Gold-Bearing Skarns

U.S. GEOLOGICAL SURVEY BULLETIN 1930

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Gold-Bearing Skarns

By TED G. THEODORE, GRETA J. ORRIS,
JANE M. HAMMARSTROM, and JAMES D. BLISS

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Gold-Bearing Skarns

By Ted G. Theodore, Greta J. Orris, Jane M. Hammarstrom, *and* James D. Bliss

Abstract

In recent years, a significant proportion of the mining industry's interest has been centered on discovery of gold deposits; this includes discovery of additional deposits where gold occurs in skarn, such as at Fortitude, Nevada, and at Red Dome, Australia. Under the classification of Au-bearing skarns, we have modeled these and similar gold-rich deposits that have a gold grade of at least 1 g/t and exhibit distinctive skarn mineralogy. Two subtypes, Au-skarns and byproduct Au-skarns, can be recognized on the basis of gold, silver, and base-metal grades, although many other geologic factors apparently are still undistinguishable largely because of a lack of detailed studies of the Au-skarns. Median grades and tonnage for 40 Au-skarn deposits are 8.6 g/t Au, 5.0 g/t Ag, and 213,000 t. Median grades and tonnage for 50 byproduct Au-skarn deposits are 3.7 g/t Au, 37 g/t Ag, and 330,000 t. Gold-bearing skarns are generally calcic exoskarns associated with intense retrograde hydrosilicate alteration. These skarns may contain economic amounts of numerous other commodities (Cu, Fe, Pb, Zn, As, Bi, W, Sb, Co, Cd, and S) as well as gold and silver. Most Au-bearing skarns are found in Paleozoic and Cenozoic orogenic-belt and island-arc settings and are associated with felsic to intermediate intrusive rocks of Paleozoic to Tertiary age. Native gold, electrum, pyrite, pyrrhotite, chalcopyrite, arsenopyrite, sphalerite, galena, bismuth minerals, and magnetite or hematite are the most common opaque minerals. Gangue minerals typically include garnet (andradite-grossular), pyroxene (diopside-hedenbergite), wollastonite, chlorite, epidote, quartz, actinolite-tremolite, and (or) calcite.

INTRODUCTION

Gold exploration efforts of the mining industry in the last few years have centered on discovery of skarn deposits, such as Battle Mountain Gold Company's Fortitude deposit in Nevada, and Elders Resources' Red Dome deposit in Queensland, Australia, as well as on discovery of disseminated, carbonate-hosted, or Carlin-type deposits. Carbonate-hosted gold deposits are generally much larger deposits than skarns but are of much lower grade. Bagby and others (1987) report median tonnage and grade values of 5.1 million tonnes and 2.5 g/t Au, respectively, for 35 Carlin-type deposits. Median tonnage and grade values for the 90 skarn deposits we report in this study are 0.279 million tonnes and 5.7 g/t Au, respectively. Some major gold skarns, such as the Lower Fortitude deposit, Nevada (5.1 million tonne, 10.45 g/t Au), and the deposit at Bau, Malaysia (2.4 million tonnes), however, contain more gold than many of the large, disseminated-type deposits and are thus extremely attractive as exploration targets. The geologic characteristics of gold-bearing skarn deposits have only recently been addressed (Meinert, 1988a,b, 1989). This paper presents descriptive and grade-tonnage information obtained from more than 90 deposits that have been referred to in the literature as "Au-bearing skarns," "Au-rich skarn," or "Au-skarn," in a format somewhat similar to models in Cox and Singer (1986) but as modified by P.B. Barton (written commun., 1986). These and many other deposits, generally referred to as gold skarns in the literature, are occasionally further differentiated into contact, or proximal, skarns and distal skarns (Sillitoe, 1983, 1987; Bonham, 1985). Special attention has been given to the mineral chemistry of gangue skarn minerals as they have previously proved useful in distinguishing skarn types.

This paper consists of a geologic description of Au-bearing skarns, presented in a form modified from that established previously for Cu-, Zn-Pb-, and Fe-skarn descriptive models (Cox and Singer, 1986) to allow rapid comparison and contrast; grade-tonnage distributions of Au-bearing skarns; and a combination references-bibliography section.

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DATA

In our examination of the geologic literature for over 300 skarns, we determined that about 65 percent of those reported detectable gold in amounts ranging from a trace to approximately 157 grams per tonne (g/t). Data are compiled for approximately 125 skarn deposits, and the deposit tonnage and gold grade distributions of 90 of those with a gold grade of 1 g/t or higher are compiled in tables 1-4 and are shown in figures 1 and 2. Grade and tonnage values (tables 2 and 3) are reported in metric units: grams per tonne (g/t) and millions of tonnes (Mt), respectively. Most of the production data in the references cited is reported in terms of troy ounces (1 troy ounce = 31.103 g) and short tons (1 short ton = 1.102 t) and was converted to the appropriate metric equivalent for this report. In many older publications, only ore tonnages and dollar amounts of gold produced are cited. Where possible, we estimated gold grades from these dollar amounts using the appropriate prevailing gold price. For example, the price of gold was fixed at $20.67 per troy ounce from 1834 to 1934, except during the Civil War and during suspensions of specie payment in

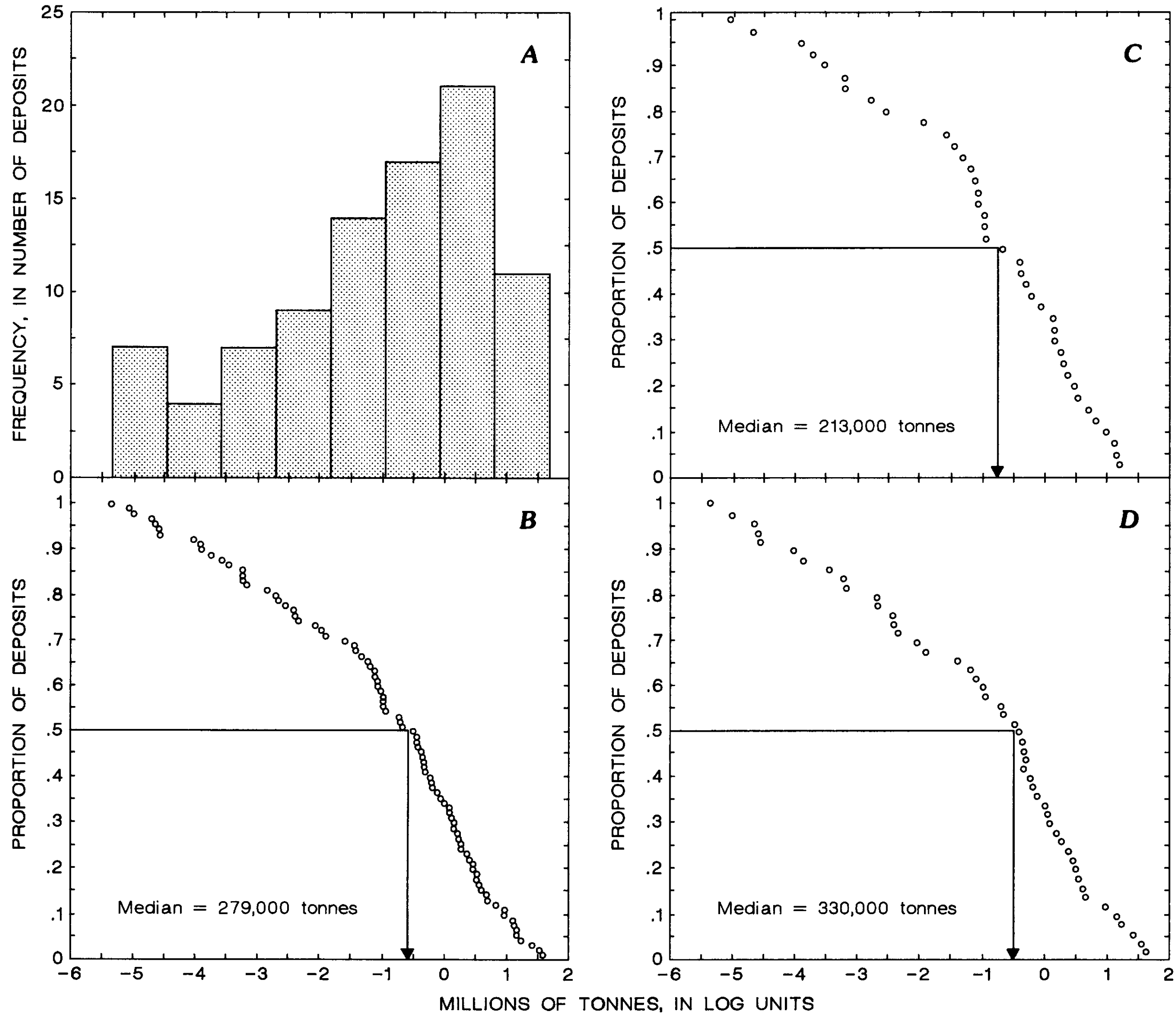


Figure 1. Distributions of tonnage for Au-bearing skarn deposits. *A*, Tonnage histogram for 90 Au- and byproduct Au-skarn deposits. *B*, Tonnage model, same data set. *C*, Tonnage model for 39 Au-skarns. *D*, Tonnage model for 59 byproduct Au-skarns.

1837 and 1857 (see discussion in Shawe, 1988).

All gold-bearing skarns can, as a first approximation, be treated as deposits in one of two subtypes that have different gold, silver, and base-metal grade distributions: (1) skarns in which gold is the primary commodity and (2) skarns in which gold had been or is being recovered as a byproduct. However, in some already mined out deposits wherein gold was recovered as a byproduct, changes in metal prices to those prevailing during the late 1980's would result in gold assuming the role of primary commodity because of sufficient gold grade. A set of criteria has been established to determine whether a deposit should be classified as an Au-bearing skarn:

1. The deposit must have an average gold grade of at least 1 g/t.

2. The mineral assemblage(s) of the deposit must include mineralogy that indicates that a skarn environment was genetically associated with introduction of gold. Meinert (1988a) emphasized that a critical mineralogic feature of Au-bearing skarn is the presence of pyroxene and garnet. However, as we discuss below, introduction of most gold in such deposits does not necessarily occur during prograde pyroxene- and garnet-stages of skarn development.

Among skarns that meet these two criteria, some were mined primarily for their precious-metal content, whereas others were either mined primarily for their base-

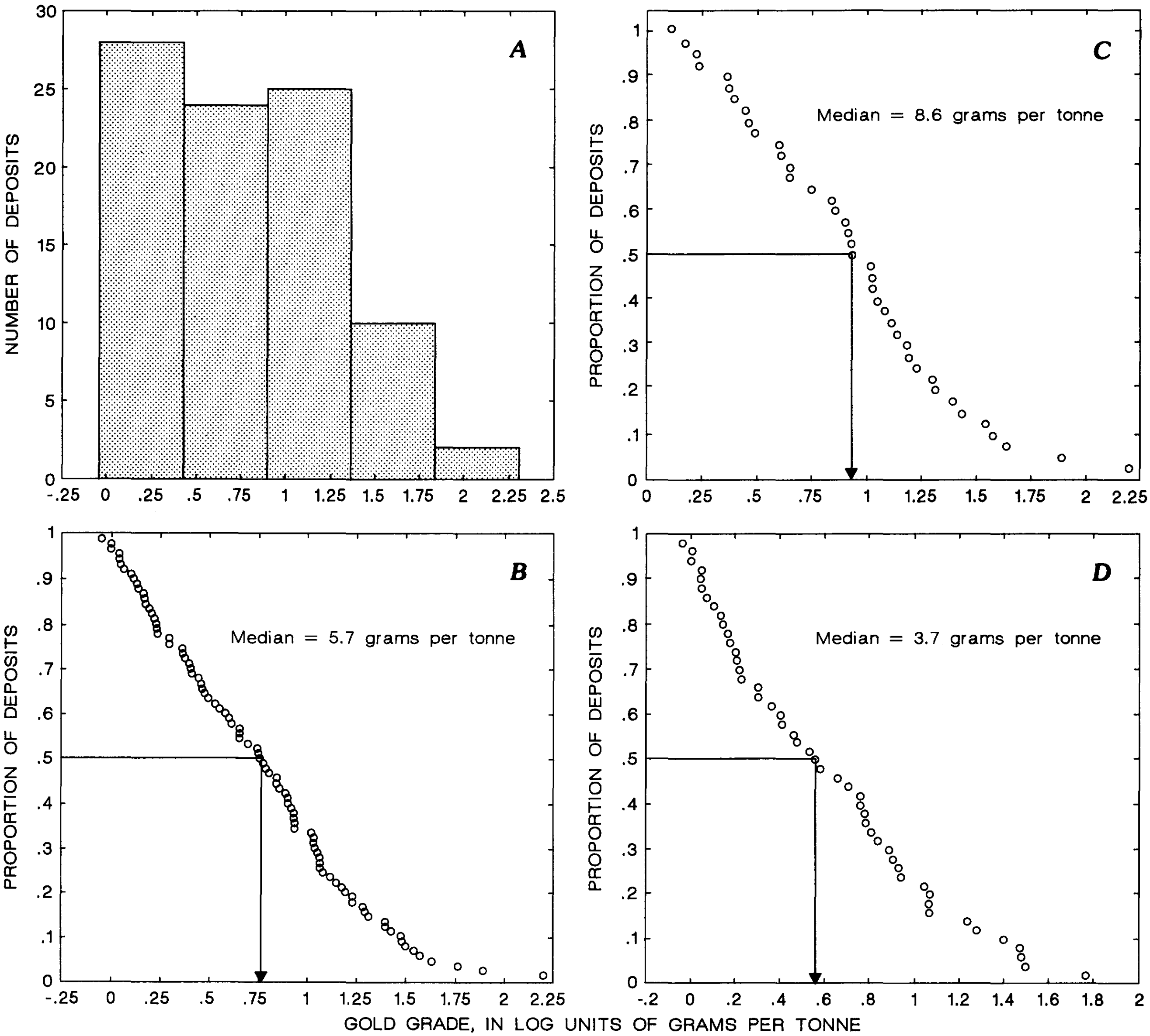


Figure 2. Distributions of gold grade for Au-bearing skarn deposits. *A*, Gold grade histogram for 90 Au- and byproduct Au-skarn deposits. *B*, Gold grade model, same data set. *C*, Gold grade model for 39 Au-skarns. *D*, Gold grade model for 59 byproduct Au-skarns.

and ferrous-metal content or were mined for precious metals but contained very large amounts of base and ferrous metals. The presence of some gold in Cu-, Fe-, and W-skarn was characterized appropriately by Lindgren (1933): "Gold is present in traces in almost all sulphide deposits of the pyrometasomatic type, and a few ounces of silver to the ton is likewise not unusual***." Skarn deposits with byproduct gold that average at least 1 g/t and with base-metal grades less than the lowest tenth percentile of a grade model of copper (0.7 percent Cu) in Cu skarns (Jones and Menzie, 1986), of zinc (2.7 percent Zn) or lead (0.87 percent Pb) in a Zn-Pb skarn model (Mosier, 1986), or of iron (36 percent Fe) in Fe skarns (Mosier and Menzie, 1986) are included in an *Au-skarn* data subset (table 2). Skarn deposits with greater than 1 g/t gold and higher base- and ferrous-metal grades that fit existing models of base- and ferrous-metal skarn-deposit types are assigned to a *byproduct Au-skarn* data subset (table 3). Orris and others (1987) presented these criteria for classification of Au-bearing skarns along with a preliminary compilation of deposits. Much of the information in that report has been updated and revised because of subsequent availability of newly released data, and a number of deposits have been added. The geologic characteristics of many deposits in our byproduct Au-skarn subset are as important from the viewpoint of a gold explorationist in the late 1980's as are the characteristics of the Au-skarn subset. Many of the byproduct Au-skarn deposits exploited at their respective grades of gold greater than 1 g/t before 1950 (table 3) undoubtedly would have been evaluated only for their precious-metal content if first discovered in the late 1980's. Admittedly, the classification scheme above is for drilled out deposits currently in production or for deposits that have been mined out, and the classification scheme strictly cannot be used to classify precious-metal-mineralized, unexploited skarns (Ettlinger and Ray, 1989). Nonetheless, the classification scheme provides a data base of precious-metal-mineralized skarns to which data from unexploited skarns may be compared. Studies by Myers and Meinert (1988), G.L. Myers (written commun., 1988), and Ettlinger and Ray (1989) have shown that metal ratios in metallized skarns may be used to discriminate effectively among types of Au-bearing skarn. Myers and Meinert (1988) suggested that true copper skarns have Au/Cu ratios (where gold grade is in grams per tonne and copper grade is in weight percent) less than about 3. On the one hand, all 20 skarns classed as Au-skarns, as we defined above, for which gold and copper grades are available, show Au/Cu ratios greater than 3 (table 2). On the other hand, 22 of 50 byproduct Au-skarns have Au/Cu ratios greater than 3 (table 3). Therefore, adoption of the classification scheme of Myers and Meinert (1988) based on that ratio would result in the addition of the 22 deposits to our Au-skarn data set (table 2). These 22 deposits, however, fit existing models for base-metal skarns. Within gold-bearing skarn, deposits of our Au-skarn subset cluster in a domain showing elevated overall abundances of gold and an increased Au/Cu ratio relative to most deposits in the byproduct Au-skarn subset for which data are available (tables 2, 3; fig. 3*A*). Ettlinger and Ray (1989, fig. 51) defined fields for gold (silver), copper, iron, and silver-poor gold-rich skarns based on Cu/Ag and Cu/Au ratios. Of the 20 deposits in our Au-skarn subset (table 2) that report grade values for Au, Ag, and Cu, 16 plot within the gold (silver) field (fig. 3*B*). The Surprise deposit,

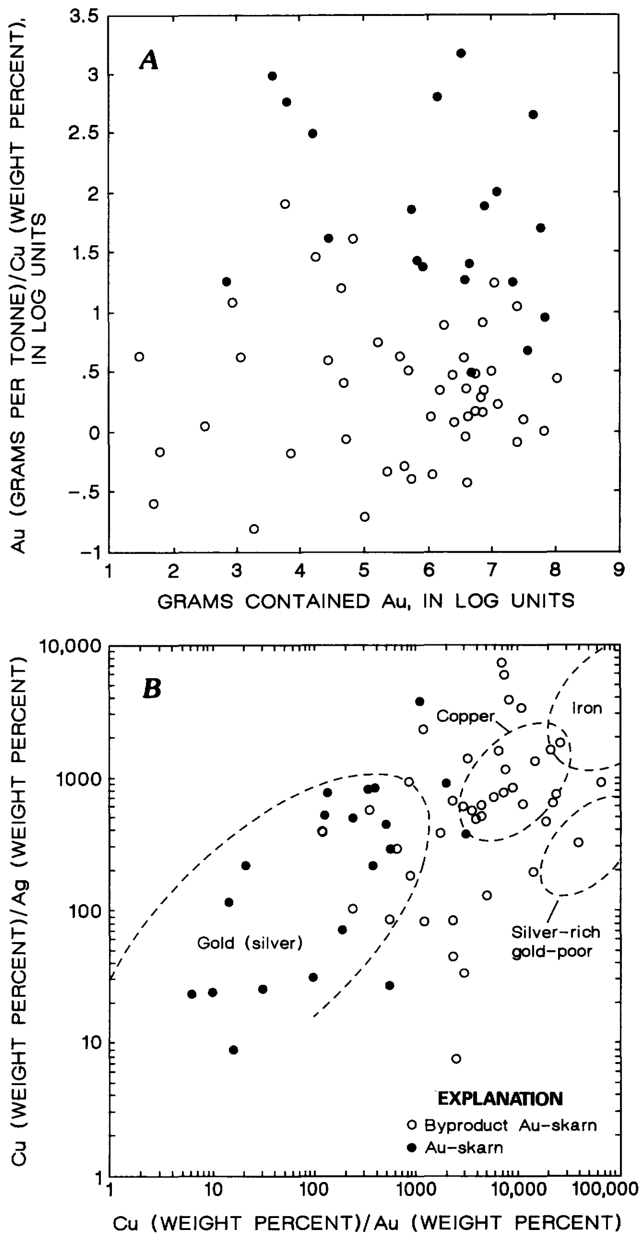


Figure 3. Gold skarn classification schemes based on metal ratios. *A*, Gold-copper ratios compared with contained gold (average grade multiplied by tonnage) for 20 Au- and for 47 byproduct Au-skarn deposits for which copper grades are available. *B*, Copper/silver ratios compared with copper/gold ratios for the same data set. Fields for gold (silver), copper, iron, and silver-rich skarns are from Ettlinger and Ray (1989).

which we included as an Au-skarn rather than a byproduct skarn, plots on the boundary of the copper skarn field. Although the Surprise deposit is copper-rich and has an average grade of 0.85 percent Cu (above the 0.7 percent Cu grade for the lowest tenth percentile grade for copper in the copper skarn model of Jones and Menzie, 1986), we included it in table 2 because it is presently being mined for gold alone. The 42 deposits in our byproduct subset (table 3) for which grade data are available for all three elements are scattered about the central region of figure 3*B*; nearly half of the deposits cluster in and near the copper skarn field. Interestingly, the one iron skarn in our byproduct subset, Larap, plots in the gold (silver) region of figure 3*B*, at a much lower Cu/Au ratio than that defined for iron skarn. Four of the seven Zn-Pb byproduct gold skarns plot outside of any of the fields defined by Ettlinger and Ray due to their low Cu/Ag ratio; one deposit plots within the gold (silver) field and two plot within the copper skarn field.

All three methods for classifying gold-bearing skarn deposits (this study, Myers and Meinert's Au/Cu ratio, and Ettlinger and Ray's Cu/Ag vs. Cu/Au ratio) converge on the conclusion that most deposits that can be mined primarily for their gold content have log Cu/Au ratios less than about 3 to 3.5 and have a slightly lower Cu/Ag ratio than copper-rich skarns. By restricting our byproduct Au-skarn data (table 3) to those known skarn systems wherein gold concentrations are greater than or equal to 1 g/t, we provide composited cumulative-distribution relations only for the Au-enriched part of Cu, Pb-Zn, and Fe skarns as defined by Jones and Menzie (1986), Mosier (1986), Mosier and Menzie (1986), and Meinert (1988a, b). According to our definitions, Au-bearing skarn may include both Au-rich and Ag-rich variants of skarn as employed in the terminology of Ray and others (1986a). An example of geologic linkage between Au-skarn deposits and byproduct Au-skarn deposits is present at Copper Canyon, Nevada (Wotruba and others, 1986; 1987a, b; Myers and Meinert, 1988). At Copper Canyon, the West ore body is an Au-bearing Cu-skarn that formed adjacent to a 38 Ma granodiorite (Theodore and Blake, 1978). However, its gold grade (approximately 0.7 g/t) is less than the 1 g/t cutoff that we use in this report for deposits to be included in our byproduct Au-skarn subset (table 3). Nonetheless, at Copper Canyon the Fortitude Au-skarn (table 2) formed in the same stratigraphic sequence of rocks as the West ore body, but at a much greater distance from the granodiorite (Wotruba and others, 1986; 1987a, b).

Deposits for which some geologic or grade-tonnage data are available are listed in tables 2 through 4. Grades, tonnages, and some geologic data available for 40 Au-skarns are listed in table 2; most of these skarns were (or are being) exploited primarily for their precious-metal content. Byproduct Au-skarns that can be classified under other skarn types, including Cu, Zn-Pb, and Fe skarns, and that have grade-tonnage and some geologic data are included in table 3. Deposits that have been described as "gold skarns" in the literature and for which complete grade-tonnage data are not available but are suspected to have average gold grades greater than or equal to 1 g/t are described in table 4. Although Schrader (1947) from his studies in the 1920's, cited production in the 1880's of extremely high grade gold (622 g/t for 272 t) from gossaniferous skarn at the Mottini Mine, IXL Mining District, Nevada (table 4), subsequent geochemical studies have failed to confirm the occurrence there of such concentrations of gold (Vanderburg, 1940; David A. John, written commun., 1989).

The Cable Mine in the Southern Flint Creek Range, Montana, has long been recognized as a gold skarn. Knopf (1933) classified the Cable Mine, along with deposits in the Hedley district of British Columbia, as a pyrometasomatic gold deposit. The production history of the Cable Mine (table 4) provides a good example of the difficulties of assigning reliable tonnage or grade values to long-lived deposits. The mine was discovered in 1866, and Emmons (1907) reported that 9,000 tons of ore produced \$172,000, mostly in gold, in 1867. Emmons and Calkins (1913) report \$400,000 from production up to 1872, including \$30,000 from one ton of ore, a single gold nugget valued at \$375, and more than \$2,000,000 in gold produced from 1877 to 1891. They also described average tailings from upper levels and partly oxidized ore of \$2.97 per ton in gold, 0.15 ounces per ton in silver, and 3.06 percent copper. Earll (1972) noted that 90 percent of the production from the district took place prior to 1900, and reported district production, including placer, of \$3,535,820 from 165,127 oz of gold and 134,904 oz of silver. The Cable area and nearby vein-controlled and oxidized ores at the Southern Cross, Gold Coin, and Pyrenees deposits are currently under exploration (Nolan Smith, oral commun., 1989) as a joint venture by Magellan Resources and Chevron Resources Company.

Paired grade-tonnage values are available for 90 ore bodies in 89 skarn systems mineralized to gold concentrations equal to or greater than 1 g/t. At Tillicum, British Columbia, two entries (table 2) are included in the statistical calculations: estimated reserves of 2 million tonnes at 6.9 g/t Au in the East Ridge zone of the deposit and proven reserves of 0.05 million tonnes at 35 g/t Au in the Heino-Money zone of the deposit (Ettlinger and Ray, 1989). The deposit tonnage estimate consists of any known production plus reserves (proven, estimated, or drilling-indicated) at a given point in time; the grade is an estimated average grade for the total tonnage. For some deposits, tonnage and grade are based on known production only. These values probably are representative of the entire ore bodies for many of those small deposits mined during the late 1800's and early 1900's. It should be noted that most of the production for over one-half of the skarns was concluded prior to 1950, and we cannot be sure that many of those deposits of base-metal skarn did not have a gold content that would be significant under today's (1989) economics. Values of tonnage and ore grades qualified as "greater than" in tables 2 and 3 were used in statistical calculations and graphs of data described below. This results in two tonnage values, one gold grade value, and two silver grade values being substituted by an unqualified numerical value. Values qualified as "less than" were not considered further in either statistical calculations or graphs of data. Iron skarn dominates the mineralized skarns worldwide, comprising approximately one-third of the deposits; however, gold contents for most of these skarns were reported in the literature as "trace," "minor," or "detectable." Only two deposits of iron skarn with grade and tonnage figures reported average gold grades exceeding 1 g/t (table 3), and 11 deposits reported grades lower than 1 g/t as deposit averages or in selected parts of a compositionally zoned skarn body. In a comprehensive data compilation for Alaskan skarns, Newberry (1986) classified 109 deposits as Fe-Au-skarns. He reported typical grades for these deposits of 40 percent Fe, 1 percent Cu, 0.1 oz Au per ton (3.4 g/t), 10 oz Ag per ton (343 g/t), and 50 ppm Co.

Several additional deposits have been described as gold skarns in one or more publications listed in the bibliography but were not included in the above tables for the following reasons: inadequate description of the deposit; inaccessibility to the publication; description(s) of the deposit showed the deposit to be inappropriately classified as a gold-bearing skarn according to the classification scheme we have adopted; or the gold grade was less than 1 g/t. These deposits include: Tennant Creek, Australia; Landusky-Zortman, Montana; Ertsberg, Indonesia; Andacollo, Chile; Equity (Sam Goosly), British Columbia; Salsigne, France; Pamlico, Nevada; Red Cloud, Nevada; Island Copper, British Columbia; and others. Ertsberg has an average gold grade below 1 g/t. Wedekind (1988) and Wedekind and others (1988) did not include garnet or pyroxene as part of the composite mineral assemblages of the deposits at Tennant Creek. Andacollo has been cited under other deposit types, and a detailed geologic description of the area is not available. Inappropriate or alternate classification of deposits and (or) lack of detailed geologic data have excluded the other deposits. Some deposits with grade and tonnage data reported were placed in table 4 because the tonnage and grade information conflicted with other known data and we were unable to resolve the conflict; an example of this situation is Mt. Biggenden, Australia. Although the Mt. Biggenden magnetite-bismuth-gold skarn is classified as an Au-skarn by Meinert (1988a) and assigned a size of 500,000 tons and a gold grade of 15 g/t, we have not included it with either our Au-skarn or byproduct Au-skarn subtypes primarily because of our uncertainty about the gold grade and tonnage of mined ore. For example, total gold production to 1969 from Mt. Biggenden is more than 7,000 oz, of which 5,751 oz was produced before 1901 (Clarke, 1969). The corresponding tonnage of ore mined is not reported. As of 1917, Dunstan (1917) calculated magnetite ore reserves as 500,000 tons, which apparently includes only "a few grains of gold per ton" (Clarke, 1969), because all of the "actinolite rock" that contained most of the gold and bismuth had been already mined out by that time. If 500,000 tons is a correct tonnage for the gold ore, then 14,500 oz of total gold production is required for an average grade of 1 g/t, and over 200,000 oz of production would be needed for a grade of 15 g/t. If the grade of 15 g/t is correct, 7,000 oz of gold could have been produced from about 16,000 tons of ore.

Pegasus Gold Corporation's Beal Gold deposit in the Siberia Mining District near Butte, Montana, described as a 9.2-million-tonne, low-grade (1.509 g/t Au), bulk minable precious-metal reserve (Hastings and Harrold, 1989), has some characteristics of skarn (N. Eric Fier, oral commun., 1989), but shows no extensive calcsilicate exoskarn gangue mineral assemblage at the present levels of exposure. Precious metals and sulfides (pyrrhotite, pyrite, chalcopyrite, trace arsenopyrite and molybdenite) are disseminated in metaconglomerate, quartzite, diopside hornfels, and potassium feldspar hornfels and also are present in veins with chlorite, quartz, adularia, and carbonate minerals. Gold is present as free gold and in association with Pb- and Bi-tellurides.

GEOLOGY

General Deposit Definition

Smirnov (1976) suggested that classification of skarns be based upon the composition of the original protolith of the skarn: calcareous, magnesian, or silicate. However, we follow the nongenetic definition of skarn proposed by Einaudi and others (1981): "replacement of carbonate [or other sedimentary or igneous rocks] by Ca-Fe-Mg-Mn silicates [resulting from] (1) metamorphic recrystallization of silica-carbonate rocks, (2) local exchange of components between unlike lithologies during high-grade regional or contact metamorphism, (3) local exchange at high temperatures of components between magmas and carbonate rocks, and (4) large-scale transfer of components over a broad temperature range between hydrothermal fluids ***and predominantly carbonate rocks." Most Au-bearing skarns owe their genesis to processes largely involving the fourth process. Thus we follow an overall classification of skarns based upon their sought-for metal content (see also Shimazaki, 1981, and Zharikov, 1970).

As recognized by Meinert (1988a), many deposits referred to as Au-skarns in the literature have been classified, or could be classified, under skarn deposit models such as Cu- and Fe-skarns by their dominant base- or ferrous-metal contents. For these deposits, gold production may be considered a byproduct of base- or ferrous-metal mining. Furthermore, Au-bearing skarn deposits commonly may be gradational into skarn that contains no gold but does contain significant other metal(s), including the Ag-rich skarns as defined by Ray and others (1986a), sediment-hosted disseminated Au-Ag deposits (also known as carbonate-hosted and Carlin-type), porphyry Cu or Cu-Mo deposits, or polymetallic replacement deposits (exemplified by the McCoy megasystem in Nevada), as well as other deposit types related to felsic to intermediate plutonic emplacement or volcanic activity. The Cove deposit, McCoy Mining District, Nevada, has been classified recently as a distal disseminated Ag-Au deposit according to a scheme proposed by Dennis P. Cox (written commun., 1989). Polymetallic veins are one of the other deposit types that may be present on the fringes of Au-bearing skarn deposits. Therefore, we have chosen to use the term "Au-bearing" skarn as most aptly describing such skarn deposits and related mineralization commonly distal to the immediate contact zone. Other commodities produced by Au-bearing skarns include silver, copper, zinc, iron, lead, arsenic, bismuth, tungsten, and tin as principal or byproduct commodities and cobalt, cadmium, and sulfur as byproducts.

In addition, we have provisionally restricted our working model of this deposit type to those Au-bearing skarns that have more than 1 g/t gold. This figure is based largely on cutoff grades that were reported as low as 1 g/t for many Au-bearing skarn operations in production in 1988 that required milling of their ore to a very fine grain size for efficient gold recovery. Some Au-skarn operations, such as McCoy, Nevada, that utilize heap-leach extraction procedures for their ores, have cutoff grades as low as 0.3 g/t for oxidized ore (Bruce A. Kuyper, oral commun., 1987), but the average deposit grade is greater than 1 g/t. Deposits with average gold grades below 1 g/t and without other economic mineralization are rarely reported in a quantitative manner in the literature and thus result in an artificially truncated data set. In an attempt to limit the influence of this reporting problem when comparing Au-bearing subsets, we have limited all our data to those with gold concentrations greater than 1 g/t or reasonably inferred by cited reporters to be greater than 1 g/t.

Gold-bearing skarns are generally calcic exoskarns with gold associated with intense retrograde hydrosilicate alteration, although Au-bearing magnesian skarns are known and in some areas are dominant. Some economically significant Au-bearing skarns (Hedley, British Columbia, and Suian, South Korea), however, are partly in endoskarn (Barr, 1980; see also Lee, 1951; Lee, 1981). Reported pyrrhotite, chalcopyrite, and "augite" enclosed in quartz monzonite at the Golden Curry deposit, Montana, may be endoskarn (Knopf, 1913; Pardee and Schrader, 1933). Significant concentrations of gold-bearing endoskarn also are present at the Nambija, Ecuador, Au-skarn deposit (table 4). In some districts, our data set includes deposits that are significantly distant from igneous contacts at current levels of erosion but still exhibit high-temperature, prograde mineral assemblages composed of garnet and (or) pyroxene. Gold-bearing skarns show diverse geometric relations to genetically associated intrusive rocks and nearby premetallization structures (fig. 4).

As presently constituted (tables 2, 3), our compilation includes some deposits that were previously considered as Cu, Fe, or Zn-Pb skarns in the classification schemes of Einaudi and others (1981) and Meinert (1988a). In some cases when establishing deposit size or grade, we have included other styles of genetically related, generally late-stage mineralization adjacent or continuous to known skarn mineralization under the size estimate and description of the Au-bearing skarn deposit when demarcation between the mineralization styles would be arbitrary.

Associated Deposits

Deposit types most commonly associated with Au-bearing skarn include Cu, Fe, Zn-Pb, and porphyry Cu skarn-related deposits. Other deposit types include porphyry Cu-Mo or Cu-Au deposits, porphyry Cu deposits, carbonate-hosted Au-Ag (see Sillitoe, 1983), polymetallic replacement and polymetallic veins, distal disseminated Ag-Au deposits (Dennis P. Cox, written commun., 1989), W skarns, Sn skarns and greisens, Au placers, and other deposits related to felsic and intermediate intrusions (Cox and Singer, 1986), including stockwork molybdenum systems such as at Red Dome, Australia, and Buckingham, Nevada. The Carissa and the Surprise Cu-Au-Ag skarn deposits are on the northern fringes of the Late Cretaceous (86 Ma) Buckingham, Nevada, stockwork molybdenum system, and they appear to be related genetically to emplacement of potassic-altered monzogranite porphyry (Schmidt and others, 1988; Theodore and others, 1989). Other examples of deposits associated with Au-skarn include skarn mineralization at Katanga, Peru, which becomes porphyry Cu-Mo mineralization at depth, and the deposit at Bau, Indonesia, that includes a large component of sediment-hosted gold mineralization as well as that hosted by skarn. Other areas that probably document transition from a skarn environment into mostly sediment-hosted systems are silver and gold mineralization at the McCoy-Cove mineralized system in north-central Nevada, gold mineralization in the general area of the Broadway, Montana, Au-skarn deposit (Sahinen, 1939), and mostly gold at the Kavak-tau area in Kirghiziya, U.S.S.R. (Dolzhenko, 1974). Near the Broadway deposit and other nearby Au-skarn-related occurrences, Au-bearing jasperoid mantles epidote-rich endoskarn that formed at the contact of Cretaceous quartz monzonite and Cambrian limestone (Sahinen, 1939). At Kavaktau, most of the gold mineralization is apparently associated with "secondary silicates," probably jasperoids in North American terminology, that are present in marble and silicate-carbonate rock beyond the outer limit of well-developed skarn assemblages. Placer gold deposits are found associated with copper and gold deposits of the Battle Mountain Mining District, Nevada, of the Helena, Bannack, and Cable Mining Districts, Montana, and in the Zeballos area, Vancouver Island, British Columbia. Gradational changes from Au-bearing skarn mineralization to another deposit type (Myers and Meinert, 1988), relatively small areas of gold enrichment within or peripheral to base- or ferrous-metal skarn mineralization, the presence of minerals that can be attributed to weak or distal development of skarn in deposit types not in a contact-metamorphic aureole, and continuous gold mineralization through multiple deposit types related to a single intrusion or series of events are common to Au-bearing skarn environments. In many gold-enriched skarn deposits of British Columbia, Ettlinger and Ray (1988) noted multiple types of gold mineralization within single deposits. For example, at the Discovery deposit at Banks Island, gold is present in skarn with massive pyrrhotite that replaces marble, as well as in brecciated quartz-pyrite veins that cross-cut skarn and marble. Ettlinger and Ray suggested that skarn and quartz-pyrite mineralization may be genetically linked. Similarly, high-grade gold mineralization (Parnell gold shoot) overprints earlier formed copper-gold skarn at Carr Fork in the Bingham district, Utah (Cameron and Garmoe, 1987).

Further studies are needed to address the problem of whether all of the gold, or some of the gold in a few deposits, represented a much later epithermal overprint on an earlier skarn system or was deposited as a continuum near the final stages of the skarn process along structures that permitted extensive development of retrograde assemblages.

In a number of mining districts that contain gold skarn deposits, ore deposits are zoned from a core area (sometimes, but not always, a porphyry copper or other stock) of Cu±Au and Ag mineralization, to an intermediate zone of Au-skarn or other types of gold mineralization, to an outermost area of dominantly Zn+Pb+Ag±Au mineralization. Blake and others (1984) demonstrated such a zonation about the middle Tertiary altered granodiorite stock of Copper Canyon in the Battle Mountain Mining District, Nevada, where the Tomboy-Minnie and Fortitude gold skarn deposits lie between an area of Cu+Au+Ag and Pb+Zn+Ag mineralization. El-Shatoury and Whelan (1970) described a zonal arrangement of ore deposits in the Gold Hill Mining District, Utah, from a central zone of W+Mo+Cu, through Cu, Cu+Au, Cu+Pb+As and Pb+Zn+Au mineralization. The Alvarado, Cane Spring, and Bonnemort skarn deposits all lie within the Cu+Au zone in the Gold Hill Mining District. In the Elkhorn Mining District,

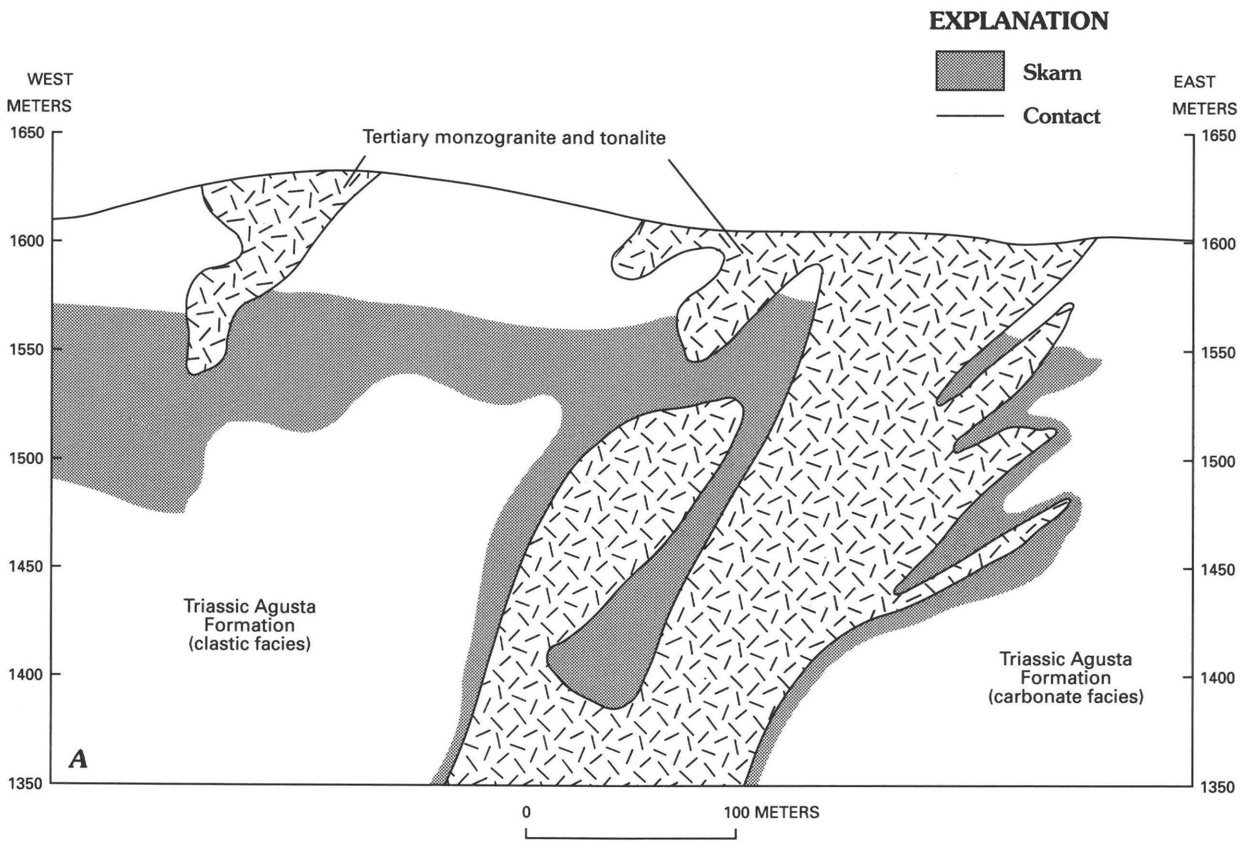


Figure 4. Schematic cross sections of Au-skarn deposits in north-central Nevada. *A*, McCoy Mine, modified from Lane (1987). *B*, Fortitude Mine, modified from Myers (1988). *C*, Surprise Mine, modified from Schmidt and others (1988).

Montana (Klepper and others, 1957), the distribution of deposits around the eastern edge of the stock of the Black Butte area suggests that the Klondyke and Dolcoath gold skarn deposits, and possibly the Golden Curry deposit to the west, represent a gold-rich zone interior to a zone of Pb+Ag mineralization.

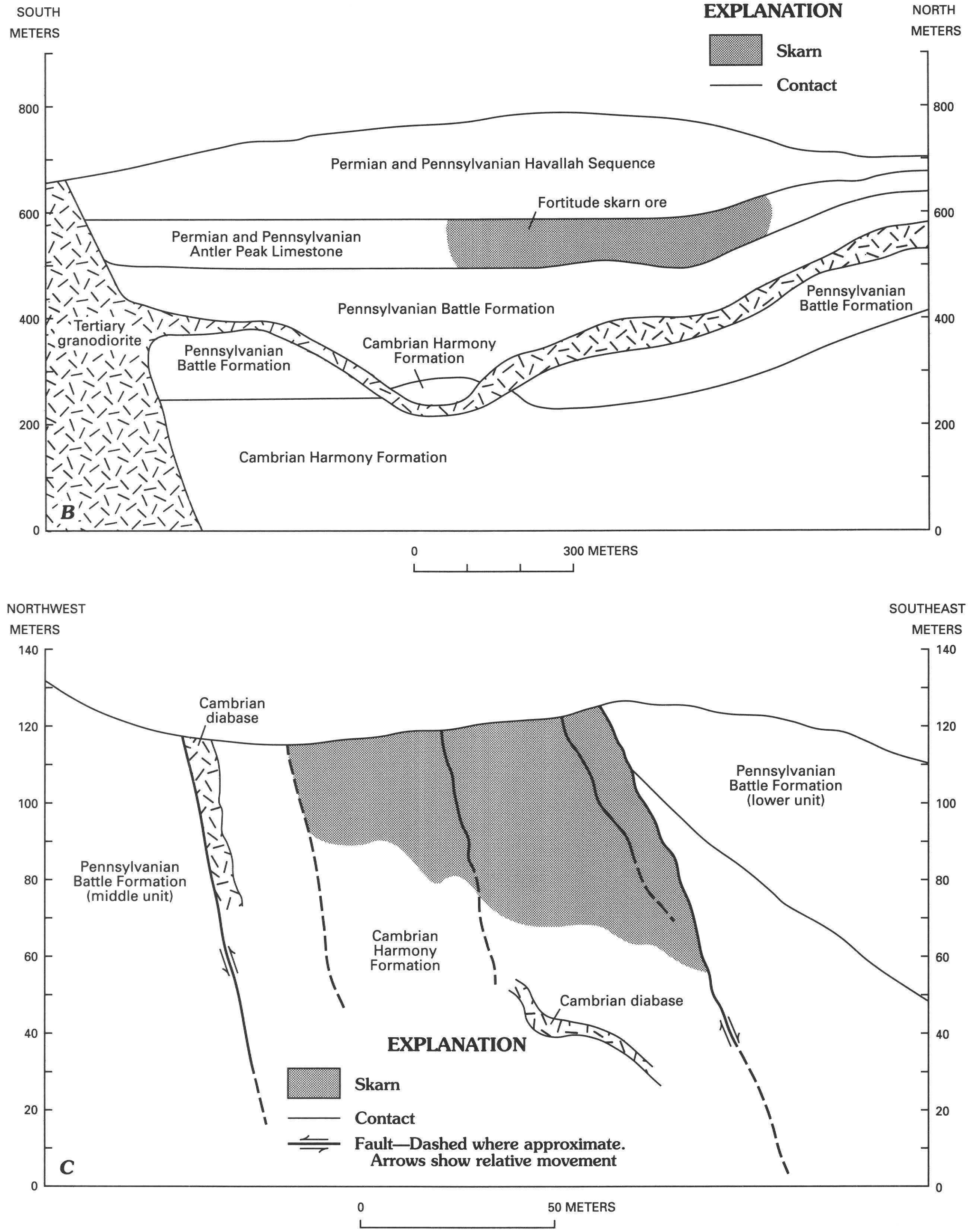


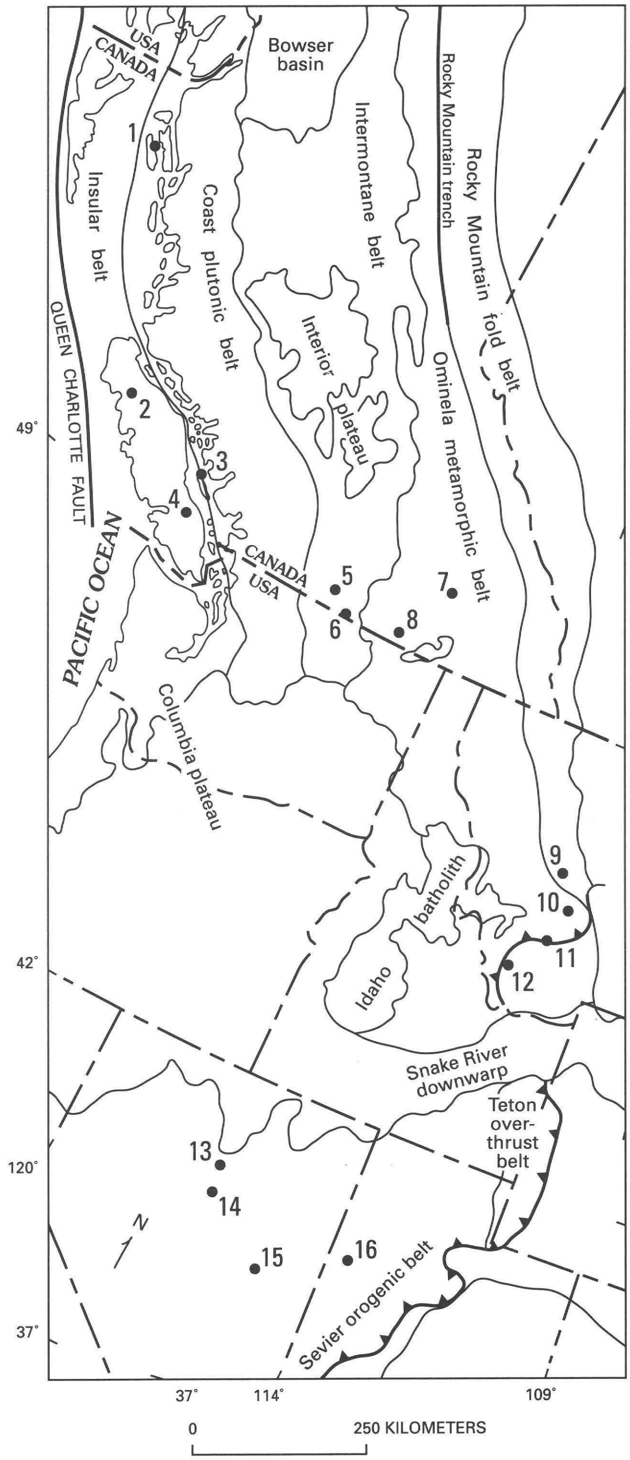
Figure 4. Continued.

Tectonostratigraphic Setting and Paleodepths

In North America, Au-bearing skarn is present most commonly in Mesozoic and Cenozoic orogenic-belt and island-arc settings (fig. 5); a few Au-bearing skarns have been found in rifted craton. The regional distribution of Au-bearing skarns may have been confined partly by emplacement of Au-enriched magmato-hydrothermal systems possibly controlled by long-active rifts intersecting the craton's edge in the continental-margin environment of western North America (Roberts, 1966). Such magmatism may be related to onset of regional-scale extensional tectonism in the northern Great Basin.

Ettlinger and Ray (1989) examined the distribution of 126 precious-metal-enriched skarns in British Columbia in terms of tectonic belt and tectonic terrane. They found that gold- and silver-bearing skarns are present throughout the four westernmost, mobile tectonic belts in British Columbia, but are absent from the easternmost, stable Foreland belt. Of the 14 terranes in which precious-metal-enriched skarns are present, Ettlinger and Ray (1989) showed that most occurrences and most producing deposits are in the Wrangellia and Quesnellia terranes. Most of the gold produced from skarns in British Columbia comes from deposits in the Quesnellia tectonic terrane, which includes the world-class gold skarn deposit at Hedley and the Greenwood Mining District. A recently announced gold skarn occurrence in northern Washington, the Buckhorn Mountain deposit (table 4), lies within the southern extension of the Quesnellia terrane into the United States (Silberling and others, 1987). A similar analysis of the terrane distribution for the 106 Fe-Au-skarn occurrences (34 producers) reported by Newberry (1986) reveals 54 occurrences (24 producers) in the Alexander terrane, followed by 26 occurrences (6 producers, including the large Nabesna deposit) in Wrangellia, and 15 occurrences (2 producers) in the Peninsula terrane. Less than 5 occurrences in each are reported for the Tracy Arm, Chulitna, Dillinger, Mystic, and Nixon Fork terranes.

Island-arc volcanic sequences, clastic sediments, and comagmatic calc-alkaline intrusions are common features of the terranes that host the largest proportions of known Au-skarn deposits in British Columbia and in Alaska (Ettlinger and Ray, 1989; Monger and Berg, 1987; Jones and others, 1987). In the conterminous United States, the important gold skarn districts of north-central Nevada lie in the Roberts terrane (Silberling and others, 1987), in a geographic position analogous to Quesnellia to the north, just west of ancestral North America proper. However, the



EXPLANATION

Au-skarn districts:

1	Banks Island/Discovery	9	Ophir/Elliston
2	Zeballos	10	Elkhorn
3	Texada Island	11	Silver Star
4	Vancouver	12	Bannack
5	Hedley	13	Battle Mountain
6	Dividend-Lakeview	14	McCoy
7	Tillicum Mountain	15	White Pine
8	Greenwood	16	Gold Hill

Thrust fault—Sawteeth on upper plate

Figure 5. Distribution of Au-skarn districts and geological provinces in the cordillera of western North America. Modified from Monger and others (1972).

gold skarn districts of southwestern Montana, and Utah occur to the east of the accreted terrane boundary.

Some of the most productive Au-skarn systems in western North America apparently formed in relatively shallow seated geologic environments, probably at 1.5-3.0 km below their respective paleosurfaces. Other Au-bearing skarn systems formed as much as 5 km below their paleosurfaces. At the Mottini Mine in the IXL Mining District, Nevada (table 4; also see Schrader (1947) and Vanderburg (1940)), gossaniferous Pb-Zn-Cu skarn with some gold is associated with emplacement of a 28-Ma, zoned granodiorite that is cogenetic with a tilted caldera (David A. John, oral commun., 1989). The Au-bearing Pb-Zn-Cu skarn apparently developed approximately 5 km below the 28-Ma paleosurface on the basis of removal of the present-day tilts in the rocks of the caldera. The 38- to 39-Ma Au-skarns at McCoy, Fortitude, Tomboy-Minnie, and Labrador, all in Nevada, regionally are clustered not far from the 34-Ma erosion surface upon which the 34-Ma Oligocene Caetano Tuff was deposited. This relation suggests that those four Au-skarn systems must have formed in a relatively shallow geologic environment—a conclusion confirmed by study of fluid-inclusion relations in the Au-skarn deposits (see below). Much less abundant are Tertiary Au-bearing skarns in cratonic environments (Bright Diamond and Iron Clad, Colorado, see Irving, 1905; Irving and Cross, 1907).

In the Soviet Union, most reported data on Au-bearing skarns seem to indicate development in geologic environments deeper than those in western North America. As such, they have been classified as medium-depth deposits according to the scheme of Bodaevskaya and Rozhkov (1977). Furthermore, according to them, Au-bearing skarns are associated with deformed Paleozoic early-eugeoclinal-stage batholiths of granite-granodiorite composition or with minor Paleozoic late-eugeoclinal stage gabbro-plagiogranite or gabbro-syenite intrusive complexes. In Australia, most known Au-bearing skarns are in the Paleozoic Tasman geoclinal belt, and some of the most significant deposits (Red Dome) are associated with late Paleozoic stocks. Worldwide distribution of some important Au-bearing skarns relative to major fold belts is shown in figure 6.

Age Range

Gold-bearing skarns are generally Mesozoic or Tertiary in the cordillera of western North America, probably middle Tertiary in the rifted cratonic regions (Bright Diamond, Iron Clad, Colorado), and probably middle Tertiary in West Sarawak, Malaysia (Bau), according to Wolfenden (1965). Several significant systems of early Paleozoic age are also known in the Soviet Union, and a significant Au-bearing skarn in Australia (Red Dome) is late Paleozoic in age. The base-metal-dominated deposits at Falun and Garpenberg Oda, in Sweden, are present in Proterozoic rocks (table 3).

Host and Associated Rocks

Gold-bearing skarn may be hosted by a wide variety of sedimentary and igneous rocks, including limestone, dolomite, shale, conglomerate, rhyolitic to andesitic tuff, and granitoids; however, a premetamorphic calcareous component is commonly present. Meinert (1988b) further noted that the overwhelming bulk of the Au-skarns are present in clastic or volcaniclastic-rich sequences. Pearson and others (1989) showed that gold-bearing skarns in the Dillon, Montana, 1° x 2° quadrangle have the same gangue minerals and same kinds of associated plutons as tungsten skarns in the area but that the tungsten skarns are mostly hosted by the Mississippian and Pennsylvanian Amsden Formation whereas gold-bearing skarns in the Bannack and Silver Star Mining Districts are in Mississippian Mission Canyon Limestone.

In general, compositionally expanded I-type (Chappell and White, 1974) felsic and intermediate plutons, dikes, sills, or stocks that may or may not be porphyritic are associated with Au-bearing skarn. Some deposits (for example, Tumco, California) may be associated with weakly to strongly peraluminous calcic granite (Smith and Graubard, 1987). In north-central Nevada, Au-skarns (Fortitude, McCoy, Northeast Extension, Surprise, Carissa, Labrador) are associated with monzogranite stocks (table 5), whereas in British Columbia many Au-bearing skarns (Tillicum Mountain, Oka) are associated with diorite to gabbro stocks (see Ray and others, 1987a, b). In addition, Keith and Swan (1987) have shown that an area in north-central Nevada with plutons that have reduced ferric:ferrous ratios (less than 0.85) correlates in part with the regional distribution of Au-bearing sediment-hosted and porphyry deposits. According to them, such reduced ratios may reflect minor assimilation of reduced crust during magma genesis. Leveille and others (1988) showed that most Au-associated plutons have low oxidation state and (or) high alkalinity when plotted in terms of an alkalinity index (K_2O+Na_2O-0.57 SiO_2) and ratio of Fe_2O_3 to FeO. Meinert (1983) presented mean compositions for igneous rocks associated with different types of mineralized skarn and noted that the most distinctive chemical trends are for parameters that reflect magmatic oxidation state and degree of differentiation, notably ferric:ferrous ratios and alkali contents. The mean igneous rock composition associated with Au-bearing skarns (J.M. Hammarstrom, unpub. data, 1989) and with other types of mineralized skarns (Meinert, 1983) is shown in figure 7. Gold-bearing skarns appear to be associated with slightly less siliceous rocks than other skarn types, and in terms of alumina, total alkalis, and calcium they are most similar to granitoids associated with iron and copper skarns (fig. 7).

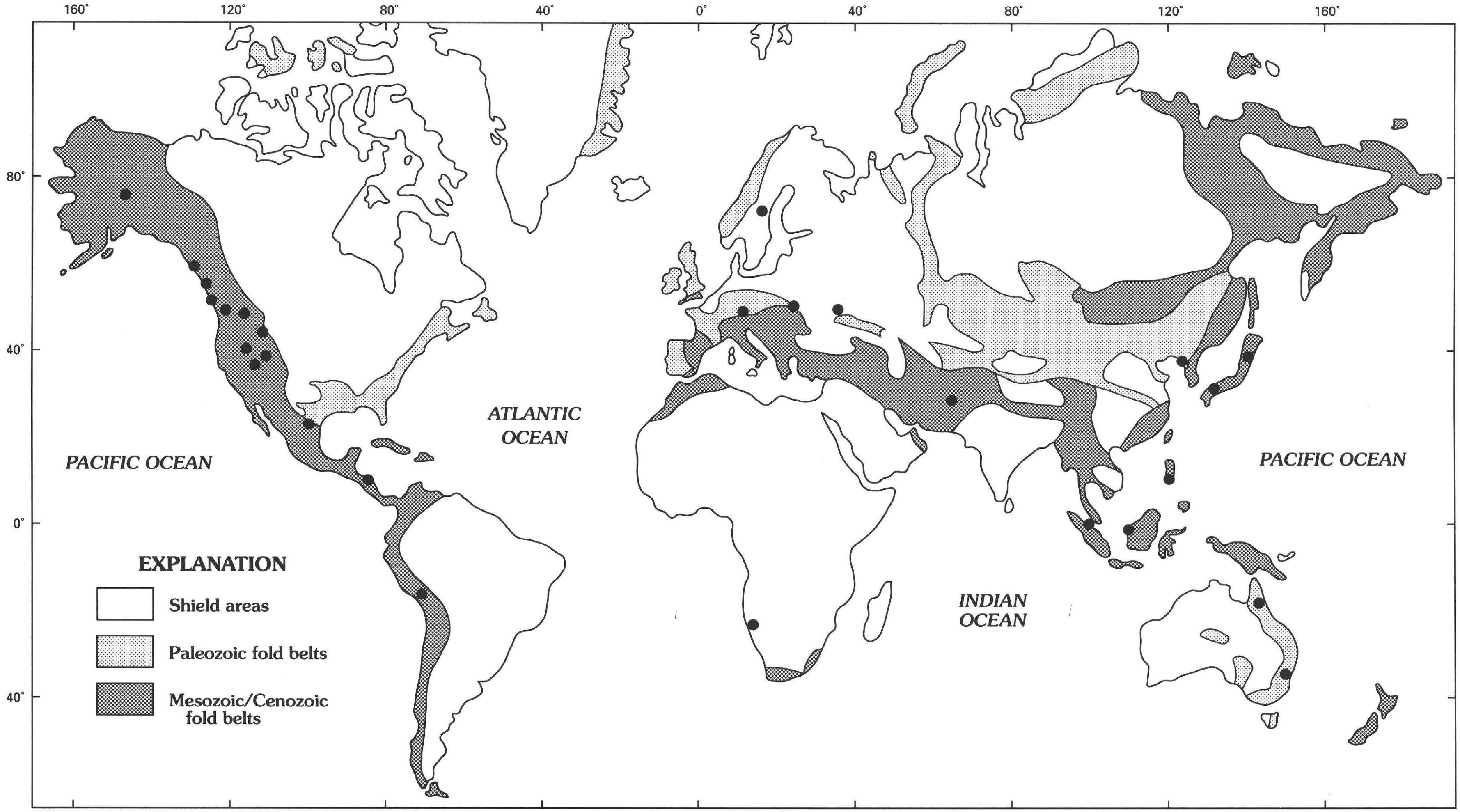


Figure 6. Worldwide distribution of major Au-bearing skarn deposits (solid dots) and fold belts.

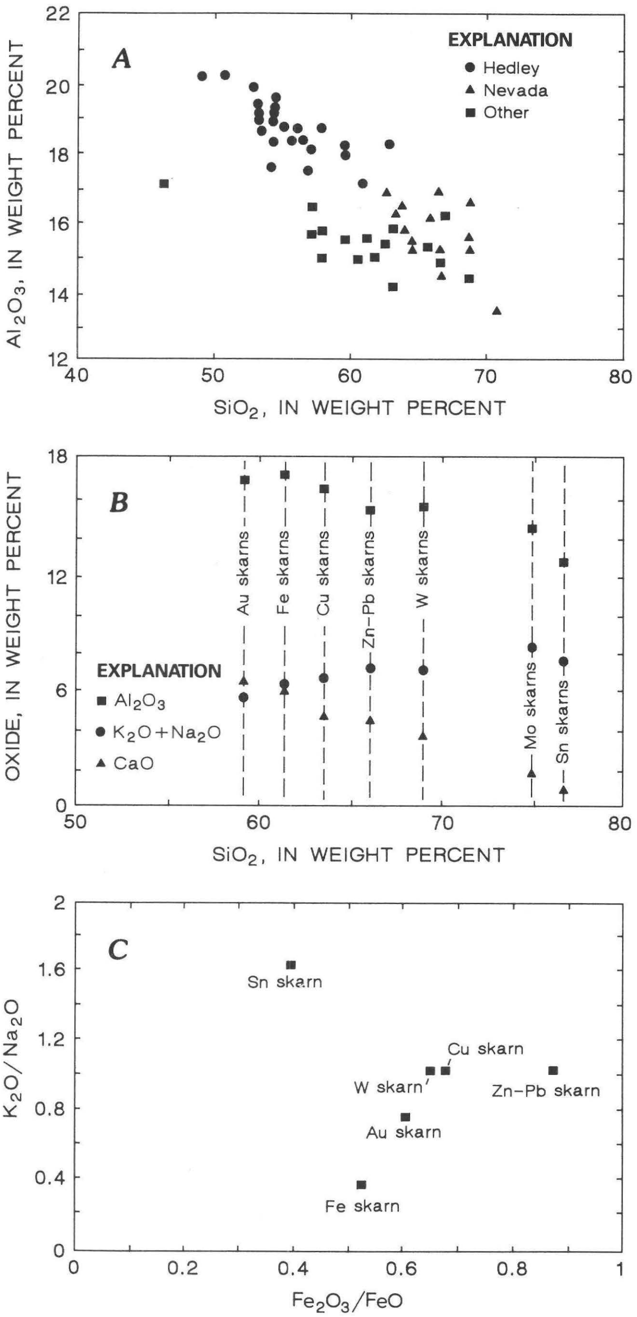


Figure 7. Chemical compositions of igneous rocks associated with major types of mineralized skarn. *A*, Al_2O_3 versus SiO_2, in weight percent, for unaltered igneous rocks associated with Au-bearing skarn deposits in the Hedley district, British Columbia (Ray and others, 1987a), in the Battle Mountain and McCoy districts, Nevada (this study), and in other districts. *B*, Mean compositions for igneous rocks associated with major skarn classes, in terms of weight percents. Squares, Al_2O_3; filled circles, K_2O+Na_2O; triangles, CaO. Data for Au-skarn, this study; data for other skarns, from Meinert (1983). *C*, Mean compositions for igneous rocks associated with major skarn classes in terms of alkali and oxidation ratios. Same data sources as in *B*.

Our preliminary compilation also suggests that the intrusions associated with Au-bearing skarns appear to be more reduced than intrusions associated with copper and (or) iron skarns, also noted by Keith and Swan (1987), and are less evolved than those associated with tin skarn mineralization. These associations do not necessarily imply that all gold in skarn originates in the nearby genetically associated pluton.

In southwestern Montana, a number of gold-bearing skarn districts lie at the periphery of the Cretaceous Boulder batholith and appear to be associated with satellite bodies and with sodic series rocks of the batholith rather than with main series rocks, as defined by Tilling (1973) on the basis of rock chemistry.

Ore Minerals

Ore minerals typically found in Au-bearing skarn include native gold, electrum, pyrite, chalcopyrite, pyrrhotite, arsenopyrite, sphalerite, galena, bismuth minerals (especially bismuthinite and native bismuth), magnetite or hematite, tellurides (commonly those of Au, Ag, Ni, and Pb), tetrahedrite, tetradymite, bornite, marcasite, loellingite, stibnite, and W- and Mo-bearing minerals. Mineral abundances for ore and gangue assemblages (table 5) were compiled for our Au-skarn data (table 2) and for our byproduct Au-skarn data (table 3), along with the minerals reported by Newberry (1986) for 106 Alaskan Fe-Au-skarn deposits. This compilation is based on the assemblages reported in tables 2 and 3 from the references cited therein. We emphasize that these data are not modal and are probably incomplete, so the actual percentages of various minerals reported are not significant. However, the relative abundance of a given mineral, the frequency of occurrence of some unusual minerals, and apparent differences in mineralogy between deposits mined primarily for gold and those where gold is recovered as a byproduct may be significant in characterizing gold skarn deposits.

Meinert (1988a, b) stated that the most abundant sulfide minerals in gold skarns are arsenopyrite, pyrrhotite, and marcasite and also noted the common occurrence of bismuth and telluride minerals. R.G. Russell (written commun., 1989) reported pyrrhotite as the principal sulfide mineral in gold exoskarn, with lesser amounts of arsenopyrite and traces of chalcopyrite, but noted that the major gold skarn deposits in the Hedley district, on which much of his model is based, are unusually arsenic-rich. Our compilation (table 5) suggests a different conclusion. Chalcopyrite is the most common sulfide mineral reported; it is reported from 85 percent or more of the deposits in all three data sets. For the Au-skarn data set, the next most common ore minerals reported (in decreasing order of occurrence) are pyrite, pyrrhotite, gold (or electrum), arsenopyrite, sphalerite, magnetite, galena, tellurides, bismuth (or bismuthinite), hematite (or specularite), molybdenite, hedleyite, and scheelite. For the byproduct Au-skarn data set, following chalcopyrite, the sequence is pyrite, magnetite, pyrrhotite, sphalerite, gold (or electrum), galena, hematite (specularite), molybdenite, arsenopyrite, scheelite, tellurides and bismuthinite. None of the byproduct Au-skarn deposits report hedleyite.

As might be expected, magnetite is the most commonly reported ore mineral in the Alaskan Fe-Au-skarn data set, galena is uncommon, and no bismuth minerals, tellurides, free gold or electrum, or scheelite are reported. In many of the deposits that report no free gold or electrum, gold is present as auriferous pyrite, gold tellurides, and auriferous jasperoid, and in some cases the mineralogic residence of gold in the system is not identified. In some deposits, silver occurs in Bi-bearing galena. Some free gold and native bismuth occur in galena, all as probable late-stage reaction products from breakdown of cosalite (ideally $Pb_2Bi_2S_5$) or galenobismutite (ideally $PbBi_2S_4$) near the northern, distal edge of the Fortitude Au-skarn deposit (T.G. Theodore, unpub. data, 1989). These samples show prominent myrmekitic or eutectoid-type intergrowths between native bismuth and galena. Some domains of mostly intergrown native bismuth and galena at the Fortitude deposit include small anhedral blebs of gold. Other phases present in very minor amounts include bismuthinite, tellurobismutite, and possibly schirmerite (ideally $3(Ag_2,Pb)S{\bullet}2\ Bi_2S_3$).

In addition, many other minerals have been reported for skarns studied in detail, including scorodite, wittichenite, sperrylite, and malayaite. Textural relations of electrum in massive pyrrhotite and in association with native bismuth and galena in clinopyroxene at the Fortitude, Nevada, deposit; gold in late-stage quartz-potassium feldspar-garnet assemblages that cut Jurassic granodiorite at the Nambija, Ecuador, Au-skarn deposit; gold in iron oxide(s) that replace pyrite and (or) pyrrhotite at the Surprise, Nevada, deposit; and gold in pyrite at the McCoy, Nevada, deposit are shown in figure 8.

Gangue Mineralogy

Typical composite assemblages in Au-bearing skarn include garnet (andradite-grossular), pyroxenes (diopside-hedenbergite), wollastonite, chlorite, epidote-clinozoisite-zoisite, scapolite, quartz, actinolite-tremolite, prehnite, potassium feldspar, plagioclase, calcite and serpentine as gangue. Additionally, various micas, ilvaite, vesuvianite, talc, sphene, fluorite, apatite, and abundant clays have been reported from several deposits (tables 2, 3).

Garnet and epidote, its typical retrograde alteration product, are the most commonly reported minerals in gold-bearing skarns (table 5), followed by pyroxene, amphibole, and chlorite. Of the 39 deposits in our gold skarn subset, 5 (13 percent) report boron minerals in the gangue assemblage, including axinite and ludwigite. No boron minerals are reported in the byproduct Au-skarn subset or in Newberry's (1986) Alaskan Fe-Au-skarn compilation Many deposits include both garnet and pyroxene, but others report only one mineral or the other or are zoned from proximal garnet-rich to distal pyroxene-rich assemblages. Pyroxene tends to be dominant in unoxidized, pyrrhotite-rich, more distal skarns, such as the Fortitude deposit, Nevada (Myers and Meinert, 1988). Massive hedenbergite skarn formed in the Black pit of the Broadway Mine in the Silver Star Mining District, Montana, distal to mineralized jasperoid at the granodiorite contact (Larry Hillesland, oral commun., 1989).

Garnet is the characteristic prograde silicate mineral of many calcic Au-bearing skarns (rocks are commonly massive garnetite); garnet is later than and replaces pyroxene. Mineral chemistry studies show that garnets are andradite-grossular solid solutions (mostly Ad_{30} to Ad_{100}) with less than 5 mole percent pyralspite components. Both isotropic and anisotropic varieties are common (fig. 9). Multiple generations of garnet are present in some deposits (for example, Fortitude, Surprise, and McCoy, Nevada). In some deposits from north-central Nevada, early garnet is colorless, anisotropic, zoned toward more Fe-rich rim compositions,

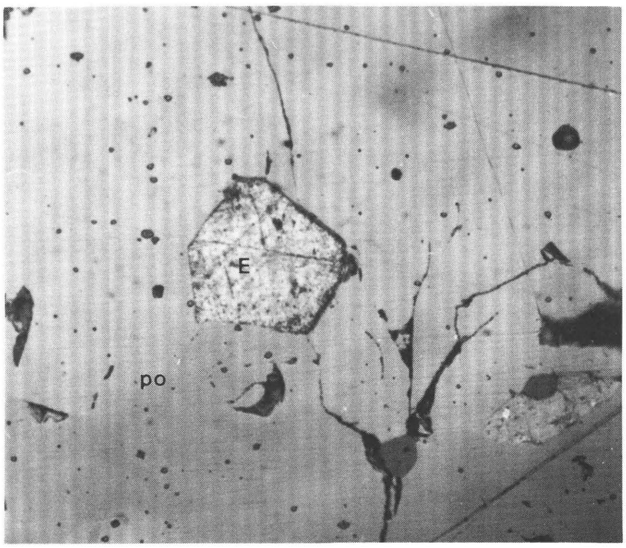


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Figure 8. Textural relations of gold and electrum in selected Au-skarn deposits. Au, gold; E, electrum; Q, quartz. *A*, Electrum in massive pyrrhotite (po) from the Lower Fortitude, Nevada, Au-skarn deposit. Plane-polarized light. *B*, Electrum associated with native bismuth (B) and galena (G) hosted by clinopyroxene (cpx) from the Lower Fortitude, Nevada, Au-skarn deposit. Backscattered electron micrograph. *C*, Gold in quartz associated with a quartz-garnet (ga)-potassium feldspar assemblage that alters granodiorite at the Nambija, Ecuador, Au-skarn deposit. Plane-polarized, reflected light. *D*, Gold in pyrite (py) associated with quartz from the McCoy, Nevada, Au-skarn deposit. Backscattered electron micrograph. *E*, Electrum (Au_6Ag_4) in limonite (L) from the 5,595-ft bench, Surprise, Nevada, Au-skarn deposit. Plane polarized, reflected light; reflectivity differences due to variations in content of silica.

and poikilitically encloses relict diopsidic pyroxene. Late garnet pods and veins are inclusion-free, are less altered than early garnets, and have distinctly yellow (in thin section), isotropic, andradite cores and colorless, anisotropic rims that have oscillatory zoning with respect to Al and Fe. Contents of 0.4 to 3 weight percent TiO_2 are common for early garnet, whereas late garnet is nearly Ti-free. Garnet compositions for representative samples of some Au-bearing skarns from north-central Nevada (fig. 10) fall within the compositional fields outlined for garnets from copper and magnetite skarns and are distinct from garnets associated with tungsten, tin, zinc, and molybdenum skarns, primarily due to more oxidized, less manganiferous compositions. Ettlinger and Ray (1989) reached similar conclusions for garnet compositions in precious-metal-enriched skarns from British Columbia.

Meinert (1988a) suggested that garnets associated with gold skarns may be more aluminous than those associated with many other skarn types. Bin and Barton (1988) inferred from a study of mineralized skarns in China that andradite components in andradite-grossular garnets of calcic skarn will decrease gradually in the following order of associated metals: W-Zn-Cu, Fe-Cu, W-Bi-Cu-Mo, Fe, Sn-Mo-Bi-W, Cu-Zn, Sn, Pb-Zn, W. Compositions as aluminous as Gr_{60} to Gr_{70} are observed for some zones in garnets from the McCoy and Surprise deposits; however, nearly pure andradites are present within the same domains at a thin-section scale. Myers and Meinert (1988) have shown that garnet in the distal Fortitude Au-skarn has compositions (Ad_{90-100} cores; Ad_{30-60} rims) that contrast with garnets in the West orebody Cu-Au-Ag skarn (Ad_{70-100}), which is proximal to altered granodiorite of Copper Canyon

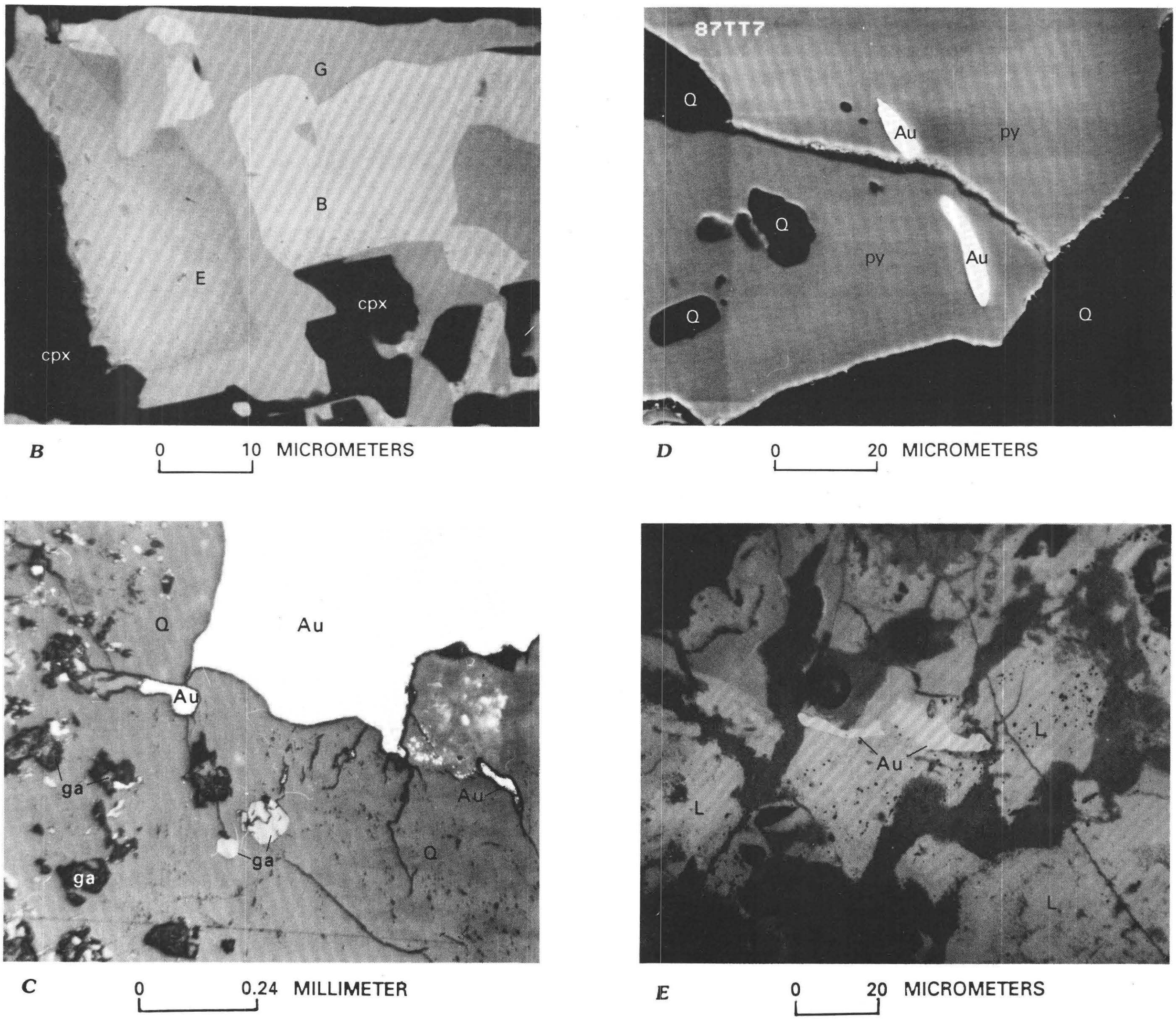

Figure 8. Continued.

(Theodore and Blake, 1978). Brooks and others (1989) reported garnet compositions of Ad_{15-100} for the McCoy deposit, Nevada, which includes the range of compositions encountered in our study of selected samples (fig. 10).

Reported hand-specimen colors for garnets from Au-skarns vary from buff to yellow to yellow-green to red to brown. Different colors can be used to distinguish among different generations and different compositions within some deposits, however, correlations of a particular color with a particular range of composition are highly variable. Einaudi (1982) noted that garnets in skarns associated with porphyry copper deposits are commonly reddish brown proximal to the stock and greenish distal to the stock. Meinert (1988a) found yellowish-tan to brown garnet in skarn formed in limestone and reddish-brown garnet in skarn formed in dolostone in moderately gold-bearing porphyry-Cu skarn in the Whitehorse Mining District, Canada. Torrey and others (1986) reported brown and green garnet (Ad_{95} to Ad_{100}) with pyroxene (Hd_{10} to Hd_{15}) in early-metasomatic stage skarn at Red Dome, Australia, red-brown garnet (Ad_{40} to Ad_{60}) with pyroxene (Hd_5 to Hd_{35}) in late-metasomatic wollastonite-garnet endo-exoskarn associated with rhyolite porphyry, and pale-green garnet (Ad_{50} to Ad_{100}) with minor pink garnet (Ad_{60} to Ad_{80}) associated with early retrograde alteration and the minerals vesuvianite, epidote, quartz, fluorite, calcite, chlorite, sphene, orthoclase, magnetite, and hematite. At Red Dome, most of the primary copper-gold-silver ore is in wollastonite-garnet skarn. Red, brown, yellow, and green garnets, all more iron-rich than Ad_{90}, formed in limestone at Carr Fork, Utah (Atkinson and Einaudi, 1978). Callow

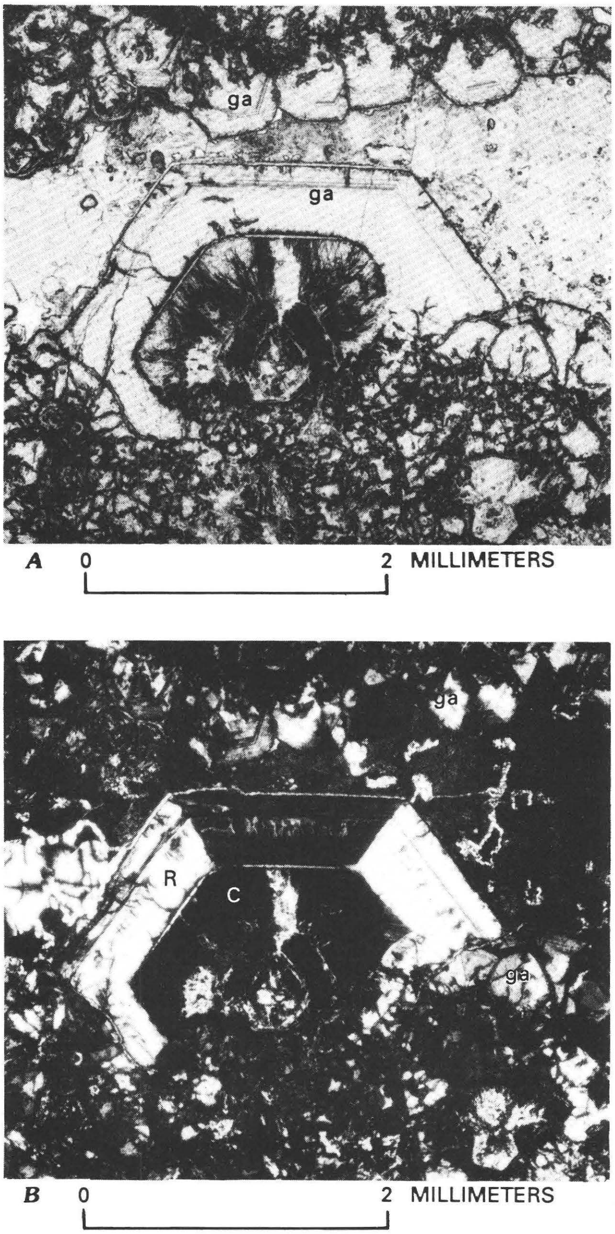

Figure 9. Photomicrographs showing complexly zoned garnets (ga) from oxidized skarn, Surprise Mine, Nevada. *A*, Plane-polarized light; note growth zone in garnet rim. *B*, Crossed nicols; garnet has isotropic, andradite core (C) and sector-twinned, anisotropic, oscillatorily zoned rim (R).

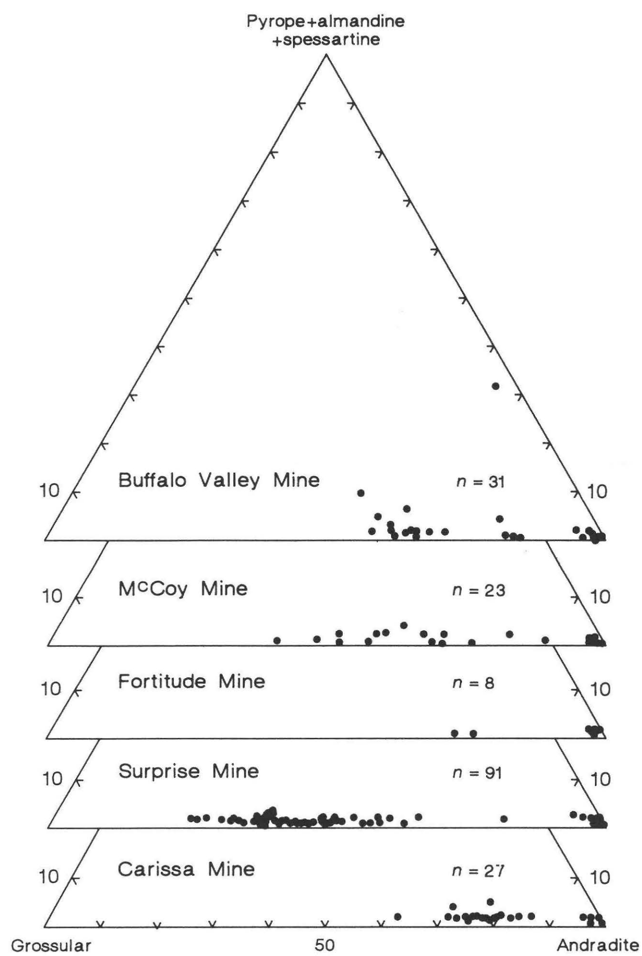

Figure 10. Ternary diagrams showing ranges of garnet compositions for representative samples from five Au-bearing skarn systems in north-central Nevada. *n*, number of samples.

(1967) presented an andradite analysis for brown garnet in garnet-clinozoisite skarn at the Thanksgiving Mine in the Philippines. Late, coarse, zoned andradite (Ad_{85} to Ad_{100}) is reported as the latest skarn mineral in some Au-bearing skarn from the Altai-Sayan region (Vakhrushev, 1972). The wider range of compositions reported for more recent (1980's) studies reflects data acquired by electron microprobe, wherein compositional data for different grains and different zones within a grain can be obtained, whereas much of the earlier data represents wet chemical analysis of a garnet separate.

Many recent studies have examined garnet zoning patterns and protolith effects on garnet composition for gold-mineralized skarn systems (for example, Beddoe-Stephens and others, 1987; Hammarstrom *in* Theodore and others, 1989; Ettlinger and Ray, 1989; Brooks and others, 1989). These studies show that (1) garnets commonly remain stable throughout extensive retrograde alteration processes, (2) TiO_2 contents of a few weight percent are typical of many garnets, especially those formed from impure carbonates or noncarbonates, and (3) although the normal zoning trends (core to rim increases in andradite content) typical of copper and base-metal skarn garnets are observed, aluminous zones and aluminous rims may be a feature peculiar to gold-mineralized systems. Ettlinger and Ray (1989) suggest that the deposition of Al-rich zones in both garnets and pyroxenes (see below) in precious-metal-enriched skarns reflects changes in availability or solubility of aluminum in the system. Alternatively, fluctuations in ferric iron-aluminum availability in the system could reflect changes in sulfidation state (J. Hemley, oral commun., 1989); that is, ore minerals (predominantly iron sulfides) could effectively deplete the iron available at silicate-hydrothermal fluid interfaces, resulting in growth of relatively aluminous zones.

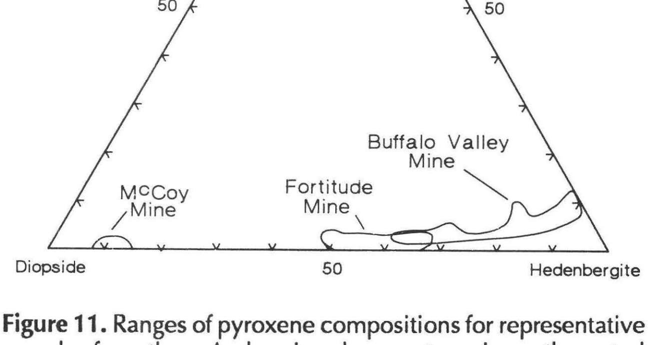

Figure 11. Ranges of pyroxene compositions for representative samples from three Au-bearing skarn systems in north-central Nevada.

Pyroxene in Au-bearing skarns is typically a diopside-hedenbergite solid solution having low manganese contents. Vakhrushev (1972) described diopside (pure to Hd_{20}) as the characteristic pyroxene of the Altai-Sayan gold skarns. Pyroxene in garnet skarn at the middle Tertiary McCoy deposit is diopside-rich (Hd_{10} to Hd_{50}, <3 percent johannsenite). Pyroxene coexisting with massive pyrrhotite, other sulfides, and late garnet at the Fortitude deposit is more iron-rich (Hd_{40} to Hd_{60}) whereas pyroxene in pale-green garnetite skarn from the 5,770-ft bench of the Buffalo Valley Mine is nearly pure hedenbergite (Hd_{80} to Hd_{92}) (table 7; fig. 11). Skarn mineral assemblages in the gold-enriched part of the Marn property, Yukon, contain iron-rich pyroxene (Hd_{40} to Hd_{80}) (Brown and Nesbitt, 1987). Brooks and others (1989) noted the presence of narrow aluminous zones in pyroxenes from the McCoy deposit. Ettlinger and Ray (1989) recognized similar zones in pyroxenes in precious-metal-enriched skarns from British Columbia and suggested that (1) the presence of high $Al_2O_3+TiO_2$ (>1.25 weight percent) in skarn pyroxene may be an indication of precious-metal potential, and (2) the presence of very iron rich (>26.0 weight percent FeO) or very iron poor (<3.5 weight percent FeO) pyroxenes may indicate a low precious-metal potential for a given skarn.

Amphibole typically replaces pyroxene as pseudomorphs in Au-skarns and is present with sulfides; reported compositions include actinolite, tremolite, ferro-tremolite, and hornblende. Representative amphibole compositions for some Nevada gold skarns are given in table 6, along with data for other minerals. In sulfidized skarn at the Fortitude deposit, ferro-actinolite (low fluorine, as much as 1 percent MnO, 2 percent Al_2O_3) is intergrown with or replaces pyroxene; pyroxene is present adjacent to massive garnet that is replaced partly by pyrrhotite and chalcopyrite (fig. 12). Actinolite is present with epidote and chlorite in sulfidized retrograde skarn at the Northeast Extension Mine, and in pyrite in garnet skarn at the Carissa Mine.

Wallrock Alteration

Metasomatic, anhydrous calcic (or magnesian) skarn assemblages in Au-bearing skarn are typically superposed on preceding contact-metamorphic assemblages and followed paragenetically in most deposits by hydrous assemblages with abundant sulfide(s) and (or) magnetite. Some deposits (Bau, Malaysia) show lateral gradation and subsequent replacement by jasperoid (Wolfenden, 1965; W.C. Bagby, oral commun., 1987). Calcic Au-bearing skarns typically are zoned from marble, wollastonite, diopside-hedenbergite, and finally grossular-andradite with or without retrograde tremolite-actinolite-epidote-chlorite assemblages. Watanabe (1943) reported in his study of the Suian Mining District, North Korea, that magnesian Au-bearing skarn may show dolomite followed by marble bearing kotoite [$Mg_3(BO_3)_2$] and ludwigite [$(Mg,Fe^{2+})_2Fe^{3+}BO_5$]; a narrow fluoborite [$Mg_3(BO_3)(F,OH)_3$]-bearing reaction zone marking the contact between skarn and marble; a marked concentration of native gold, bismuth, chalcopyrite, pyrrhotite, and cubanite just inside the reaction zone; diopside; clinohumite; and, finally, diopside partly replaced by phlogopite—all zones developed across 25–35 cm. At the Surprise, Nevada, gold skarn, limonite, fine-grained quartz, copper oxide(s), and calcite occur interstitial to massive garnet; garnet is crosscut and replaced by veins of limonite and chlorite (Schmidt and others, 1988). In this deposit, gold is present as electrum in limonite (fig. 8) associated with quartz, calcite, and secondary copper minerals. The only sulfides remaining in extensively oxidized high-grade ore currently (1989) exposed at the Surprise Mine are pyrite remnants in limonite and tiny blebs of various sulfides encapsulated in late, euhedral quartz crystals. The Buffalo Valley, Nevada, gold skarn shows widespread development of nontronite throughout much of the exposed ore.

Structural Setting

Gold-bearing skarn may occur in the immediate vicinity of, or relatively distal from, weakly mineralized intrusive rocks, commonly where wallrocks are extensively brecciated or faulted (fig. 4). On a local scale, gold-enriched dikes and small plutons astride hinge regions of broad anticlinal arches seem to have been an important structural control (Madrid, 1987). The Bau Mining District, Malaysia, lies along the axis of a major anticline flanked by synclinal basins (Wolfenden, 1965).

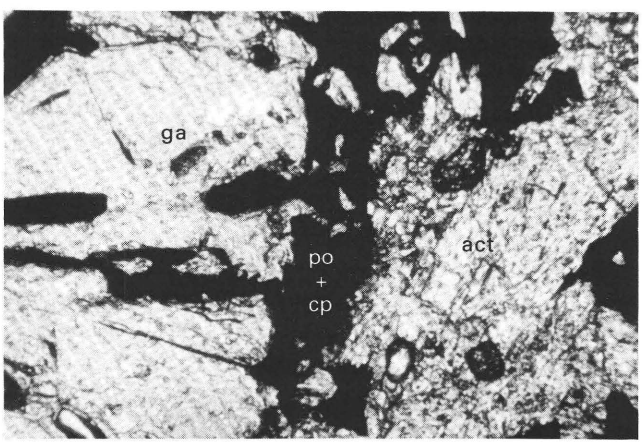

Figure 12. Photomicrograph showing massive garnet (ga), partly replaced by pyrrhotite (po) and chalcopyrite (cp) and separated from a pod of actinolite (act) grains by pyrrhotite; Fortitude Mine, Nevada.

Dimensions of Ore in Typical Deposits

Overall dimensions of ore in Au-bearing skarn are highly variable; dimensions possibly increase with distance from the genetically associated intrusive rock and as grade decreases. Geologic configuration of such deposits is largely a function of respective geometries of mineralizing magma and premineralization structures, favorable replacement sequences, and impermeable barriers to fluid flow, if present. However, eventual configuration of economic dimensions of deposits results from cut-off grades that are influenced highly by factors such as pre-mining topography (R.G. Russell, written commun., 1989).

Dimensions of Alteration or Distinctive Haloes

Alteration haloes that surround Au-bearing skarn are highly variable in size, from very restricted to as much as several kilometers from inferred loci of mineralizing systems. In some systems, the overall size of the alteration zone has been enhanced by the presence of premineralization structures that channeled fluid flow. Nonetheless, in a largely carbonate terrane, the Au-bearing skarns are almost always found within the outer limit of conversion of carbonate sequences to marble.

Effect of Weathering

The economic limits of some deposits are entirely within the oxide zone. In fact, gold grade is commonly higher in the oxide zone than in the equivalent sulfide zone. The oxide zone in some deposits includes coarsely crystalline vivianite along fractures in areas showing limited overall amounts of iron oxide development and limited amounts of subjacent iron sulfide(s) (R.G. Benson, written commun., 1988). At the McCoy, Nevada, Au-skarn, samples from the 5,080-ft bench show some extremely small, micrometer-sized crystals of greenockite (CdS) concentrated at interfaces between chalcopyrite and chalcocite. In this deposit, some chalcocite also appears to be associated paragenetically with a silver-selenide mineral, possibly $Ag_2(S, Se)$. Nontronite layers are commonly interbedded with some garnet skarn and locally concentrated along fractures in some deposits. At Browns Creek, Australia, gold-bearing nontronite was the major target of mining activity inasmuch as it typically contained greater than 10 g/t gold (Creelman and others, 1988). The term "nontronite" is used as a field term for iron-rich, yellow-green montmorillonite that swells upon treatment with ethylene glycol; a Mössbauer spectrometic study of one such clay from skarn in the Harmony Formation near the Surprise Mine shows that nearly all of the iron present in the sample is ferric iron. Thus, nontronite is the main component of the clay layer there. Clay layers include quartz and calcite and may include relict skarn silicates (pyroxene, garnet, and epidote). Oxidized karst-collapse breccia developed in marble as a result of marble reacting with acidic ground water at Red Dome (Torrey and others, 1986). At this deposit, acidic ground water probably resulted from breakdown of sulfides in the surrounding pyritic halo of the Au-skarn.

Effect of Metamorphism

Gold-bearing skarn systems could undergo regional metamorphism to yield gneiss-hosted Au deposits with a resultant loss of most contact-metasomatic features. The Tumco deposit, California, which has been metamorphosed to amphibolite grade and is provisionally included by us with Au-bearing skarn (Smith and Graubard, 1987; Tosdal and Smith, 1987), may be an example of such a process. However, some relatively extensive tin-tungsten-base-metal skarns in Alaska show readily recognizable prograde and retrograde contact-metasomatic assemblages through a superposed greenschist dynamothermal event (Newberry and others, 1986). In these Sn skarns, strain is confined largely to 1-m-wide zones at the margins of skarn where calc-silicate porphyroclastic mylonite is present. Skarn away from the contact shows some kinked chalcopyrite-bornite exsolution lamellae, but no cleavage or foliation. The Falun deposit in Sweden is hosted by Proterozoic granite, amphibolite, and quartz porphyry (Grip, 1978). Greenstone-hosted Au-Ag-W-As deposits in the Southern Cross greenstone belt of western Australia may represent Archean analogues of Phanerozoic gold skarn deposits (Mueller, 1988).

Geochemical Signatures

Geochemical signatures for Au-bearing skarn include anomalous gold primarily in an environment of retrograde-altered, sulfidized skarn. The associated pyrite in some Au-skarn deposits is reported to contain 0.1 to 250 ppm Au (Vakhrushev, 1972). At Bau, Malaysia, anomalous antimony (in stibnite) and arsenic (in scorodite) are present with gold in wollastonite-bearing skarn assemblages and in colloform-banded quartz and jasperoid, all distal to quartz- and calcite-flooded, calc-silicate gold ore (Wolfenden, 1965; W.C. Bagby, oral commun., 1987). In other Au-bearing skarn systems, quartz-calcite veins contain anomalous gold. In addition, gold mineralization and highly anomalous concentrations of gold in some skarn systems (Akshiryak Range, U.S.S.R.) are found mostly in fine-grained, gray to light-gray, highly silicified sequences of rock in carbonate beyond the outer limit of established skarn (Dolzhenko, 1974). Many Au-bearing skarns in British Columbia contain elevated abundances of arsenic, bismuth, and tellurium (Ray and others, 1987b; Ettlinger and Ray, 1989). The bismuth minerals reported from some Au-skarns include native bismuth, bismuthinite, wittichenite, hedleyite, maldonite, and Bi-bearing galena (Meinert, 1988b). Theodore and others (1989) report major-element and trace-element data for garnet skarns associated with gold mineralization at Copper Basin, Nevada, including low-grade, oxidized ore from the Surprise Mine (29 ppb Au, 6 ppm Ag, <10 ppm Bi, 57 ppm As, 4 ppm Sb, 3 ppm Co, 25 ppm Cu). Finally, surface expression of some Au-skarn systems (Red Dome, Australia; Surprise, Nevada) includes relatively abundant, fracture-controlled secondary copper minerals (Torrey and others, 1986; Schimdt and others, 1988).

The Au/Ag ratio in rock apparently increases laterally outward (away from the center of the associated intrusion) in some productive copper-bearing calcic skarn systems toward ore (Fortitude, Nevada) that is approximately 0.6 km from the exposed, genetically associated intrusion. The Fortitude Au-skarn is close to a relatively sharp boundary between marble and sulfidized calc-silicates (Blake and others, 1984; Theodore and others, 1986; Wotruba and others, 1987a, b; Myers and Meinert, 1988). In other Au-skarn systems that are predominantly zoned vertically close to the related intrusive rocks (Red Dome, Australia), much of the gold ore is near the original intrusion-wallrock contact and interior to massive magnetite developed at the calc-silicate-marble interface (Torrey and others, 1986). Surrounding rocks in many systems typically show high local thresholds for many associated base and ferrous metals and, for some deposits, arsenic, bismuth, selenium, and tellurium values in particular may be relatively high both within and peripheral to the Au-bearing skarn (Ray and others, 1987b).

Zonation of gold in Au- and Pb-Zn-bearing skarn (Ban Ban, Australia; Thanksgiving, Philippines; Tomboy-Minnie, Nevada) seems to show inconsistent patterns. At Ban Ban, gold in unreported trace abundances may coincide with known distribution of silver, which varies directly with lead and zinc concentrations that are, in turn, constrained tightly to the central part of associated garnet skarn (Ashley, 1980). At Thanksgiving, irregularly distributed sphalerite-pyrite pods that replace andradite skarn show higher gold contents than pyrite-magnetite replacement pods (Callow, 1967). At Tomboy-Minnie, local metal zoning of the gold orebodies shows high concentrations of gold (more than 0.05 troy oz/ton or more than 1.7 g/t); these high concentrations of gold show increased abundances of zinc and silver (more than 500 ppm and more than 0.1 troy oz/ton, or more than 3.4 g/t respectively) on the granodiorite side of the gold orebody. Such metal-zoning relations constitute a local reversal of the district-wide zoning from Cu+Au+Ag, through Au+Ag, to finally Pb+Zn+Ag (Theodore and others, 1986).

Zonation of gold in some Fe-skarn systems that contain byproduct gold (Benson Lake, British Columbia) seems to be related directly to the abundance of sulfide associated with magnetite (Eastwood, 1965). At the Merry Widow pit of the Benson Lake cluster of magnetite skarns, concentrates of chalcopyrite were reported to contain as much as 1 oz gold per ton of chalcopyrite.

Significant concentrations of gold have been reported, although specifics are unavailable, in many of the Paleozoic W skarns in the Soviet Union (table 4). Gold is an associated minor metal in approximately one-half of the W-skarn deposits in the Ural Mountains, U.S.S.R. (Rabchevsky, 1988). These skarns are reported to be associated with Devonian- to Permian-age granitoid bodies (Rabchevksy, 1988). In addition, selected samples of Mesozoic W skarns from Alaska are reported to contain as much as 30 ppm gold (R.J. Newberry, oral commun., 1987; Newberry and others, 1987). Tin skarns in China and Australia have reported significant Au or Au-enriched areas (see Stormont and Ge Jiou, table 4).

At a more detailed level, nontronite layers from some Au-bearing, calcic skarn deposits show significant concentrations of silver and copper and variable, but enhanced levels of other trace elements, such as tin (table 8). Spectral analyses of garnets from four Au-bearing skarn deposits in the Altai-Sayan study (Vakhrushev, 1972) show trace-element signatures distinct from those of garnets from Fe skarns: copper and zinc (tens to hundreds of parts per million), molybdenum, scandium, gallium, and tin (10 to 50 ppm each) are present in all the garnets from Au-skarn; some garnets carry several hundred parts per million arsenic, as much as 30 ppm lead, and similar concentrations of silver as well. In contrast, garnets from Fe skarns have titanium, chromium, vanadium, nickel, cobalt, and germanium as a characteristic trace-element suite and lack the elements associated with Au-skarn garnets or show inconsistent distributions of them.

The single report of platinum associated with gold skarn that we found is in northern Sumatra, where Bowles and others (1985) described a reference to 8 ppm Pt and 4 ppm Au in wollastonite-garnet skarn; however, they point out that some confusion exists over the precise locality of the occurrence.

Isotopic Signatures

Isotopic data are not available for a great number of Au-bearing skarns. However, the range in $\delta^{34}S$ values for sulfides is clustered tightly in one examined system: +2.7 to +4.7 permil for the Tomboy-Minnie deposit (Theodore and others, 1986). Such values suggest a magmatic source, and minimal contribution from heavy, crustal sulfur that was highly homogenized. An associated Cu skarn adjacent to the intrusion, the West orebody, shows more scattered values of $\delta^{34}S$, +1.1 to +5.1, in sulfides there, possibly reflecting disequilibria resulting from passage of retrograde fluids. Derivation of the associated altered granodiorite apparently was primarily from crustal components, to judge from initial neodymium isotopic compositions (Farmer and DePaolo, 1984).

Fluid Inclusions

Boiling, high-salinity fluids are associated with the early, prograde paragenetic stages of many Au-bearing skarn systems. The fluid-inclusion signature of skarn probably is most easily inferred from fluid inclusions trapped in quartz in the associated intrusive rocks if optical limitations preclude study of fluid inclusions in garnet or pyroxene. For example, possible involvement of high-salinity fluids some time during the generation of Au-bearing skarn may be implied by occurrence of halite-bearing fluid inclusions in quartz phenocrysts of a genetically associated granitoid. In some deposits (Tomboy-Minnie, Nevada), early fluids associated with diopside-quartz assemblages were dominantly $CaCl_2$-brines and were boiling at temperatures higher than 500 °C. Fluids then were progressively enriched in sodium and potassium over time, and during hydrosilicate stages, temperatures ranged from 320 to 500 °C at the time actinolite formed, and from 220 to 320 °C at the time chlorite became dominant in the assemblages (Theodore and others, 1986). Much of the gold is paragenetically late, deposited from NaCl-rich brines at temperatures less than 300 °C. However, genetic association of highly saline brines with skarn does not guarantee presence of a metal-bearing deposit somewhere in the environment of the skarn. Some Tertiary garnet-pyroxene skarn in the northern Battle Mountain Mining District shows fluid-inclusion signatures highly suggestive of many porphyry copper systems, yet the skarn is barren of any associated metal deposits (Theodore and Hammarstrom, 1989). At the Fortitude, Nevada, deposit, initial fluid-inclusion studies indicate that the Au-skarn was formed by fluids ranging from 300 to 450 °C and with salinities much less than 26 weight percent NaCl equivalent (Myers and Meinert, 1988). At Red Dome, Australia, copper-gold-silver ores apparently were deposited during a retrograde stage attendant with the circulation of relatively low-salinity (less than 10 weight percent NaCl equivalent), possibly meteoric-dominant fluids at temperatures in excess of 350–380 °C (Torrey and others, 1986; Ewers and Sun, 1988). In other skarn systems, gold also was deposited mostly during low-temperature stages: Alae-Sayan, U.S.S.R. (250–150 °C), Central Tadzhikistan, U.S.S.R. (350–250 °C), Sayakskig, U.S.S.R. (greater than 250–225 °C), and Kochulak, U.S.S.R. (270–240 °C; 190–170 °C) (table 4). Deposition of most gold close to the calc-silicate-marble interface, as reported in many Au-bearing skarns (Myers and Meinert, 1988), may reflect a combination of protracted solubility of gold in bisulfide complexes and build-up of HCO_3^- in the fringe environment of evolving skarn (Gumenyuk and Glyuk, 1983), thereby decreasing the solubility of gold owing to a change in pH (Henley, 1984). Gold solubility relations at 250 °C, a temperature considered by many to approximate thermal conditions in most Au-bearing skarns during paragenetic stage(s) of gold deposition, culminate at oxygen activity-pH conditions compatible with pyrite stability (Romberger, 1988). As Romberger (1988) further noted, if most gold is transported as a bisulfide complex, gold deposition may be accomplished by any chemical reaction or physicochemical process that decreases chemical activity of sulfur components dissolved in aqueous fluids circulating through skarn, including deposition of sulfide minerals and loss of sulfur components because of boiling.

Geophysical Signatures

Well-developed, local magnetic highs result from increased abundance of pyrrhotite and (or) magnetite in some Au-skarn systems (see Wotruba and others, 1987a, b). However, other Au-skarn systems are associated mostly with pyrite in their unoxidized parts (McCoy) and show no distinctive magnetic signatures (Bruce A. Kuyper, oral commun., 1987).

Ore Controls/Exploration Guides

In established mining districts zoned from mostly proximal copper-dominant deposits to distal precious-metal-dominant and base-metal-dominant veins, all stratigraphic sequences favorable for development of skarn in the zone of precious-metal deposits should be considered as permissive hosts for development of Au-bearing skarn. Polymetallic veins and polymetallic replacement deposits showing geochemical signatures and sulfide mineral assemblages similar to those at many Au-bearing skarns (for example, the Fe-As-Zn-Cu-Bi-Au- and Sb-bearing ores at the Matsuo Mine, Japan; Matsukuma, 1962) may be high-level or lateral reflections of Au-bearing skarn. Other guides include: reported gold in base- and ferrous-metal skarn systems; gold placers in regions permissive for the formation of skarn (R.G. Russell, written commun., 1989), especially if the placer gold is intergrown with bismuth minerals, including bismuth oxides or bismuth tellurides (Theodore and others, 1987; Theodore and others, 1989). Anomalous values of bismuth, tellurium, arsenic, selenium, and cobalt are useful geochemical signatures for some gold-bearing skarns (tables 2, 3; Brooks and Meinert, 1989).

Metal ratios in jasperoids, which commonly occur in or on the fringes of gold skarn systems, may also provide useful geochemical signatures for exploration. Faults cutting skarns and intersecting structures are important pathways along which retrograde assemblages and associated ores are concentrated. R.G. Russell (written commun., 1989) distinguishes between barren, early, high-temperature contact skarn formed adjacent to intrusive rocks and mineralized, fracture-enhanced exoskarn developed in Au-skarn systems.

Although pyroxene (hedenbergite)- and pyrrhotite-rich distal skarns host gold mineralization in some deposits, such as the Fortitude, garnet-pyroxene (diopsidic) and chalcopyrite or pyrite-rich proximal skarns are the locus of gold mineralization at other deposits, such as McCoy. Further studies on Au-bearing skarn deposits may reveal relatively reduced (Fortitude) and oxidized (McCoy) types of gold-bearing skarn, such as have been recognized for tungsten skarns (Einaudi and others, 1981).

GRADES AND TONNAGES OF GOLD–BEARING SKARNS

Graphs of grades and tonnages of 40 Au-skarns from table 2 and 50 byproduct Au-skarns from table 3 are shown in figures 1, 2, and 13. Gold grade must be 1 g/t or higher to be included, as described above. Median tonnage for the Au-skarn subtype is about 213,000 tonnes (fig. 1*C*), and median tonnage for the byproduct Au-skarn subtype is about 330,000 tonnes (fig. 1*D*). For the Au-skarn subtype there is a strong negative correlation between gold grade and tonnage (linear correlation coefficient = -0.69); this relation is slightly weaker for the byproduct Au-skarn subtype (linear correlation coefficient = -0.54). The Au-skarn subtype has a median gold grade of about 8.6 g/t and a median silver grade of about 5.0 g/t (figs. 2*C* and 13*A*). The determination of median silver grade for the Au-skarn subtype is based upon values of silver grade available for 29 of 40 deposits (table 2). Meinert (1988a) tabulated Au, Ag and Cu grades for various types of skarns. The fourteen deposits he classified as gold skarns all have gold grades greater than 1 g/t Au and largely overlap our data set. Median gold grade for Meinert's gold skarn set is 6.5 g/t; median silver grade for the nine deposits that report silver is 9 g/t. For the byproduct Au-skarn subtype, the medians are 3.7 g/t gold and approximately 34 g/t silver. Nearly 90 percent of the byproduct Au-skarns report silver (table 3). Silver content appears to have a strong correlation with base-metal content. As a comparison, the median gold grade for 14 porphyry copper-related Cu skarns, as reported by Meinert (1988a), is approximately 0.3 g/t and the median silver grade is approximately 8 g/t (note that these values are higher than those reported by Singer, 1986) for gold in porphyry copper-related skarns.

We found wide variations in gold grade distributions. In fact, values of gold grade reported during various stages of exploration and development of many deposits typically show significant adjustments, usually in a descendent manner. Furthermore, tests of the gold grade distribution for Au-skarns indicate that the addition of approximately 40 deposits with grades less than 3.7 g/t would be required to change the median to a value approximately the same as that of the byproduct Au-skarn subtype.

As already described, skarns that contain byproduct gold show no statistically significant differences in tonnage distributions from Au-skarns exploited almost exclusively for their precious-metal content (figs. 1, 2). This relation is primarily a reflection of the highly variable exploitability of many polymetallic skarn systems under a wide range of economic circumstances. Tonnages of deposits that comprise the Au-skarn subtype vary widely, from approximately 9 tonnes to 15 million tonnes (table 2), primarily because of a combination of both differing economic circumstances and

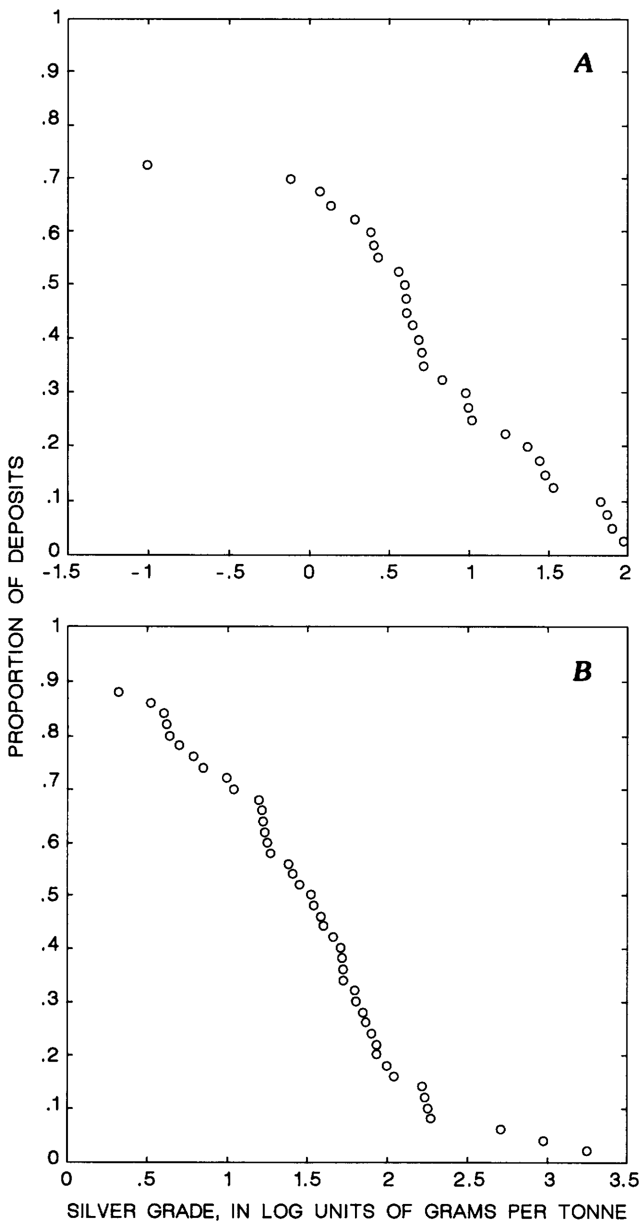

Figure 13. Distributions of silver grade for Au-bearing skarns. *A*, Silver grade model for 29 Au-skarn deposits. *B*, Silver grade model for 44 byproduct Au-skarn deposits.

advances in metallurgical techniques over the many years these types of deposits have been mined. However, there is a marked difference in cumulative distributions for gold and silver grades of Au-skarn and byproduct Au-skarn as defined previously: Au-skarns have a median gold grade of 8.6 g/t and byproduct Au-skarns have a median grade of 3.7 g/t. Median silver in Au-skarns is 5 g/t as compared to 37 g/t in byproduct Au-skarns (fig. 13). Both gold (greater than 1 g/t) and silver grade populations as currently reported are significantly different between the Au-skarn and byproduct Au-skarn subtypes. Median silver grades were determined from silver data available for 29 of 40 deposits included in the Au-skarn subset, and for 44 of 50 deposits included in the byproduct Au-skarn subset. It should also be noted that in element-versus-element plots for byproduct Au-skarn and Au-skarn subtypes, byproduct Au-skarns (or Au-rich Cu-skarn deposits in the terminology of many others), for instance, plot in a cluster spatially separate from most Au-skarns and tend to represent the Cu-rich part of the domain with gradational and overlapping relations with other skarns; these types of relations hold for many other elements (fig. 14*A*). However, as shown by the graph of these data (fig. 14*A*), strengths of association of gold grade for copper grade in the two subsets of Au-bearing skarn seem to show extremely weak correlations between gold grade and copper grade; correlation coefficients for the two subsets of types of Au-bearing skarn are less than 0.2. Gold and copper grades are available only for 20 of 40 Au-skarn deposits (table 2), which may in part be an indication of an underreporting of copper contents for some deposits because of its economic insignificance during the time many of those deposits were being mined. Nonetheless, very significant gold grades can occur in some very Cu-rich skarns. Many Au-skarn deposits show a strong spatial association between gold and copper within the deposits themselves. A plot of gold grades versus silver grades for both subsets of Au-bearing skarn shows that most Au-skarns have silver grades lower than byproduct Au-skarns (fig. 14*B*). Gold grades compared with silver grades for the Au-skarns have a correlation coefficient of approximately +0.4, and for the byproduct Au-skarns a correlation coefficient of approximately +0.2. One important exploration implication is that economically viable Au-bearing skarn deposits may be associated with Cu, Pb-Zn, Fe, or W skarn, and although the median gold grade of these byproduct Au-skarns is lower, the highest grades are similar to those of the Au-skarn subtype. Perhaps the only types of metal-bearing skarn that might be excluded from consideration as permissive for the occurrence of significant concentrations of gold and silver are tin-skarn and lithophile-element (beryllium, fluorine, tungsten, molybdenum, tin, and zinc) skarn associated with two-mica granite. Significant gold or silver mineralization is not known in classic Sn-skarn regions in Cornwall (Hosking, 1964) or Malaysia (Hosking, 1977, 1979). However, some Au- and Bi-bearing skarns (Stormant) are known in the Moina Mining District, Tasmania, Australia, which is largely known for its Sn-W skarn and greisen deposits (Collins and Williams, 1986). Lithophile-element skarn is associated with numerous Late Cretaceous, peraluminous, two-mica granitoids across a broad region in the eastern Great Basin of the United States (Barton, 1987; Barton and others, 1988). Significant concentrations of gold have not been reported from this lithophile-element-skarn environment. However, silver is present in many of these lithophile-element skarns in apparently genetically associated silver-base-metal, quartz-carbonate veins (Barton, 1987).

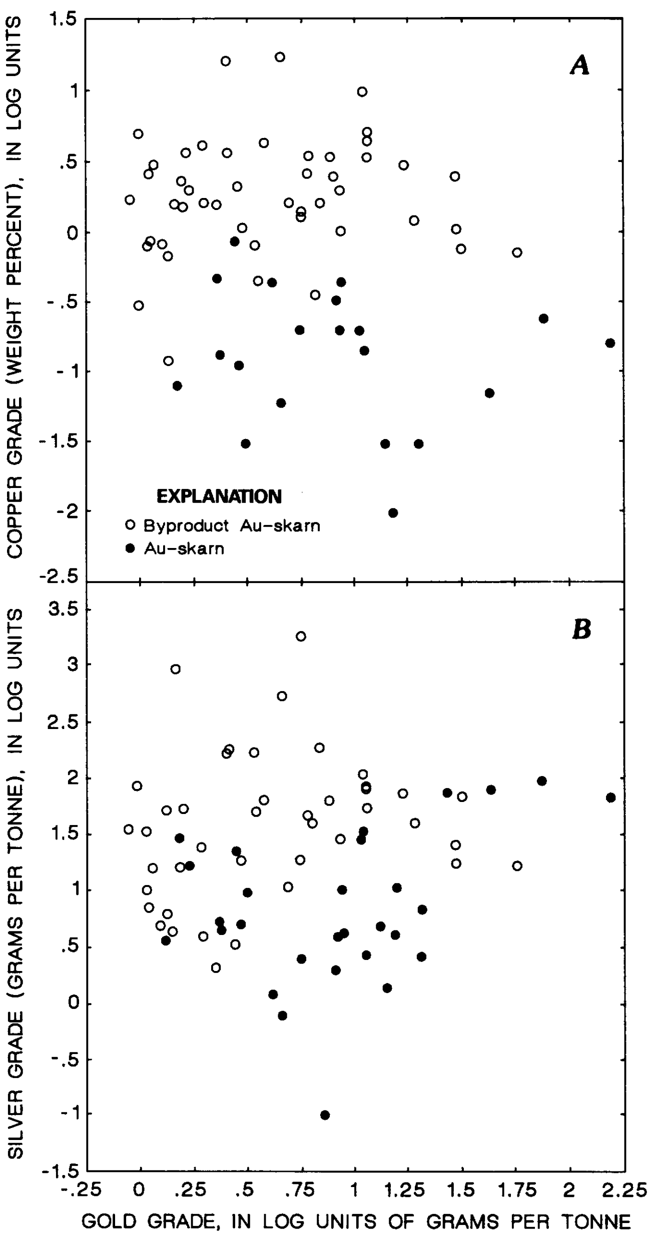

Figure 14. Gold grade compared with copper grade and silver grade. *A*, Gold grade compared with copper grade for Au-skarns and byproduct Au-skarns; *B*, Gold grade compared with silver grade for Au-skarns and byproduct Au-skarns.

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TABLES 1–8

Table 1. Abbreviations used in tables

Term	Abbreviation	Term	Abbreviation	Term	Abbreviation
		Mineral name			
actinolite	act	forsterite	fo	prehnite	preh
amphibole	amph	galena	gal	pyrite	py
andradite	an	garnet	gar	pyrolusite	pyr
ankerite	ank	goethite	goe	pyroxene	px
apatite	ap	grossular	gros	pyrrhotite	po
argentite	arg	hedenbergite	hed	quartz	qtz
arsenopyrite	apy	hedleyite	hedl	realgar	real
azurite	azur	hematite	hem	scapolite	scap
biotite	biot	hessite	hes	scheelite	sch
bismuthinite	bism	hornblende	horn	scorodite	scor
bornite	bor	jasper	jas	sericite	ser
calcite	cal	K-feldspar	k-spar	serpentine	serp
carbonate minerals	carbs	leucopyrite	leucopy	siderite	sid
cerargyrite	crg	limonite	lim	spadaite	spa
cerussite	cer	loellingite	loel	specularite	spec
chalcocite	cc	ludwigite	lud	sphalerite	sph
chalcopyrite	cpy	magnesite	mags	spinel	spin
chlorite	chl	magnetite	mag	stibnite	stib
chrysocolla	chr	malachite	mal	stilpnomelane	stilp
clinopyroxene	clinopx	maldonite	mald	telluride(s)	tell
clinozoisite	clinoz	marcasite	marc	tenorite	ten
covellite	cov	molybdenite	moly	tetradymite	tetd
cubanite	cub	muscovite	musc	tetrahedrite	tet
cummingtonite	cum	native bismuth	Bi	tourmaline	tour
cuprite	cup	native copper	Cu	tremolite	trem
diopside	diop	native gold	Au	vermiculite	ver
dolomite	dol	native silver	Ag	vesuvianite	ves
electrum	elec	nontronite	non	white mica	wm
enargite	enar	orpiment	orp	wolframite	wolf
epidote	ep	oxide(s)	ox	wollastonite	wol
feldspar	feld	phlogopite	phlg	zoisite	zoi
fluorite	fl	plagioclase	plag		
		Rock type			
agglomerate	agglom	hornfels	hfs	sandstone	sst
andesite	and	limestone	ls	sedimentary	sed
argillite	argl	manganiferous	mang	sediments	seds
calcareous	calc	marble	mar	shale	sh
carbonaceous	carb	monzonite	monz	siltstone	sltst
conglomerate	congl	mudstone	mdst	skarn	skn
dolostone	dolos	porphyry	porph	slate	sl
greenstone	grnst	quartzite	qtzite	volcanic rocks	volcs

Table 1. Abbreviations used in tables—Continued

Term	Abbreviation	Term	Abbreviation	Term	Abbreviation
		Age			
Tertiary	Tert.	Carboniferous	Carb.	Proterozoic	Prot.
Miocene	Mio.	Pennsylvanian	Penn.	Early	E.
Eocene	Eoc.	Mississippian	Miss.	Middle	M.
Mesozoic	Mes.	Devonian	Dev.	Late	L.
Cretaceous	Cret.	Silurian	Sil.	early	e.
Jurassic	Jur.	Ordovician	Ord.	middle	m.
Triassic	Tri.	Cambrian	Camb.	late	l.
Paleozoic	Pal.	Precambrian	Prec.	Upper	U.
Permian	Perm.				
		Other			
average	avg	million	M	sequence	seq
Formation	Fm.	million years	Ma	short ton (2000 lb)	st
gram	g	tonne(s) (metric tons)	t	trace	tr
Group	Gp.				

Country	Country code	Country	Country code
Afghanistan	AFGH	Philippines	PLPN
Australia, New South Wales	AUNS	Papua New Guinea	PPNG
Australia, Queensland	AUQL	South-West Africa (Namibia)	SAFR
Australia, Tasmania	AUTS	Spain	SPAN
China	CHNA	Sweden	SWDN
Colombia	CLBA	Thailand	THLD
Canada, British Columbia	CNBC	United States, Alaska	USAK
Canada, Quebec	CNQU	United States, California	USCA
Canada, Yukon Territory	CNYT	United States, Colorado	USCO
Ecuador	ECDR	United States, Idaho	USID
Indonesia	INDS	United States, Montana	USMT
Japan	JPAN	United States, Nevada	USNV
Mexico	MXCO	Soviet Union	USSR
Malaysia	MYLA	United States, Utah	USUT
Nicaragua	NCRG	United States, Washington	USWA
North Korea	NKOR	Federal Republic of Germany	WGER
Peru	PERU		

Table 2. Gold-bearing skarns in which gold and silver are major commodities exploited

[p, metal present in unquantified amount; other abbreviations listed in table 1]

Name	Location (mining district)	Host lithology	Formation age/ name	Igneous rocks	Age	Ore minerals	Gangue minerals
Bau	MYLA	mar, sh	L. Jur./Bau Ls.	acid porph stocks & dikes	Mio.	Au, apy, py, sph, stib, real, orp, scor	chl, diop, ep, gar, wol, ves, qtz, cal, rare plag, ap, preh
Beano	CNBC (Zeballos)	ls, and tuff	Tri.-Jur./ Quatsino Fm. Bonanza volcs.	diorite-rhyolite porph sill	Jur.	po, cpy, apy, mag, hedl	act, qtz, cal, chl, clinopx, Cl-amph
Broadway (Victoria)	USMT (Silver Star)	ls	Miss./Mission Canyon Ls.	Boulder batholith, Rader Creek pluton, qtz monz	Cret.	auriferous jas, cup, mal, argentiferous lead ore, py, po, cpy	jas, lim, ep, gar, cal, py, serp hed, chl, non, diop
Brown's Creek	AUNS	ls & mdst in tuff	Ord./ Angullong Tuff	Carcoar Granite diorite	Dev.	Au, apy, cpy, py, po, ten, tet, bor	act, diop, ep, gar, wol, ves, trem, clinoz, phlg, sid, clay, chl
Buffalo Valley	USNV (Battle Mountain)	chert, argl, ls	Penn.-Perm./ Havallah seq.	granodiorite porph	Tert.	py (Au?), hem, Au, cpy, Ag, mal, chr	qtz, lim, px, cal, ep, gar, non
Canty	CNBC (Hedley)	ls, sltst, limy argl, tuff	L. Tri./ Nicola Gp.	Hedley intrusions, qtz diorite sills	E. Jur.	Au, apy, py, cpy, po	clinopx, cal, gar, ep, qtz, scap, k-spar, albite
Discovery	CNBC (Banks Island)	mar	Pal.(?)	Coast plutonic complex	Cret.(?)	py, po, cpy, mag, apy, sph	gar, px, chl, qtz, cal, amph
Dividend-Lakeview	CNBC	ls, grnst, qtzite, and flows & tuffs	Perm.-Tri./ Kobau Gp. or Perm/Anarchist Gp.	Nelson/Osoyoos batholith, qtz diorite-granodiorite	Cret.	mag, cpy, py, po, apy, Au, Bi, marc, hedl	qtz, cal, ep, gar, chl, Ch-amph, act, sphene, clay, minor diop
Esmeralda	USMT (Ophir)	ls, and, grano-diorite, mar	Pal., Cret.	granodiorite, and	Cret.	Au, cpy, mal, jas	gar, ep
Excelsior	USMT (Bannack)	ls	Miss./ Madison Ls.	Bannack stock granodiorite		auriferous py, Au in goe, Ag, bor, tetd, spec, hem	gar, cal, ep, qtz
Fortitude (Lower Fortitude)	USNV (Battle Mountain)	calc seds	Antler Sequence	granodiorite stock	Tert.	po, cpy, apy, elec, bism, Bi, tell, marc, gal, mag, sph	clinopx(hed), gar(an), act, chl, preh, ep, qt
French (Oregon)	CNBC (Hedley)	ls boulder congl, limy argl, tuff	L. Tri./ Nicola Gp.	Hedley intrusions, porph qtz diorite, sills	E. Jur.	po, cpy, py, bor, apy, Cu, sch	clinopx, gar, ep, qtz, cal, axinite, wol, clinoz, biot, trem-act, k-spar
Golden Curry	USMT (Elkhorn)	ls, qtz monz	Camb./ Wolsey Fm.	Boulder batholith, qtz monz	Cret.	po, bism, tetd, cpy, mag	gar, diop, cal, ep

Ore control	Tonnage (millions of tonnes)	Au (g/t)	Ag (g/t)	Base metals	Comments	References
contact zone, fractures, permeable lithology	2.4	7.2	0.1	---	Area includes skn, vein, and replacement mineralization in irregular pods and lenses along joints and fractures; contains 0.002% Sb	1, 2, 3, 4
---	0.000021	157	67	0.16% Cu	Contains Au, Ag, Cu,Bi, Te, Co; Au-poor iron skarns nearby; similar setting for nearby Hiller property (potential Au skn based on assays >1 g Au/t)	5, 6, 7
contact zone between qtz	0.0272	37.6	p	Cu p Pb p	Ore concentrated in jasper zone along granodiorite-ls contact; px-gar skn locally	8, 9
lst-tuff contact, fractures	0.39	8.7	10	0.44% Cu	Contains As, Sb	10
intense qtz-py silicification in fractured skn near porph	1.81 (0.0027	1.71 13.88	--- 17.6	--- Cu p)	Skn assemblages are rare in pit but more common at depth; produced approx 9,200 oz Au during fiscal 1988; geologic gold reserves, 110,900 oz in 1988 (1924–51 production: 1,380 oz Ag from 0.0024 Mt, 0.80% Cu from 542 t of ore, 1937–39); Horizon Gold Inc./Chevron Resources	11, 12, 13
Cahill Creek fault zone, lithology	0.0015	10.8	p	---	Size based on 1939 and 1941 production; mineralization probably hosted by upthrown, fault-bounded sediments within the fault zone; contains Au, W, As, Co, Ag; Mascot Gold Mines Ltd.	5, 7, 14, 15 16
fracture zone at granodiorite-mar contact	0.038	17.1	p	p	Probable reserves indicated by drilling; Au in skn and in qtz-py veins; additional reserves (0.0955 Mt of ore at 16.21 g/t) for a massive sulfide vein (Tel zone) that cuts mar and metapelite; Trader Resources Corp.	7
contact zone, structure	0.1113	4.5	0.79	0.06% Cu Pb p Zn p	Gar-ep skn replaces volcs and mar; contains As, Co, Bi, Te	5, 7, 17, 18, 19
contact zone between granodiorite and ls	0.00000907	20.5	6.8	---	Skn explored by 120-m-long adit; surface cuts contain ls, and, jas—all of which probably contain Au	20
contact zone between granodiorite and ls	0.000599	27	74.1	Cu p	Production reported for 1902, 1917–19; 385 t contained 3.2% Cu; estimate 0.0058 Mt produced 36.5 g Cu/t before 1914	21, 22
favorable lithology	5.1	10.45	27.8	0.2% Cu	Porph Cu skn, polymetallic veins; Battle Mountain Gold Co.	23, 24, 25, 26
hinge zone of anticline	0.068	19.9	2.6	0.03% Cu	8700 t of unmined ore reported to contain as much as 85 g/t Ag and 2% Cu; contains W, As, Mo, Bi, Co, Sb	5, 7, 14, 27
contact zone	0.089	8.3	4	0.33% Cu; Fe p	Production data for 1904–51. Four types of ore present: mag veins, jasperoid lodes, massive mag-po, and massive po-cpy in px gangue	28, 29

Table 2. Gold-bearing skarns in which gold and silver are major commodities exploited—Continued

Name	Location (mining district)	Host lithology	Formation age/ name	Igneous rocks	Age	Ore minerals	Gangue minerals
Golden Leaf	USMT (Bannack)	ls	Miss./ Madison Ls.	Bannack stock granodiorite	Tert.	Au, Ag, tet, crg, cpy, bor, mal, gal, cer, sph, mag	qtz, gar, py, cal, ep, chl, sid, ves
Good Hope 1	CNBC (Hedley)	tuff, argl, ls	L. Tri./ Nicola Gp.	Hedley intrusions, qtz diorite	E. Jur.	apy, py, cpy, po, Bi, moly, hedl	clinopx, gar, cal, wol, ep, biot, qtz
Hardcash (Dolcoath)	USMT (Elkhorn)	ls	Camb./Park Sh.	Boulder batholith	Cret.	bism, tetd, cpy	gar, ep, diop, cal
Labrador	USNV (Battle Mountain)	calc sh, calc sst, arkose, calc congl	U. Camb./ Harmony Fm. M. Penn./ Battle Fm.	granodiorite porph	Tert.	Au, py, po, lim	gar, ep, chl, cal, qtz
La Luz (Siunna)	NCRG	ls, limy sh, agglom, tuff	Mine Series	granodiorite	Tert.	Au, cpy, py, hem	ep
Lebedskoe (Kaurchak)	USSR	ls, calc sh, dolos	E. Pal.	diorite	Pal.	Au, apy, sph, tet, Pb tell, mag, cpy, hem, py, cc, po, gal, sph, ten, bor	gar (an, gros), diop, hed, trem, ep, clinoz, wol, act
Marshall	CNBC (Greenwood)	ls, siliceous sltst, argl, congl	L. Tri./ Brooklyn Gp.	microdiorite granodiorite	L. Tri.	cpy, py, po, sph, Au, minor mag, hem, gal, marc	chl, gar, diop, amph, ep
Mascot Fraction	CNBC (Hedley)	sltst, ls, congl, tuff	L. Tri./ Nicola Gp. (Hedley Fm.)	Hedley intrusions, porph qtz diorite, gabbro, sills & dikes	E. Jur.	apy, po, cpy, mag, bor, mald, hedl	px, gar, wol, biot, k-spar, cap, cal, qtz, preh, ap, axinite
McCoy	USNV (McCoy)	ls, dolos, qtzite	Tri./ Augusta Mountain Fm. Tri./Cane Spring Fm.	Brown stock granodiorite	Tert. (39.7 Ma)	Au, py, cpy, cc, cov, sph, gal, po, hem, mag	gar, px, ep, cal, qtz, chl, amph, ves, feld
Midas	USUT (Gold Hill)	ls	Manning Canyon Sh. & Oquirrh Fm.	qtz monz	Tert.	py, apy, Cu sulfides	wol, diop, gar, ves
Molly B	CNBC	tuff, argl, ls	Jur./ Haselton Gp.	Coast Range batholith	Cret.(?)	py, po, cpy, moly, sch	gar, ep, px, qtz
Mt. Hamilton	USNV (White Pine)	sh, ls, calc sh	Camb./ Secret Canyon Sh.	Seligman and Monte Cristo stocks, granodiorite	Cret.	Au, sch, moly, cpy, py, apy, sph, gal, bor, tetd, py, hem	gar, qtz, ep, cal
Navachab	SAFR	turbidites, clastics	L. Prec.	2 mica granite	Camb.	---	---
Nickel Plate	CNBC (Hedley)	ls, limy argl, qtzite, tuffs, sltst, congl	L. Tri./ Nicola Gp. (Hedley Fm.)	Hedley intrusions, qtz diorite, gabbro, sills & dikes	E. Jur. (180 Ma)	Au, elec, apy, cpy, py, po, tetd, sph, marc, gal, moly, mag, titanite, hedl, tell, cobaltite, erythrite, platinum, Bi, maldonite, gersdorffite, Cu, pyrargyrite	gar, clinopx, cal, axinite, scap, ap, clinoz, ep, biot, trem-act, qtz, preh, wol
Northeast Extension	USNV (Battle Mountain)	calc congl	M. Penn./ Battle Fm.	granodiorite stock	M. Tert.	po, cpy, py, Au	act, ep, sphene, k-spar, chl
Pagaran Siayu	INDS (Muara Sipongi area)	ls, and volcs	Perm./ Silungkang Fm.	Muara Sipongi intrusions, granodiorite, diorite	L. Jur.	Ag, Au, cpy, bor, tetd, tell, apy, sph, gersdorffite	gar, wol, diop, qtz, preh, chl, cal

Ore control	Tonnage (millions of tonnes)	Au (g/t)	Ag (g/t)	Base metals	Comments	References
contact zone between granodiorite and ls	0.0875	10.8	34.1	<0.01% Cu; Trace Zn 0.06% Pb	Production figures for 1909–41; Cu, Pb, Zn production for lower tonnages of ore; oxidized to 100-m depth	21, 22
fault cutting skn	0.0114	15.6	10.5	---	Same stratigraphic horizon as French mine	5, 7, 14, 15, 16
replaced bed	0.003	8.52	4.13	0.20% Cu 0.006% Pb	---	28, 29
northeast- & northwest-striking faults	0.907	1.3	3.7	---	Minable reserves. Ore associated with oxidized py along faults cutting gar skn; Battle Mountain Gold Co.	30
fault/hanging wall andesite	15	4.1	1.2	0.44% Cu	---	31, 32, 33
---	0.12	4	---	---	Estimated tonnage and grade (ref. 37). Au in py, 0.8 to 30 ppm; Au in cpy, 13.6 ppb; low quantity of sulfide in deposit (few percent)	1, 34, 35, 36, 37, 38
crest isoclinal fold at contact of ls with underlying siliceous sltst	0.00019	77.3	92.8	0.24% Cu; 0.29% Zn; 1.19% Pb	Described as Au-enriched Cu skn	5, 7, 17, 39
skn-mar contact	0.6186	11.2	2.76	0.14% Cu	Forms part of same deposit as Nickel Plate; As-Au skn; Mascot Gold Mines Ltd./Corona Corp.	7, 14, 15, 16, 40, 41
contact between ls and stock, endoskarn, shears, bedding planes, faults	13.2	1.5	30	0.08% Cu	Distal disseminated Cove Ag-Au deposit nearby with 16.4 Mt of 2.6 g Au/t and 111 g Ag/t; Echo Bay Minerals Co.	42, 43, 44, 45, 46, 47
bedding	0.0006	25	p	---	Production estimated for 1902 data; estimate 86 t higher grade ore pre-1897; lower grade production reported for 1904	48
---	0.00029	2.36	4.5	0.13% Cu	---	7, 49
contact zone between granodiorite and calc sh; retrograde alteration	7	1.7	17.1	Cu p W p Mo p	Au associated mostly with intense retrograde alteration of gar-py skn; sulfide-bearing qtz veins overprint skn; Westmont Mining Inc.	50
---	9.75	2.5	---	---	Purported to be a skn deposit; Erongo Mining and Exploration Co. Pty. Ltd.	51, 52
contact zone	2.986	13.96	1.39	0.03% Cu	Forms part of same deposit as Mascot Fraction; As-Au skn; Mascot Gold Mines Ltd./ Corona Corp.	1, 7, 14, 53, 54, 55, 56, 57, 58
favorable lithology	1.4	2.9	5.1	0.11% Cu	Porph Cu skns, polymetallic veins; Battle Mountain Gold Co.	59
contact zone regional faults	0.113	5.6	2.5	0.2% Cu	Production for 1936–39; numerous Au-Ag-Cu skarns in this area of West Sumatra; N.V. Mijnbouw Maatschappij Moeara Sipongi	3, 60, 61

Table 2. Gold-bearing skarns in which gold and silver are major commodities exploited—Continued

Name	Location (mining district)	Host lithology	Formation age/ name	Igneous rocks	Age	Ore minerals	Gangue minerals
Red Dome (Mungana)	AUQL (Chillagoe)	sst, chert, andesite, lithic congl, ls	Sil.-Dev./ Chillagoe Fm.	qtz feldspar porph dikes & sills	Carb.- Perm.	Au, bor, mag, sph, Pb & Ag tells, cc, wittichenite, cpy, moly	gar, wol, clinopx
Rokuromi	JPAN	biot schist, ls	Carb./ Utakai Fm.	qtz diorite, granodiorite	Mes.	po, apy	gar, ep, others
Second Relief	CNBC	basalts, tuffs	L. Jur./ Rossland Gp. (Elise Fm.)	Nelson batholith diorite porph dike		py, po, cpy, mag, moly	gar, ep, qtz, amph, clinopx, biot, carb
Sheahen-Grants	AUNS	sltst, sh, sl, mostly calc	Ord./ Malongulli Fm.	granodiorite	Dev.(?)	Au, po, mald, py, apy, cpy, sph, Au-Bi-sulfide	px, horn, bio, ep, trem, preh, cal, qtz, chl
Silverado	CNBC	metavolc, ls	---	granodiorite	Jur.-Tert.	sph, cpy, po, mag	px, gar, ep, qtz, cal
Suian	NKOR	schist, qtzite, sl, dolos, ls	---	Suian granite stock	Mes.(?)	Au, apy, cpy, gal, py, po, sph, bism, tetd, loel, moly, borate minerals	gar, diop, phlg, act, lud, chl, talc, trem, wol
Surprise	USNV (Battle Mountain)	calc sh, calc sst	U. Camb./ Harmony Fm.	---	Cret.(?)	elec, py, cpy, mal, lim, hem, sph	gar, diop, chl, cal, qtz, amph, ap, k-spar, non
Tillicum (Heino-Money, East Ridge)	CNBC (Tillcum Mountain)	tuffaceous seds, calc slst, argl	E. Jur./ Rossland Gp.	qtz monz	E. Jur.(?)	Ag, Au, gal, po, sph,	act, gar, feld, trem, clinoz, py, apy, cpy, marc, biot, qtz, cal, k-spar tetd, elec
Tomboy-Minnie	USNV (Battle Mountain)	calc congl	M. Penn./ Battle Fm.	granodiorite porph	Tert.	Au, cpy, gal, py, po, sph, apy	act, chl, ep, trem, clays, musc
Tul Mi Chung	NKOR	schist, qtzite, sl, dolos, ls	---	Suian granite stock	---	Au, apy, cpy, gal, py, po, sph, bism, tetd, loel	gar, diop, phlg, act, lud, talc, trem, wol, chl

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Ore control	Tonnage (millions of tonnes)	Au (g/t)	Ag (g/t)	Base metals	Comments	References
intrusive contact	13.8	2.3	5.25	0.46% Cu; 1% Zn	Deposit includes mineralization in breccia and qtz vein stockwork; associated with Cu and Zn-Pb skns; Murray reports a Zn grade of 1.8%; Elders Resources Ltd.	62, 63
---	0.081	8	2	---	Fe (mag) skarns; adjacent to Kamaishi	64
dike contact, fault contact	0.206	15.1	4.16	0.0098% Cu; 0.0005% Pb; 0.0002% Zn	Production data for 1900–48; anomalous As, Bi; skn overprints volcs and porph diorite; skn cut by later qtz veins, sulfides	7
multistage contact metasomatism of reactive bed	1.52	4.53	---	---	Tonnage and grade composited from recorded production and drill-proven geologic reserve	65, 66
faults	0.00013	42.8	79.2	0.07% Cu Zn p	Skn cut by faults	7, 67, 68, 69
contact zone	0.53	13	4.9	---	Cu skns; worked from ancient times; grade and (or) tonnage may be underestimated	11, 70, 71
favorable beds, faults	1.53	2.77	23.1	0.85% Cu	Mineable reserves; associated with Late Cret. porph Cu skns and polymetallic veins; Battle Mountain Gold Co.	30
contact zone, permeable lithology	0.05 2	35 6.9	p p	Zn p; Pb p Zn p; Pb p	Proven reserves (ref. 7) for the Heino-Money zone, and estimated reserves for the East Ridge deposit (0.34-Mt core of deposit grades 10.3 g/t Au); two phases of metal deposition—Au, apy, ±sph, qtz, calc silicates followed by Ag-gal, apy, sph; Esperanza Exploration Ltd.	7, 72, 73, 74, 75, 76, 77
---	3.54	3.1	9.6	0.03% Cu; Zn p; Pb p	Associated with Mid.-Tert. porph Cu skns and polymetallic veins; Battle Mountain Gold Co.	31, 78
contact zone	0.4	12	---	---	---	70, 71

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Table 3. Gold-bearing skarns in which gold and silver are byproduct commodities

[p, metal present in unquantified amount; other abbreviations listed in table 1]

Name	Location (mining district)	Host lithology	Formation age/ name	Associated igneous rocks	Age	Ore minerals	Gangue minerals
			Fe skarns with byproduct gold				
Larap	PLPN	calc seds including ls, calc sh, arkose	Eoc.(?)/ Universal Fm.	diorite, granodiorite, syenite stocks, dikes	Mio.	mag, hem, py, po, moly, cpy, bor, gal, sph, cobaltite	gar, px, ep, amph, cal, chl, ap, k-spar, scap albite
Nabesna	USAK	ls, dolos, marl, mafic volcs	Tri./ Chitistone Ls.	monzodiorite stock	104–114 Ma	py, mag, cpy, Au, po, gal, sph, apy, stib	gar, wol, ves, ep, act, horn, chl, scap, ap, serp, qtz
			Cu skarns with byproduct gold				
Apex	CNBC (Queen Charlotte)	ls, volcs	Tri./Kunga Fm. or Kamutsen Fm.	San Christoval batholith-qtz diorite	E. Jur.	py, cpy, mag	qtz, cal, gar, ep
Bailey Day	USNV (Battle Mountain)	calc sst	U. Camb./ Harmony Fm.	---	Tert. (?)	py(Au), cpy, mal, chr, azur, ten, hem, lim, Au, Ag	ep, k-spar, sphene, gar, chl, biot
Benson Lake	CNBC (Vancouver)	ls, volcs	U. Tri. & L. Jur./ Vancouver Series Quatsino Ls. & Karmutsen volcs.	Benson Lake stock qta diorite	Jur.	cpy, mag, bor, py, po, apy	gar, ep, cal, chl
Blue Bell	USMT (Elliston)	qtz monz	Cret.	qtz monz	Cret.	mal, azur, Au, moly, py	gar, ep, qtz, scap
Bluestone	USNV (Yerington)	ls	Tri.	granodiorite	Jur.	cpy, py	ep, gar, minor diop
Carissa	USNV (Battle Mountain)	sh, calc sh, ls	U. Camb./ Harmony Fm.	granodiorite-monzogranite	Tert. or Cret.	Cu carbs, Fe ox, py, cpy, po, sch	ep, diop, gar, qtz, cal, chl, clays
Coast Copper	CNBC (Vancouver)	ls, and volcs	U. Tri. & L. Jur./ Vancouver Series Quatsino Ls. & Karmutsen volcs.	diorite-gabbro	---	cpy, bor, mag	---
Concepcion del Oro	MXCO	ls, sltst	granodiorite stock	Mes.	Eoc.	cpy, py, mag, hem, enar, tet, gal, sph, po, ten, bism, cosalite, wittichenite	an, chl, diop, ep, px, plag, ves, zoi, scap, act, ilvaite
Copper Queen	CNBC (Texada Island)	ls, mar	Tri./ Marble Bay Ls..	diorite porph	Mes. (?)	bor, cpy, Ag, tet, moly, sch	gar, px, ep, cal
Cornell	CNBC (Texada Island)	ls, mar	Tri./ Marble Bay Ls.	gabbroic suite-diorite porph	Mes. (?)	cpy, bor, po, mag, marc, Ag, py, moly, tet, sch	cal, gar, diop, ep, serp
Crevice Creek (McNeil)	USAK	ls, argl, chert, metavolcs	U. Tri./ Kamishak Fm. Jur./Talkeetna Fm.	granodiorite stock of Pilot Knob	Jur. (?)	py, cpy, mag	ep, gar
Cyclone	USMT (Ophir)	ls	Pal.	porphyritic granite	Cret.	mal, Au	gar, qtz, ver
Empire	USID (Alder Creek)	dolomitic ls	Miss.	granite, porph dikes	---	cpy, py, po, secondary Cu minerals	gar, px

Ore control	Tonnage (millions of tonnes)	Au (g/t)	Ag (g/t)	Base metals and Fe	Comments	References
				Fe skarns with byproduct gold		
fractures, sediment contact with unconformably overlying volcs	>18	1.37	6.2	0.12% Cu 43% Fe	Deposit grades into Cu-Mo porph at lower levels ; 0.08% Mo, 0.02% Ni, 0.03% Co; Pim Bessemaer	1, 2, 3, 4,
contact zone	0.08	25	p	Fe p	Main Au ores are py veins along fractures; minor Au in mag and po bodies; no Fe production; Nabesna Mining Corp.	6, 7
				Cu skarns with byproduct gold		
---	0.000099	58.1	17	0.70% Cu	Based on 1945 production; note that Ettlinger and Ray (1989) report reserves of 163,000 t for Ag-Cu Alpine (Apex Star) skn of 34% Fe, 0.90% Cu, 24.6 g/t Ag, no Au reported	8, 9, 10
favorable bed, structure	0.0023	19.2	38.9	1.2% Cu	Additional Au-ore tonnages discovered in 1980's at this deposit; associated with Cu and Au skns, polymetallic veins	11
ls-and contact	1.26	1.98	4	1.6% Cu	Coast Copper Co., Ltd.	8, 9, 12, 13
---	0.0000045	6.9	186	1.62% Cu	Gar apparently veins qtz monz	14
---	0.378	2.86	3.34	2.08% Cu	Associated with a porph Cu deposit	15, 16, 17
favorable bed	0.0091	17.1	73.7	2.96% Cu	Associated porph Cu deposit; Battle Mountain Gold Co.	11, 18
lst-and contact	2.99	2.31	>2.1	1.56% Cu 33.3% Fe	Adjacent to Benson Lake mine; Quatisino Copper-Gold Mines Limited and Empire Development	19
contact zone	15	1.7	---	2% Cu Fe p Pb p Zn p	In Zactecas; endoskarn present	1, 2, 20, 21
contact zone	0.0041	11.5	87	4.4% Cu	Based on 1903–17 production; reported Mo, W	9, 22, 23,24
contact zone	0.0407	11.6	53.9	3.4% Cu	Based on 1897–19 production; Vanada Mining Co., Ltd. (1943)	9, 22, 23, 24
---	0.000011	4.5	514	17.5% Cu	Ep-gar skn bodies in ls adjacent to stock; mag zones; magnetic anomalies around stock	5, 25, 26
contact zone	0.000028	10.96	110	9.7	Based on 1942–61 production; Ag grade from 23 t; Cu grade from 22 t	14
contact zone	0.694	1.65	53.89	3.64% Cu	---	27

Table 3. Gold-bearing skarns in which gold and silver are byproduct commodities—Continued

Name	Location (mining district)	Host lithology	Formation age/ name	Associated igneous rocks	Age	Ore minerals	Gangue minerals
			Cu skarns with byproduct gold—Continued				
Esashi (Akagane)	JPAN	ls	Carb./Shiba & Yonezato Fms.	qtz porph, granodiorite	Cret.	cpy, py, bism, Bi, sch, cub	diop, ep, gar, tour, amph, hed
Gold Bug	USMT (Bannack)	ls	Miss.	granodiorite	Tert.	auriferous py, Au, auriferous tetd	qtz, cal, gar, goe, ep, mal
Il'mensk (ul'ma)	USSR	---	---	diorite (?)	---	---	gar, px
Jumbo	USAK (Jumbo)	mar	L. Pal./ Wales Gp.	granodiorite stock	E. Cret.	Au, cpy, sph, moly, hem, py, po, spec	diop, gar, wol, ep, act, horn, chl, scap, plag, qtz
Katanga	PERU	ls, sh	Cret./equivalent of Ferrobamba & Tintaya Ls.	qtz dioritie, qtz monz	Tert.	cpy, py, bor, chal, chr, mal, brochantite, mag, Au, Ag	gar, trem
Klondyke	USMT (Elkhorn)	dol	Dev./Jefferson Fm.	Boulder batholith near Black Butte stock-gabbro diorite	Cret.	tetd, py, cpy, lim, mal	diop(?), gar, trem, cal, chl
Lily	CNBC	grnst, ls	L. Tri./ Karmutsen Fm. E. Jur./Kunga Fm.	Jedway stock	L. Cret.	mag, po, cpy, py, sph	gar, act, chl, cal
Little Billie (Vananda)	CNBC (Texada Island)	ls, mar	Tri./ Marble Bay Ls.	felsic granodiorite, qtz monz	Mes. (?)	cpy, bor, Ag, Au, py, po, sph, mag, moly, sch, marc, gal, tell	cal, diop, gar, ep, act, wol, amph, ves, qtz
Lucky Mike (Last Chance)	CNBC	grnst, ls, breccia, agglom	L. Tri./ Nicola Gp.	acidic dikes, granite-diorite	Jur. (?)	py, po, cpy, sch	gar, px, ep, cal
Marble Bay	CNBC (Texada Island)	ls, mar	Tri./Marble Bay Ls.	diorite	Mes. (?)	cpy, bor, po, mag, marc, Ag, Au, py, sph, moly, tet	ep, gar, cal, diop, wol?, trem, qtz
Morning (Ikeda)	CNBC	ls, basalt	L. Tri./ Karmutsen Fm. Kunga Fm.	Collision Bay diorite stock, Carpenter qtz monz stock	L. Cret.- E. Tert.	mag, py, cpy, po, apy, bor	gar, px, qtz
Mother Lode	CNBC (Greenwood)	sharpstone congl, ls	L. Tri./ Brooklyn Gp.	Wallace Creek granodiorite	L. Jur.	cpy, py, hem, mag, Au	ep, gar, cal, qtz, act, trem, chl
Natalevskoe	USSR	ls, calc sh, dolos	Pal.	diorite, syenite, aplite	Pal.	cpy, bor, apy, py, po, bism, sph, mag, moly, cc, Au, gal, elec, Bi, cub, Pb tell, Ni selenide, tet, ten, Ag	an-gros, diop, trem, wol, ep-clinoz, fo, phg, serp, ves, scap, spin, fl, chondrodite, clinohumite, preh, ap, chl, sphene

Ore control	Tonnage (millions of tonnes)	Au (g/t)	Ag (g/t)	Base metals and Fe	Comments	References
Cu skarns with byproduct gold—Continued						
---	3.796	1.1	10.1	0.8% Cu 23.7% Fe	Deposit has 5 ore bodies, largely skn but some disseminated veins; 5.9%pyrite, reported Bi	28
granodiorite-ls contact; ore generally exterior to gar skn	0.0021	31.7	70.3	0.76% Cu 0.31% Pb	Tonnage and grade figures represent 1922–41 production; originally staked as Dakota claim	29, 30
---	0.1	1	---	5% Cu	Estimated tonnage and grade (ref. 31); in northeastern Altai Mountains; Au-Cu mineralization in skn may predate associated diorite	31, 32, 33
contact zone	0.1115	1.97	24.5	4.1% Cu Fe p	Production data for 1907–44; estimated 0.28 Mt ore reserves of 45% Fe, 0.73% Cu	5, 6, 34, 35
contact, fissures	2	6.1	46.5	3.5% Cu Fe p	In Chillioroya region; Mitsui Mining and Smelting Co.(?)	36, 37
fractures, bedding planes	0.0006	30.3	17.4	1.04% Cu 1.58% Pb	Based on 1915–57 production. Cu grade for 375 t ore; Pb grade for 16.3 t ore; similar to nearby Hardcash deposit	38, 39
---	0.0134	3.82	64.3	4.28% Cu	Veinlike masses in altered and sheared grnst	9, 10, 40
granodiorite-mar contact	0.0637	5.7	18.8	1.3% Cu Fe p	Deposit size based on production; reported Mo; Texada Mines Ltd.	22, 23
---	0.000024	2.58	178	3.65% Cu 3.31% Pb	---	9, 44
---	0.199	7.75	63.4	3.4% Cu Fe p	Deposit size based on production; Ideal Basic Industries, Inc.	22, 23
faults, intrusive contacts	0.000029	30	25.8	2.49% Cu Zn p Fe p	Production from Cu claims; ore in dikelike sulfide bodies along faults and contacts	9, 10, 42
faults	4.24	1.27	5	0.82	Includes Sunset property; Gold Mines Resources, Ltd.	8, 9, 22, 43, 44, 45
steep fracture-skn intersection	0.48	5	11	1.6% Cu	Estimated tonnage and grade (ref. 31); 3 stage magnesian skn; numerous small podlike bodies of ore form at intersection of steeply dipping fractures; gold is relatively fine (avg about 930); only a few percent sulfide in deposit	31, 46, 47, 48, 49, 50

Table 3. Gold-bearing skarns in which gold and silver are byproduct commodities—Continued

Name	Location (mining district)	Host lithology	Formation age/ name	Associated igneous rocks	Age	Ore minerals	Gangue minerals
			Cu skarns with byproduct gold—Continued				
Old Sport	CNBC	ls, and volcs	L. Tri./ Quatsino Ls.	Coast Copper Stock diorite/ gabbro	Jur.	cpy, po, bor, cpy, py, mag, apy	cal, ep, gar, amph, diop, chl, qtz
Pauline	USAZ (Helvetia-Rosemont)	ls	Cret.	qtz latite porph	Tert.-Cret.	gal, cer, cpy, py, sph, moly, Au, Ag, spec	gar, qtz, ep
Phoenix	CNBC (Greenwood)	sharpstone congl, ls, argl, tuff	L. Tri./ Brooklyn Gp.	granodiorite of Nelson batholith	Cret.	po, cpy, py, hem, spec, minor mag, Ag, Au	amph, ep, gar, qtz, cal, chl
Pioneer-Lilyama	USCA (El Dorado, CO)	hfs, mar	---	horn grano-diorite	Mes.	py, cpy, bor, mag, hem, minor sch	gar, ep, qtz, feld, ves, cal
Rosita	NCRC	ls, mar	Cret.	diorite, monz	Tert.	cpy, py, po, mag, bor, cc, mal, cup	gar, ep
Seven Devils district	USID	ls	Tri./Martin Bridge Ls. (?)	Deep Creek stock-qtz diorite	Cret.	cpy, bor, cc, mal, azurite, chr, cov, sch-powellite	gar, ep, diop, hed, trem, act
Sinyuzhinskoe	USSR	ls, calc sh, dolos	Pal.	diorite	Pal.	Au, apy, Ni & Pb tells, ten, tet, moly, mag, bor, cc, cpy, py, gal, sph, po	gar(an-gros), diop-hed, wol
Vieja	CLBA	---	---	Ibaque batholith	130–150 Ma	cpy, gal, py, spec	cal, ep, marmetite, qtz
Yaguki	JPAN	sh, ls	Perm.	granodiorite	Cret.	cpy, po, cub, mag, W, Bi, hem, bism, cobaltite, sph, gal, moly	ep, gar(an), qtz, px, preh, babingtonite, chl, act, plag
Yreka	CNBC	limy tuffs, and ls	L. Jur./ Bonanza Gp.	qtz-feldspar porph dikes & sills	---	po, cpy, py, sph, mag, spec	---
Zackly	USAK	mar	Tri.	qtz monzodiorite	Cret.	cpy, born, py, Au, Cu, mal, lim, chalcedony	gar (an), wol, px, clinopx
			Porphyry Cu skarn related byproduct gold				
Carr Fork Parnell ore body	USUT (Bingham)	ls	L. Penn./ Bingham Mine Fm., Parnell ls.	Bingham stock-qtz monz porph	Tert.	py, cpy, po, apy, hem, mag, tet-tennantite	gar, diop, qtz, sid, clay

Ore control	Tonnage (millions of tonnes)	Au (g/t)	Ag (g/t)	Base metals and Fe	Comments	References
			Cu skarns with byproduct gold—Continued			
ls-volc contact	2.658	1.46	4.41	1.55% Cu 20.6% Fe	Ls beds in volcs; may be Cu-rich part of zoned system; nearby Merry Widow, Kingfisher, and Ravel deposits produced 3.4 Mt iron ore; grab samples from Merry Widow assay as high as 19 g Au/t; Coast Copper Co. Ltd. (1968)	8, 9, 22, 51
ls-dike contacts	0.000136	8.57	28.6	2% Cu 2% Pb	Although ls and qtz latite porph both silicated, bulk of sulfides is in skn; erratic py in porph	52, 53
congl-lst contact, faults	26.96	1.12	7.12	0.85% Cu Pb p	Includes Knob Hill and several other claims; mine was closed in 1978 and reclaimed; Granby Co.	8, 9, 22, 44, 45, 54, 55
faults	0.004296	1.57	16.5	2.3% Cu	Bulk of sulfides associated spatially with mag; some syenite porph as dike	56, 57
---	3.45	1.17	15.8	3% Cu	Gar-ep skn is deeply weathered; Rosita Mines, Ltd.	1, 46, 58, 59
ls, xenoliths in qtz diorite, fractures	0.00071	2.54	165	16.1% Cu 10.0% Pb	Composited production from 1943–51 for Arkansas-Decorah, South Peacock, and Helena mines; Pb grade for 131 t of ore; Pb-rich zones in some mines; W present.	60, 61
---	0.65	8	---	2.5% Cu	Au in stage II py, 0.1 to 1.6 ppm; Au in cpy; 0.93 ppb; deposit has only small amount of sulfide (a few percent)	46, 47, 48, 49
---	0.45	0.9	35	1.7% Cu	---	62
---	> 1.08	3.4	171	0.8% Cu	Deposit is 1 km by 310 m and as much as 70 m thick	1
limy tuffs	0.495	1.1	33.5	2.6% Cu	Uke Resources, Ltd.	8
contact zone, faults	1.25	> 6	p	2.6% Cu	Estimated reserves. Assays up to 6.6% Cu, 4.4 g/t Au. Zoned	5
			Porphyry Cu skarn related byproduct gold			
faults, distance to stock, elevation	0.8	8.7	4.2	1.02%	Drill-indicated resource for Parnell gold shoot. Multistage mineralization: high-grade Au in py-qtz and py-clay overprint on Cu-Au-Ag skn. Avg 1.9 g Au/t in garnetized ls. Byproduct Au was produced 1979–81 at Carr Fork mine from estimated reserves of 61 Mt of ore of avg grade 1.89% Cu, 0.38% g Au/t, 10.6 g Ag/t, and 0.027% Mo	63, 64, 65

Table 3. Gold-bearing skarns in which gold and silver are byproduct commodities—Continued

Name	Location (mining district)	Host lithology	Formation age/ name	Associated igneous rocks	Age	Ore minerals	Gangue minerals
			Porphyry Cu skarn related byproduct gold—Continued				
Ok Tedi	PPNG	---	---	---	---	cpy, gal, py, po, sph, mag, marc	act, cal, gar, px, trem, talc
			Zn-Pb skarns with byproduct gold				
Chichibu	JPAN	sl, sst, chert, ls	Pal.	qtz diorite	Mio. 7.9, 8.2 Ma	cpy, sph, py, mag	gar, clinopx, ep, act, cal, qtz
El Sapo	CLBA	---	---	Ibaque batholith	130–150 Ma	cpy, gal, py, mag, bor	gar, wol, marmetite, qtz
Falun	SWDN	ls, qtzite	Prot./Leptite Series	granite, qtz porph dikes, amphibolite	Prot.	py, cpy, po, sph, gal, mag, Au, gahnite, weibullite	trem, talc, act, diop, qtz, biot, anthophyllite, chl, almandine, cummingtonite, ophicalcite, cordierite, andalusite
Garpenberg Oda	SWDN	dolos, qtzite, mica, schist	Prot./Leptite Series	granite	Prot.	sph, gal, py, po, cpy, Au	trem, qtz, mica, talc, fl, tour, diop, gahnite
Maxfield	USUT (Big Cottonwood)	ls	Miss./ Gardison Ls.	diorite	Tert.	py, gal, tet, sph, Cu-stained oxide minerals	cal, qtz, sepiolite, diop, ep, mica, wol, gar
SE Afghanistan	AFGH	---	---	---	---	py, cpy, cc, rare Mo	---
Thanksgiving	PLPN (Baguio)	ls, minor congl, sst, sh, lithic tuff	Mio./Zig-Zag Series	diorite porph	---	py, sph, apy, cpy, gal, hem, mag, Au tell, Au	chl, gar, cal, qtz, clinoz, ep, act-trem, ves
Tsumo	JPAN	dolomitic mar	Pal./Koseiso Fm.	diorite, granodiorite, granite	Cret.	cpy, mag, malayaite	qtz, clay, phlg, gar, trem, chondrodite, wol, hed
Woodlawn-Kentucky-Utah	USUT (Big Cottonwood)	ls	Miss./ Deseret Ls.	Alta stock, granodiorite	Tert.	mag, cpy, py, gal, cer, arg, Au, sph	trem, calcsilicates

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2. Philippine Bureau of Mines and Geosciences, 1986
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4. Frost, 1965
5. Nokleberg and others, 1987
6. Newberry, 1986
7. Wayland, 1943
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10. Sutherland Brown, 1968
11. Roberts and Arnold, 1965
12. Laznicka, 1985
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29. Geach, 1972
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39. Klepper and others, 1957
40. British Columbia Minister of Mines Annual Report, 1981
41. Cockfield, 1948
42. Young and Uglow, 1926
43. Canada Department of Energy, Mines and Resources, 1980
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44. Church, 1986
46. Boyle, 1979
47. Vakhrushev, 1972
48. Ivankin and Rabinovich, 1972
49. Vakhrushev and Tsimbalist, 1967

Ore control	Tonnage (millions of tonnes)	Au (g/t)	Ag (g/t)	Base metals and Fe	Comments	References
			Porphyry Cu skarn related byproduct gold—Continued			
---	40	1.6		1.5% Cu	---	1, 66
			Zn-Pb skarns with byproduct gold			
---	0.5	3.6	52	0.45% Cu 6%Zn Pb p Fe P	Cu is restricted to gar-bearing skn; 12% pyrite; Nitchitsu Mining Co., Ltd.	67, 68
---	0.33	11.5	79.8	5.1% Cu 16.21% Pb	---	62, 69
lithology, contact zone	35	3	18	1.06% Cu 4.1% Zn 1.4% Pb	Associated with Fe skn; deposit is zoned	70
structure, contact zone	9.6	1	86	0.3% Cu 5.2% Zn 3.6% Pb	Deposit has well-developed zoning	70
fissures	0.00486	5.65	1774	19.7% Pb 1.4% Cu	Average grades reported for 1902–40 production	71, 72
---	0.227	<5	>100	3% Zn 9% Pb	Average composition reported from Pb-Zn exploration of Cu-skarn mineralization	73
contact, favorable beds & structures	1.7	6.41	40.55	0.36% Cu 4.47% Zn	Mined largely for Au-Ag; reported Cd; Banquet Explorations, Ltd.	2, 74
---	4.9	1.36	50.9	0.68% Cu 2.43% Zn	Two ore bodies: Tsumo, Maruyama	67, 75
contact	0.000368	1.48	933	11.9% Pb 2.64% Zn	Pb-Ag-Zn production from bedded replacement fissure	71, 72

50. Bazhenov, 1968
51. TRM Engineering Ltd., 1986
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54. Hedley, 1981
55. Little, 1983
56. Clark and Carlson, 1956
57. Cox and others, 1948
58. Bevan, 1973
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60. Cook, 1954
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69. D.A. Singer, oral commun., 1988
70. Grip, 1978
71. James, 1979
72. Calkins and Butler, 1943
73. Bybochkin and Kats, 1972
74. Callow, 1967
75. Geological Survey of Japan, 1980

Table 4. Gold-bearing skarn deposits and deposits purported to be gold-bearing skarns for which grade and tonnage data are unavailable

[Abbreviations listed in table 1]

Mine name	Location (mining district)	Description	Reference(s)
Akshiyryak Range	USSR (Kirghiziya)	280-Ma granite (K/Ar, biot) intrudes carbonate-siliceous sequence. Au mineralization is associated with skarnoid & secondary silicified rocks in mar & silicate-carbonate rocks gradationally farther out than skarn. Au is mainly in highly silicified rock that contains wol, locally ves, px. Dark-gray highly silicified rock contains po, py, Au (as 0.1-mm-wide flakes).	Dolzhenko, 1974
Alae-Sayan	USSR	Skn includes px, gar, amph, serp, and late qtz with Cu, Pb, Zn, As, Sb, Cd. Fluids: high Cl; Na/K=1.1 to 1.5:1. Early skarns formed at 480–890 °C. Au deposited at 250–150 °C.	Indukaev, 1977
Alvarado	USUT (Gold Hill)	Cu-Au skn formed in Miss. Ochre Mountain Ls. near Tertiary Gold Hill qtz monz stock. Ore includes Au, py, cpy, gal, bor, cc, mag, mal, lim, chalcanthite, jarosite. Gangue consists of wol, diop, ap, gar, spa, zoi, ves, trem, serp, qtz. Nolan (1935) reports $120,000 in Au produced 1892–1895.Channel sample assays range from tr to 5.8 g Au/t, tr to 387 g Ag/t, tr to 1.9% Cu. Woodman Mining Co.	Nolan, 1935; Wilson, 1959; El-Shatoury and Whelan, 1970
Ban Na Lom	THLD	Au, py, cpy associated with qtz deposition during or after retrograde skn formation. Although 3 skn types are recognized, Au mineralization is associated with relatively coarse grained gar-ep skn. Calcic skn is thought to be a metasomatically transformed tuff sequence.	Pisutha-Armond and others, 1984
Blue Grass	USMT (Bannack)	Gar-ep-cal skn veined by qtz as much as 5 m wide; veins not continuous. Ore along contact between granodiorite & ls mined from 40- by 7-m open cut.	Geach, 1972
Bright Diamond	USCO	Ore in flat shoots about 3 m thick; Au localized in mag-py; porph dike as much as 10 m wide nearby.	Irving, 1905; Irving and Cross, 1907
Buckhorn Mountain	USWA	Described as a gold-bearing skn in Okanogon Co., Washington, that displays geological similarities to some major gold skn deposit in Nevada. Exploration in progress. Crown Resources Corp. and Gold Texas Resources Ltd.	Mining Journal, 1989
Bumblebee	USMT (Ophir)	Gar skn showing superimposed faults. Explored by 30-m-deep shaft. Mal in qtz stringers in skn.	McClernan, 1976; Mineral Resource Data System, 1989, record DC09691
Cable	USMT (Cable)	Mineralized ls pendant of Camb. Hasmark dol, calc sh of Silver Hill Fm. in Eoc. Cable granodiorite stock. Primary ore: py, cpy, mag, po, Au, gal, sph, apy, tetd, marc. Oxidized ore: lim, hem, cc, bor, mal, azurite, Cu, Mn ox. Gangue minerals: gar, px, amph, wol, qtz, cal, dol, sid, mica, scap. Mag skn (Pomeroy mine) nearby. Most production pre-1900; total production for district, which includes Cable placer, estimated at 165,127 oz Au, 134,583 oz Ag. Nearby structurally controlled vein mineralization and oxidized ores occur at Southern Cross, Gold Coin, and Pyrenees deposits; Magellan Resources-Chevron Resources Co.	Earll, 1972; Emmons and Calkins, 1913; Emmons, 1907; Holmes, 1982; Meinert, 1988a; Holser, 1950
Cadia	AUNS	Au-bearing skn in area of Fe skn.	McLeod, 1965
Cane Springs	USUT (Gold Hill)	Cu-Au skn formed in Miss. Ochre Mountain Ls. near Tert. Gold Hill qtz monz porph stock. Ore: Au, py, cpy, bor, cc, cov, moly, mal. Gangue: gar, wol, diop, ves, zoi, qtz, cal, spa. Produced $50,000 to $70,000 gold 1892–95; 42 t ore assayed at 36.6 g Au/t, 103 g Ag/t, and 5.5% Cu in 1914; 1,479 t ore produced 1931–35. Recent assays reported by El-Shatoury and Whelan (1970) range from tr to 21.2 g Au/t, tr to 6.8 g Ag/t, and 0.12 to 1.03% Cu.	Nolan, 1935; Wilson, 1959; El-Shatoury and Whelan, 1970

Table 4. Gold-bearing skarn deposits and deposits purported to be gold-bearing skarns for which grade and tonnage data are unavailable—Continued

Mine name	Location (mining district)	Description	Reference(s)
Carlés (Salas, Asturias)	SPAN	Apy-cpy-py-Au in qtz-veined skn; 5- to 100-μm-size Au associated with apy.	Rau-Figueroa and others, 1985
Carr Fork	USUT (Bingham)	Gar-diop-act-ep-wol skn associated with porph Cu mineralization.	Atkinson and Einaudi, 1978; Reid, 1978
Central Tadzhikistan	USSR	Au-Cu-As in px & gar-px skn associated with L. Miss.- E. Perm. granodiorite & qtz diorite rocks; overall trapping temperatures of fluid inclusions range from 450° to 750°C; Au ores deposited paragenetically late in two stages: early py-apy, late tet-cpy at 250°–350°C.	Morozov, 1976; Morozov and others, 1974; Morozov and others, 1973
Charmitan	USSR	Four ore-forming stages: Au-Bi-tell, py-apy, Au-sulfide polymetallic, qtz-cc.	Proskuryakov and others, 1979
Chihuahua district Chihuahua	MXCO	Au-Ag-Pb-Cu skn occurs at ls-diorite contact. Over 2,100 kg Au was produced 1928–49 from approx 60,000 t ore, with grade ranging from 0.1 to >100 g Au/t.	D.L. Mosier (oral commun., 1987)
Chillioroya area Chumbivilcas	PERU	Cu-Ag-Au ore occurs in small bodies of gar-mag skn at ls-qtz monz porph contact. Ore minerals include cpy, py, bor, cc, Au. Grades are reported as "few" g Au/t, about 5% Cu, <100 g Ag/t for 2–10 Mt ore. Katanga (table 2) is found in this area.	Mineral Resource Data System, 1981, record W002200; Frank Simon (written commun., 1960)
Culverwell	USNV (Pennsylvania)	Skn associated with mag replacement pods in Camb. ls. Ep replaces monz-diorite; some skn includes copper ox, py, cpy. Grab samples assay as much as 85 g Au/t.	Mineral Resource Data System, 1984, records M241646 and M032085
Dutro	USMT (Blue Cloud)	Free Au, cassiterite, Bi reported from hydrosilicate altered skn including qtz, jas, trem, opal.	Knopf, 1933
East Sayan Mtns. (Medrezhye and Konstantinovskoe deposits)	USSR (Siberia, middle Asia)	Au ores preferentially formed in calcic skn from Cl-SO4-Ca Na-bearing fluids (Na/K=2:1 to 6:1; Cl/F=31:1) at 220°–420°C; Cl>F in leachates from productive Au skn.	Korobeynikov, 1976a, b, c; Korobeynikov and Chernyaev, 1976; Korobeynikov and Matsyushevskiy, 1973
El Fenomeno	MXCO	Au, Cu are reported to occur in this W skn mined during WWI and 1937–44; possible additional ore exists. Sch, secondary Cu minerals, py, po, cpy, apy occur in gangue of gar, ves, axinite, dio, qtz, cal. Main ore body was fan-shaped tactite zone at contact of L. Pal. mar & Cret.-Tert. diorite. In northern Baja California.	Salas, 1975; Fries and Schmitter, 1945; Leonard, 1989
First Chance	USMT	Au reportedly produced, together with W, from xenoliths of Dev. Jefferson Ls. in granodiorite.	Pardee, 1918; Kaufmann, 1963
Ge Jiou Yun Nan	CHNA	Sn-Au skn formed during Mes. contact metasomatism.	Sang and Ho, 1987
Geunteut area Sumatra	INDS	Geunteut granodiorite (14.3 Ma) intrudes L. Jur. & E. Cret. ls of Woyla Gp. Mineralization includes cpy, py, bor, azur, mal.	Bowles, 1984
Gissaro-Alay	USSR (central Tadzhikistan)	W-apy-Au-Cu skn containing px, gar, qtz, feld, amph, dol, wm.	Khasanov, 1982
Glassford Creek	AUQL	Gar-mag-ep-wol-hem-act skn in ls at granite contact; ore minerals include cpy, bor, po, hes, Bi, Au, secondary Cu minerals; 735 t Cu, 80 kg Au 725 kg Ag were produced 1905–7.	Murray, 1986
Goldstrike	USNV (Carlin)	Au-bearing skn occurs at the No. 9 Pit & at Skarn Hill at the Goldstrike Mine (includes several types of ore bodies); skn formed in Dev. ls, informally named the Popovich Ls., beneath the Roberts Mountain thrust. At West No. 9 Pit, Au mineralization occurs in 160-Ma(?) granodiorite. Skn assemblages include gar, diop, act, chl, Au. American Barrick Resources, Inc.	R.J. Roberts (oral commun., 1989); Schafer and Buffa, 1988

Table 4. Gold-bearing skarn deposits and deposits purported to be gold-bearing skarns for which grade and tonnage data are unavailable—Continued

Mine name	Location (mining district)	Description	Reference(s)
Gould-Corry	USMT (Red Lion-Hidden Lake)	Au reportedly produced from Au-Ag-Cu-W skn in Camb. ls intruded by Cret. granodiorite; gar, ep, goe, qtz present.	Earll, 1972
Hua Tong An Hui	CHNA	Cenozoic Cu-Mo-Au skn.	Sang and Ho, 1987
Huarca	PERU (Cuzco)	Irregular patches of Cu-Ag-Au ore in garnetite at contact of qtz monz porph with ls. Minerals include cpy, mag, minor bor & cc. Average grades of <1 to 2 g Au/t are reported for 1–10 Mt of ore.	Frank Simon (written commun., 1960)
Hudson Group	USMT (Silver Star)	Gar-ep skn developed in Camb. ls near contact with Cret. qtz monz of Boulder batholith; average grade reportedly 32–42 g Au/t, 42–52 g Ag/t; serp, sid, cal, asbestos present.	Sociedad Nacional de Mineria y Petroleo (Peru), 1969
Iron Clad	USCO	Ore in flat shoot; Au localized in mag-py as replacement with silicates of blue-gray ls.	Winchell, 1914; Sahinen, 1939
Kaliostrovskoe	USSR	Large blocks of ls engulfed totally by granitoid rock.	Irving, 1905; Irving and Cross, 1907
Kochulak Dalnagorsk region	USSR	Au-tell-tet stage formed at homogenization temperatures of 240°–270°C and 170°–190°C, together with Ag, Pb, Cu tell at lower temperatures (130°–150°C).	Ivankin and Rabinovich, 1972
Kommunar district	USSR (Altai-Sayan)	In 8 deposits, Au associated with py, po, cpy, mag primarily in qtz-act veined skn developed in Camb. sed-volcs sequence as result of emplacement of L. Camb. px diorite & monz.	Genkin and others, 1983
Kaznetskiy Alatau and Gornyi Altai	USSR	Au-bearing skn formed at 280°–700°C from homogenization temperatures in qtz & gar.	Lobanov, 1972
La Gloria	MXCO	Small Au-bearing W skn with Cu, Mo. Sch cpy, auriferous py, apy, moly occur in E. Cret. ls adjacent to granite. Gangue minerals include gar, ep, tour. Reserves of W-Mo ore are estimated at 25,000 t. In State of Sonora.	Pavlova, 1983
La Sonora	MXCO	A small Au-Cu skn in Pal. ls associated with L. Cret.-E. Tert. granite. Minerals include Cu-ox. In State of Sonora.	Perez Segura, 1985; Radelli, 1985; Leonard, 1989
Lucky Strike	AUNS	South of Bathurst, near Beuraga.	Perez Segura, 1985; Leonard, 1989
Many Peaks	AUQL	Gar-mag-cal skn in shear zone with py, cpy; 8,650 t Cu, 130 kg Au were produced from 1910–18.	Murray, 1986
Marn (Mini Grid)	CNYT	Assemblage elec (Au_{60-40})-Bi-bism-hes associated with cub exsolution in cpy or as blebs in apy, all hosted by px ($diop_{20-40}$)-act ($trem_{25-35}$)-po skn; avg grade 1.4 g Au/t, 2.8 g Ag/t.	Brown and Nesbitt, 1984, 1987
Midas	USUT (Gold Hill)	Ls beds in Manning Canyon Fm. altered to wol-gar-diop-ves skn near qtz monz; associated with oxidized and sulfidized Cu & Pb-Ag ore. Minor production (86 t, avg $56 Au per st produced before 1897).	Nolan, 1935; Thompson, 1973
Midas (Berg Creek)	USAK	Cu-Au skn in Tri. Nizina Ls adjacent to Jur. granodiorite-qtz monzodiorite pluton. Ore: mag, py, cpy, Au. Gangue: ep, gar,qtz. Grab samples assay as high as 8 g Au/t, 10 g Ag/t, 20% Cu.	Nokleberg and others, 1987
Mottini	USNV (IXL)	Au skn in U. Tri. sh, sst, sltst associated with 28-Ma granodiorite. Produced 272 t ore, avg $375 Au per st (est. 564 g Au/t, assuming a price of $20.67/troy oz); Ag, Cu, Pb, Ni present. Gangue of gar, cal, qtz, mag, spec, Fe and Mn ox. Ore consists of free Au, Ag & sulfides (py, gal, cpy).	Schrader, 1947; D.A. John (oral commun., 1989)
Mount Biggenden	AUQL	Gar-cal skn at granite contact; ore minerals include mag, bism, Bi, cpy, py, apy; 185 kg Au, about 235 t Bi produced 1890–1901; 378,725 t magnetite produced from adjacent skn from 1967 to present.	Murray, 1986

Table 4. Gold-bearing skarn deposits and deposits purported to be gold-bearing skarns for which grade and tonnage data are unavailable—Continued

Mine name	Location (mining district)	Description	Reference(s)
Nambija	ECDR	Gar skn, including k-spar altered to chl, ep, cal; includes Au, sch, auriferous py, apy; related to emplacement of Jur. batholithic rocks; grade reportedly may be as high as 30 g Au/t; notable concentrations of Au at qtz-qtz boundaries and qtz-gar-k-spar flooded portions of endoskarn.	E. Salazar (written commun., 1987); Minera Nambija (written commun., 1988)
Natal Sumatra	INDS	Skn has formed where L. Cret. Manunggal batholith (87 Ma) intrudes E. Cret. Soma Fm. & U. Jur., Lower Cret. Woyla Gp. sed rocks; both include meta-vols, ls, meta-ls members. Skn has formed at margins of batholith & in xenoliths of ls. Mineralization includes py, mag, Au, Ag, Cu-Pb-Zn minerals.	Bowles, 1984
New Calumet	CNQU	Pb-Zn-Ag ores; Grenville province. Ore shoots, masses occur in Grenville biot gneiss near its contact with an overlying amphibolite. Minerals include sph, py, marc, po, gal, cpy, apy, Ca & Mg silicates. Production (1943–68): 3.74 Mst at 6% Zn, 1.7% Pb. Reserves (1968): 0.282 Mst at 4.51% Zn, 1.08% Pb, 2.34 oz Ag/st, 0.014 oz Au/st. Consolidated Professor Co.	Boyle, 1982; Canada Department of Energy, Mines and Resources, 1980
New World district	USMT	Cu-Pb-Au skn in Camb. ls & shaly ls associated with Tert. rhyodacite porph & other intrusions. Ore: Au, gal, sph, py, cpy, spec. Gangue: gar, ep, trem, ves, qtz, ank. Daisy mine produced 13 carloads of gold ore in 1888 that averaged $50 per ton (est. 83 g Au/t). Skn gangue reported at other mines, prospects in district. Crown Butte Mines, Inc. developing New World Project for Au, Cu in 1987.	Lovering, 1929; Reed, 1950; Elliott, 1979; Elliott (oral commun., 1989); Lawson, 1988
Nixon Fork-Medfra	USAK	Group of Cu-Au skn deposits at contact (of ls) of Ord. Telsitna Fm. with L. Cret. monz pluton; in fractures, roof pendants. Ore: cpy, py, bor, Bi, lim, mal, Au. Gangue: diop, gar, ep, plag,qtz, ap, act. Produced 1.24 to 1.87 Mg Au, with Cu, Ag. Some deposits have grades as high as 113 g Au/t, 1.5 to 2.0% Cu.	Nokleberg and others, 1987; Newberry, 1986
Novo Brdo	YUGO	Skn & replacement mineralization in ls along schist-ls & dacite-ls contacts; ore minerals include sph, gal, po, cpy, marc; main skn mineral is gar. Ore contains 1–5% Pb, 1–8% Zn, about 100 g Ag/t, 3–4 g Au/t.	Jankovic, 1982
Oka	CNBC	Au in sulfide pods along skn-mar contacts & in faults; associated with diorite sills & reported to be similar to Mascot deposit 50 km to southwest. Fairfield Minerals Ltd. has identified several areas of mineralization along 5-km soil geochemical anomaly through mapping, chip sampling, trenching. Future drilling is planned on basis of chip sample analyses with 0.24–1.12 oz Au/st. Contains Au, Ag, Cu, As, Zn.	Skillings' Mining Review, 1987; Ettlinger and Ray, 1988, 1989
Olkhovskii West Siberia	USSR	Ord. diabase, diorite porph, qtz porph, aplite dikes intrude M. Camb. carbonate & tuffaceous rocks. Au-bearing mineralization occurs in gar-px skn & in qtz-sulfide veins. Ore minerals include cpy, sph, gal, bism; Au, Ag tells. Alteration includes chloritization, sericitization, slight serpentinization. Deposit is considered to have formed at medium depth, moderate temperature.	Smirnov and others, 1981
Primor'ye area	USSR (Far East)	Sch-Au-py skn formed under relatively reducing conditions; some associated Au-wolf deposits; mafic granite intruded into Sikhole Alin folded belt; some apy, mica, po; hed, gros, ves, cum, ep, act, tour, stilp, bustamite; mag, cc assemblages in skn.	Stepanov, 1977, 1981; Stepanov and others, 1976a, 1976b; Stepanov and Kuryakova, 1973; Makiyevskiy, 1978, 1979; Efimova and others, 1982; Piskunov and Makiyevskiy, 1978
Sara Alicia	MXCO	Small Au-Cu skn in Jur.-Cret. ls(?) associated with L. Cret.-E. Tert. granitic intrusives. In State of Sonora.	Perez Segura, 1985; Leonard, 1989

Table 4. Gold-bearing skarn deposits and deposits purported to be gold-bearing skarns for which grade and tonnage data are unavailable—Continued

Mine name	Location (mining district)	Description	Reference(s)
Sayakskiy region	USSR	High-temperature zones of skn contain three assemblages: (1) Au1: gersdorffite ($NiS_2 \times NiAs_2$)-apy-cobaltite (>250° C); (2) Au_2: Bi-cpy-po (250°C) with ep, act; (3) Au_3: wittichenite (Cu_3BiS_3)-moly-bor-cpy (225°C).	Fomichev and Kuznetsova, 1972
Shul Kou Shan	CHNA	Pal. contact metasomatic deposit. Skn mined for Pb, Zn, Au.	Sang and Ho, 1987
Spring Hill	USMT (Helena)	Gar-px skn developed in Miss. Madison Ls; skn altered to qtz-ank-cal-chl assemblage with Au-apy-po-py-cpy-gal inore; much of ore reported to be px-rich.	Pardee and Schrader, 1933
Stormont	AUTS	Au-Bi skn in Moina district, area known primarily for Sn-W skn, veins, greisens. Deposit is in Ord. Gordon Ls., associated with Dev. granite. Had minor production 1928–34. Reported Au values at Moina skn, 4.5 ppm.	Green, 1975; Collins and Williams, 1986; Kwak and Askins, 1981
Sylvester K	CNBC	Lenticular bodies of Au-bearing skn concordant with enclosing rocks of Tri. Brooklyn Fm., associated with micro-diorite stocks, dikes of L. Jur. to E. Cret. age. Mineralization consists of massive py, mar, po, minor cpy in calcic exoskn. Deposit has lim-goe cap several meters thick.	Church, 1984; Canada Department of Energy, Mines and Resources, 1986
Terrazas	MXCO	Au-bearing Cu skn along ls-diorite contact. Skn runs 2–3% Cu as cup, azur, mal, cpy, Cu. Associated Pb-Ag veins. In State of Chihuahua.	Salas, 1975; Gonzalez, 1956; Clark and Goodell, 1983; Leonard, 1989
TP (claims)	CNBC	As much as 15 g Au/t, 3.9% Co in chip samples from mag-calgar-amph skn in pre-Tri. gneiss, schist, mar of Yukon Gp. Skn zone is 15 by 200 m, controlled by two NW.-trending fracture zones. Four types of skn present.	Ettlinger and Ray, 1988
Union Amalgamated	USNV (Manhattan)	Sulfide-bearing skn veined by Au-bearing qtz; developed in Pal. marine sed & metamorphic rocks; possibly related to 16-Ma caldera or Cret. intrusion.	Shawe and others, 1986
West Park	USUT (Snake Creek)	Skn formed along contact of Miss. ls with Tert. granodiorite Peak Stock); ore includes cpy, bor, mag; average grade production 1946–50: 3% Cu, 17.2 g Ag/t, 1.57 g Au/t.	U.S. Bureau of Mines, Strategic Minerals Examination, 1950; Mineral Resource Data System, 1984, record D011978

Table 5. Mineral abundances for gold-bearing skarns

[Data are reported as a percentage of the number of deposits in the data set that report a given mineral present]

Data set	Au-skarn	Byproduct Au-skarn	Alaskan Fe-Au skarn
Reference	This study, table 2	This study, table 3	Newberry, 1986
Number of deposits	39	47	106
Ore minerals (in percent)			
Au/electrum	62	36	0
pyrite	72	91	72
pyrrhotite	67	51	42
chalcopyrite	85	96	90
arsenopyrite	51	17	6
magnetite	33	64	77
hematite/specularite	20	28	25
sphalerite	46	38	8
galena	28	34	1
Bi or bismuthinite	23	9	0
hedleyite	13	0	0
telluride minerals	26	9	0
molybdenite	18	23	11
scheelite	8	15	0
Gangue minerals (in percent)			
garnet	82	91	78
pyroxene	72	60	42
epidote	72	66	70
amphibole	46	45	41
chlorite	46	34	28
prehnite	13	2	0
vesuvianite	13	13	8
wollastonite	31	21	6
scapolite	8	13	9
boron minerals	13	0	0

Table 6. Analytical data for some igneous rocks associated with gold-bearing skarn deposits in north-central Nevada

[n.d., not detected;—, no data]

Analysis	1	2	3	4
SiO_2	64.0	70.5	66.2	63.6
Al_2O_3	15.1	14.5	15.1	16.5
Fe_2O_3	2.0	1.0	[1]3.34	[1]2.82
FeO	3.1	.16	—	—
MgO	3.5	1.5	2.5	2.5
CaO	3.5	.95	4.1	6.8
Na_2O	1.5	2.1	3.1	2.7
K_2O	4.3	6.1	2.9	2.3
TiO_2	.51	.47	.50	.56
P_2O_5	.16	0	.16	.21
MnO	.02	0	.03	.05
Other[2]	1.94	2.0	1.65	1.40
Au (ppb)	n.d.	100	42.4	<1
Cu (ppm)	990	1,500		
K_2O/Na_2O	2.87	2.90	.94	.84
Fe_2O_3	.65	6.25	—	—

1. Altered granodiorite sill at north edge of West ore body, a Cu-Au skarn deposit related to 38-Ma altered granodiorite of Copper Canyon. Fortitude Au-bearing skarn deposit lies just north of West ore body and is also probably genetically related to altered granodiorite of Copper Canyon. Analysis from Theodore and others (1973) (loc. 12, sample MB-40).
2. Altered granodiorite of Copper Canyon. Analysis from Theodore and others (1973)(loc. 9, sample MB-18).
3. McCoy granodiorite stock, 5,300-ft bench McCoy Mine sample 87JH013. XRF analysis by J. Taggart, A. Bartel, and D. Siems. Gold determined by INAA, G. Wandless, analyst.
4. Granodiorite dike at South shaft, Buffalo Valley Mine, sample 87TT228. Same methods as 3.

[1]Total iron as Fe_2O_3.

[2]Other = H_2O^+, H_2O^-, CO_2 for analyses 1, 2; = loss on ignition for analyses 3, 4.

Table 7. Representative data for minerals in gold skarns from north-central Nevada

[Total iron as FeO for pyroxene, idocrase, amphibole; total iron as Fe_2O_3 for garnet. Values are in weight percent. n.d., not detected]

Analysis	1	2	3	4	5	6	7	8	9	10
Mineral	Pyroxene		Garnet				Idocrase	Amphibole		
SiO_2	50.4	53.8	35.1	34.8	37.6	34.9	36.2	50.5	51.2	55.0
Al_2O_3	.36	.65	6.35	.01	13.0	0	14.4	1.25	4.49	2.49
FeO (Fe_2O_3)	18.2	3.40	23.4	32.5	13.8	31.7	3.40	27.1	12.4	8.12
MgO	6.99	16.49	.27	.29	.29	.29	2.71	6.34	15.4	18.7
CaO	23.2	25.6	34.4	33.0	35.8	33.5	34.6	11.4	12.6	13.0
Na_2O	.11	.02	0	0	0	0	.01	.11	.33	.12
K_2O	0	0	n.d.	n.d.	n.d.	n.d.	.01	.06	.29	.07
TiO_2	.01	.02	.49	0	.48	0	3.67	.04	.10	.05
MnO	.66	.20	.33	.23	.31	.30	.12	.92	.06	.28
F	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.97	.01	.06	.09
Cl	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.61	.01	.18	0
Total	99.8	100	100	101	101	101	95.3	97.7	96.9	97.9

1. Fortitude deposit sample 85TT243; average of 7 grains in massive pyrrhotite ore.
2. McCoy deposit, samples 86TT134 and 86TT137; average of 5 grains in massive oxidized garnet skarn.
3. Fortitude deposit, drill core sample of garnet-bearing sulfidized skarn; colorless, anisotropic zone.
4. Yellow isotropic andradite zone in same garnet grain as 3.
5. Surprise deposit, drill core sample of oxidized garnet skarn; colorless, anisotropic rim of large, euhedral zoned grain.
6. Yellow isotropic andradite core in same grain as 5.
7. McCoy deposit, sample 87TT137; average of 3 grains in idocrase-rich pod in garnet skarn.
8. Fortitude deposit, sample 85TT243; ferro-actinolite in pyroxene-bearing sulfidized skarn.
9. Northeast Extension deposit, sample 87TT2; actinolitic hornblende in epidote-amphibole-quartz-chlorite-sulfide skarn; no garnets or pyroxenes present.
10. Actinolite in sample 87TT2.

Table 8. Chemical signatures of nontronite clay layers associated with gold-bearing skarns

[—, not detected; N.D., not determined]

Sample[1]	85JH115		85JH142	86TT135	88TT63	87JH004
Method[2]	a	b	a	b	b	b
			Weight percent			
Al	—	0.33	—	1.5	0.12	2.94
Ca	1	.73	10	15	5.8	3.65
Fe	10	8.2	10	7.3	5.3	12.7
Mg	1	.89	.5	7.7	.13	.29
Na	—	.02	—	.19	.02	—
K	—	<.05	—	.37	<.05	<.05
P	—	.01	—	.1	.1	.12
Ti	.1	.08	.1	.1	.01	.51
			Parts per million			
Mn	100	660	1000	760	977	2150
Ag	2	30	7	8	<2	12
As	—	<10	—	20	40	30
B	10	—	10	—	—	—
Ba	200	160	500	82	13	17
Be	—	<1	—	2	<1	3
Bi	—	10	—	<10	<10	<10
Cd	—	<2	50	2	5	<2
Ce	—	<4	—	7	<4	993
Co	5	210	—	14	2	17
Cr	50	46	70	44	9	1350
Cu	200	320	20	3800	1	6050
Ga	—	<4	—	8	<4	23
La	—	<2	—	4	7	636
Li	—	7	—	7	9	23
Ni	15	12	—	12	5	553
Pb	20	100	—	11	6	326
Sc	7	4	—	6	<2	20
Sn	—	<10	—	100	<10	20
Sr	100	53	200	61	49	164
V	100	71	100	40	23	53
Y	—	3	20	3	9	16
Zn	500	550	200	400	240	564
Zr	50	—	200	—	—	—
Hg[3]	0.03		N.D.	0.08	N.D.	N.D.
Au[3]	.07		N.D.	5.1	0.04	0.42
Pd[3]	.001		N.D.	.001	N.D.	N.D.
Pt[3]	<.010		N.D.	<.010	N.D.	N.D.
Rh[3]	<.001		N.D.	<.001	N.D.	N.D.
W[3]	5.0		N.D.	5.0	N.D.	N.D.

1 Analyses were done on bulk samples of earthy, yellow-green clay layers in skarns. X-ray diffraction studies show that all samples are mixtures of clay and significant amounts of quartz and calcite or pyroxene. All samples have characteristic smectite peaks at 14 angstrom that expand to about 17 angstrom with glycolation. Microprobe work on 85JH115 confirms the Fe-rich nature of clay. Samples are from skarns in the Harmony Formation (85JH115) and in the Battle Formation (85JH142) in Battle Mountain Mining District, the McCoy Mine (86TT135) in McCoy Mining District, the Buffalo Valley Mine (88TT63), and the Surprise Mine (87JH004).

2 Elements sought for but not detected at limit of methods a and b include Au, Mo, and W. (a) Six-step direct current arc semi-quantitative spectrographic analyses; analyses performed in U.S. Geological Survey exploration research laboratories by Betty Adrian and Olga Ehrlich; X-ray studies by Steve Autley and Ted Botinelly. (b) Quantitative inductively coupled plasma direct reader emission spectroscopy by M. Malcolm in U.S. Geological Survey analytical laboratories; X-ray work by Karen Gray.

3 Trace analysis and chemical separation by C. Gent, R. O'Leary, B. Libby, N. Rait, and S. Wilson in U.S. Geological Survey analytical laboratories.

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