quartz and calcite and may include relict skarn silicates (pyroxene, garnet, and epidote). Oxidized karst-collapse breccia developed in marble as a result of marble reacting with acidic ground water at Red Dome (Torrey and others, 1986). At this deposit, acidic ground water probably resulted from breakdown of sulfides in the surrounding pyritic halo of the Au-skarn.

Effect of Metamorphism

Gold-bearing skarn systems could undergo regional metamorphism to yield gneiss-hosted Au deposits with a resultant loss of most contact-metasomatic features. The Tumco deposit, California, which has been metamorphosed to amphibolite grade and is provisionally included by us with Au-bearing skarn (Smith and Graubard, 1987; Tosdal and Smith, 1987), may be an example of such a process. However, some relatively extensive tin-tungsten-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 the margins of skarn where calc-silicate porphyroclastic mylonite is present. Skarn away from the contact shows some kinked chalcopyrite-bornite exsolution lamellae, but no cleavage or foliation. The Falun deposit in Sweden is hosted by Proterozoic granite, amphibolite, and quartz porphyry (Grip, 1978). Greenstone-hosted Au-Ag-W-As deposits in the Southern Cross greenstone belt of western Australia may represent Archean analogues of Phanerozoic gold skarn deposits (Mueller, 1988).

Geochemical Signatures

Geochemical signatures for Au-bearing skarn include anomalous gold primarily in an environment of retrograde-altered, sulfidized skarn. The associated pyrite in some Au-skarn deposits is reported to contain 0.1 to 250 ppm Au (Vakhrushev, 1972). At Bau, Malaysia, anomalous antimony (in stibnite) and arsenic (in scorodite) are present with gold in wollastonite-bearing skarn assemblages and in colloform-banded quartz and jasperoid, all distal to quartz- and calcite-flooded, calc-silicate gold ore (Wolfenden, 1965; W.C. Bagby, oral commun., 1987). In other Au-bearing skarn systems, quartz-calcite veins contain anomalous gold. In addition, gold mineralization and highly anomalous concentrations of gold in some skarn systems (Akshiryak Range, U.S.S.R.) are found mostly in fine-grained, gray to light-gray, highly silicified sequences of rock in carbonate beyond the outer limit of established skarn (Dolzhenko, 1974). Many Au-bearing skarns in British Columbia contain elevated abundances of arsenic, bismuth, and tellurium (Ray and others, 1987b; Ettlinger and Ray, 1989). The bismuth minerals reported from some Au-skarns include native bismuth, bismuthinite, wittichenite, hedleyite, maldonite, and Bi-bearing galena (Meinert, 1988b). Theodore and others (1989) report major-element and trace-element data for garnet skarns associated with gold mineralization at Copper Basin, Nevada, including low-grade, oxidized ore from the Surprise Mine (29 ppb Au, 6 ppm Ag, <10 ppm Bi, 57 ppm As, 4 ppm Sb, 3 ppm Co, 25 ppm Cu). Finally, surface expression of some Au-skarn systems (Red Dome, Australia; Surprise, Nevada) includes relatively abundant, fracture-controlled secondary copper minerals (Torrey and others, 1986; Schimdt and others, 1988).

The Au/Ag ratio in rock apparently increases laterally outward (away from the center of the associated intrusion) in some productive copper-bearing calcic skarn systems toward ore (Fortitude, Nevada) that is approximately 0.6 km from the exposed, genetically associated intrusion. The Fortitude Au-skarn is close to a relatively sharp boundary between marble and sulfidized calc-silicates (Blake and others, 1984; Theodore and others, 1986; Wotruba and others, 1987a, b; Myers and Meinert, 1988). In other Au-skarn systems that are predominantly zoned vertically close to the related intrusive rocks (Red Dome, Australia), much of the gold ore is 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 high local thresholds for many associated base and ferrous metals and, for some deposits, arsenic, bismuth, selenium, and tellurium values in particular may be relatively high both within and peripheral to the Au-bearing skarn (Ray and others, 1987b).

Zonation of gold in Au- and Pb-Zn-bearing skarn (Ban Ban, Australia; Thanksgiving, Philippines; Tomboy-Minnie, Nevada) seems to show inconsistent patterns. At Ban Ban, gold in unreported trace abundances may coincide with known distribution of silver, which varies directly with lead and zinc concentrations that are, in turn, constrained tightly to the central part of associated garnet skarn (Ashley, 1980). At Thanksgiving, irregularly distributed sphalerite-pyrite pods that replace andradite skarn show higher gold contents than pyrite-magnetite replacement pods (Callow, 1967). At Tomboy-Minnie, local metal zoning of the gold orebodies shows high concentrations of gold (more than 0.05 troy oz/ton or more than 1.7 g/t); these high concentrations of gold show increased abundances of zinc and silver (more than 500 ppm and more than 0.1 troy oz/ton, or more than 3.4 g/t respectively) on the granodiorite side of the gold orebody. 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 gold in some Fe-skarn systems that contain byproduct gold (Benson Lake, British Columbia) seems to be related directly to the abundance of sulfide 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