UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DESCRIPTION AND GRADES AND TONNAGES OF GOLD-BEARING SKARNS

by

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Open-File Report 87-273

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1987

INTRODUCTION

A significant proportion of mining industry's interest in the last few years has been centered on the discovery of deposits such as Battle Mountain Gold Company's Fortitude deposit, Nevada and Experanza Exploration's Red Dome deposit, Queensland, Australia. These and many other deposits have been generally referred to as gold skarns in the literature and occasionally further differentiated into contact, or proximal, skarns and distal skarns (Sillitoe, 1984, 1987; Bonham, 1986). To allow easy comparison with established types of skarn, this paper presents descriptive and grade-tonnage information based on data collected for over 80 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). Grade and tonnage data are available for 62 of these deposits and their grade and tonnage distributions are shown in figures 1 and 2. Gold-bearing skarns can, as a first approximation, be treated as deposits in one of two subtypes: (1) skarns in which gold has been recovered as a byproduct but due to changes in price structures now assumes the role of primary commodity given sufficient gold grade and (2) skarns in which gold is the primary commodity. The two types of Au-bearing skarns apparently do not differ in currently recognizable geologic terms.

As recognized by Meinert (1987), many deposits referred to as Au-skarns by others were already classified, or could be classified, under deposit models such as Cu- and Fe-skarns by their dominant base- or ferrous-metal contents. Further, some Au-bearing skarn deposits are gradational into sediment-hosted disseminated Au-Ag (also known as carbonate-hosted and Carlin-type) or polymetallic replacement deposits. As a result, the term "gold-bearing" skarn more aptly applies to all such skarn deposits and a set of criteria have been established to determine whether a deposit should belong to either of the two subtypes we propose under the general classification Au-bearing skarn: <u>Au-skarn</u> and <u>byproduct Au-skarn.</u>

The criteria for the Au skarn subtype are as follows:

1. The deposit must have an average grade of at least 1 g Au per tonne and have been exploited primarily for gold.

2. The mineral assemblage(s) of the deposit must include mineralogy distinctive of the skarn environment. Herein we follow the non-genetic 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 predominently carbonate rocks.*** Most Au-bearing skarns, nevertheless, owe their genesis to processes largely involving process (4). Thus we follow an overall classification of skarns based upon their sought-for metal content. Smirnov (1976), however, suggested that classification of skarns be

based instead upon the composition of the original protolith of the skarn: calcareous, magnesian, or silicate.

Among all remaining skarns, either mined primarily for their base- and ferrous-metal content or mined for precious metals and containing very large amounts of base- and ferrous-metals as described by various authors in Cox and Singer (1986), some contain a significant amount of Au as a byproduct. Such skarn deposits with byproduct Au that average at least 1 g/tonne and with base-metal grades less than approximately the lowest 10th percentile of the grade model of Cu in Cu skarns (Jones and Menzie, 1986), of Zn or Pb in the Zn-Pb skarn model (Mosier, 1986), or of Fe in Fe skarns (Mosier and Menzie, 1986) have been included with the Au-skarn data set (table 1). Skarn deposits with greater than 1 g Au/tonne and higher base- and ferrous-metal grades fit existing base- and ferrous-metal skarn deposit types with byproduct Au and have been assigned to our byproduct Au-skarn data set (table 2). Thus, by *a priori* restricting our byproduct Au-skarn data (table 1) to those known skarn systems wherein Au concentrationns are greater than or equal to 1 g/tonne, we provide composited cumulative distribution relations only for the Au-enriched portion of Cu, Pb-Zn, and Fe skarns as defined by Jones and Menzie (1986), Mosier (1986a, b) and Meinert (1987). As will be described below, these skarns that contain byproduct Au show no statistically significant differences in tonnage distributions from the Au-skarns exploited almost exclusively for their precious metal content. This relation is primarily a reflection of the variability of many polymetallic skarn systems under a wide range of economic circumstances. However, there is a marked difference in the cumulative distribution plot for Au and Ag grades of Au-skarn and byproduct Au-skarn as defined previously: Au-skarns have a median Au grade of 6.8 g/tonne and byproduct Au-skarns have a median grade of 3.4 g/tonne. Median Ag in Au-skarns is 2.3 g/tonne as compared to 14 g/tonne in byproduct Au-skarns. Just over 60 percent of the Au-skarns have reported Ag as compared to nearly 80 percent of the byproduct Au-skarns. Ag content appears to have a strong correlation with base metal content. As a comparison, the median Au grade for 14 porphyry Cu-related Cu skarns as reported by Meinert (1987) is approximately 0.3 g/tonne and the median Ag grade is approximately 8 g/tonne (note these values are higher than those reported by Singer, 1986).

Deposits for which some geologic and (or) grade-tonnage data are available are listed in tables 1 through 3. Table 1 lists data for Au-skarns exploited primarily for their precious metal content and with little or no base-metals for which grades and tonnages and some geologic data are available. Table 2 lists byproduct Au-skarns that can be classified under other skarn types including Cu, Zn-Pb, Fe, and other skarns and for which we have grade-tonnage and some geologic data. Table 3 lists deposits that have been described as "gold skarns" in the literature, but for which grade-tonnage data were not available. Table 4 lists the abbreviations used in the preceding tables.

Additional deposits have been described in one or more publications listed in the bibliography as gold skarns but were not included in the tables for the following reasons: inadequate description of the deposit; our failure to locate 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/tonne. These deposits include: Tennent 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; Ban Na Lom, Thailand; and others. Although the Mt. Biggenden, Austrialia magnetite-bismuth-gold skarn is classified as a Au-skarn by Meinert (1987) and assigned a size of 500,000 tons and a Au grade of 15 g/ton, we have not included it with either our Au-skarn or byproduct Au-skarn subtypes primarily because of our uncertainty about the Au grade and tonnage of mined Au ore. Total Au production to 1969 from Mt. Biggenden is more than 7,000 oz, of which 5,751 oz were producted before 1901 (Clarke, 1969). The tonnage of mined ore is not reported with those values of Au extracted. In 1917, Dunstan (1969) calculated magnetite ore reserves as 500,000 tons, which apparently includes only "a few grains of gold per ton" (Clarke, 1969) in as much as all of the "actinolite rock" that contained the bulk of the gold and bismuth had been already mined out by that time.

In the process of constructing the grade-tonnage diagrams and analyzing the data, we were able to identify both Au (>1 g/tonne) and Ag grades as significantly different between the Au-skarn and byproduct Au-skarn subtypes in addition to the expected differences in base- and ferrous-metal contents. It should also be noted that in element versus element plots for the byproduct Au-skarn and Au-skarn subtypes, Au-rich Cu-skarns deposits do not plot in a cluster spatially separate from Au-skarns but instead tend to represent the Cu-rich part of the domain with gradational and overlapping relationships with other skarns; this type of relationship holds for the other elements (see figs. 3 and 4). The tonnages of our Au-skarn subtype with relatively little base- and precious-metals and those skarns containing significant base metals can not be differentiated statistically. One important exploration implication is that economically viable Au-bearing skarn deposits may occur in association with Cu, Pb-Zn, or Fe skarn and although the median Au grade of these byproduct Au-skarns is lower, the highest grades are similar to those of the Au-skarn subset. Perhaps the only metal-bearing skarn environment that might be excluded from consideration as permissive for the occurrence of significant concentrations of Au and Ag is the tin skarn environment associated with two-mica granite. Significant Au or Ag mineralization is not known in the classic tin-skarn regions in Cornwall (Hosking, 1964) or Malaya (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).

The remainder of this paper is divided into 3 sections: a geologic description of Au-bearing skarns presented in a form similar to that of established Cu, Zn-Pb, and Fe skarn models (Cox and Singer, 1986) to allow rapid comparison and contrast; grade-tonnage distributions of Au-bearing skarns; and a combination references-bibliography section.

Acknowledgments: We would like to acknowledge the assistance of the following people who contributed data or expertise to this paper: William C. Bagby, Donald A. Singer, Gail M. Jones, W. David Menzie, Dan L. Mosier, and James J. Rytuba of the U.S. Geological Survey, Menlo Park, Calif.; David W. Blake, R.G. Benson, and Patrick R. Wotruba of Battle Mountain Gold Company; and Edward I. Bloomstein of Santa Fe Mining.

GEOLOGIC DESCRIPTION

Deposit type: Au-bearing skarn; includes a Au-skarn subtype and a byproduct Au-skarn subtype as described above.

Other Names: Au-rich skarn; precious-metal skarn.

Date of Compilation: May, 1987

Principal Commodities: Au and Ag

Byproducts: Cu,Zn,Fe,Pb, As,Bi,W,Sb,Co,Cd,S

Examples of Typical Deposits: Fortitude, USNV
Nickel Plate/Hedley, CNBC
Red Dome, AUQL

Relative Importance of Deposit Type: As much as 250,000 oz Au per year produced from some deposits (Fortitude). Many major discoveries are possible in the future for this deposit type. To this date (1987), more than 30,000,000 ounces Au produced from skarn (Meinert, 1987).

Descriptive/Genetic Synopsis: Provisionally restricted to Au-bearing (>1.0 g Au/tonne) skarn based largely on cut-off grades reported as low as 1 g/tonne in some Au-skarn systems currently (1987) in production. Generally calcic exoskarn with Au associated with intense retrograde hydrosilicate alteration. Some economically significant Au-bearing skarns (Hedley), however, are partly in endoskarn (Barr, 1980; see also Lee, 1951). Includes deposits in some districts significantly distant from intrusive contacts at current levels of erosion but still exhibiting mineral assemblages common to calcic and magnesian skarns. As presently constituted (table 1), includes some deposits previously considered as Cu, Fe, or Zn-Pb skarns in classification schemes of Einaudi and others (1981) and Meinert (1987). Figure 5 shows shows some of the possible spatial relationships of Au-bearing skarns to related intrusions.

Associated Deposits: Cu, Fe, Zn-Pb, and W skarns; porphyry Cu, skarn-related deposits; sediment-hosted Au-Ag (see Sillitoe, 1983); polymetallic replacement and polymetallic veins; Au placers; other deposits, including stockwork Mo systems as at Red Dome, related to felsic and intermediate intrusions.

General References: Zharikov, 1970
Boyle, 1979
Einaudi and others, 1981
Sillitoe, 1983
Wotruba and others, 1986
Meinert, 1987

Regional Geologic Attributes

Tectonostratigraphic setting: In North America, mostly cordilleran and island-arc settings; some in rifted craton. Emplacement of Au-enriched magmato-hydrothermal systems possibly controlled by long-active rifts intersecting the craton edge in continental-margin environment of western North America. 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 depths below the respective paleosurface. Much less abundant are Tertiary Au-bearing skarns in cratonic environments (Bright Diamond, Iron Clad, see Irving, 1905; Irving and Cross, 1907). On a somewhat more local scale, emplacement of Au-enriched dikes astride the hinge region of broad anticlinal arches seems to have been an important structural control. In the Soviet Union, most Au-bearing skarns have been classified as medium-depth deposits according to the scheme of Bodaevskaya and Rozhkov (1977). Further, according to them, Au-bearing skarns are associated with Paleozoic early-eugeoclinal stage, deformed batholiths of granite-granodiorite composition, or with Paleozoic late eugeoclinal stage, minor 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.

Age Range: Generally Mesozoic or Tertiary in cordillera of western North America, middle-Tertiary in rifted craton (Bright Diamond, Iron Clad), and probably middle-Tertiary in West Sarawak, Malaysia (Bau) according to Wolfenden (1965). Several significant systems of lower Paleozoic age are also known in the Soviet Union and a significant Au-bearing skarn in Australia (Red Dome) is late Paleozoic in age.

Local Geologic Attributes

Host Rocks: Wide variety of sedimentary and igneous rocks including limestone, dolomite, shale, conglomerate, rhyolitic to andesitic tuff, and granitoid; however, a pre-metamorphic calcareous component is commonly present.

Associated Rocks: 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; some deposits (Tumco) may be associated with weakly- to strongly-peraluminous calcic granite (Smith and Graubard, 1987) that intrudes metavolcanic rock (Tosdal and Smith, 1987).

Opaque Minerals: Native Au, electrum, and in order of frequency of occurrence: pyrite, chalcopyrite, pyrrhotite, arsenopyrite, sphalerite, galena, bismuth minerals (especially bismuthinite and native Bi), magnetite or hematite, tellurides (including Au, Ag, Ni, Pb), tetrahedrite, tetradymite, bornite, loellingite, and W- and Mo-bearing minerals. In some deposits, Ag occurs in Bi-bearing galena. In addition, many other minerals have been reported.

Gangue Minerals: Typical skarn assemblages include garnet (andradite-grossular), diopside and other pyroxenes, wollastonite, chlorite, epidote-clinozoisite-zoisite, scapolite, quartz, actinolite-tremolite, calcite and serpentine. Various micas, ilvaite, idocrase, talc, sphene and apatite have been reported for several deposits.

Garnet is the characteristic silicate mineral of the calcic Au 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. Garnets in Au skarns are similar to those of copper and magnetite skarns. Both isotropic and birefringent anisotropic varieties are common. Multiple garnet generations occur in some deposits (e.g., Fortitude, Surprise, McCoy). Early garnets are colorless, anisotropic, zoned towards more Fe-rich rim compositions, and poikilitically enclose relict diopsidic pyroxenes. Late garnet pods and veins are inclusion-free, less altered than early garnets, and have distinctly yellow (in thin section), isotropic, andradite cores and colorless, anisotropic rims that are oscillatorily zoned with respect to Al and Fe. TiO_2 contents of 0.4 to 3 weight percent are common for early garnets whereas late garnets are nearly Ti-free. Late, coarse, zoned andradites (Ad_{85} to Ad_{100}) are reported as the latest skarn mineral in some Au-bearing skarns from the Altai-Sayan region (Vakhrushev, 1972).

Pyroxenes are diopside-hedenbergite solid solutions having low Mn contents. Vakhrushev (1972) describes diopside (pure to Hd_{20}) as the characteristic pyroxene of the Altai-Sayan gold skarns. Pyroxenes in sulfide-free garnet skarn samples from the late Cretaceous Copper Basin Cu deposits (J.M. Hammarstrom, unpub. data, 1987) and the middle Tertiary McCoy deposit are diopside-rich (Hd_{10} to Hd_{50}, <3% Jo) whereas pyroxenes coexisting with massive pyrrhotite, other sulfides, and late garnet at the Fortitude deposit are more iron-rich (Hd_{40} to Hd_{60}).

Amphibole typically replaces (pseudomorphs) pyroxene in Au-skarns; reported compositions include actinolite, tremolite, ferro-tremolite and hornblende. In sulfidized skarn at the Fortitude deposit, ferro-actinolite (low F, up to 1% MnO, 2% Al_2O_3) is intergrown with, or replaces, pyroxene.

Wallrock Alteration: Metasomatic, anhydrous calcic (or magnesian) skarn assemblages superposed on preceding contact metamorphic assemblages and followed paragenetically by hydrous assemblages with abundant sulfide(s) and (or) magnetite. Some deposits (Bau) 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. Magnesian Au-bearing skarn may show dolomite followed by kotoite [$Mg_3(BO_3)_2$]- and ludwigite [$(Mg,Fe^{2+})_2Fe^{3+}BO_5$]-bearing marble; 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 Au, bismuth, chalcopyrite, pyrrhotite, and cubanite just interior to the reaction zone; diopside; clinohumite; and, finally, diopside partly replaced by phlogopite—all zones developed across 25-35 cm (Watanabe, 1943).

Structural Setting: Immediate vicinity of, or relatively distal from, weakly mineralized intrusive rocks, commonly where wallrocks are extensively brecciated or faulted.

Dimensions of Ore in Typical Deposits: Highly variable; overall dimensions possibly increase with distance from intrusion as grade decreases.

Overall configuration of deposits largely a function of respective geometries of mineralizing magma and pre-mineral structures, favorable replacement sequences, and impermeable barriers to fluid flow, if present.

Dimensions of Alteration or Distinctive Halos: Highly variable, from very restricted to as much as several kilometers from inferred locus of mineralizing system. In some systems, the overall size of the alteration zone has been enhanced by the presence of pre-mineral structures that channeled fluid flow.

Effect of Weathering: Some deposits are entirely within oxide zone. Au grade may be higher in oxide zone than in equivalent sulfide zone. Oxide zone in some deposits includes vivianite along fractures (probably after iron sulfide(s)). Nontronite layers commonly interbedded with garnet skarn. The term "nontronite" is used as a field term for iron-rich yellow-green montmorillonite that swells upon glycolation; oxidation state of iron unknown. Clay layers include quartz and calcite and may include relict skarn silicates (pyroxene, garnet and epidote). Major proportion of some deposits (Red Dome) hosted by oxidized karst-collapse breccia developed in marble as a result of marble reacting with acidic ground water (Torrey and others, 1986). Acidic ground water probably resulted from breakdown of sulfides in the surrounding pyritic halo of the Au-skarn there.

Effect of metamorphism: Au-bearing skarn systems could be metamorphosed regionally to yield gneiss-hosted Au deposit as exemplified possibly by the Tumco deposit which has been metamorphosed to amphibolite grade (Smith and Graubard, 1987; see also Tosdal and Smith, 1987). However, some relatively extensive Sn-W-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 margins of skarn where calc-silicate porphyroclastic mylonite occurs. Skarn away from the contact shows some kinked chalcopyrite-bornite exsolution lamellae, but no cleavage or foliation.

Geochemical signatures: Anomalous Au in environment of retrograde-altered skarn. Associated pyrite in some Au-skarn deposits reported to contain 0.1 to 250 ppm Au (Vakhrushev, 1972). Anomalous Sb (in stibnite), As (in scorodite), and Au in wollastonite-bearing skarn assemblages flooded with colloform-banded quartz and jasperoid (Bau) all distal to quartz-and calcite-flooded, calc-silicate Au ore (Wolfenden, 1965; W.C. Bagby, oral commun. 1987). Quartz-calcite veins containing anomalous Au. In addition, gold mineralization and highly anomalous concentrations of Au in some skarn systems (Akshiryak Range, USSR) occur mostly in fine-grained, gray to light gray, highly silicified sequences of rock in carbonate beyond the outer limit of established skarn (Dolzhenko, 1974). The surface expression of some Au-skarn systems (Red Dome) includes relatively abundant, fracture-controlled secondary copper minerals (Torrey and others, 1986).

Nontronite layers from some Au-bearing, calcic skarn deposits show significant concentrations of Ag and Cu and variable, but enhanced levels of other trace elements, such as Sn (table 5). 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 iron skarns: Cu and Zn (tens to hundreds of ppm levels), Mo, Sc, Ga and Sn (10 to 50 ppm each) occur in all the garnets from Au-skarn; some garnets carry several hundred ppm As, up to 30 ppm Pb and similar concentrations of Ag as well. In contrast, garnets from Fe skarns have Ti, Cr, V, Ni, Co and Ge as a characteristic trace element suite and lack the elements associated with Au-skarn garnets or show inconsistent distributions of them.

Au/Ag ratio in rock increases laterally outward (away from center of associated intrusion) in some productive copper-bearing calcic skarn systems toward ore (Fortitude) that is approximately 0.6 km from intrusion, and that is close to a diffuse boundary between marble and calc-silicates (Blake and others, 1984; Theodore and others, 1986; Wotruba and others, 1987a,b). In other Au-skarn systems that are predominantly zoned vertically close to the related intrusive rocks (Red Dome), much of the Au ore occurs 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 widespread high local thresholds for many associated base- and ferrous metals and, some deposits, As, Bi, Se and Te in particular.

Zonation of Au in Au- and Pb-Zn-bearing skarn (Ban Ban, Thanksgiving, Tomboy-Minnie) seems to show inconsistent patterns. At Ban Ban, Au in trace abundances may coincide with known distribution of Ag which varies directly with Pb and Zn concentrations that are in turn constrained tightly to the central portion of associated garnet skarn (Ashley, 1980). At Thanksgiving, irregularly distributed sphalerite-pyrite pods that replace andradite skarn show higher Au contents than pyrite-magnetite replacement pods (Callow, 1967). At Tomboy-Minnie, local metal zoning of the Au ore bodies shows high concentrations of Au (>0.05 oz/ton) enveloped by increased abundances of Zn and Ag (>500 ppm and >0.1 oz/ton, respectively). 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 Au in some Fe skarn systems that contain byproduct Au (Benson Lake) seems to be related directly to the abundance of sulfide associated with magnetite (Eastwood, 1965). At the Merry Widow pit of the Benson Lake, British Columbia cluster of magnetite skarns, concentrates of chalcopyrite were reported to contain as much as 1 oz Au per ton of chalcopyrite.

Isotopic signatures: Range in $\delta^{34}S$ values for sulfides is clustered tightly: +2.7 to +4.7 $^{o}/oo$ 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 body that occurs adjacent to the intrusion, the West ore body, 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 associated altered granodiorite primarily from crustal components based on initial Nd isotopic compositions (Farmer and DePaolo, 1984).

Fluid inclusions: Boiling, high salinity fluids are associated with many Au-bearing skarn systems studied to date. Fluid-inclusion signature of skarn probably is most easily inferred from fluid inclusions of associated intrusive rocks. For example, possible involvement of high-salinity fluids some time during generation of Au-bearing skarn may be implied by occurrence of halite-bearing fluid inclusions in quartz phenocrysts of genetically associated granitoid. In some deposits (Tomboy-Minnie), early fluids associated with diopside-quartz assemblages were dominantly $CaCl_2$-brines and boiling at temperatures higher than 500 ^{o}C. Fluids then were progressively enriched in Na and K over time, and during hydrosilicate stages, temperatures ranged from 320 to 500 ^{o}C at time actinolite formed, and from 220 to 320 ^{o}C at time chlorite became dominant in the assemblages (Theodore and others, 1986). Much of the Au is paragenetically late, deposited from NaCl-rich brines at temperatures less than 300 ^{o}C. At Red Dome, Cu-Au-Ag ores apparently were deposited during a retrograde stage attendant with the circulation of relatively low salinity (<10 weight percent NaCl equivalent), possibly meteoric-dominant fluids at temperatures in excess of 350-380 ^{o}C (Torrey and others, 1986). In other skarn systems, Au also was deposited mostly during low-temperature stages: Alae-Sayan (250-150 ^{o}C), Central Tadzhikistan (350-250 ^{o}C), Sayakskig (>250-225 ^{o}C) and Kochulak (270-240 ^{o}C; 190-170 ^{o}C) (see table 3). Deposition of most Au close to calc-silicate-marble interface as reported in many Au-bearing skarns may reflect a combination of protracted solubility of Au and build-up of HCO_3^- in the fringe environment of evolving skarn (Gumenyuk and Glyak, 1983), thereby decreasing the solubility of Au owing to a change in pH (see Henley, 1984).

Geophysical signatures: Local magnetic high(s) resulting from increased abundance of pyrrhotite and (or) magnetite.

Ore controls/exploration guides: In established districts zoned from mostly proximal base metal-dominant deposits to distal precious metal-dominant deposits, 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 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 reflections of deep Au-bearing skarn. Other guides: reported Au in base- and ferrous-metal skarn systems; Au placers in region of well-developed skarn, especially if the placer Au is intergrown with bismuth oxide(s) or bismuth telluride(s).

GRADES AND TONNAGES OF AU-BEARING SKARNS

Grades and tonnages of Au-skarns and buproduct Au-skarns are shown. The gold grade had to be 1 g/tonne or higher to be included. Allowable levels of Cu, Zn, Pb, and Fe for the Au-skarn sub set were determined as being equal to or lower than the lowest 10th percentile of grades in the grade models for Cu, Zn-Pb, and Fe skarns (Jones and Menzie, 1986; Mosier, 1986; Mosier and Menzie, 1986). The tonnages and grades of Cu, Zn-Pb, and Fe skarns with reported byproduct gold are also shown on the diagrams-- there is no statistical difference in the tonnages. The median tonnage for both subsets is about 400,000 tonnes (fig. 6). For the Au-skarn subset, there is a strong inverse relationship between Au grade and tonnage (r= -.64); this relationship is weaker for the byproduct Au-skarn subset (r=-.55). The Au-skarn subset has a median Au grade of 6.8 g/tonne and a median Ag grade of 2.3 g/tonne (figs. 7, 8). For the byproduct Au-skarn subset, the medians are 3.4 g Au/tonne and 14 g Ag/tonne.

The reader should be aware that the authors found wide variations in the Au grade distributions during different stages of the compilation; tests of the Au grade distribution for Au-skarns indicate that addition of 6-8 deposits with grades near the 1 g/tonne cutoff could change the median to a value not significantly different from that of the byproduct Au-skarn subset, although the possibility of such additions is not high. In addition, the difference in medians between the two subsets is less than some reporting differences or errors, especially those in the older literature.

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Table 1. Gold-bearing skarns where gold and silver are the major commodities exploited

Name	Location	Host Lithology	Formation Age/Name	Associated Igneous Rocks	Age	Ore Minerals	Gangue Minerals	Ore Control
Alvarado	USUT	lst	Camb Ochre Mountain	qtz monzonite		Au,py,gal,cpy,bor,cc, mag	wol,mags,diop,ap,gar, spa,zoi,ves,trem,serp	fractures, contact zone
Bau	MYLA	msr,sh	Wolsey Fm	acid porph stocks and dikes	mid-Mio	Au,apy,py,sph,stib, real,orp	chl,diop,ep,gar,wol, ves	contact zone, fractures, permeable lithology
Brown's Creek	AUNS	lst & mdst in tuff	Ord Angullong Tuff	Carcoar Granite		Au,apy,cpy,py,po,ten, tet,bor	act,diop,ep,gar,wol, ido,trem,clinozoi	lst-tuff contact, fractures
Buffalo Valley	USNV		Miss-Perm Havallah seq	granodiorite porph	mid-Tert	py(Au?)		intense qtz-py silicification in fractured skn near porphyry
Central Zeballos	CNBC	lst	U. Tri Quatsino Fm	granodiorite		cpy,po	diop	contact zone
Cone Springs	USUT	lst	Camb Ochre Mtn	qtz monzonite		Au,py,cpy,bor,cc,cov, moly	wol,gar,diop,ves,zoi	
Fortitude	USNV	calc seds	Antler seq	granodiorite stock	mid-Tert	cpy,apy,py,po,elec, bism,Bi,tells	chl,diop,gar	favorable lithology
French	CNBC	lst, limy arg	Tri Nicola Fm	Coast Intrusives		apy,po,py,bor,cpy	gar,ep,qtz	
Gold Curry	USMT	lst, qtz monzonite		qtz monzonite		po,bism,tetd,cpy,mag	gar,diop,calc,ep	contact zone
Golfo de Oro	MXCO	carb-calc sh, sltst	Barrance Fm	dacite porph dikes	Laramide	Au-gal,py,po,sph,tet		ox zone near breccia pipe
Hedley Mascot	CNBC	lst, limy arg, qtzite		Toronto stock granodiorite	U. Jur?	apy,py,sph	gar,px	contact zones
La Luz (Siunna)	NCRC	lst, limy sh, agglom, tuff	Mine Series	granodiorite	Tert	Au,cpy,py,hem	ep	fault/hanging wall andesite
Lebedskoe (Kaurchak)	USSR			diorite		Au,apy,sph,tetd,Pb tells,mag,cpy,hem,py, cc	gar,ad,gros,diop,hed, act,trem,ep,clinoz,	
Marshall	CNBC	lst, chert	Triassic seds	qtz monzonite, granodiorite		cpy,py,po,sph	chl,gar	crest isoclinal fold
McCoy	USNV	lst, dol, qtzite	Tri Augusta Fm	granodiorite, diorite			act,trem	ox zone of contact skn
Midas	USUT	lst	Manning Canyon & Oquirrh Fm	qtz monzonite		py,apy,Cu sulfides	wol,diop,gar,ves	bedding
Nickel Plate	CNBC	lst, limy arg, qtzite, tuffs, flows		granodiorite, porph gabbro and diorite sills and dikes	Cret	apy,cpy,po,tetd	gar,px	contact zone
Northeast Extension	USNV	calc. cong	M. Pennsy. Battle Fm	granodiorite stock	mid-Tert	po,cpy,py,Au	act,ep,sphene,k-spar chl	favorable lithology
Pagatan Siayu	INDS	lst	Pal Silungkang Fm	granodiorite	Mes	Ag,Au	gar,wol	contact zone
Red Dome	AUQL	ss, chert, andesite, lithic congl, lst	Chillagoe Fm	qtz feldspar porph dikes and sills	Perm-Carb	Au,bor,mag,sph,Pb & Ag tells,cc,witticenite, moly	gar,wol,clinopx,	intrusive contact
Reicher Trost	WGER	dol, mica schist		granite		loel,leucopy,gal,sph, cpy,py		
Rokuromi	JAPN	biot schist, lst		qtz diorite, granodiorite		po,apy	gar,ep,others	
Siana	PLPN	carb lst, mang and calc sh		diorite or granodiorite		Au,cpy,gal,py,sph, tells		contact zone, favorable lithology
Southern Cross	USMT	dol, lst, sh, schist, gneiss	Hasmark Fm	granite		py,po,arg,mag,Bi sulfotellurides	green mica	fissures, ox areas
Suian	NKOR	schist, qtzite, sl, dol, lst		Suian granite stock		Au,apy,cpy,gal,py,po, sph,bism,tetd,loel	gar,diop,phlog,act, lud,chl,talc, trem,wol	contact zone
Surprise	USNV	calc sh, calc ss	U. Camb Harmony Fm		mid-Tert?	secondary Cu minerals	calc sillicatess,goe, clays,gar	favorable beds
Tillicum	CNBC	tuffaceous sed rocks	Miss-Penn Milford Grp	Goat Canyon-Halifax stock-diorite porph	Cret-Jur	Ag,Au,gal,po,sph,py	act,gar,feld,trem, clinozoi,biot	contact zone, permeable lithology
Tomboy-Minnie	USNV	calc congl	mid-Perm Battle Fm	granodiorite porph	mid-Tert	Au,cpy,gal,py,po,sph, apy	act,chl,ep,trem,clays, musc	
Tourmaline	USMT	sediments,andesite	Prec			py,po,apy	act,ep,fl,tour	at sediment-andesite contact?
Tul Mi Chung	NKOR	schist,qtzite,sl,dol, lst		Suian granite stock		Au,apy,cpy,gal,py,po, sph,bism,tetd,loel	gar,diop,phlog,act, lud,chl,talc trem,wol	contact zone
Villalta	CNBC	lst,mar,volcs	Sicker Grp	diorite-dacite porphs		apy,hem,marc,mag,sid	calc,ilvaite,serp, goe	

Table 1. Gold-bearing skarns where gold and silver are the major commodities exploited—Continued

Name	Tonnage (tonnes x 10^6)	Au (g/t)	Ag (g/t)	Cu (%)	Zn (%)	Pb (%)	Other Grades
Alvarado	0.0011	17.	3.6				
Bau	2.4	7.2	0.1				Sb 0.002%
Brown's Creek	0.39	8.7	10.	0.44			
Buffalo Valley	0.435	2.4					
Central Zeballos	0.038	16.9	11.4	0.019			
Cone Springs	0.0045	20.					
Fortitude	10.6	8.2	28.5	0.2			
French	0.65	20.5	0.697				
Gold Curry	0.93	8.5	4.2	0.33		0.0005	
Golfo de Oro	5.	4.5	10.				
Hedley Mascot	0.627	11.6	2.8	0.14			
La Luz (Siunna)	16.	4.1	1.2	0.44			
Lebedskoe (Kaurchak)	0.12*	4.*					
Marshall	0.0454	17.					
McCoy	9.	1.92	34.				
Midas	0.0021	25.					
Nickel Plate	3.08	15.5	1.39	0.03			
Northeast Extension	1.4	2.9	15.1	0.11			
Pagaran Siayu	0.113358	5.6	2.5	0.2			
Red Dome	13.8	2.3	5.25	0.46	1		
Reicher Trost	0.0057	20.	0.1				
Rokuromi	0.16	4.1	1.				
Siana	5.4	5.05	10.				
Southern Cross	0.4	13.	16.	0.088			
Suian	0.53	13.	4.9				
Surprise	1.75	2.8					
Tillicum							
Heino-Money Zone	0.126	20.6					
East Zone	5.	1.					
Tomboy-Minnie	3.54	3.1	9.6	0.03			
Tourmaline	0.27	4.4					
Tul Mi Chung	0.4	12.					
Villalta	0.181	5.1					

*-estimated value

Table 1. Gold-bearing skarns where gold and silver are the major commodities exploited—Continued

Name	Comments/Associated Deposit Types	Company	References
Alvarado	small Cu skarns		Nolan, 1935
Bau	area includes skarn, vein, and replacement mineralization	Borneo Co. and others	Boyle, 1979 Wolfenden, 1965 Bowles, 1984
Brown's Creek		Hickey Mines	Taylor, 1983
Buffalo Valley		Horizon Gold	T.G. Theodore (unpub. data, 1987)
Central Zeballos			CNBC Minfile No. 92L018**
Cone Springs	small Cu and As skarns; Gold Hill district		Nolan, 1935
Fortitude	porphyry Cu skarn, polymetallic veins; Battle Mountain district	Battle Mountain Gold Co.	Argall, 1986
French			CNBC Minfile**
Gold Curry			Roby and others, 1960
Golfo de Oro	Au,Mo,U in breccia pipe		Bonham, 1985
Hedley Mascot		Good Hope Resources Ltd.	MR 198* Barr, 1980
La Luz (Siunna)		La Luz Mines Ltd.	Sillitoe, 1983 Plecash and others, 1963
Lebedskoe (Kaurchak)	Au in py: 0.8 to 30 ppm; Au in cpy: 13.6 ppb		Vakhrushev, 1972 Ivankin and Rabinovich, 1972 Vakhrushev and Tsimbalist, 1967 E.I. Bloomstein (written commun., 1987) Tveritonov, 1966
Marshall		Canbec Resources Ltd.	MR 198*
McCoy		Tenneco	Kuyper, 1987 Tingley and Smith, 1982 Schrader, 1934 Kral, 1947
Midas	small Cu and As skarns; Gold Hill district		Nolan, 1935
Nickel Plate		Mascot Gold Mines Ltd.	Boyle, 1979 Lee, 1951 MR 198* Barr, 1980
Northeast Extension	porphyry Cu skarns, polymetallic veins; Battle Mountain district	Battle Mountain Gold Co.	Wotruba and others, 1986 Mining Engineering, 1986
Pagaran Siayu	many other skarns including Cu and Pt skarns	N.V. Mijnbouw Maatschappij Moeara Sipongi	Bowles and others, 1985
Red Dome	Cu and Zn-Pb skns; Chillagoe district	Elders Resources Ltd.	Torrey and others, 1986 Murray, 1986
Reicher Trost	worked intermittently for centuries		Maclaren, 1908 Lindgren, 1933
Rokuromi	Fe (magnetite) skarns; adjacent to Kamaishi	Nihon Kogyo (1950)	Grant, 1950
Siana	this deposit is described as having features of skarn and "Carlin-type" deposits	Surigao Consolidated Mining Co.	Philip. Bur. Mines, 1986
Southern Cross	Cable Cu-Au skarn is nearby (see table 2)	Southern Cross Gold Mining Co.	Emmons and Calkins, 1913 Earll, 1972
Suian	Cu skarns; worked from ancient times	Seoul Mining Co.?	Gallagher, 1963 Watanabe, 1943 Boyle, 1979
Surprise	porph Cu skarns, polymetallic veins; Battle Mountain district		Meinart, 1987 T.G. Theodore (unpub. data, 1987)
Tillicum		Esperanza Explorations Ltd.	McClintock and Roberts, 1984 Roberts and McClintock, 1984a, 1984b
Tomboy-Minnie	porph Cu skarns, polymetallic veins, Battle Mountain district	Battle Mountain Gold Co.	Sillitoe, 1983 Blake and others, 1984
Tourmaline		Tourmaline Gold Mining Co.	Roby and others, 1960
Tul Mi Chung		Seoul Mining Co.?	Gallagher, 1963 Watanabe, 1943
Villalta		Canamin Resources	Grove, 1981 MR 198*

*MR 198: See Canada Department of Energy, Mines, and Resources, 1984
**CNBC Minfile: British Columbia Ministry of Energy and Petroleum Resources, 1981

Table 2. Iron, copper, and zinc-lead skarns that contain gold as a significant by-product

Name	Location	Host Lithology	Formation Age/Name	Associated Igneous Rocks	Age	Ore Minerals	Gangue Minerals	Ore Control
FE SKARNS WITH BY-PRODUCT AU								
Larap	PLPN							
Nabesna	USAK	lst,dol,marl,mafic volcs	Tri Chitistone Lst	monzodiorite stock	104-114 Ma	py,mag,cpy,Au,po,gal, sph,apy,stib	gar,wol,ido,ep,act, hnbl,chl,scap,ap,serp, qtz	
CU SKARNS WITH BY-PRODUCT AU								
Bailey Day	USNV	calc ss	U. Camb Harmony Fm		mid-Tert?	py(Au),cpy,mal,chrys, azur,tenor	ep,k-spar,sphene,gar chl,biot	favorable bed
Benson Lake	CNBC			qtz diorite	Jur	cpy,mag,bor		
Bluestone	USNV				Cret	cpy,py	ep,gar	
Cable	USMT	lst (marble), calc sh	Camb Hasmerk Fm	granodiorite		Au,apy,cpy,py,po,mag, spec,sid,tells, gal, sph	act,biot,calc,chl,diop, ep,gar,ser,dol	roof pendent
Carr Fork	USUT							
Coast Copper	CNBC	lst, andesitic volcanics	Quatsino Lst, Karmutsen volcanics	diorite-gabbro		cpy,bor,mag		lst-ande contact
Concepcion del Oro	MXCO	lst, sltstone		grandiorite stock	U. Eoc	cpy,py,mag,hem,enar, tet,gal,sph,po,ten, bism,cosalite, wittichenite	ad,chl,diop,ep,gar,px plag,ido,zol,scap	
Copper Mountain	USAK	lst, dol, mafic volcs	Pre-Ord Wales Grp	diorite, monzodiorite, qtz	101-105 Ma	cpy,py,mag,hem,bor	ep,gar,px,scap,qtz	contact zone
Copper Queen	CNBC							
Cornell	CNBC			granodiorite to qtz granodiorite; feldspar porph		cpy,po,mag,mar	ep,gar	
El Sapo	CLBA			Ibeque batholith	130-150 Ma	cpy,gal,py,mag,bor	gar,wol,marm,qtz	
Empire	USID	dolomitic lst	Mise	granite, porph dikes		cpy,py,po,secondary cumins	gar,px	
Il'menak (Ul'ma)	USSR			diorite?			gar,px	
Marble Bay-Gladys C	CNBC			granodiorite		cpy,po,mag,mar	ep,gar	
Natalevskoe	USSR			diorite, syenite aplite		cpy,bor,apy,py,po,bism, sph,mag,moly,cc,Au, elec,Bi,cub,Pb tell, Ni selenide,tet	ad-gros,diop,trem,wol, ep-clinoz,fo,phlog, serp,ves,scap,spin, chondrodite,clinohemite, preh,ap,chl,sphene, fluorite	steep fracture - skarn intersection
OK Tedi	PPNG					cpy,gal,py,po,sph,mag, mar	act,calc,gar,px,trem, talc	
Old Sport	CNBC	lst,andesitic volcs	U. Tri Quatsino Lst	Island Intrusives diorite	Jur	cpy,bor,cpy,py,po,mag		
Oregon	CNBC			granodiorite		cpy,py,Au		
Rosita	NCRG			diorite, monzonite	Tert	cpy,py,po,mag,bor,cc, mal,cup		
Snowshoe (N. Phoenix)	CNBC			qtz diorite, diorite	Jur-Cret	cpy,py,po,mag,hem		
Sinyuzhinekoe	USSR			diorite		Au,apy,Ni & Pb tells, ten,tetd,moly,mag,bor, cc,cpy	gar,ad-gros,diop-hed, wol	
Tsumo	JPAN	dolomitic marble				malay,mag,cpy	gar,wol,heden,qtz, phlog,trem,chondrodite	
Vanada	CNBC		dike			cpy,po,mag,mar	ep,ger	
Vieja	CLBA			Ibaque batholith	130-150 Ma	cpy,gal,py,spec	calc,ep,marm,qtz	
Yaguki	JPAN	sh, lst	Perm	granodiorite	mid-Cret	cpy,po,cub,mag,W,Bi, hem,bism,cobaltite,sph, gal,moly	ep,gar(an),qtz,px,preh, babingtonite,chl,act, plag	
ZN-PB SKARNS WITH BY-PRODUCT AU								
Falun	SWDN							
Garpenberg Oda	SWDN							
SE Afghanistan								
Thanksgiving	PLPN	lst, minor congl,sst, sh,lithic tuff		diorite porph		py,sph,apy,cpy,gal,hem mag,Au tells,rare Au	chl,gar,calc,qtz,clinoz	contact, favorable beds and structures
OTHER SKARNS WITH BY-PRODUCT AU								
Gold Hill (United States)	USUT	lst	Camb Ochre Mtn Fm	qtz monzonite, qtz porph		apy,gal,py,sph,po	gar,chl,qtz	

Table 2. Iron, copper, and zinc-lead skarns that contain gold as a significant by-product—Continued

Name	Tonnage (tonnes x 10^6)	Au (g/t)	Ag (g/t)	Cu (%)	Zn (%)	Pb (%)	Fe (%)	Other Grades
FE SKARNS WITH BY-PRODUCT AU								
Larap	18.	1.37	6.2	0.12			43.	0.08% Mo; 0.03% Co; 0.02% Ni
Nabesna	0.080	25.						
CU SKARNS WITH BY-PRODUCT AU								
Bailey Day	0.0023	19.2	38.9	1.2		0.009		
Benson Lake	1.26	1.98	4.0	1.6				
Bluestone	0.378	2.86	3.34	2.08				
Cable	0.24	22.	18.	>1				
Coast Copper	2.99	2.31	>2.1	1.56				
Concepcion del Oro	15.	1.7		2.				
Copper Mountain	0.0058	4.5	320	10.				
Cornell	0.0408	11.4		3.3				
Empire	0.694	1.65	53.89	3.64				
Il'mensk (Ul'ma)	0.1*	2.*		5.*				
Marble Bay	0.285	5.46	43.7	2.39				
Natalevskoe	0.48*	5.*	11.*	1.6*				
Ok Tedi	36.	1.6		1.5				
Old Sport	2.63	1.4	4.5	1.57				
Oregon	0.00873	5.1	84.6	2.0				
Rosita	3.4496	1.17	15.8	3.0				
Snowshoe	0.6	1.94	9.6	1.05				
Sinyuzhinskoe	0.65*	8.*		2.5*				
Tsumo	3.3	1.51	58.	0.6				
Vanada	0.0635	5.88		1.57				
Vieja	0.45	0.9	35.	1.7				
Yaguki Mine	>1.08	3.4	171	0.8				
ZN-PB SKARNS WITH BY-PRODUCT AU								
El Sapo	0.33	11.5	79.8	5.1		16.21		
Falun	35.	3.0	18.	1.06	4.1	1.4		
Garpenberg Oda	9.6	1.0	86.	0.3	5.2	3.6		
SE Afghanistan	0.227	<5.	100.		3.	9.		
Thanksgiving	1.7*	6.41	40.55	0.36	4.47			
OTHER SKARNS WITH BY-PRODUCT AU								
Gold Hill (United States)	0.022	1.0	55	0.02	0.40	0.86		10.7% As

*estimated value

Table 2. Iron, copper, and zinc-lead skarns that contain gold as a significant by-product—Continued

Name	Comments	Company	References
FE SKARNS WITH BY-PRODUCT AU			
Larap		Pim-Bessemaer	Einaudi and others, 1981
Nabesna			Nokleberg and others, 198 Newberry, 1986 Wayland, 1943
CU SKARNS WITH BY-PRODUCT AU			
Bailey Day	Cu and Au skarns, polymetallic veins		Roberts and Arnold, 1965
Benson Lake	Vancouver district		Laznicka, 1973
Bluestone	Yerington district		Knopf, 1918 Einaudi, 1982
Cable	associated Fe skarns, Southern Cross Au skarn nearby (table 1)	J.C. Savery (1877)	Boyle, 1979 Earll, 1972 Emmons and Calkins, 1913
Carr Fork	associated porphyry Cu deposit		Atkinson and Einaudi, 1978
Coast Copper		Quatsino Copper-Gold ML and Empire Development	MR 198*
Concepcion del Oro	in Zacatecas		Einaudi and others, 1981 Laznicka, 1973
Copper Mountain	Ketchikan district	Alaska Consolidated Copper	Nokleberg, Newberry, 1968
Cornell	on Texada Island		Little, 1970
El Sapo			Jurada, 1982 D.A. Singer (written commun., 1985)
Empire	Alder Creek District		Koschman, and Bergendahl, 1968
Il'mensk (Ul'ma)	In northeastern Altai mountains; Au-Cu mineralization in skarn may predate associated diorite.		E.I. Bloomstein (written commun., 1987) Bulynnikov, 1948 Tveritinov, 1966
Marble Bay	on Texada Island		Little, 1970
Natalevskoe	3 stage magnesian skarn; numerous small pod-like bodies of ore form at intersection of steeply-dipping fractures		Vakhrushev, 1972 Ivankin and Rabinovich, 1972 Vakhurshev and Tsimbalist, 1967 E.I. Bloomstein (written commun., 1987) Bazhenov, 1968
Ok Tedi			Einaudi and others, 1981
Old Sport	associated with veins and replacement deposits		CNBC Minfile no. 92L-035**
Oregon			MR 80/7+
Rosita		Rosita Mines, Ltd	Bevan, 1973
Sinyuzhinskoe	Au in stage II py: 0.1 to 1.6 ppm; Au in cpy 0.93 ppb		Vakhrushev, 1972 Ivankin and Rabinovich, 1972 Vakhrushev and Tsimbalist, 1967 E.I. Bloomstein (written commun., 1987) Tveritinov, 1966
Snowshoe			Laznicka, 1973
Tsumo			Grant, 1950
Vanada	on Texada Island		Little, 1970
Vieja			Jurada, 1982
Yaguki			Einaudi and others, 1981
ZN-PB SKARNS WITH BY-PRODUCT AU			
Falun	Fe skarn; deposit is zoned		Grip, 1978
Garpenberg Oda	deposit has well-developed zoning		Grip, 1978
SE Afghanistan			Bybochkin and Kats, 1972
Thanksgiving	Mined largely for Au-AG	Benguet Expl., Ltd.	Philip. Bur. Mines, 1986
OTHER SKARNS WITH BY-PRODUCT AU			
Gold Hill (United States)		United States Smelting, Refining and Mining Co.	Nolan, 1935

*MR 198: see Canada Department of Energy, Mines, and Resources, 1984
**MR 80/7: see Canada Deparment of Energy, Mines, and Resources, 1980
+CNBC Minfile: see British Columbia Ministry of Energy and Petroleum Resources, 1981

Table 3. Gold-bearing skarn deposits and deposits purported to be gold-bearing skarns for which grade-tonnage data are unavailable

Mine Name	Location	Description	Reference(s)
Alae-Sayan	USSR	Skarn includes px, gar, amph, serp, and late quartz with Cu, Pb, Zn, As, Sb, Cd. Fluids: high Cl; Na/K=1.1 to 1.5:1. Early skarns formed 480-890 °C. Au deposited 250-150 °C.	Indukaev, 1977
Akshiyryak Range	USSR (Kirghiziya)	280 Ma granite (K/Ar, bio) intrudes carbonate-siliceous sequence. Au mineralization association with skarnoid and secondarily silicified rocks in marbles and silicate-carbonate rocks gradationally beyond skarn. Au localized mainly in highly silicified rock containing wol, and locally idoc and px. Dark gray highly silicified rock contains po, py, and native Au (as 0.1 mm wide flakes).	Dolzhenko, 1974
Cadia	AU	Au-bearing skarn in area of Fe skarn.	McLeod, 1965
Carlés (Salas, Asturias)	SPAN	Apy-cpy-py-native Au in quartz-veined skarn; 5-100 m-sized Au associated with asp.	Rau-Figueroa and others, 1985
Central Tadzhikistan	USSR	Au-Cu-As in px and gar-px skarn associated with late Miss.-early Permian granodiorite and qtz diorite rocks; overall trapping temperatures of fluid inclusions range 450-75 °C; Au ores deposited paragenetically late in two stages; early py-apy, late tet-cpy at 350-250 °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, and quartz-cc.	Proskuryakov and others, 1979
East Sayan Mtns. (Medrezhye and Konstantinovskoe deposits)	USSR (Siberia, middle Asia)	Gold ores preferentially formed in calcic skarn from Cl-SO_4-Ca-Na-bearing fluids (Na/K=2 to 6:1; Cl/F=31:1) at 420-220 °C; Cl>F in leachates from productive Au skarns.	Korobeynikov, 1976, 1977 Korobeynikov and Chernyaev, 1976 Korobeynikov and Matsyushevskaya, 1973
Geunteut area	INDS Sumatra	Geunteut granodiorite (14.3 Ma) intrudes late Jur and early Cret lst of Woyla Group. Mineralization includes cpy, py, bor, azur, mal.	Bowles, 1984
Gissaro-Alay	USSR (central Tadzhikistan)	W-apy-Au-Cu skarn containing px, gar, qtz, feld, amph, dol, wm.	Khasanov, 1982
Kaliostrovskoe	USSR	Large blocks of limestone engulfed totally by granitoid rock.	Ivankin and Rabinovich, 1972
Kochulak	USSR (Dalnagorsk region)	Au-tell-tet stage formed at homogenization temperatures of 270-240 °C and 190-170 °C together with Ag, Pb, and Cu tells at lower temperatures (150-130 °C).	Genkin and others, 1983

Table 3. Gold-bearing skarn deposits and deposits purported to be gold-bearing skarns for which grade-tonnage data are unavailable—Continued

Mine Name	Location	Description	Reference(s)
Kommunar district	USSR (Altai-Sayan)	In eight deposits, Au associated with py, po, cpy, mag primarily in qtz-act veined skarn developed in Cambrian sedimentary-volcanic sequence as result of late Cambrian px diorite and monzonite.	Lobanov, 1972
Kaznetskiy Alatau and Gornyi Altai	USSR	Au-bearing skarn formed at 700-280 °C from homogenization temperatures in qtz and gar.	Pavlova, 1983
Marn	CNYT	Assemblage electrum (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 skarn	Brown and Nesbitt, 1984
Natal	INDS Sumatra	Skarn has formed where late Cret Manunggal batholith (87 Ma) intrudes early Cret Soma Fm and late Jur to early Cret Woyla Group sediments; both include metavolcanics, lst and metalst members. Skarn has formed at margins of batholith and in xenoliths of lst. Mineralization includes py, mag, Au, Ag, Cu-Pb-Zn minerals.	Bowles, 1984
New Calumet	CN	Pb-Zn-Ag-Au ores; Grenville province.	Boyle, 1982
Primor'ye	USSR (Far East)	Scheelite-Au-py skarn formed under relatively reducing conditions; some associated Au-wolf deposits; mafic granite intruded into Sikhole Alin folded belt; some apy, mica, and po; hed, gross, ves, cum, ep, act, tour, stilp, bustanite, and mag and cc assemblages in skarn.	Stepanov, 1977, 1981 Stepanov and others, 1976a, 1976b Stepanov and Kuryakova, 1973 Makiyevskiy, 1978, 1979 Efimova and others, 1982 Piskunov and Makiyevskiy, 1978
Sayakskiy region	USSR	High temperature zones of skarn contain three assemblages: 1) Au_1- gersdorffite ($NiS_2 \cdot NiAs_2$)-apy-cobaltite (>250 °C); 2) Au_2- Bi-cpy-po (250 °C) with ep and act; 3) Au_3- wittichenite (Cu_3BiS_3)-MoS_2-bn-cp (225 °C).	Fomichev and Kuznetsova, 1972
Stormont	AUTS	Au-Bi skarn in the Moina district, an area known primarily for Sn-W skarns and greisens.	
Tetreault	CNQU	Pb-Zn-Ag-Au ores; Grenville province.	Boyle, 1982
Union Amalgamated	USNV (Manhatten district)	Sulfide-bearing skarn veined by gold-bearing quartz; developed in Paleozoic marine sedimentary and metamorphic rocks; possibly related to 16 Ma caldera.	Shawe and others, 1986

Table 4. Abbreviations

Minerals

Mineral Name	Abbreviation
actinolite	act
amphibole	amph
andradite	an
apatite	ap
arsenopyrite	apy
azurite	azur
biotite	biot
bismuthinite	bism
bornite	bor
calcite	calc
chalcopyrite	cpy
chlorite	chl
chyrsocolla	chr
clinozoistie	clinoz
cubanite	cub
cummingtonite	cum
diopside	diop
dolomite	dol
electrum	elec
epidote	ep
feldspar	feld
fluorite	fl
galena	gal
garnet	gar
goethite	goe
grossular	gros
hedenbergite	hed
hematite	hem
hornblende	horn
idocrase	ido
jasper	jas
K-feldspar	k-spar
limonite	lim
loellingite	loel
ludwigite	lud
magnesite	mags
magnetite	mag
marcasite	mar
molybdenite	moly
muscovite	musc
phlogopite	phlg
plagioclase	plag
prehnite	preh
pyrite	py
pyroxene	px
pyrrhotite	po
quartz	qtz
scapolite	scap
scheelite	sch
serpentine	serp
siderite	sid
spadaite	spa
sphalerite	sph
spinel	spin
stibnite	stib
stilpnomelane	stilp
telluride(s)	tell
tenorite	teno
tetrahedrite	tet
tetradymite	tetd
tourmaline	tour
tremolite	trem
vesuvianite	ves
white mica	wm
wolframite	wolf
wollastonite	wol
zoisite	zoi

Other

Other	Abbreviation
agglomerate	agglon
argillite	arg
calcareous	calc
carbonaceous	carb
conglomerate	congl
dolostone	dol
formation	Fm
group	Grp
limestone	lst
manganiferous	mang
marble	mar
mudstone	mdst
oxide	ox
porphyry	porph
quartzite	qtzite
sandstone	ss
sedimentary	sed
sediments	seds
shale	sh
skarn	skn
slate	sl
volcanics	volcs

Country Codes	Country
AFGH	Afghanistan
AUNS	Australia, New South Wales
AUQL	Australia, Queensland
CNBC	Canada, British Columbia
INDS	Indonesia
JPAN	Japan
MXCO	Mexico
MYLA	Malaysia
NCRC	Nicaragua
PLPN	Phillipines
PPNG	Papua-New Guinea
SWDN	Sweden
USAK	United States, Alaska
USID	United States, Idaho
USMT	United States, Montana
USNV	United States, Nevada
USUT	United States, Utah
WGER	West Germany

Ages

Age	Abbreviation
Tertiary	Tert
Miocene	Mio
Mesozoic	Mes
Cretaceous	Cret
Jurassic	Jur
Triassic	Tri
Paleozoic	Pal
Permian	Perm
Carboniferous	Carb
Mississippian	Miss
Ordovician	Ord
Cambrian	Camb
lower	L.
upper	U.

Table 5. Chemical signatures of nontronite clay layers associated with Au-bearing skarns. [-, not detected]

Sample[1]	85JH115		85JH142	85JH187	86TT135
Method[2]	a	b	a	a	b
Al (%)	-	0.33	-	-	1.5
Ca (%)	1	0.73	10	0.1	15
Fe (%)	10	8.2	10	2	7.3
Mg (%)	1	0.89	0.5	0.15	7.7
Na (%)	-	0.02	-	-	0.19
K (%)	-	<0.05	-	-	0.37
P (%)	-	0.01	-	-	0.1
Ti (%)	0.1	0.08	0.1	0.15	0.1
Mn (ppm)	100	660	1000	100	760
Ag (ppm)	2	30	7	3	8
As (ppm)	-	<10	-	-	20
B (ppm)	10	-	10	20	-
Ba (ppm)	200	160	500	1500	82
Be (ppm)	-	<1	-	1.5	2
Bi (ppm)	-	10	-	-	<10
Cd (ppm)	-	<2	50	-	2
Ce (ppm)	-	<4	-	-	7
Co (ppm)	5	210	-	-	14
Cr (ppm)	50	46	70	30	44
Cu (ppm)	200	320	20	7	3800
Ga (ppm)	-	<4	-	-	8
La (ppm)	-	<2	-	-	4
Li (ppm)	-	7	-	-	7
Ni (ppm)	15	12	-	10	12
Pb (ppm)	20	100	-	-	11
Sc (ppm)	7	4	-	-	6
Sn (ppm)	-	<10	-	-	100
Sr (ppm)	100	53	200	150	61
V (ppm)	100	71	100	15	40
Y (ppm)	-	3	20	10	3
Zn (ppm)	500	550	200	-	400
Zr (ppm)	50	-	200	200	-

[1] Analyses were done on bulk samples of earthy, yellow-green clay lyaers 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 A that expand to about 17 A with glycolation. Microprobe work on 85JH115 confirms the Fe-rich nature of the clay. Samples are from skarns in the Harmony Formation (85JH115) and in the Battle Formation (142) in the Battle Mountain Mining District and the McCoy gold mine in the McCoy Mining District, Nevada. Sample 85JH187 from Hancock magnetite mine in the McCoy Mining District.

[2] Elements sought, but not detected at the limit of the method, include Au, Mo and W. a) 6-step D.C. 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 ICP direct reader emission spectroscopy by M. Malcolm in U.S. Geological Survey analytical laboratories; X-ray work by Karen Gray.

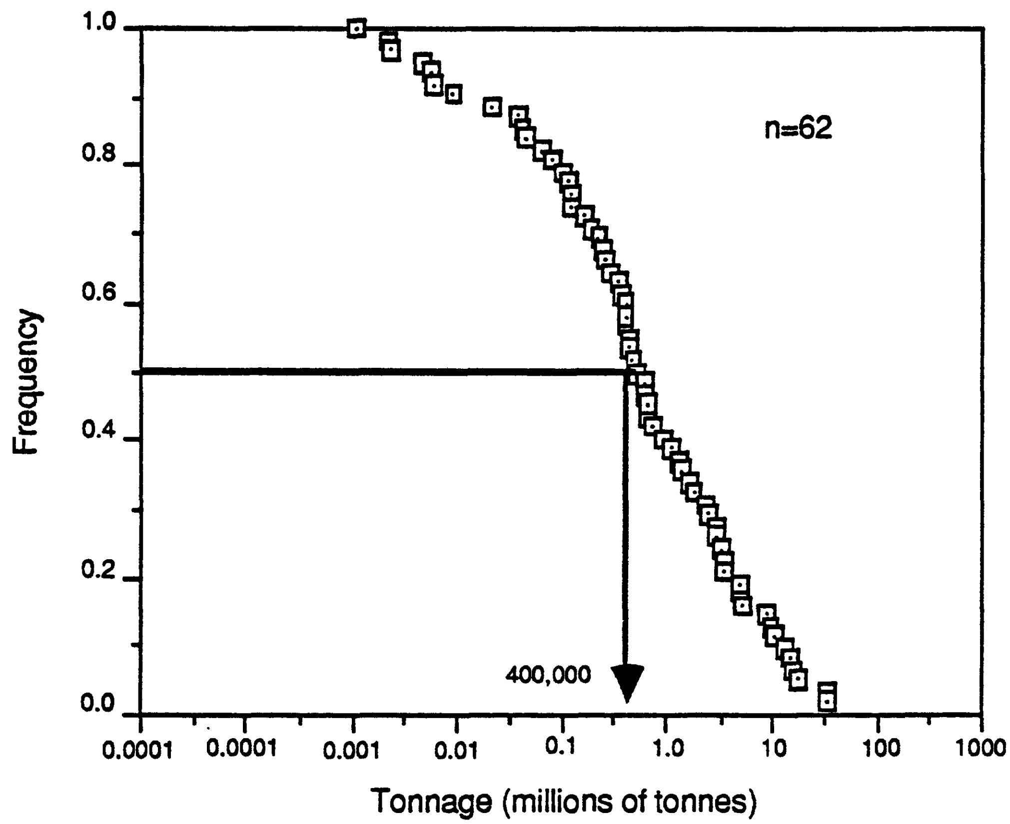

Figure 1. Frequency plot of tonnages of all Au-bearing skarns (see text). Data combined from table 1 (Au-skarn) and table 2 (byproduct Au-skarn).

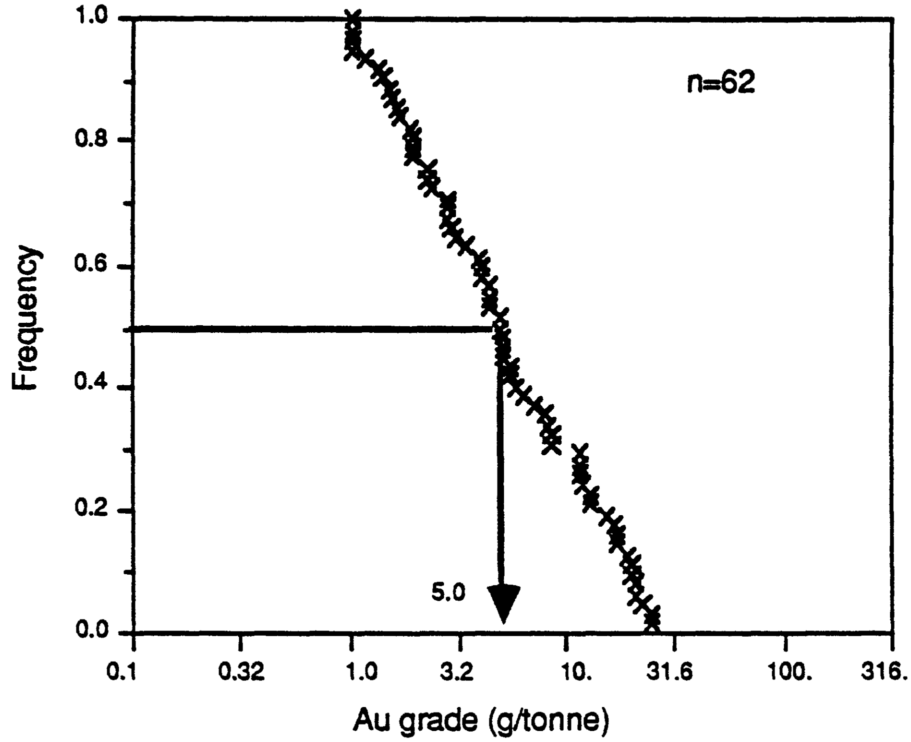

Figure 2. Frequency plot of Au grades of all Au-bearing skarns (see text). Data combined from table 1 (Au-skarn) and table 2 (byproduct Au-skarn).

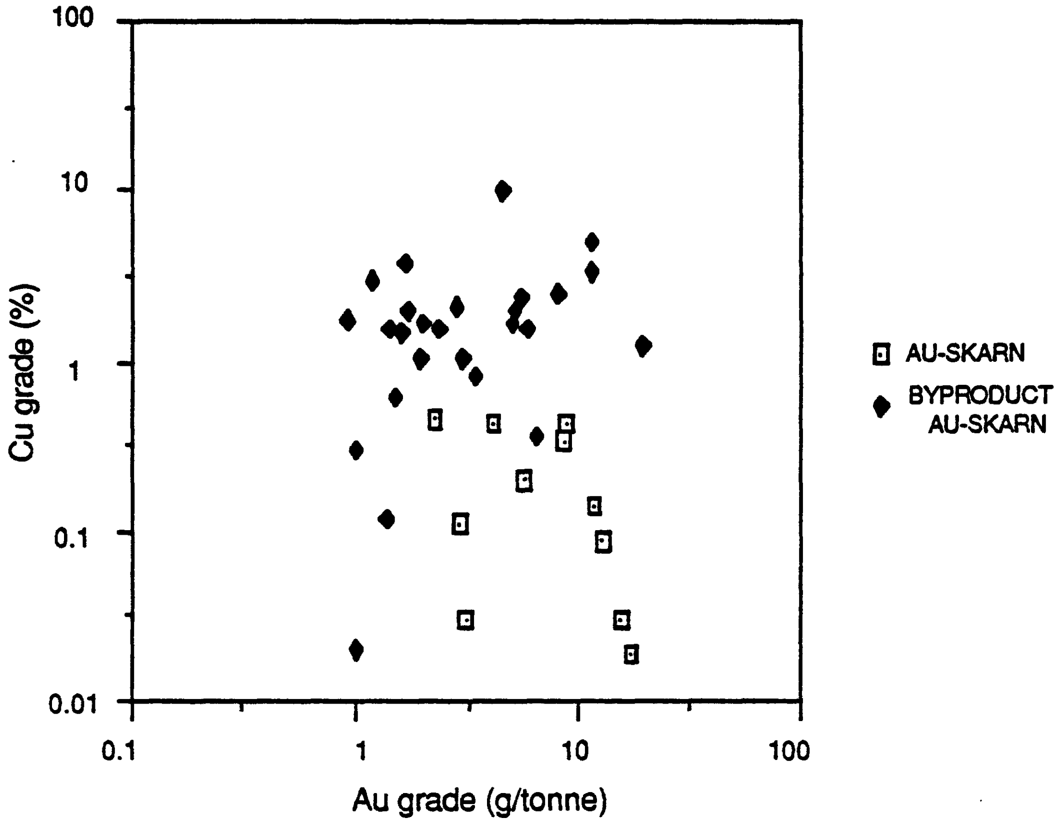

Figure 3. Plot showing Au grades vs. Cu grades for Au-bearing skarns (see text). All values of Au >1 g/tonne. Data from table 1 (Au-skarn) and table 2 (byproduct Au-skarn).

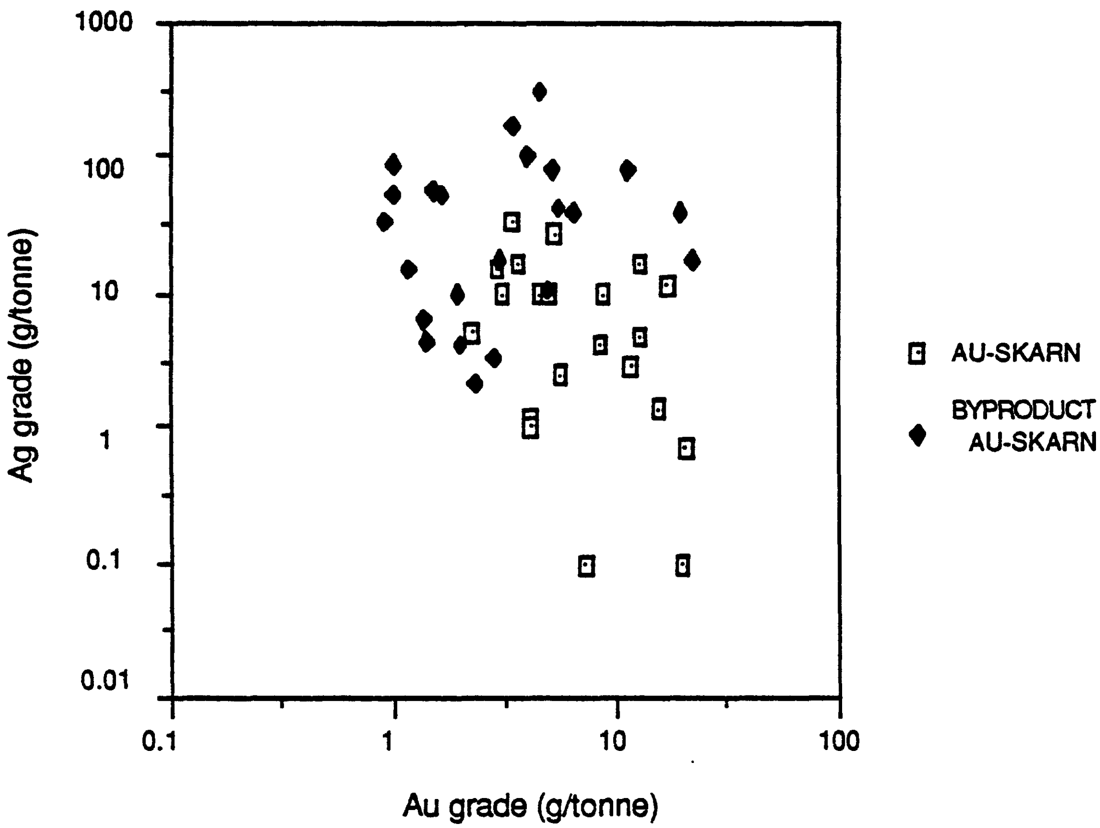

Figure 4. Plot showing Ag grades vs. Au grades for Au-bearing skarns (see text). All values of Au >1 g/tonne. Data from table 1 (Au-skarn) and table 2 (byproduct Au-skarn).

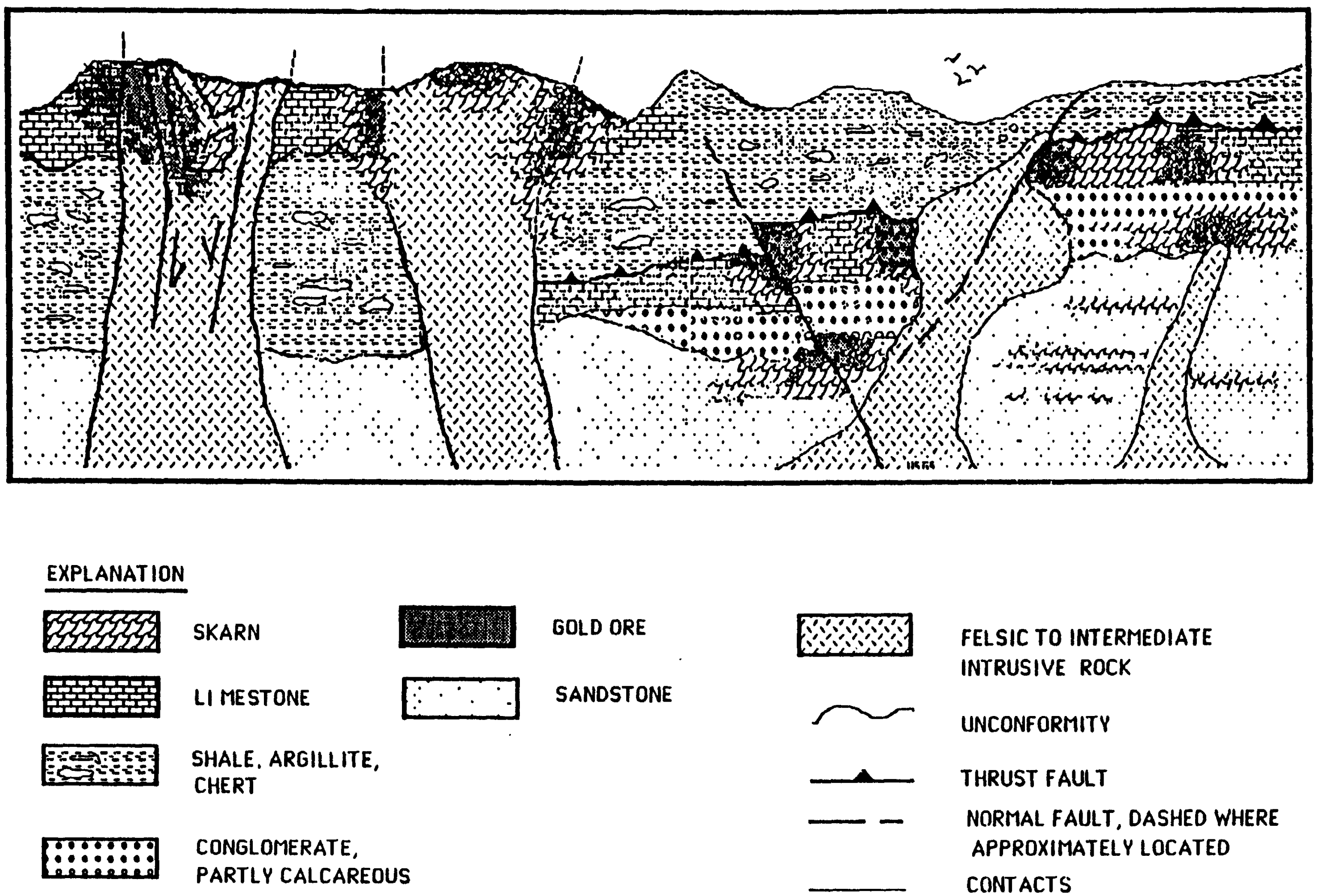

Figure 5. Schematic diagram showing spatial relations of Au bearing skarns and structure.

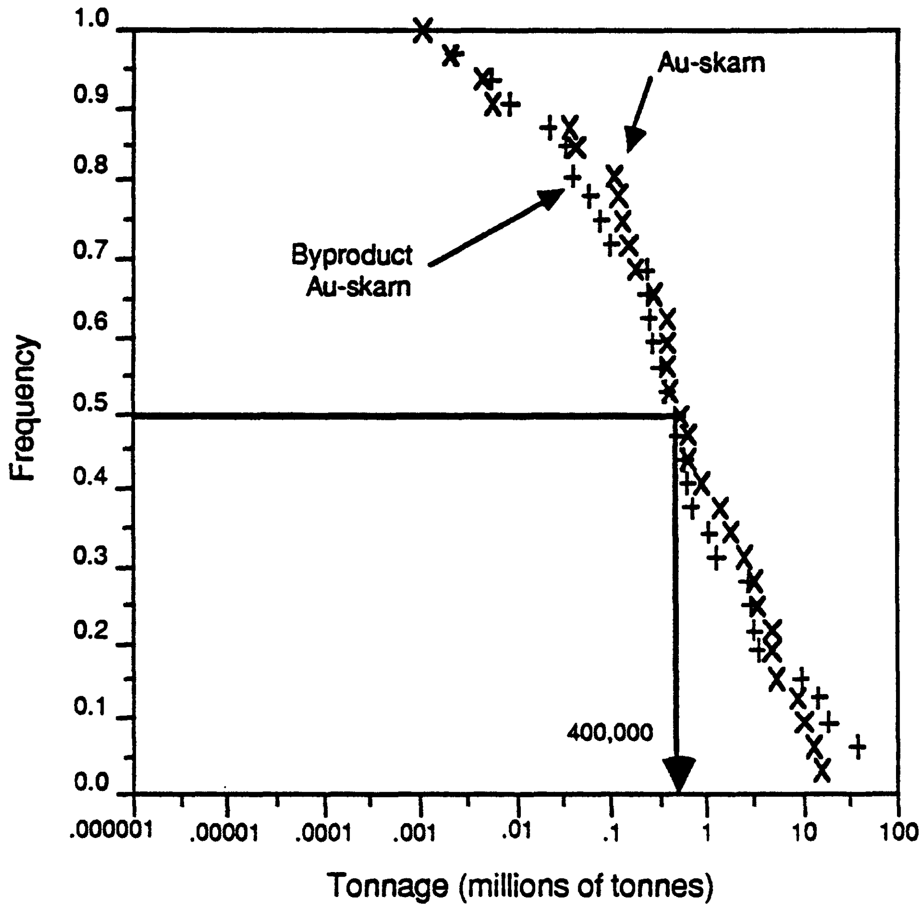

Figure 6. Frequency plot of tonnages of Au-bearing skarns (see text). Data from table 1 (Au-skarn) and table 2 (byproduct-Au skarn) plotted independently.

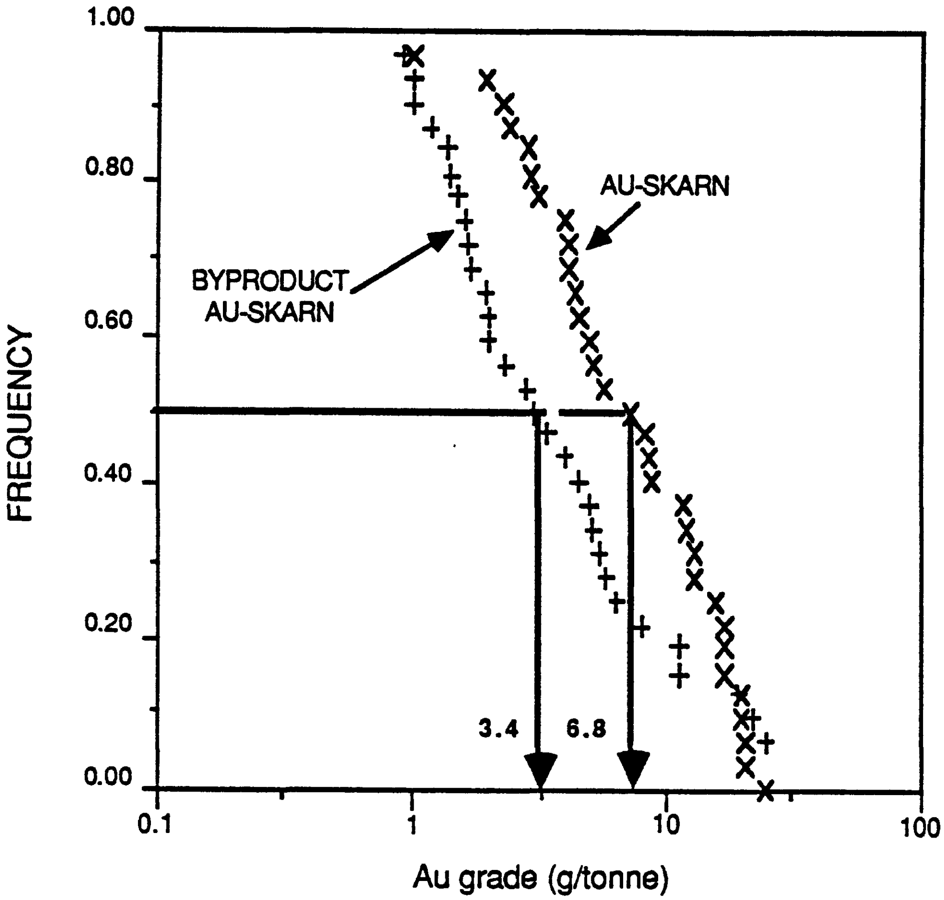

Figure 7. Frequency plot of Au grades of Au-bearing skarns (see text). Data from table 1 (Au-skarn) and table 2 (byproduct Au-skarn) plotted independently.

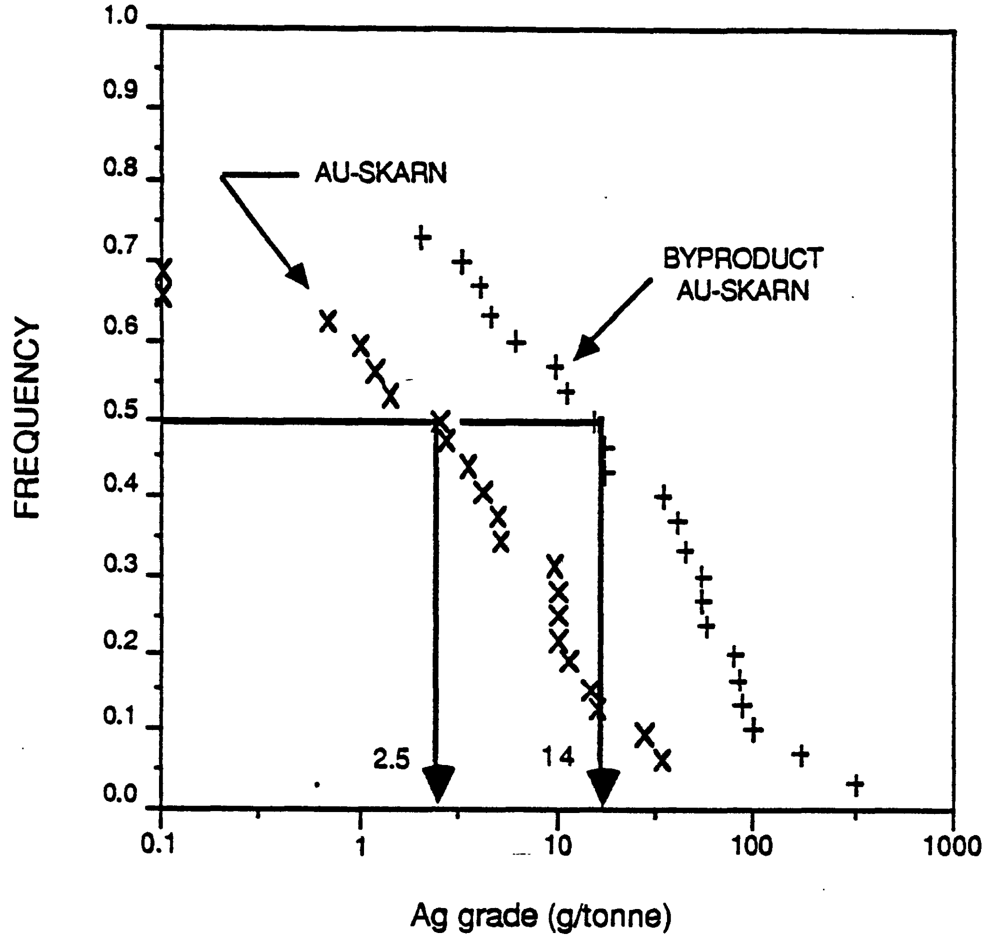

Figure 8. Frequency plot of Ag grades for Au-bearing skarns (see text). Data from table 1 (Au-skarn) and table 2 (byproduct Au-skarn) plotted independently.