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,

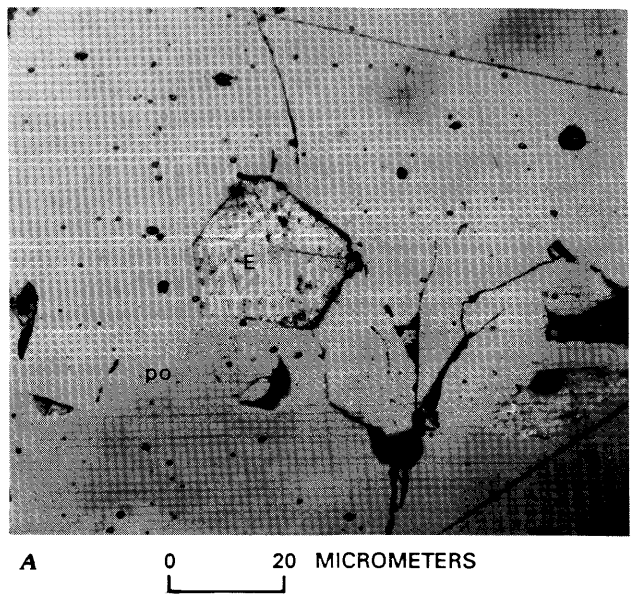

Figure 8. Textural relations of gold and electrum in selected Au-skarn deposits. Au, gold; E, electrum; Q, quartz. *A*, Electrum in massive pyrrhotite (po) from the Lower Fortitude, Nevada, Au-skarn deposit. Plane-polarized light. *B*, Electrum associated with native bismuth (B) and galena (G) hosted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

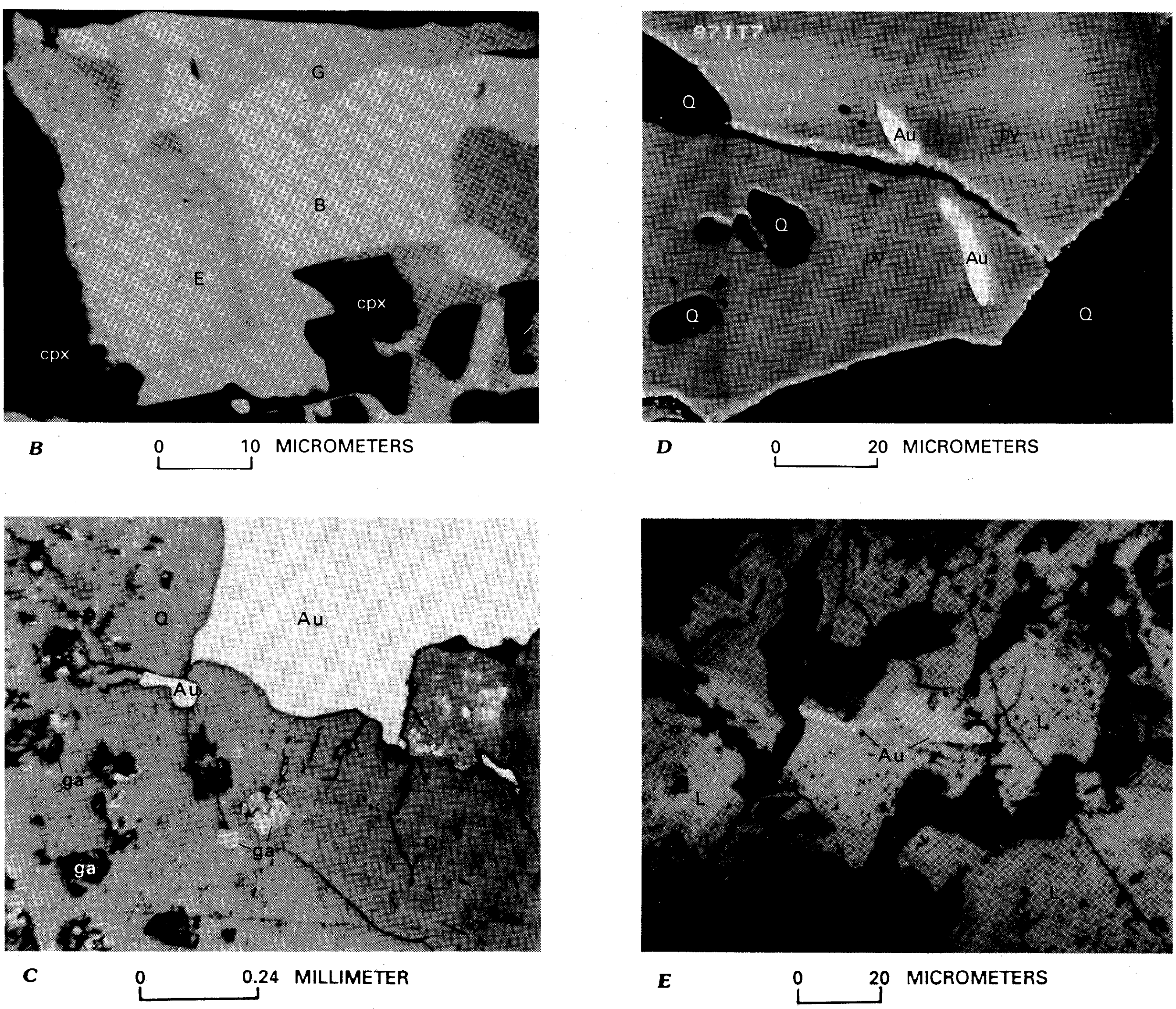

Figure 8. Continued.

(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

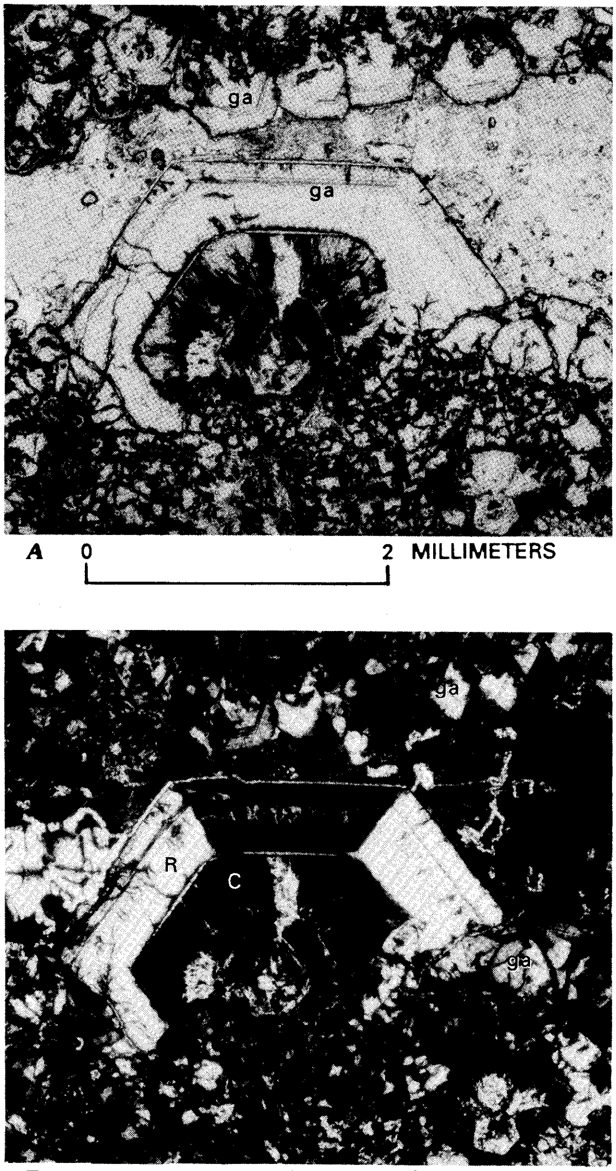

Figure 9. Photomicrographs showing complexly zoned garnets (ga) from oxidized skarn, Surprise Mine, Nevada. *A*, Plane-polarized light; note growth zone in garnet rim. *B*, Crossed nicols; garnet has isotropic, andradite core (C) and sector-twinned, anisotropic, oscillatorily zoned rim (R).

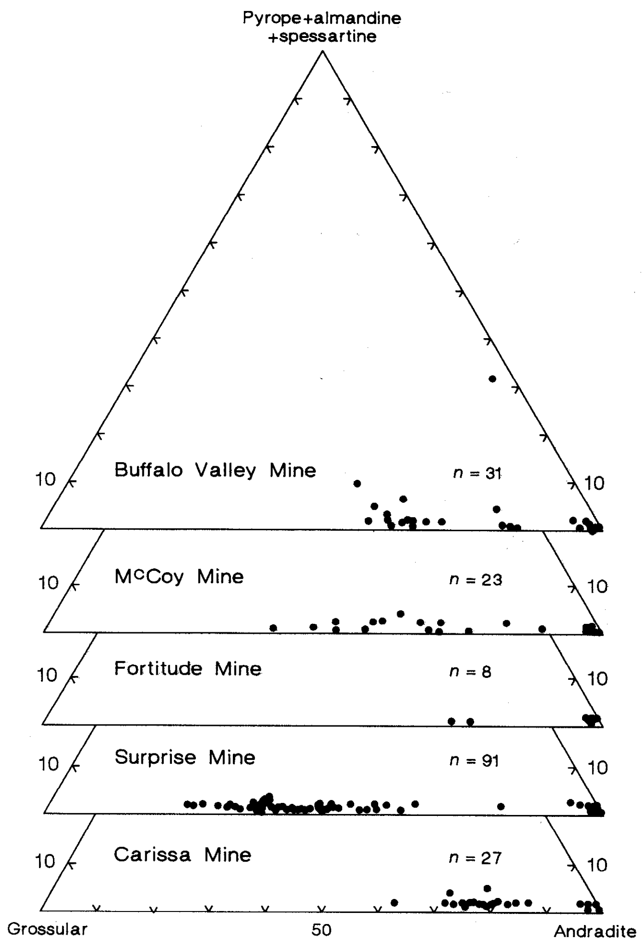

Figure 10. Ternary diagrams showing ranges of garnet compositions for representative samples from five Au-bearing skarn systems in north-central Nevada. *n*, number of samples.

(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.

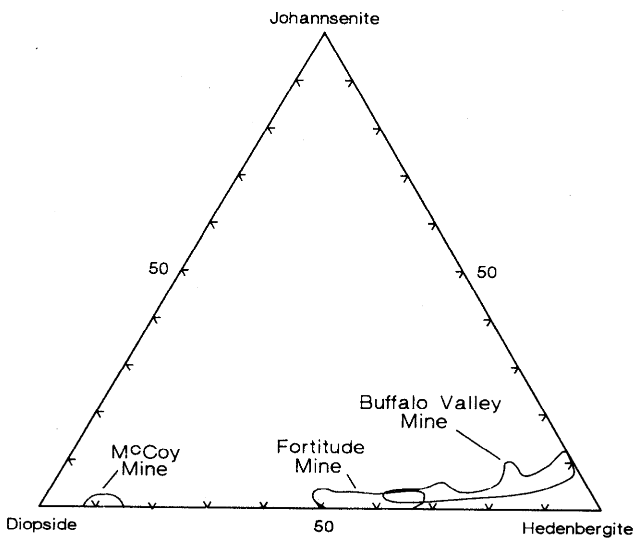

Figure 11. Ranges of pyroxene compositions for representative samples from three Au-bearing skarn systems in north-central Nevada.

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,