Mineral Deposit Studies

GOLD SKARNS: THEIR DISTRIBUTION, CHARACTERISTICS AND PROBLEMS IN CLASSIFICATION*

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KEYWORDS: Economic geology, gold skarn, precious metal enriched skarn, back arc basin, Proterozoic mobile belt, skarn classification, bismuth tellurides, porphyry copper districts.

INTRODUCTION

Historically, skarn deposits throughout the world have been an important source of iron, copper, molybdenum, lead, zinc, tin and tungsten. However, some skarns also contain economically recoverable amounts of gold, silver and rarely, platinum; the importance of this class of skarn deposit as either a primary or byproduct source of precious metals has only recently been widely recognized. All mineralized skarns contain some precious metals, ranging from parts per billion levels up to economic quantities. In the latter case the precious metals may be the primary commodity recovered but most gold and nearly all silver produced from skarns have been derived as byproducts of base or ferrous metal mining. It is not yet possible to present a precise definition of "gold skarn" or "precious metal enriched (PME) skarn" based either on mineral content, geological environment of formation or precious metal grade. However for the purpose of this paper, gold skarns are defined as those in which gold is the predominant, and in some cases only economic mineral present, while PME skarns include any ferrous or base metal skarns that contain gold, silver or platinum in sufficient quantities to be economically recoverable.

Skarn deposits worldwide have produced more than 1000 tonnes of gold (Meinert, 1988) and the skarns of British Columbia have contributed nearly 10 per cent of this total (Ettlinger and Ray, 1989). Between 1904 and 1961 the gold skarns in the Hedley mining camp (Figure 2-1-1) produced over 50 tonnes of gold, mostly from the Nickel Plate mine. Despite this 60-year history of Canadian gold production from skarns, only recently were gold skarns recognized as a distinct class of deposit (Orris *et al.*, 1987; Meinert, 1988). Gold skarns were not distinguished in either the classical paper by Einaudi *et al.*, (1981), which outlines and defines the six major classes of ferrous and base metal skarns (Fe, Cu, W, Pb-Zn, Mo and Sn), or in the geological synopsis of Canadian mineral deposits by Eckstrand (1984). However, recent discoveries of major precious metal enriched (PME) skarn deposits such as the Fortitude and McCoy in Nevada (Tingley and Smith, 1982; Wotruba *et al.*, 1986; Kuyper, 1987), and the Red Dome (Torrey *et al.*, 1986; Ewers and Sun, 1988) in Australia (Figure 2-1-2), and the reopening of the Nickel Plate mine in British Columbia as an open-pit operation (Simpson and Ray, 1986) indicates PME-skarns represent exploration targets with both high grade and large tonnage potential.

DISTRIBUTION PME-SKARNS

The worldwide distribution of some PME-skarn deposits is shown in Figure 2-1-2 and available data concerning their sizes and grades is outlined in Table 2-1-1. Although base metal skarns are developed in a wide variety of geological environments, tectonic regimes and hostrock lithologies (Zharikov, 1970; Einaudi *et al.*, 1981; Kwak, 1987), gold skarns throughout the world are more restricted, and are mostly concentrated in the Phanerozoic mobile belts. They are commonly found in the same geological environment as copper and iron skarns, and there is a worldwide spatial and temporal association between gold skarns and the copper porphyry provinces (Figure 2-1-2). The temporal relationship is suggested by the observation that both the gold skarns and porphyry copper deposits of North and South America are largely Mesozoic or Cenozoic in age, while the gold skarns of Australia and Russia, like their spatially associated porphyry provinces, are predominantly Paleozoic.

The close association between gold skarns and porphyry copper districts is seen in the Canadian Cordillera; many of the alkalic and calcalkalic porphyry systems lie close to the location of the Mesozoic initial 0.704-0.705 $^{87}Sr/^{86}Sr$ ratio lines, as defined by Armstrong (1988) (W. McMillan, personal communication, 1989) which mark the transition between Phanerozoic ensimatic crust to the west and Precambrian sialic crust to the east. Similarly, the gold skarns of the Hedley camp, the Dividend-Lakeview mine, and the Oka occurrence (Ettlinger and Ray, 1989) lie close to this transition. An examination of the Mesozoic and Cenozoic initial $^{87}Sr/^{86}Sr$ ratios may assist exploration for iron, base metal and gold skarns throughout the North American Cordillera.

The location and distribution of PME skarns in British Columbia is shown in Figure 2-1-1. Over 90 per cent of gold production from skarn in the province was derived from mineralization hosted in carbonate-bearing oceanic island arc, back arc or marginal basin assemblages present in the Intermontane and Omineca belts, while only 9 per cent was produced from the westernmost Insular Belt. The latter belt contains low-potassium immature island arc rocks as well as calcalkaline continental margin arc rocks and tholeiitic oceanic flood basalts, none of which are as favorable for PME skarn developement as the mature, shoshonitic arc and marginal basin sequences present in the Intermontane and Omineca belts. Despite the presence of abundant carbonate sequences and some tungsten and tin skarns, no skarn-related gold has been recovered from the Foreland Belt which is underlain by cratonic basement.

Almost all of the gold skarn mineralization in the Canadian Cordillera is genetically related to high to intermediate level, I-type, late oceanic island arc plutonism. Much of the miner-

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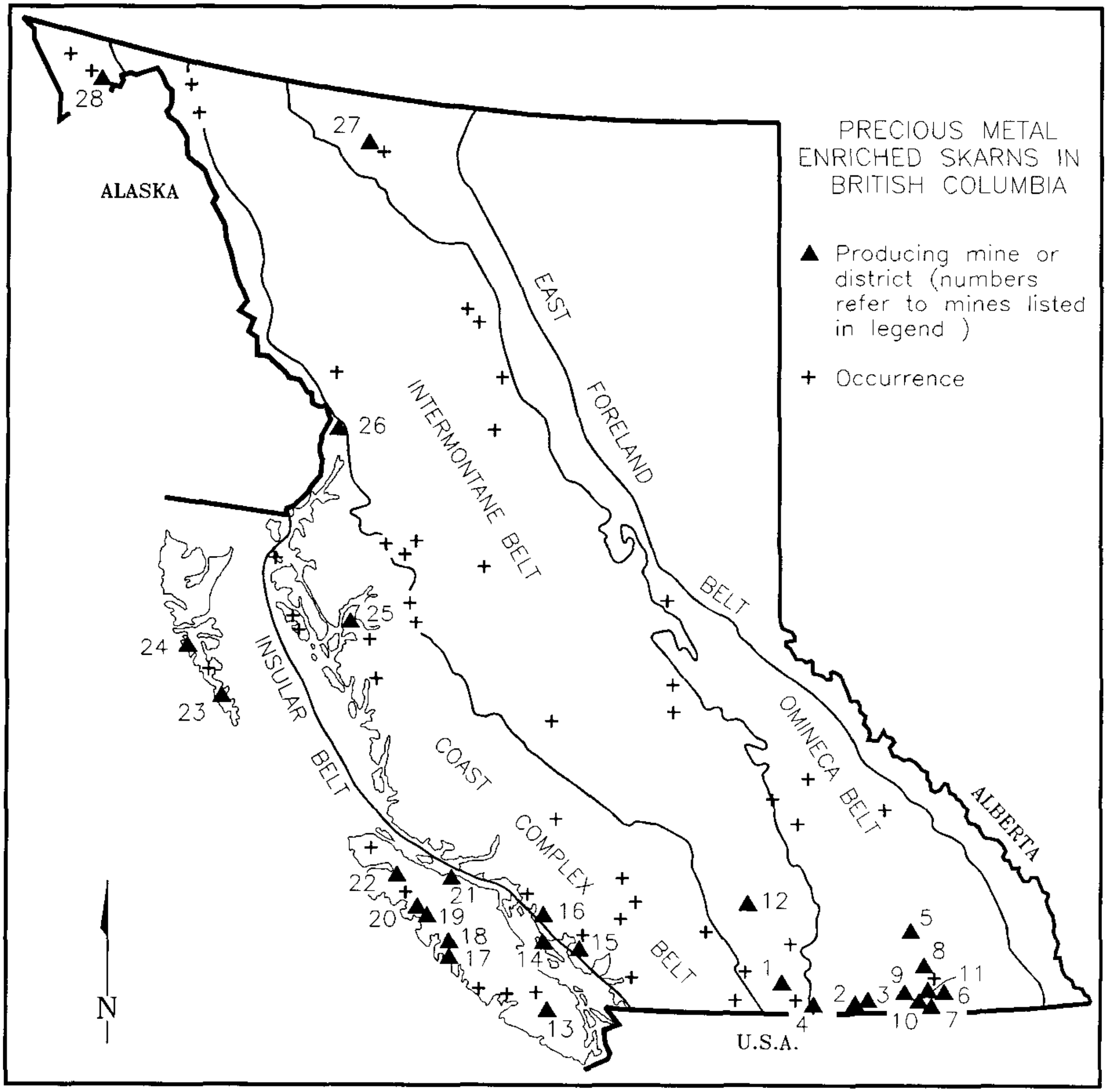

Figure 2-1-1. Distribution of PME skarns in British Columbia.

alization is also hosted in coeval arc superacrustals, although some precious metal enriched copper and iron skarn deposits such as those on Texada and Vancouver islands are exceptions; they are associated with Early to Mid-Jurassic continental margin intrusions of the Bonanza magmatic arc, and are hosted in Triassic or older, lithologically favorable oceanic rocks that were unrelated to the arc. Plutons associated with plate collision and accretion, or those exposed in the deeply eroded root zones of arcs, as possibly present in the Coast Belt of British Columbia (Figure 2-1-1) are less favorable for gold skarn mineralization; only 0.001 per cent of the total gold from skarn has come from the Coast Belt. Some gold skarns, such as those in the Hedley camp, are developed in calcareous clastic sediments that were deposited across a structural hinge zone marking the fracture-controlled edge of a back arc or marginal basin. Such rifted basin margins are particularly favorable for gold skarns because the controlling basement structures can preferentially channel the arc-related plutons into suitable carbonate-rich host rocks. Over 80 per cent of the PME-skarn occurrences in the British Columbia are associated with impure, often organic-rich and permeable limestone or marble-rich

Legend for Figure 2-1-1

Precious metal enriched (PME) skarn producing mines in British Columbia.

1 = Hedley camp (Nickel Plate, Hedley Mascot, French, Good Hope and Canty mines).
2 = Greenwood camp (Phoenix, Marshall, Motherlode, Greyhound, Morrison, Emma, Sunnyside and Oro Denoro mines).
3*= Loyal Canadian.
4 = Dividend-Lakeview.
5*= Tillicum Mountain camp (Heino-Money zone and Silver Queen).
6 = Salmo-Malarctic and Jackpot mines.
7*= Mormon Girl.
8 = Orinoco and Elk mines.
9*= Sir Douglas Haig.
10*= Rely 1.
11 = Second Relief.
12*= Lucky Mike.
13 = Blue Grouse.
14 = Texada Island camp (Little Billie, Paxton, Prescott, Yellow Kid, Cornell, Marble Bay and Copper Queen mines).
15 = Cambrian Chief.
16*= Roadside.
17 = Dewdney.
18 = Silverado.
19*= Geo-Star.
20*= Beano.
21 = Hab.
22 = Old Sport and Merry Widow mines.
23 = East Copper, Lily and Morning mines.
24 = Tasu.
25*= Gribble Island.
26*= Molly B.
27*= Contact.
28 = Maid of Erin.
*= Minor producers (<5 kg Au or 10 kg Ag).

sequences that also contain some argillite, tuff or minor volcanic flow componants. Regionally, some mature arc or back arc sequences favorable for gold skarns, such as the Triassic Nicola and Takla groups of British Columbia, include potassium-rich volcanic shoshonites and limestone-boulder breccias or olistostromes; the latter reflect the unstable sedimentary environment that prevailed in the basin-margin facies.

CHARACTERISTICS OF GOLD SKARNS

Gold and silver enrichment is mainly associated with calcic skarns; PME-magnesian skarns are very rare. The overall silicate mineral assemblages associated with gold skarns are similar to those in end-member iron and some base metal skarns, and thus cannot neccessarily be used to distinguish skarns with precious metal potential. However, gold skarns tend to be richer in pyroxene relative to garnet, and compared to copper skarns, their pyroxenes are commonly more iron-rich. Economic gold mineralization is more common in the exoskarn than the endoskarn, and the amount of exoskarn alteration associated with precious metal mineralization varies considerably from narrow zones less than 10 metres wide up to large envelopes many hundreds of metres thick; at the Nickel Plate deposit for example, the envelope totals between 0.75 to 1.5 cubic kilometres of alteration. The morphology of the envelopes varies from stratiform to subcircular to vein-like and sharply discordant, and the gold-sulphide mineralization is commonly found close to the outer, pyroxene-rich margins of the skarn.

The intrusive rocks associated with gold skarns range compositionally from granite to gabbro although quartz diorite and diorite are the most common. The intrusions, which are believed to have been emplaced at shallow to intermediate depths, vary from large stocks to narrow sills and dikes which may occur as swarm complexes. Some recent workers (Dawson *et al.*, 1990, this volume) suggest that the sill-dike complex at Hedley was intruded into wet, unconsolidated sediments which would imply that they and the related skarn fluids were emplaced at a high level under relatively low confining pressures. However, this conclusion is controversial since fluid inclusion data (Ettlinger *et al.*, in press) and textural features suggest that the Nickel Plate deposit was emplaced at high temperatures and intermediate depths.

The majority of the PME skarns in the North American Cordillera are genetically related to subalkalic, I-type intrusions with calcalkaline affinities. Many intrusions are also porphyritic with phenocrysts of hornblende and/or plagioclase; the latter may exhibit marked oscillatory and reverse composition zoning that may indicate the intrusions were derived from hybridized magmas or volatile-rich melts. The low initial $^{87}Sr/^{86}Sr$ ratios of these rocks suggest they were derived either from upper mantle material, or more likely represent recycled oceanic crust. Although no gold skarns associated with alkalic rocks have yet been identified in British Columbia, some high-level alkalic intrusions related to gold-bearing porphyry copper deposits are associated with skarn-like garnet-pyroxene-epidote-scapolite alteration assemblages (Preto, 1972; Hodgson *et al.*, 1976)

Many PME skarns exhibit variable mineralogical zoning patterns similar to those described in iron and base metal skarns. Recognition of these zones, often manifest as garnet-dominant proximal zones and pyroxene and/or wollastonite-rich distal zones, may assist in exploration. The Fortitude gold skarns (Myers and Meinert, 1989) and some of the smaller Hedley skarns include an outermost alteration halo of biotite and potassium feldspar that predates the garnet-pyroxene assemblages. Also at Nickel Plate, the gold mineralization was coeval with widespread scapolitization; this and the presence of chlorine-rich amphiboles in some other PME skarns (Ettlinger and Ray, 1989) suggests that hypersaline fluids may be important for the transportation and precipitation of gold in some skarns.

The degree of retrograde alteration (chlorite, epidote, tremolite-actinolite) overprinting the silicate assemblages varies enormously in PME skarns, and cannot be used to

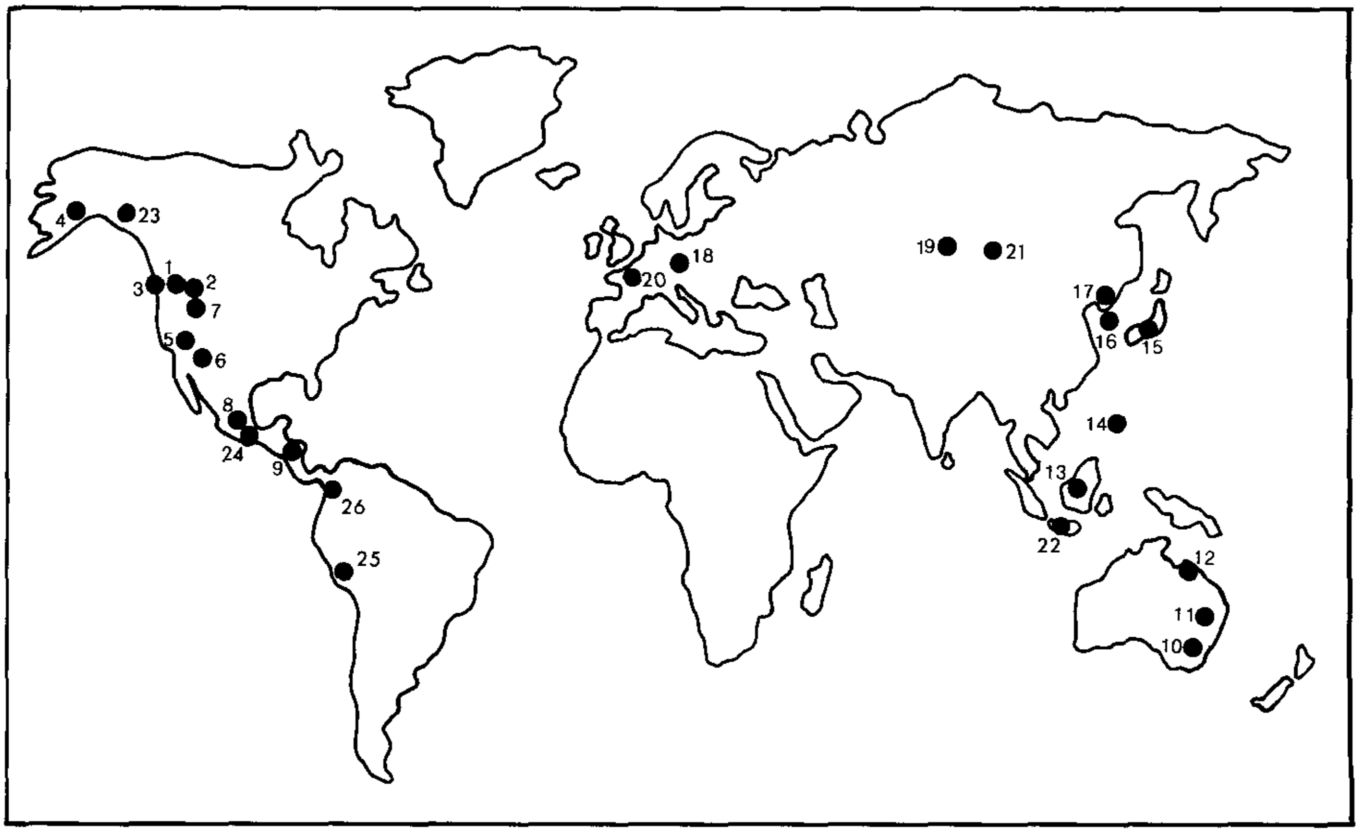

Figure 2-1-2. A: World distribution of some PME skarns. B: World-wide distribution of porphyry copper provinces. For legend *see* Table 2-1-1 (from McMillan and Panteleyev, 1988).

indicate gold potential. Most gold skarns, like iron skarns, are characterized by low-manganese (<1 weight per cent MnO_2) grandite garnets and low-manganese (<4 weight per cent MnO_2), iron-rich hedenbergitic pyroxenes. Data are sparse, but there appears to be no consistent core-to-rim compositional zoning in garnets in gold skarns; the Nickel Plate garnets exhibit variable zoning although grossular cores and andraditic rims are most common, while at the Fortitude gold skarns the reverse is seen (Myers and Meinert, 1989). The gold skarns at Tillicum Mountain in British Columbia are notable in containing manganese-rich garnets that range from 45 to 68 mole per cent pyralspite (Ray *et al.*, 1986; Ettlinger and Ray, 1989). These may represent gold-enriched mineralization with lead-zinc skarn affinities, or magmatically related skarn-like mineralization controlled within brittle-ductile shears, similar to those described by Mueller (1988) in Western Australia.

Gold mineralization in skarn is usually associated with opaque minerals that were mainly introduced after the prograde skarn assemblages. Pyrrhotite, arsenopyrite, chalcopyrite, pyrite, bornite, sphalerite, magnetite, and bismuth and/or tellurium minerals are the most common opaques in PME skarns. Less commonly, cobaltite, scheelite, molybdenite and galena are also present. Gold commonly occurs as microscopic inclusions in the sulphides, and in some deposits it is difficult to visually distinguish ore from waste. There is also a highly variable trace element association; PME skarns may be enriched in As, Te, Bi, Ag, Cu, Co, Zn, Sb, Fe, W, Pb, Ni, Mo or Pt. Many gold skarn deposits exibit systematic geochemical variations throughout the envelope; at the Fortitude and Nickel Plate mines, for example, the copper grades in the skarn increase toward the endoskarn intrusions. The presence of lead, silver, nickel or, most commonly, bismuth tellurides, is a distinctive characteristic of gold skarns, as is the common presence of native bismuth and other bismuth minerals; the tellurides recorded include hedleyite, tetradymite, altaite and hessite. Other minerals reported in gold skarns include bismuthinite, wittichninite, breithauptite, lollingite and maldonite.

Sparse fluid-inclusion data on PME skarns such as Red Dome and Fortitude (Ewers and Sun, 1988; Myers and Meinert, 1989) suggest prevailing temperatures of 260°C to 450°C and fluids with salinities of 2 to 26 weight per cent NaCl equivalent. Higher temperatures for the Nickel Plate gold skarn are suggested (Ettlinger *et al.*, in press) with the garnet-pyroxene skarn crystallizing between 460°C and 480°C, but with local temperatures reaching 800°C; homogenization temperatures in scapolite associated with gold indicate the later mineralization occurred in the range of 320°C to 400°C.

Garnet and pyroxene compositions suggest PME skarns can develop in a variety of oxidizing states (Figure 2-1-3). The Texada Island and Red Dome PME skarns formed under intermediate to relatively oxidizing conditions, similar to those determined by Einaudi *et al.*, 1981 and Einaudi (1982) for iron skarns and copper porphyry related skarns. By

Erratum: To accompany Ray *et al.*, page 240, Geological Fieldwork 1989, Paper 1990-1

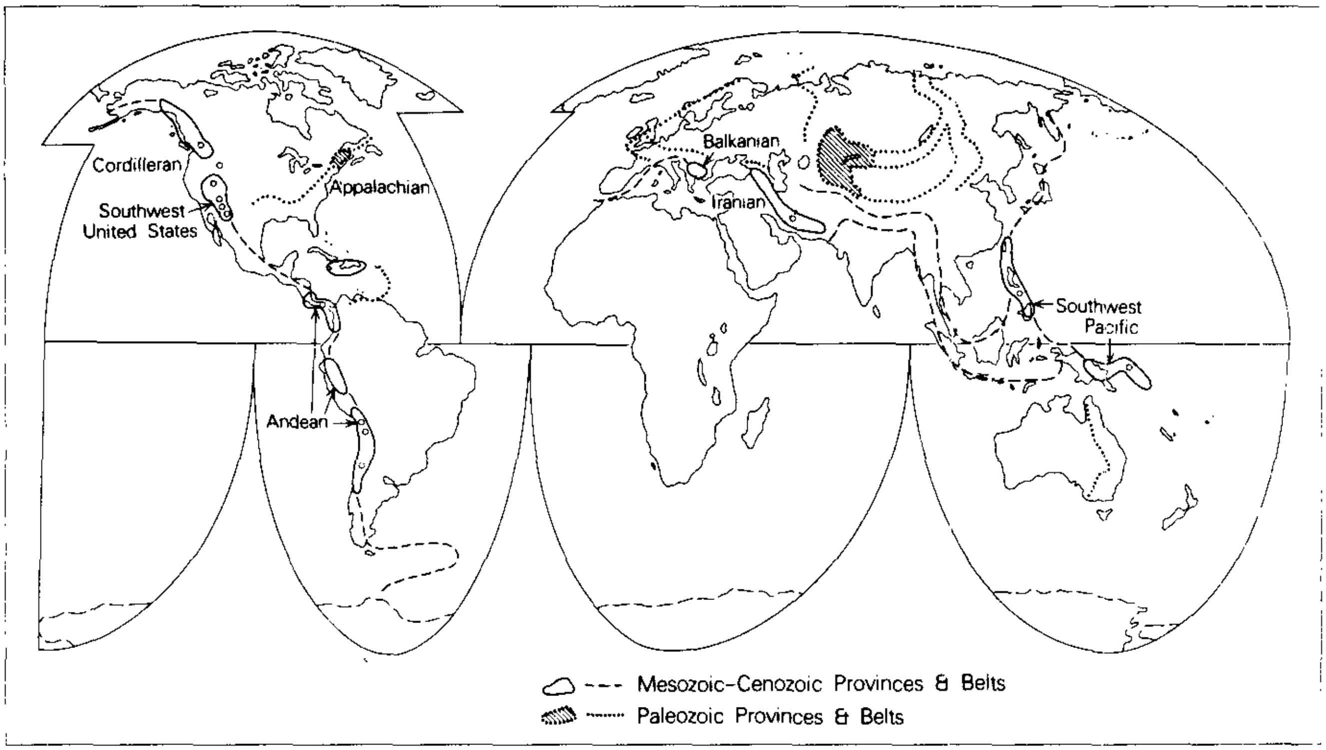

Figure 2-1-2B. World-wide distribution of porphyry copper provinces.

TABLE 2-1-1
SELECTED PME-SKARNS OF THE WORLD (*see* Figure 2-1-2)

Number in Figure 2-1-2	DEPOSIT	SIZE (tonnes)	Au (g/t)	Ag (g/t)	Cu (%)
1	Nickel Plate and Hedley-Mascot, B.C. (underground)	3 600 000	14.0	1.4	0.1
1	Nickel Plate Hedley, B.C. (open pit)	8 900 000*	4.5*	3.0**	0.1
2	Phoenix, B.C.	26 956 000	1.1	7.1	0.9
3	Texada Island, B.C. (Cu-Au skarns)	310 000	2.4	16.0	3.0
4	Zackly, Alaska	1 200 000	5.5	30.0	2.7
4	Nixon Fork, Alaska	NA	NA	NA	NA
5	Fortitude, Nevada	10 300 000	6.9	24.7	0.1
5	McCoy, Nevada	8 700 000	1.9	NA	0.1
6	Carr Fork, Utah	61 000 000	0.4	10.7	1.8
7	Cable, Montana	1 000 000	6.0	5.0	3.0
7	Golden Curry, Montana	930 000	8.5	4.2	0.33
7	Southern Cross, Montana	400 000	13.0	16.0	0.1
8	Golfo de Oro, Mexico	5 000 000	4.5	10.0	NA
8	Concepcion del Oro, Mexico	15 000 000	1.7	NA	2.0
9	La Luz, Nicaragua	16 000 000	4.1	1.2	0.44
10	Browns Creek, Australia	740 000	7.5	9.0	0.4
11	Mount Biggendon, Australia	500 000	15.0	NA	NA
12	Red Dome, Australia	13 800 000	2.0	4.6	0.46
13	Bau, Malaysia	2 400 000	7.2	0.1	NA
14	Siana, Philippines	5 400 000	5.1	10.0	NA
14	Thanksgiving, Philippines	1 700 000	6.4	40.6	0.4
15	Rokuromi, Japan	160 000	4.1	1.0	NA
16	Suian, North Korea	530 000	13.0	4.9	NA
17	Tul Mi Chung, North Korea	400 000	12.0	NA	NA
18	Reicher Trost, West Germany	<10 000	20.0	0.1	NA
19	Siniukhinskoe, USSR	NA	8.0	37.7	3.9
20	Salsigne*** France	1 500 000	13	33	0.15
21	Lebedskoe (Kaurchack) USSR	120 000	4.0	NA	NA
22	Pagaran Siayu Indonesia	110 000	5.6	2.5	0.2
23	Nabesna Alaska	80 000	23	NA	NA
24	Naica, Mexico	10 000 000	0.4	180	0.4
25	Huarca, Peru	500 000	2.0	10	3.0
25	Katanga Peru	2 000 000	6.1	46.5	3.0
26	Vieja Colombia	450 000	1.0	35	1.7
26	El Sapo Colombia	330 000	11.5	79.8	5.1

Data source for most deposits see Orris *et al.*, (1987); Ettlinger and Ray (1989); Meinert (1988). Data source for No. 19: Ettlinger and Meinert (*in review*); for No. 23: Wayland (1943); for Nos. 24-28: G.J. Orris, personal communication, 1989.

NA = values not available.

* Recently downgraded to 8 250 000 tonnes grading 3.02 g/t Au (Corona Corporation announcement, Dec. 1988).

** Estimated silver grade.

*** There is some uncertainty whether Salsigne represents a skarn deposit (G.J.Orris, personal communication (1989)).

contrast, all the gold skarns in the Hedley camp developed in a relatively reduced state (Figure 2-1-3); this conclusion is supported by the abundance of pyrrhotite and arsenopyrite, the presence of native bismuth, and the general scarcity of pyrite at Hedley. At the porphyry-related Fortitude deposit, the composition of the pyroxene-garnet assemblages (Myers and Meinert, 1989) suggests that the proximal copper-rich skarn developed under relatively oxidized conditions, while the distal gold mineralization formed under more reduced conditions (fields A and B respectively, Figure 2-1-3).

Based largely on spatial relationships, many workers have suggested that the intrusions were the primary source of both the skarn-forming fluids and metals in base and ferrous metal skarns. At the Nickel Plate mine, the gold is also believed to have originated from magmatic fluids (Dolmage and Brown, 1945; Ray *et al.*, 1988), and studies indicate the fluids were saline and high temperature (Ettlinger *et al.*, in press).

PROBLEMS WITH THE CLASSIFICATION OF GOLD AND PME SKARNS

Base and ferrous metal skarns have been classified using a number of criteria, including the predominant metal commodity present, as outlined by Einaudi *et al.*, (1981)

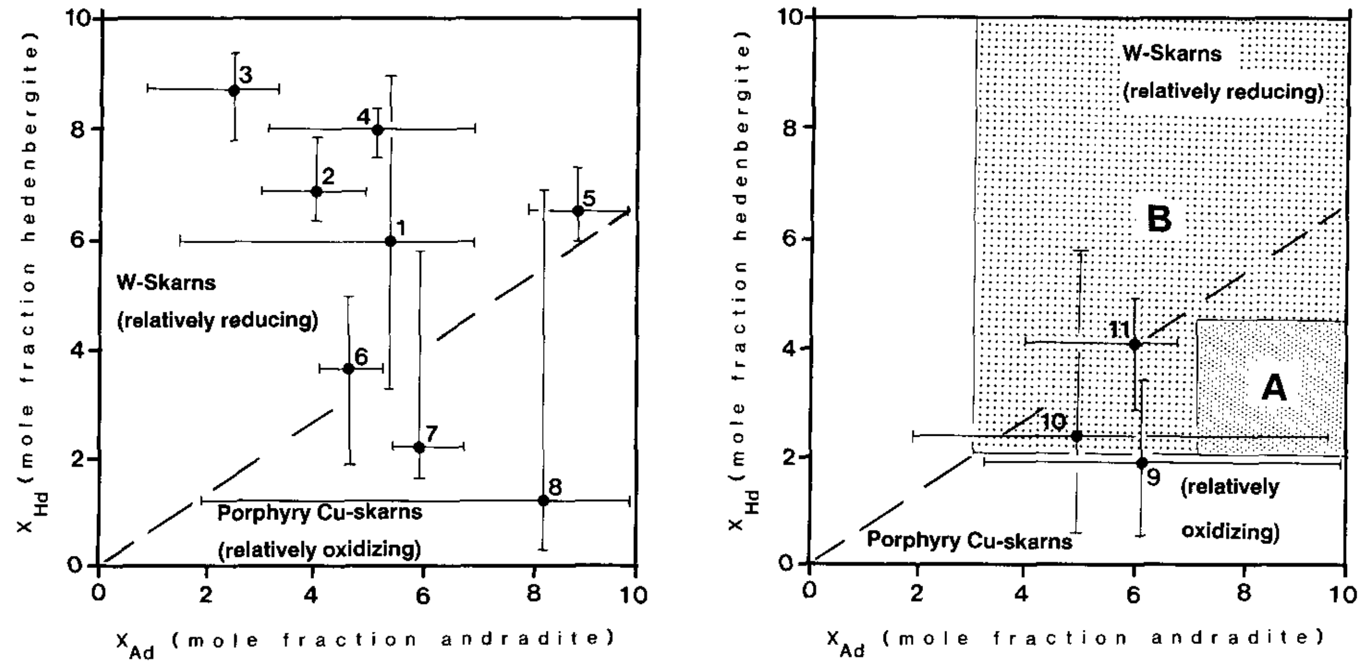

Figure 2-1-3. Plot of mole fraction Hd versus mole fraction Ad, illustrating the relative oxidation states of some gold, PME-copper and PME-iron skarns. Upper left field = relatively reducing W-skarns, lower right field = relatively oxidizing porphyry copper skarns, after Einaudi, (1982); (plot made on two diagrams due to density of data): 1 = Nickel Plate (Au), Hedley, BC; 2 = Canty (Au), Hedley, BC; 3 = Good Hope (Au), Hedley, BC; 4 = Peggy (Au), Hedley, BC; 5 = French (Au), Hedley, BC; 6 = Bob skarn (Au), Banks Island, BC; 7 = TP skarn (Au), Atlin, BC; 8 = Red Dome (Cu, Au), Australia; 9 and 10 = Little Billie (Cu, Au) and Florence (Au,Cu), Texada Island, BC; 11 = Texada Iron (Fe, Au), Texada Island, BC. Shaded area A = proximal Cu-rich skarn (West ore body), Copper Canyon, Nevada; shaded area B = more distal Au-rich skarn (Fortitude), Copper Canyon, Nevada. Note relatively reduced states for the Hedley and Fortitude gold skarns and oxidized to intermediate states for the Copper Canyon Cu-rich skarn, the TP gold skarn and the PME skarns at Red Dome and Texada Island. Data for 1 to 7 and 9 to 11 from Ettlinger and Ray (1989) and Ray and Dawson, (in preparation), for 8 from Ewers (personal communication, 1988), for shaded fields A and B from Myers and Meinert (1989). Bar lines show range of X Hd and X Ad values; centre points = average values except for Red Dome which shows mean values.

However, gold skarns are difficult to classify in relation to the six main skarn classes as the base and ferrous metals are commonly present in percentage quantities while gold is an extremely high-value commodity that generally only reaches concentrations of a few parts per million. Thus, small changes in either gold concentration or metal prices can progressively alter the classification of a deposit from an end-member ferrous or base metal skarn to an end-member gold skarn. A continuum probably exists between end-member gold skarns such as the Nickel Plate and Fortitude deposits, and end-member copper and iron skarns with little or no precious metal enrichment. Compared to some copper skarns, iron skarns tend to have less overall gold enrichment; if present, gold is usually concentrated in relatively small, isolated areas of the deposit where the magnetite ore is sulphide and copper rich. Although gold is sufficiently enriched in many copper skarns, such as the Phoenix deposit in British Columbia (Figure 2-1-1), to provide a major economic support to the mining operation, it is generally much lower grade in iron skarns and only recovered as a byproduct.

In the North American Cordillera gold enrichment at economically recoverable grades is rare in molybdenum and tin skarns and uncommon in lead, zinc and tungsten skarns. However, since gold-enriched tungsten skarns are reported in the Yukon (Brown, 1985), Japan (Shimazaki, 1980) and the U.S.S.R. (Khasanov, 1982) these skarns can provide exploration targets for precious metal deposits.

Orris *et al.* (1987) examined the gold grades and tonnages of some producing skarn deposits and designed a useful classification scheme. By their definition "gold skarns" average 1 ppm gold or more and must have been exploited primarily for gold, while "byproduct gold skarns" include any skarn mined, primarily for base or ferrous metals, where significant amounts of byproduct gold were recovered. However, this classification is limited since it is restricted to producing deposits and cannot be used to classify mineralized skarn occurrences.

Another method of classifying gold, copper and iron skarns is by comparing the Cu/Ag versus Cu/Au ratios of mineralized skarns. This method has the advantage that metal ratios can be determined from either assay or production data, although grab sample assays or older production data are often unreliable. The Cu/Au and Cu/Ag ratios of 40 deposits from around the world, described in the literature by various authors as "gold", "copper" or "iron" skarns, are listed in Tables 2-1-2, 2-1-3 and 2-1-4. The ratios of these deposits are plotted in Figure 2-1-4 and the main fields for gold, copper and iron skarns are empirically determined from the clustering of points. Deposits described as "gold skarns" tend to have Cu/Ag and Cu/Au ratios less than 1000 while most of those described as "copper skarns" have Cu/Au ratios ranging mainly between 2000 and 25 000, and Cu/Ag ratios ranging from 500 to 2500. In contrast the "iron skarns" generally have the highest Cu/Au and Cu/Ag ratios, ranging from 20 000 to 160 000 and 2500 to 5000, respectively (Figure 2-1-4).

Four deposits described in the literature and listed as gold skarns in Table 2-1-2 do not fall within the gold skarn field outlined in Figure 2-1-4; these are the Cable (No. 5), Red Dome (No. 8), Surprise (No. 9) and La Luz (No. 16). It is possible that the Red Dome deposit with its average grades of 2 grams gold per tonne and 0.46 per cent copper (Torrey *et al.*, 1986) represents a gold-enriched copper-skarn, rather than a true end-member gold skarn.

SUMMARY

Precious metal enriched skarns and gold skarns are preserved and exposed worldwide in Phanerozoic mobile belts, where they are preferentially hosted in carbonate-rich assemblages deposited in back arc and marginal basin environments, or in mature oceanic arcs that may contain potassium-rich volcanic sequences. Rifted basin margins are favorable sites for gold skarns because the controlling structures can preferentially channel the arc plutons into suitable basin-edge carbonate sediments; the unstable sedimentary environments in the basin margin facies may result in the deposition of slump carbonate deposits, limestone-boulder breccias or olistostromes. By contrast, immature island arcs, arcs formed along sialic continental margins and the deeply eroded root zones of magmatic arcs are less favorable for gold skarns.

Gold skarns in the Canadian Cordillera are mostly related to intermediate to high-level, I-type island arc plutonism of calcalkaline, subalkaline affinities and dioritic composition. In many cases the intrusions are coeval with the arc volcanism, but some PME skarns are formed when younger plutons intrude considerably older but lithologically favorable hostrocks.

Gold skarns show an overall spatial and temporal association with the world's copper porphyry districts, and some deposits, such as the Fortitude in Nevada, are intimately related to porphyries. Others, such as the Nickel Plate deposit are probably not directly associated with porphyry systems although often they too are developed in regions of copper porphyry mineralization. The worldwide spatial relationship between gold skarns and the porphyry districts outlines potential areas for gold skarn exploration. Besides

TABLE 2-1-2
Cu/Au AND Cu/Ag RATIOS OF DEPOSITS DESCRIBED AS "GOLD SKARNS" (*see* FIGURE 2-1-4)

Number in Figure 2-1-4	Name	Cu/Au	Cu/Ag	Reference or Data Source
1	Hedley Mascot, B.C.	125	510	Ettlinger and Ray (1989).
2	Nickel Plate, B.C. (underground)	23	235	National Mineral Inventory production data; Ray *et al.* (1988).
3	Nickel Plate, B.C. (open pit)	222	333	Mascot Gold Mines Ltd. report – Nov. 1987.
4	Browns Creek, Australia	533	444	Meinert (1988).
5	Cable, Montana	5000	6000	Earll (1972).
6	Fortitude, Nevada	200	56	Blake *et al.* (1984). Wotruba *et al.* (1986).
7	Minnie-Tomboy, Nevada	357	111	Blake *et al.* (1984). Theodore *et al.* (1986). Meinert (1988).
8	Red Dome, Australia	2300	1000	Torrey *et al.* (1986).
9	Surprise, Nevada	2500	372	Meinert (1988).
10	Northeast Extension Nevada	379	73	Wotruba *et al.* (1986). Orris *et al.* (1987).
11	Pagaran Siayu, Indonesia	357	800	Orris *et al.* (1987).
12	Thanksgiving, Philippines	162	35	Bryner (1969).
13	Southern Cross, Montana	68	55	Earll (1972). Orris *et al.* (1987).
14	Salsigne, France	115	45	Elevatorski (1981)
15	Golden Curry, Montana	388	785	Orris *et al.* (1987).
16	La Luz, Nicaragua	1073	3666	Orris *et al.* (1987).

TABLE 2-1-3
Cu/Au AND Cu/Ag RATIOS OF DEPOSITS DESCRIBED AS "COPPER SKARNS" (*see* FIGURE 2-1-4)

Number in Figure 2-1-4	Name	Cu/Au	Cu/Ag	Reference or Data Source
17	Clifton District, Utah	33333	213	Elevatorski (1982). Meinert (1988).
18	Frankie, Utah	23529	1270	Elevatorski (1982). Meinert (1988).
19	Geo-Star, B.C.	24000	2118	Ettlinger and Ray (1989).
20	Moncocco, Utah	33333	211	Elevatorski (1982). Meinert (1988).
21	Phoenix, B.C.	7611	1198	Church (1986).
22	Phoenix, B.C.	12000	800	Production data quoted by Meinert (1988).
23	Rosita, Nicaragua	17778	2667	Meinert (1988).
24	Victoria, Nevada	79000	1692	Atkinson *et al.* (1982). Meinert (1988).
25	Whitehorse Copper District	19821	1568	Tenney (1981); Meinert (1986).
26	Yaguki, Japan	2665	51	Einaudi *et al.* (1981).
27	Copper Queen, Texada Island, B.C.	3851	509	Peatfield (1987).
28	Zackly, Alaska	4909	900	Production data quoted by Meinert (1988).
29	Cornell, Texada Island, B.C.	2905	623	Ettlinger and Ray (1989).
30	Little Billie, Texada Island, B.C.	2256	683	Ettlinger and Ray (1989).
31	Marble Bay, Texada Island, B.C.	4397	537	Ettlinger and Ray (1989).

TABLE 2-1-4
Cu/Au AND Cu/Ag RATIOS OF DEPOSITS DESCRIBED AS "IRON SKARNS" (*see* FIGURE 2-1-4)

Number in Figure 2-1-4	Name	Cu/Au	Cu/Ag	Reference or Data Source
32	Iron King	160000	20000	Warner *et al.* (1961). Meinert (1988).
33	It, Alaska	20000	2667	Warner et al. (1961). Myers (1984, 1985a, 1985b).
34	Larap	1000	200	Einaudi *et al.* (1981).
35	Magnetite Cliff.	13333	3200	Elevatorski (1981).
36	Mamie, Alaska	30166	4525	Warner *et al.* (1961). Myers (1984, 1985a, 1985b).
37	Mount Andrew, Alaska	38625	2809	Warner *et al.* (1961). Myers (1984, 1985a, 1985b).
38	Poor Man	3000	1500	Warner *et al.* (1961). Myers (1984, 1985a, 1985b).
39	Prince of Wales District, Alaska.	29625	3656	Production data quoted by Meinert (1988).
40	Texada Iron mines B.C.	30112	1130	Meinert (1984); Peatfield (1987).

the relatively well known North American Cordillera, the porphyry copper belts of South America, the Himalayas, Iran and southeast Asia, particularly where carbonate successions are preserved, can be expected to contain economic gold skarn deposits; in Thailand for example, numerous gold skarn prospects are currently being explored (Pisutha-Arnond *et al.*, 1984).

Gold skarns occur in the same geological environment as iron skarns and oceanic island arc hosted copper skarns; like iron skarns they are commonly related to primitive, ocean-crust-derived dioritic intrusions with low initial $^{87}Sr/^{86}Sr$ ratios, tend to be enriched in arsenic and cobalt, and are sporadically associated with late scapolite alteration. Similarly, they are characterized by manganese-poor grandite garnets (<1 weight per cent MnO_2) and manganese-poor, iron-rich hedenbergitic pyroxenes (<4 weight per cent MnO_2). However, they are atypical of base metal skarns in commonly containing arsenic, bismuth and telluride minerals. Precious metal enrichment can occur in skarns formed in either reduced or oxidized conditions, although preliminary evidence suggests end-member gold skarns favour more reduced states. Many PME skarns associated with iron skarns or copper porphyries tend to develop in more oxidizing environments while all the Hedley gold skarns formed under reduced conditions. The presence of scapolite and chlorine-rich amphiboles in some deposits suggests chlorine-

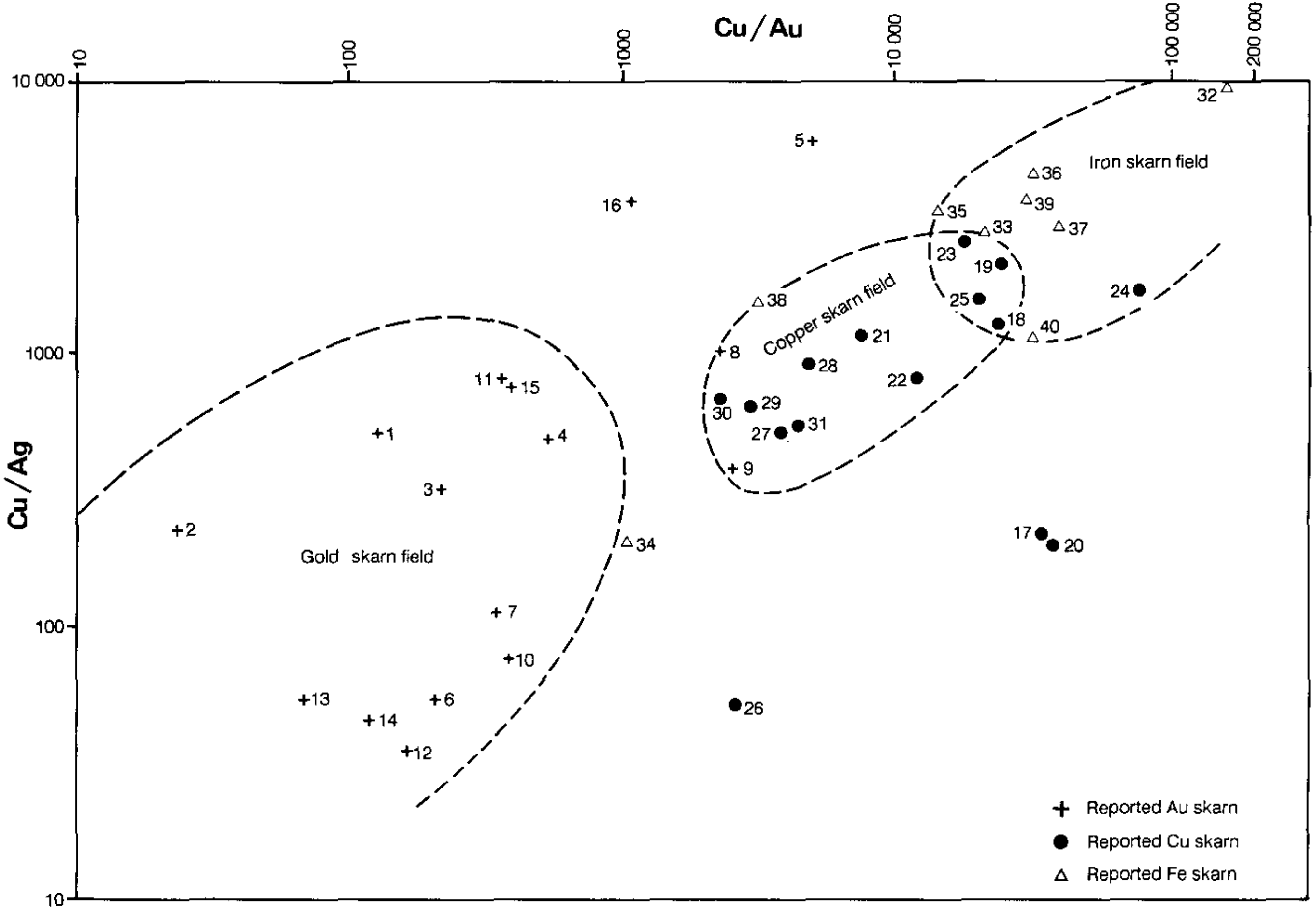

Figure 2-1-4. Plot showing Cu/Ag versus Cu/Au ratios of the 40 deposits listed in Tables 2-1-2, 2-1-3 and 2-1-4 and described by various authors as "gold", "copper" or "iron" skarns. Note: fields have been empirically drawn around the main clustering of points to outline the three skarn classes.

rich fluids were important for the transportation and precipitation of gold in skarns, and the gold is believed to have been derived from, and largely carried in magmatic fluids.

For a variety of reasons, gold skarns cannot be adequately classified using the criteria employed to classify and define base and ferrous metal skarns, although using Cu/Ag versus Cu/Au ratios can broadly differentiate gold, copper and iron skarns. Further study may indicate that gold skarns, like copper porphyries, can be divided into different subclasses dependant on such features as the predominant base or ferrous metal content (if any), the association with alkalic or calcalkalic plutonism, and the environment and depth of formation. To most exploration geologists, however, PME-skarns can be regarded as skarns that contain gold, silver or rarely, platinum, in sufficient quantities to be economically recoverable as either primary or byproduct commodities. A continuum probably exists between end-member gold skarns and end-member copper and iron skarns containing little or no precious metal enrichment.

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