gold skarn districts of southwestern Montana, and Utah occur to the east of the accreted terrane boundary.

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 below their respective paleosurfaces. Other Au-bearing skarn systems formed as much as 5 km below their paleosurfaces. At the Mottini Mine in the IXL Mining District, Nevada (table 4; also see Schrader (1947) and Vanderburg (1940)), gossaniferous Pb-Zn-Cu skarn with some gold is associated with emplacement of a 28-Ma, zoned granodiorite that is cogenetic with a tilted caldera (David A. John, oral commun., 1989). The Au-bearing Pb-Zn-Cu skarn apparently developed approximately 5 km below the 28-Ma paleosurface on the basis of removal of the present-day tilts in the rocks of the caldera. The 38- to 39-Ma Au-skarns at McCoy, Fortitude, Tomboy-Minnie, and Labrador, all in Nevada, regionally are clustered not far from the 34-Ma erosion surface upon which the 34-Ma Oligocene Caetano Tuff was deposited. This relation suggests that those four Au-skarn systems must have formed in a relatively shallow geologic environment—a conclusion confirmed by study of fluid-inclusion relations in the Au-skarn deposits (see below). Much less abundant are Tertiary Au-bearing skarns in cratonic environments (Bright Diamond and Iron Clad, Colorado, see Irving, 1905; Irving and Cross, 1907).

In the Soviet Union, most reported data on Au-bearing skarns seem to indicate development in geologic environments deeper than those in western North America. As such, they have been classified as medium-depth deposits according to the scheme of Bodaevskaya and Rozhkov (1977). Furthermore, according to them, Au-bearing skarns are associated with deformed Paleozoic early-eugeoclinal-stage batholiths of granite-granodiorite composition or with minor Paleozoic late-eugeoclinal stage 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. Worldwide distribution of some important Au-bearing skarns relative to major fold belts is shown in figure 6.

Age Range

Gold-bearing skarns are generally Mesozoic or Tertiary in the cordillera of western North America, probably middle Tertiary in the rifted cratonic regions (Bright Diamond, Iron Clad, Colorado), and probably middle Tertiary in West Sarawak, Malaysia (Bau), according to Wolfenden (1965). Several significant systems of early Paleozoic age are also known in the Soviet Union, and a significant Au-bearing skarn in Australia (Red Dome) is late Paleozoic in age. The base-metal-dominated deposits at Falun and Garpenberg Oda, in Sweden, are present in Proterozoic rocks (table 3).

Host and Associated Rocks

Gold-bearing skarn may be hosted by a wide variety of sedimentary and igneous rocks, including limestone, dolomite, shale, conglomerate, rhyolitic to andesitic tuff, and granitoids; however, a premetamorphic calcareous component is commonly present. Meinert (1988b) further noted that the overwhelming bulk of the Au-skarns are present in clastic or volcaniclastic-rich sequences. Pearson and others (1989) showed that gold-bearing skarns in the Dillon, Montana, 1° x 2° quadrangle have the same gangue minerals and same kinds of associated plutons as tungsten skarns in the area but that the tungsten skarns are mostly hosted by the Mississippian and Pennsylvanian Amsden Formation whereas gold-bearing skarns in the Bannack and Silver Star Mining Districts are in Mississippian Mission Canyon Limestone.

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 are associated with Au-bearing skarn. Some deposits (for example, Tumco, California) may be associated with weakly to strongly peraluminous calcic granite (Smith and Graubard, 1987). In north-central Nevada, Au-skarns (Fortitude, McCoy, Northeast Extension, Surprise, Carissa, Labrador) are associated with monzogranite stocks (table 5), whereas in British Columbia many Au-bearing skarns (Tillicum Mountain, Oka) are associated with diorite to gabbro stocks (see Ray and others, 1987a, b). In addition, Keith and Swan (1987) have shown that an area in north-central Nevada with plutons that have reduced ferric:ferrous ratios (less than 0.85) correlates in part with the regional distribution of Au-bearing sediment-hosted and porphyry deposits. According to them, such reduced ratios may reflect minor assimilation of reduced crust during magma genesis. Leveille and others (1988) showed that most Au-associated plutons have low oxidation state and (or) high alkalinity when plotted in terms of an alkalinity index (K_2O+Na_2O-0.57 SiO_2) and ratio of Fe_2O_3 to FeO. Meinert (1983) presented mean compositions for igneous rocks associated with different types of mineralized skarn and noted that the most distinctive chemical trends are for parameters that reflect magmatic oxidation state and degree of differentiation, notably ferric:ferrous ratios and alkali contents. The mean igneous rock composition associated with Au-bearing skarns (J.M. Hammarstrom, unpub. data, 1989) and with other types of mineralized skarns (Meinert, 1983) is shown in figure 7. Gold-bearing skarns appear to be associated with slightly less siliceous rocks than other skarn types, and in terms of alumina, total alkalis, and calcium they are most similar to granitoids associated with iron and copper skarns (fig. 7).

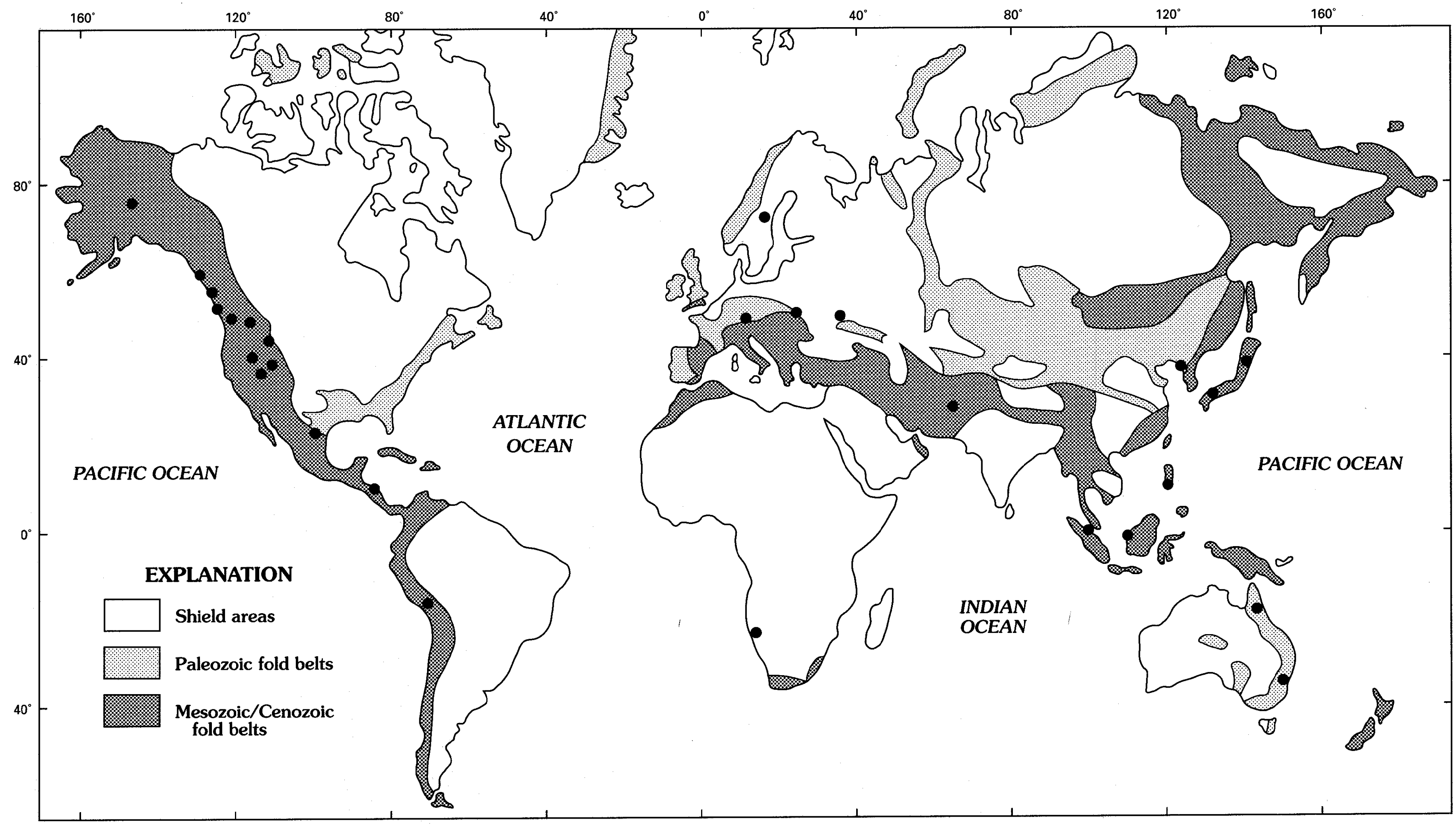

Figure 6. Worldwide distribution of major Au-bearing skarn deposits (solid dots) and fold belts.

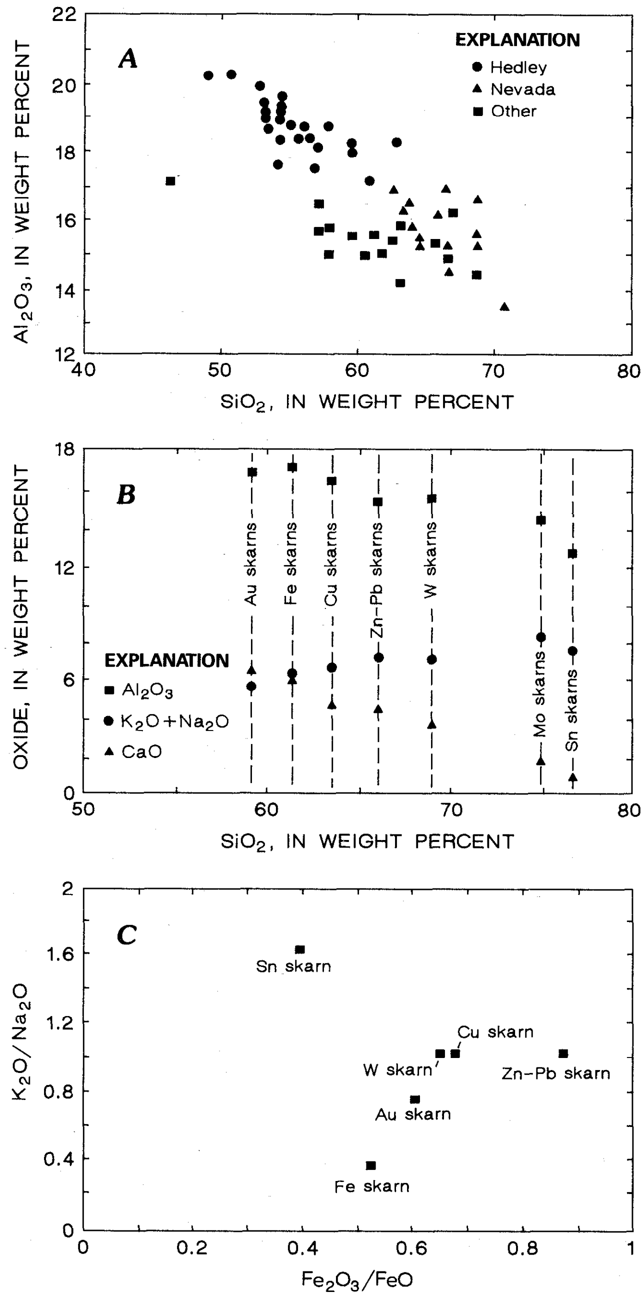

Figure 7. Chemical compositions of igneous rocks associated with major types of mineralized skarn. *A*, Al_2O_3 versus SiO_2, in weight percent, for unaltered igneous rocks associated with Au-bearing skarn deposits in the Hedley district, British Columbia (Ray and others, 1987a), in the Battle Mountain 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