlled alteration followed by fracture-controlled alteration, (5) formation at shallow depths, (6) close correlation between copper and gold grades, and (7) similarities in characteristics of hydrothermal fluids present in fluid inclusions. The similarities suggest that alkalic deposits form the more consistently gold-enriched end-member of a continuum of porphyry deposits that ranges from calc-alkalic copper-molybdenum deposits through high-potassium calc-alkalic copper-molybdenum-gold deposits and silica-saturated alkalic deposits to silica-undersaturated highly alkalic deposits. Many of the differences among deposit types may reflect variation in the composition of fluids derived from magmas of different composition.

Differences in tectonic setting may also contribute to differences among porphyry deposits. Porphyry deposits in British Columbia formed from earliest Jurassic to Tertiary time, but alkalic deposits formed only between about 183 and 212 Ma in intraoceanic volcanic arc assemblages in Quesnellia and northern Stikinia prior to accretion of those terranes onto North America. This contrasts with calc-alkalic deposits, which with the exception of the Highland Valley deposits formed in continental volcanic arc settings or over crust with a significant continental component. The occurrence of globally uncommon, silica-undersaturated alkalic deposits in both Quesnellia and northern Stikinia suggests that portions of those terranes are closely related.

INTRODUCTION

Porphyry base and precious metal deposits have been intensely studied, and many of their fundamental characteristics are now well known (see reviews by Titley and Hicks, 1966; Sutherland-Brown, 1976b; Hollister, 1978; Titley and Beane, 1981; Beane and Titley, 1981; Titley, 1982). A point which has generated considerable discussion has been identification of broadly applicable criteria which may be employed to partition porphyry deposits into subtypes and the implications of the consequent subdivisions to deposit genesis. Among the methods of classification which have been employed are tectonic setting (Titley and Beane, 1981; Kesler, 1973; Kesler and others, 1975), metal assemblage and ratios (Kesler, 1973; Titley, 1978; Sillitoe, 1979; Sinclair and others, 1982; Cox and Singer, 1988; Sillitoe, 1990), petrography of associated intrusions (Guilbert and Lowell, 1974; Hollister, 1978), chemical composition of associated igneous suites (Hollister, 1978), and depth and style of emplacement of mineralization and associated intrusions (Sutherland-Brown, 1976a). Barr and others (1976) presented the first descriptions of the subject of this review, a subgroup of porphyry deposits in British Columbia which have a copper-gold metal assemblage and are associated with igneous rocks of alkalic chemical composition.

This paper reviews recent advances in understanding of alkalic copper-gold porphyry deposits in the Canadian Cordillera. We first present capsule geologic summaries of six districts. These descriptions form a basis for developing the general characteristics of alteration, mineralization, and igneous association of the class, proposing a further classification into two subtypes, and drawing comparisons with calc-alkalic deposits. McMillan and Panteleyev (this volume) provide general background information on porphyry deposits in the Canadian Cordillera, and detailed information on individual deposits may be found in Sutherland-Brown (1976b) and in the upcoming CIM Special Volume 46 (Schroeter, in press).

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Table 1. Size, grade, and gold content of selected Canadian Cordilleran porphyry copper deposits (after Schroeter and others, 1989; Harris, 1991; Sutherland Brown, 1976; and other sources).

		DEPOSIT NAME	TYPE *	SIZE MILLION TONNES	COPPER (PERCENT)	GOLD (g/t) RECOVERED	GOLD (g/t) CONTAINED	CONTAINED GOLD TONNES	SILVER (g/t)	MOLYBDENUM (PERCENT)	
		PRE- AND SYN-ACCRETION									
		ALKALIC CLASS									
		Terrane: Quesnellia									
1201	1	Copper Mountain	V	32	1.08R**	0.1800	-	5.8	4.3R*	-	✓
120101	2	Similco/Ingerbelle	V	158	0.43R	0.1300	-	20.5	0.7R	-	✓
1200	3	Afton/Ajax	V	69	0.63	0.4700	0.560	38.5	2.1R	-	✓
1513	4	Mount Polley/ Cariboo Bell	V	48	0.44	-	0.583	28.0	-	-	✓
1261	5	Lorraine	V	10	0.67	-	0.210	2.1	-	-	X
1512	6	Mount Milligan	V	298	0.22	-	0.445	132.6	-	-	X
		Terrane: Stikinia									
1445	7	Red Chris	V	41	0.56	-	0.320	13.1	-	-	X
1516	8	Galore Creek	V	125	1.06	-	0.400	50.0	7.7	-	X
1615		Copper Canyon	V	32	0.75	-	1.170	37.9	17.1		X
151501	9	Kerr	V	60	0.86	-	0.340	20.4	2.0	-	✓
		PRE- AND SYN-ACCRETION									
		CALCALKALIC CLASS									
		Terrane: Quesnellia									
1238	10	Brenda	P	183	0.25	0.0140	0.031	5.7	1.1R	0.040	✓
1225	11	Lornex	P	669	0.42	0.0005	0.006	4.0	1.7R	0.010	✓
1222	12	Bethlehem	P	131	0.48	0.0120	0.013	1.7	0.7R	-	✓
1224	13	Valley	P	911	0.47	0.0005	0.006	0.8	1.7R	0.010	✓
1226	14	Highmont	P	160	0.22	-	0.004	0.6	-	0.022	✓
	15	JA	P	286	0.43	-	?	?	?	0.017	1857
1221	16	Gibraltar	P	935	0.31	-	0.007	6.5	0.15R	0.008	✓
151402	17a	Kemess North	C?	173	0.18	-	0.010	1.9	-	-	✓
151401	17b	Kemess South	C?	200	0.22	-	0.620	124.3	-	-	X
		Terrane: Stikinia									
1231	18	Schaft Creek	V	910	0.30	-	0.11 TO 0.34	100 TO 300	1.2	0.020	X
		Terrane: Wrangellia									
1237	19	Hushamu (Expo)	V	173	0.28	-	0.342	59.0	-	0.009	X
1236	20	Island Copper	V	373	0.37	0.1000	0.200	74.6	0.9	0.020	✓
1632	21	Red Dog	V?	31	0.31	-	0.446	13.9	0.007	-	✓
		POST-ACCRETION									
		CALCALKALIC CLASS									
1249	22	Fish Lake	C?	976	0.24	-	0.460	449.0	-	-	✓
1444	23	Poison Mountain	C?	159	0.33	-	0.310	49.3	-	0.010	✓
1263	24	Catface	C	138	0.46	-	0.05?	UNCERTAIN	-	-	✓
1258	25	Granisle	C	66	0.42R	0.0900	0.130	8.6	1.3R	-	✓
	26	Bell Copper 1259	C	143	0.42R	0.2000	0.400	57.2	0.48R	-	✓
	27	Morrison Gold 1260	C	86	0.42	-	0.340	29.2	3.4	-	✓
	28	Berg 1256	C	238	0.39	-	0.050	11.9	2.8	0.030	✓
	29a	Huckleberry 1241	C	77	0.41						✓
	29b	Huckleberry East "	C	75	0.47						✓
	30	Casino 1250	C	558	0.26		0.331	184.8		0.025	✓

*** Deposit Type: P= Plutonic; V= Volcanic; C= Classic** **** R means recovered amount**

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check Fig 1. alk/calc-alk.

Porphyry Copper Deposits of the Canadian Cordillera

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W/ Porph Cu Deps of Am Cord. Ariz. Geol. Soc Dig. 20 (1995)

ABSTRACT

Porphyry copper deposits in the Canadian Cordillera, in contrast to those in the Southwestern United States, occur in accreted terranes comprised dominantly of island arc rocks. Further, many of the Canadian deposits are considerably older (latest Triassic and Early Jurassic) than most of the American deposits, but younger (Cretaceous and Tertiary) deposits also occur. Older deposits are frequently linked to consuming-margin, island-arc processes that took place before or during accretion of the island arc terrane to North America. Younger deposits are post-accretionary and apparently related to basement structures like those that localized the northeast-trending Stikine and Skeena arches in north-central British Columbia.

Deposits in the Cordillera have been classified according to their physical characteristics, their chemistry, and their metal budgets. They formed within batholiths, in the root zones of contemporaneous volcanic complexes, and, like most of those in the Southwestern United States, in association with high level intrusions into unrelated country rock. Associated intrusions are both calcalkalic and alkalic, and the alkalic varieties are further subtyped into those that are nearly silica saturated and those that are clearly undersaturated. Metal signatures vary from copper-molybdenum with low precious metal contents through copper-molybdenum-gold to copper-gold and, locally, gold-only types. Gold is apparently more abundant in deposits formed at shallower levels in the crust, both in the roots of volcanoes and with high level stocks. Both calcalkalic and alkalic types can be gold-enriched. The calcalkalic examples generally also contain molybdenum, whereas the alkalic examples tend to be molybdenum-poor.

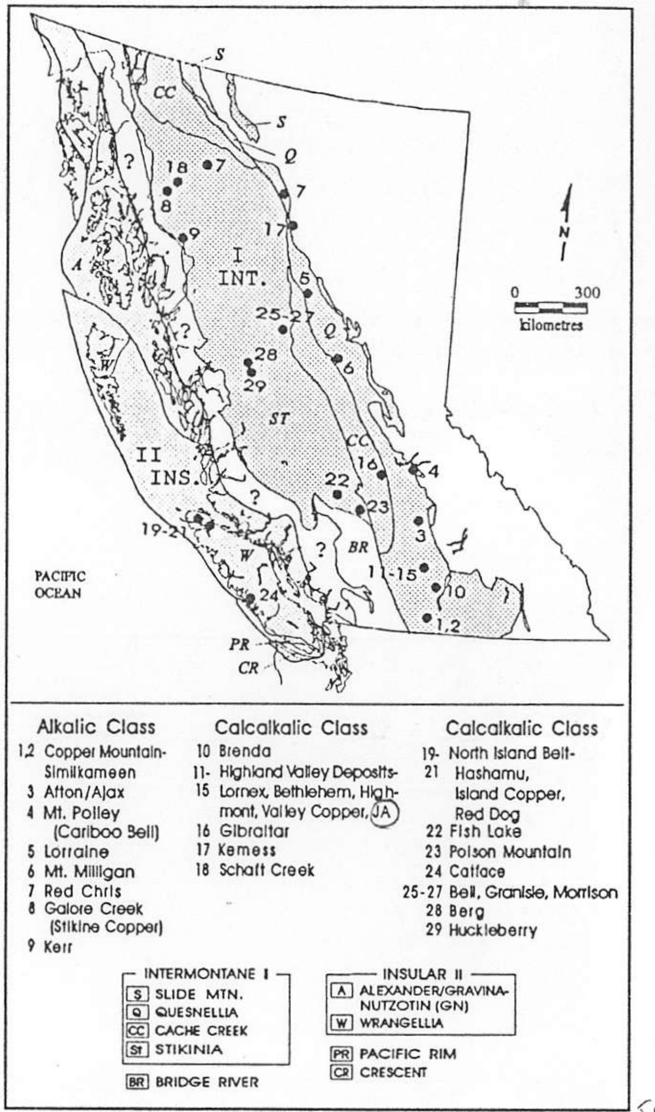

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Figure 1. Distribution of porphyry copper deposits relative to tectonic terranes in the Canadian Cordillera.

INTRODUCTION

Porphyry deposits occur in orogenic belts worldwide and are usually related to subduction-generated plutonism and volcanism at consuming plate margins. Most deposits occur either in island-arcs or at continental margins. Most are Mesozoic or Cenozoic in age, but older examples also occur.

In the Canadian Cordillera, porphyry deposits occur in the Intermontane Belt and less commonly in the Insular Belt (fig. 1). Excellent detailed information about these porphyry copper and porphyry molybdenum deposits has been provided in Sutherland Brown (1976). Updated information and data on new deposits will be presented in Canadian Institute of Mining, Metallurgy and Petroleum Special Volume 46 to be published in 1995. This new volume will feature descriptions of more than 50 deposits from Washington, British Columbia, Yukon, and Alaska.

Currently combined base and precious metal deposits present the most attractive exploration targets in the Canadian Cordillera; fortunately many porphyry copper deposits contain significant gold and silver values. Schroeter and Lane (1991) compiled production and reserve statistics which show that in 1991 more than half of British Columbia's gold reserves (fig. 2) and 80 per cent of its copper reserves were contained in porphyry deposits. It is estimated that 20 per cent of the gold and 48 per cent of the silver produced in British Columbia in 1993 were byproducts from base metal mines; total production is estimated at 13.42 tonnes gold and 180.67 tonnes silver. Gold production from individual base metal deposits ranks with the largest lode-gold

Table 1. Size, grade, and gold content of selected Canadian Cordilleran porphyry copper deposits (after Schroeter and others, 1989; Harris, 1991; Sutherland Brown, 1976; and other sources).

		DEPOSIT NAME	TYPE *	SIZE MILLION TONNES	COPPER (PERCENT)	GOLD (g/t) RECOVERED	GOLD (g/t) CONTAINED	CONTAINED GOLD TONNES	SILVER (g/t)	MOLYBDENUM (PERCENT)
		PRE- AND SYN-ACCRETION — ALKALIC CLASS								
		Terrane: Quesnellia								
1201	1	Copper Mountain	V	32	1.08R**	0.1800	-	5.8	4.3R*	-
120101	2	Similco/Ingerbelle	V	158	0.43R	0.1300	-	20.5	0.7R	-
1200	3	Afton/Ajax	V	69	0.63	0.4700	0.560	38.5	2.1R	-
1513	4	Mount Polley/ Cariboo Bell	V	48	0.44	-	0.583	28.0	-	-
1261	5	Lorraine	V	10	0.67	-	0.210	2.1	-	-
1512	6	Mount Milligan	V	298	0.22	-	0.445	132.6	-	-
		Terrane: Stikinia								
1445	7	Red Chris	V	41	0.56	-	0.320	13.1	-	-
1516	8	Galore Creek	V	125	1.06	-	0.400	50.0	7.7	-
1615		Copper Canyon	V	32	0.75	-	1.170	37.9	17.1	
151501	9	Kerr	V	60	0.86	-	0.340	20.4	2.0	-
		PRE- AND SYN-ACCRETION — CALCALKALIC CLASS								
		Terrane: Quesnellia								
1238	10	Brenda	P	183	0.25	0.0140	0.031	5.7	1.1R	0.040
1225	11	Lornex	P	669	0.42	0.0005	0.006	4.0	1.7R	0.010
1222	12	Bethlehem	P	131	0.48	0.0120	0.013	1.7	0.7R	-
1224	13	Valley	P	911	0.47	0.0005	0.006	0.8	1.7R	0.010
1226	14	Highmont	P	160	0.22	-	0.004	0.6	-	0.022
	15	JA	P	286	0.43	-	?	?	?	0.017 1857
1281	16	Gibraltar	P	935	0.31	-	0.007	6.5	0.15R	0.008
151402	17a	Kemess North	C?	173	0.18	-	0.010	1.9	-	-
151401	17b	Kemess South	C?	200	0.22	-	0.620	124.3	-	-
		Terrane: Stikinia								
1231	18	Schaft Creek	V	910	0.30	-	0.11 TO 0.34	100 TO 300	1.2	0.020
		Terrane: Wrangellia								
1237	19	Hushamu (Expo)	V	173	0.28	-	0.342	59.0	-	0.009
1236	20	Island Copper	V	373	0.37	0.1000	0.200	74.6	0.9	0.020
1632	21	Red Dog	V?	31	0.31	-	0.446	13.9	0.007	-
		POST-ACCRETION — CALCALKALIC CLASS								
1249	22	Fish Lake	C?	976	0.24	-	0.460	449.0	-	-
1444	23	Poison Mountain	C?	159	0.33	-	0.310	49.3	-	0.010
1263	24	Catface	C	138	0.46	-	0.05?	UNCERTAIN	-	-
1258	25	Granisle	C	66	0.42R	0.0900	0.130	8.6	1.3R	-
	26	Bell Copper 1259	C	143	0.42R	0.2000	0.400	57.2	0.48R	-
	27	Morrison Gold 1260	C	86	0.42	-	0.340	29.2	3.4	-
	28	Berg 1256	C	238	0.39	-	0.050	11.9	2.8	0.030
	29a	Huckleberry 1241	C	77	0.41					
	29b	Huckleberry East "	C	75	0.47					
	30	Casino 1250	C	558	0.26		0.331	184.8		0.025

*** Deposit Type: P= Plutonic; V= Volcanic; C= Classic** **** R means recovered amount**