associated with magnetite (Eastwood, 1965). At the Merry Widow pit of the Benson Lake cluster of magnetite skarns, concentrates of chalcopyrite were reported to contain as much as 1 oz gold per ton of chalcopyrite.

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

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

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

Isotopic Signatures

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

Fluid Inclusions

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

Geophysical Signatures

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

Ore Controls/Exploration Guides

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

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

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

GRADES AND TONNAGES OF GOLD–BEARING SKARNS

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

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