Gold; Fess Foster, Golden Sunlight Mines, Inc.; Sharon E. Lewis, Montana Bureau of Mines and Geology; Nolan Smith, Philipsburg, Montana, and Robert G. Russel, Coeur d'Alene, Idaho.

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

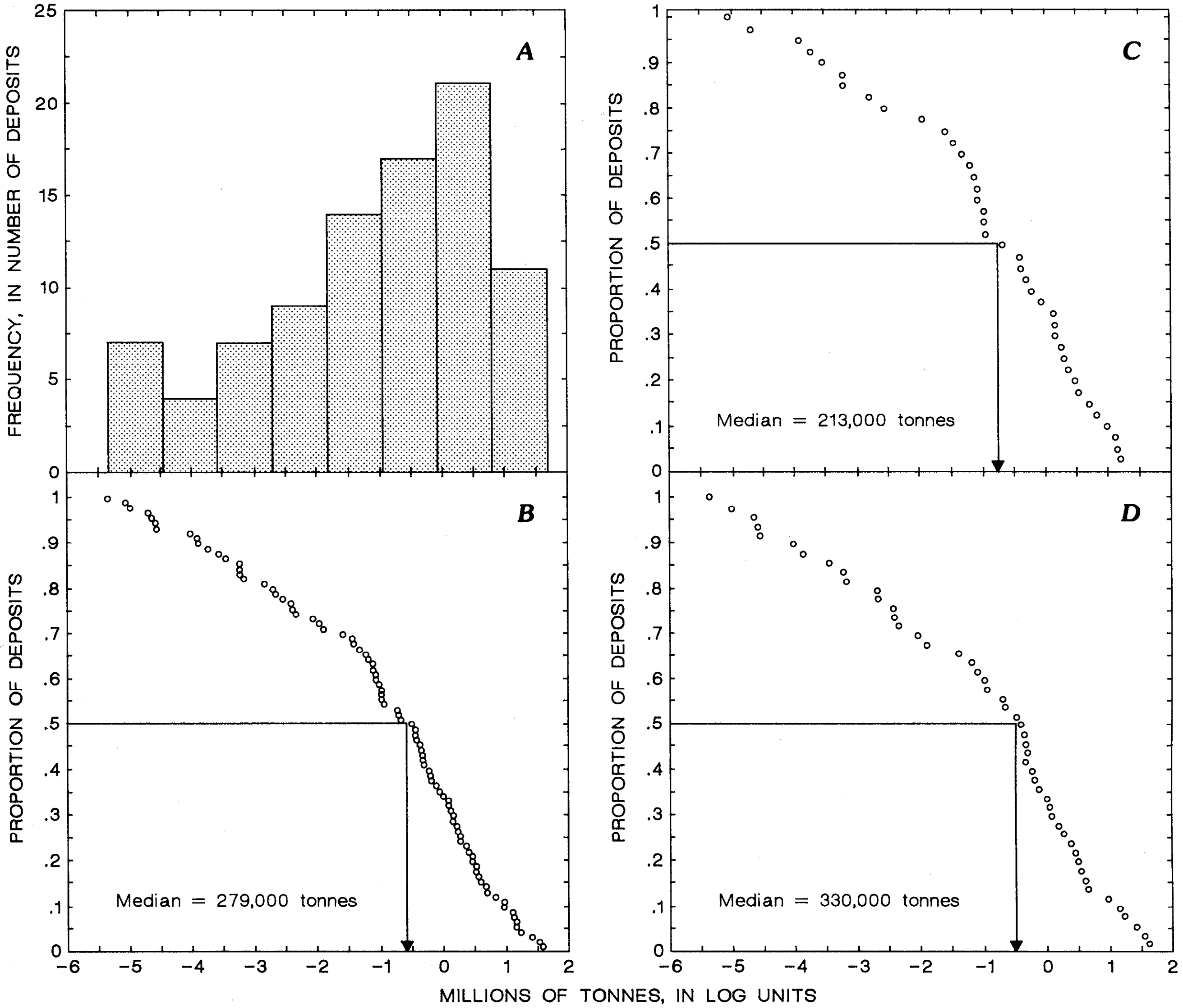

Figure 1. Distributions of tonnage for Au-bearing skarn deposits. *A*, Tonnage histogram for 90 Au- and byproduct Au-skarn deposits. *B*, Tonnage model, same data set. *C*, Tonnage model for 39 Au-skarns. *D*, Tonnage model for 59 byproduct Au-skarns.

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-

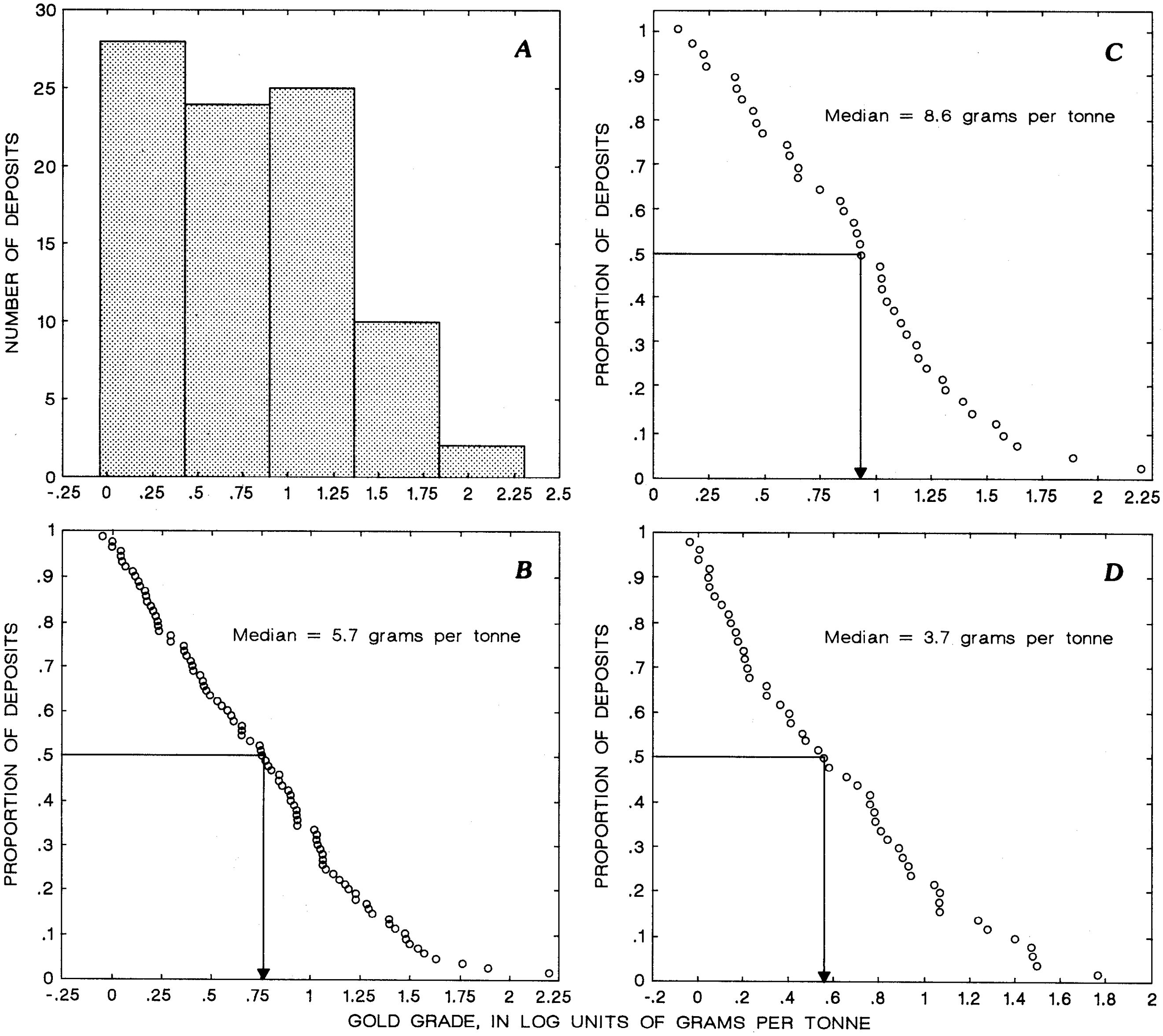

Figure 2. Distributions of gold grade for Au-bearing skarn deposits. *A,* Gold grade histogram for 90 Au- and byproduct Au-skarn deposits. *B,* Gold grade model, same data set. *C,* Gold grade model for 39 Au-skarns. *D,* Gold grade model for 59 byproduct Au-skarns.

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,

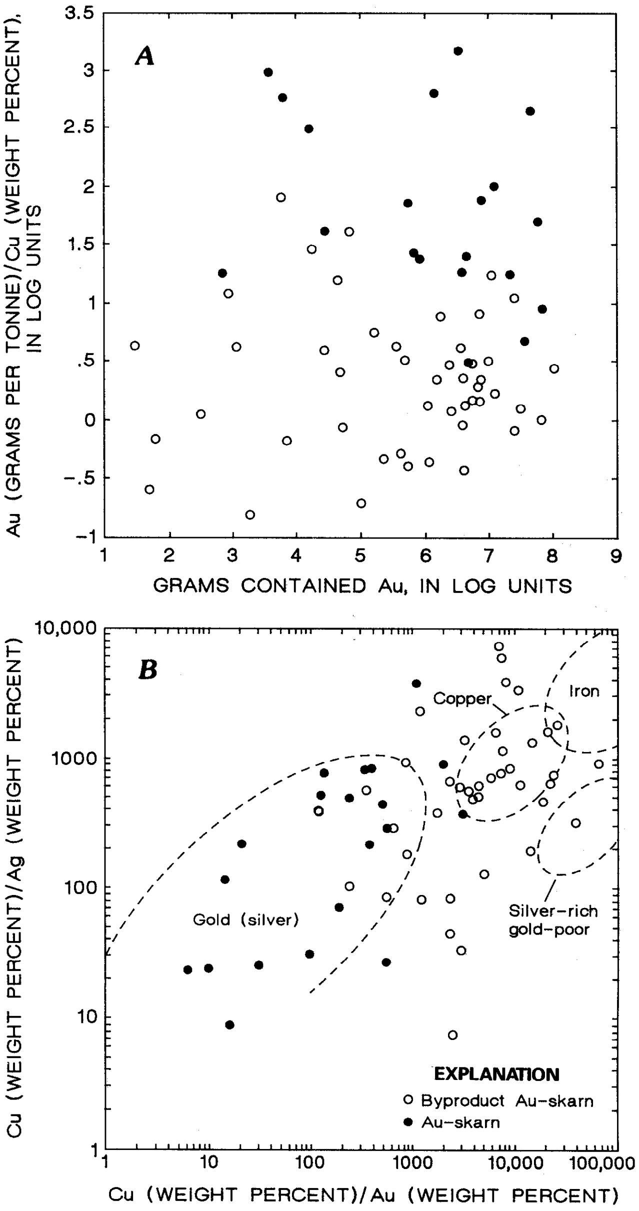

Figure 3. Gold skarn classification schemes based on metal ratios. *A*, Gold-copper ratios compared with contained gold (average grade multiplied by tonnage) for 20 Au- and for 47 byproduct Au-skarn deposits for which copper grades are available. *B*, Copper/silver ratios compared with copper/gold ratios 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