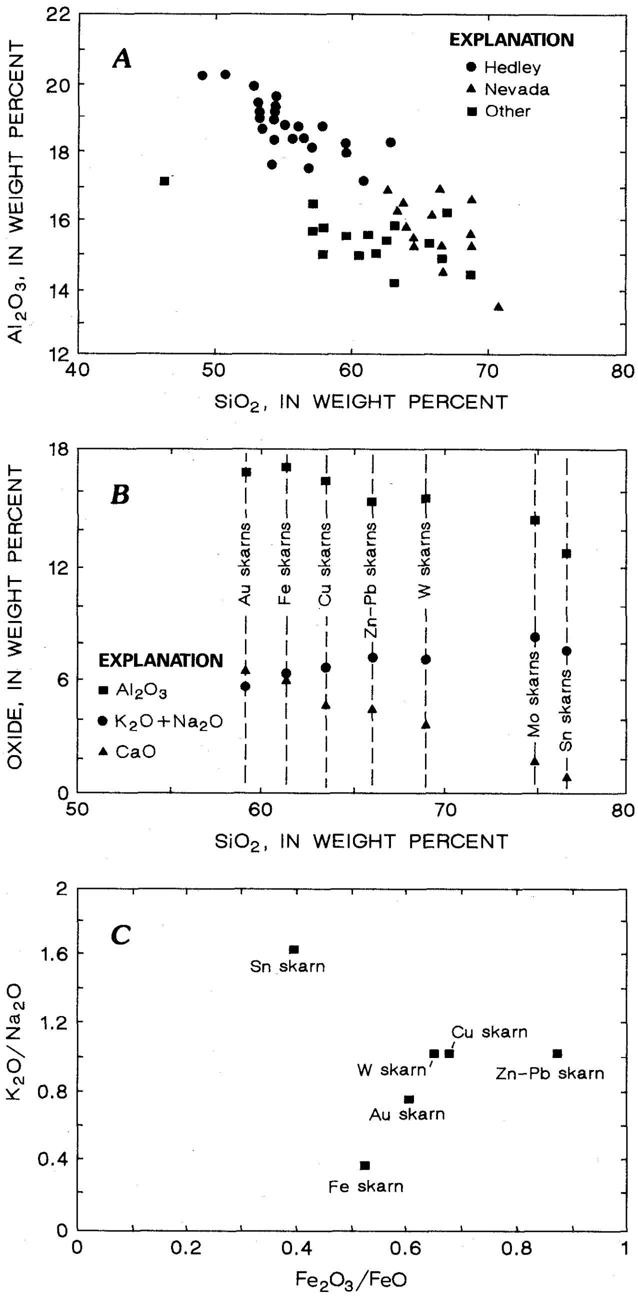

Figure 7. Chemical compositions of igneous rocks associated with major types of mineralized skarn. *A*, Al_2O_3 versus SiO_2, in weight percent, for unaltered igneous rocks associated with Au-bearing skarn deposits in the Hedley district, British Columbia (Ray and others, 1987a), in the Battle Mountain 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 $3(Ag_2,Pb)S{\cdot}2\,Bi_2S_3$).

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,

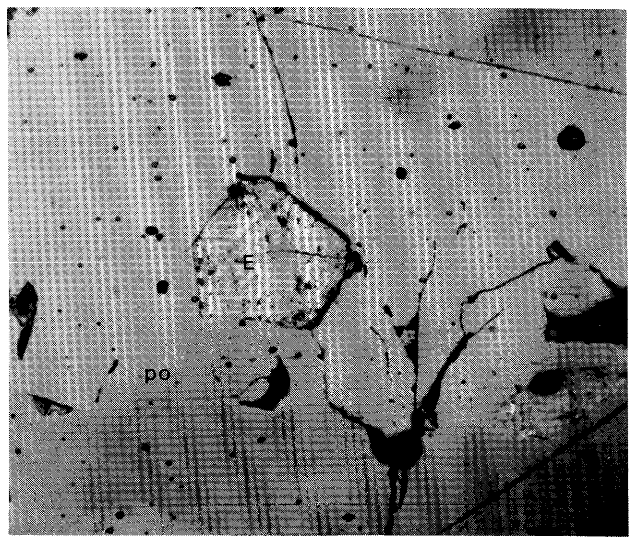

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Figure 8. Textural relations of gold and electrum in selected Au-skarn deposits. Au, gold; E, electrum; Q, quartz. *A*, Electrum in massive pyrrhotite (po) from the Lower Fortitude, Nevada, Au-skarn deposit. Plane-polarized light. *B*, Electrum associated 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.