

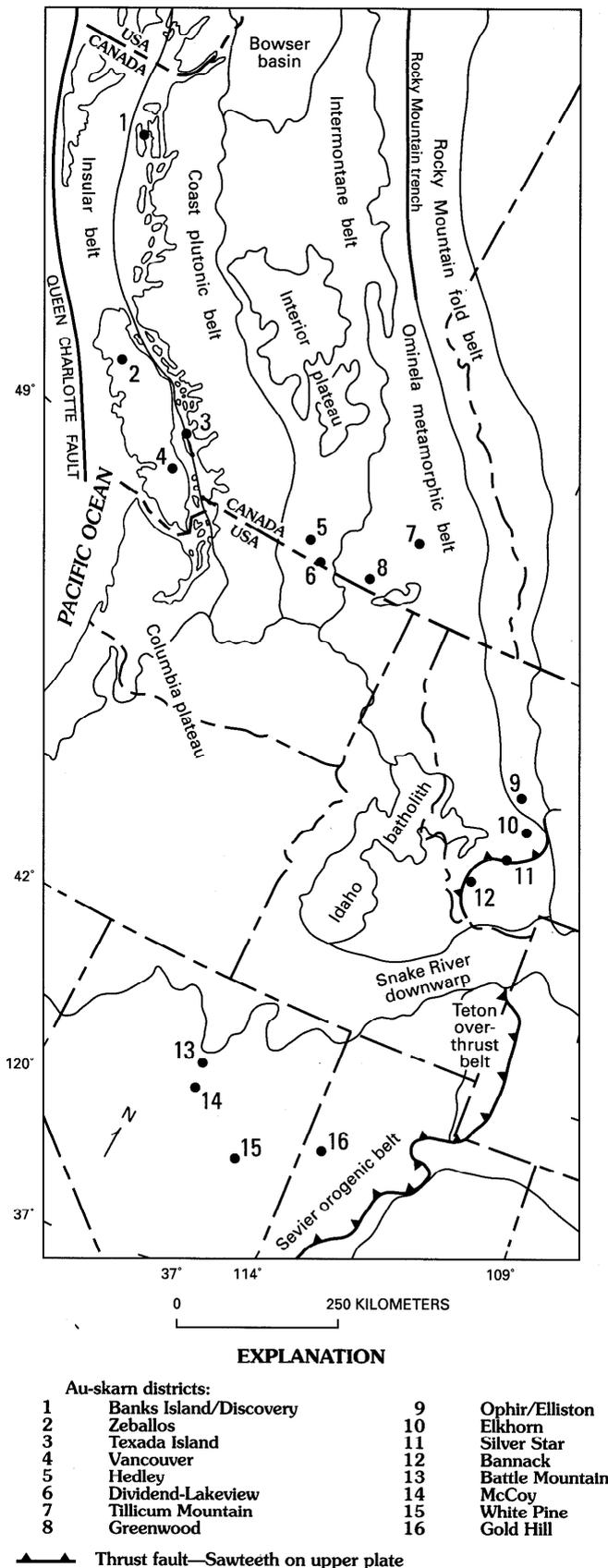
Tectonostratigraphic Setting and Paleodepths

In North America, Au-bearing skarn is present most commonly in Mesozoic and Cenozoic orogenic-belt and island-arc settings (fig. 5); a few Au-bearing skarns have been found in rifted craton. The regional distribution of Au-bearing skarns may have been confined partly by emplacement of Au-enriched magmato-hydrothermal systems possibly controlled by long-active rifts intersecting the craton's edge in the continental-margin environment of western North America (Roberts, 1966). Such magmatism may be related to onset of regional-scale extensional tectonism in the northern Great Basin.

Ettliger and Ray (1989) examined the distribution of 126 precious-metal-enriched skarns in British Columbia in terms of tectonic belt and tectonic terrane. They found that gold- and silver-bearing skarns are present throughout the four westernmost, mobile tectonic belts in British Columbia, but are absent from the easternmost, stable Foreland belt. Of the 14 terranes in which precious-metal-enriched skarns are present, Ettliger and Ray (1989) showed that most occurrences and most producing deposits are in the Wrangellia and Quesnellia terranes. Most of the gold produced from skarns in British Columbia comes from deposits in the Quesnellia tectonic terrane, which includes the world-class gold skarn deposit at Hedley and the Greenwood Mining District. A recently announced gold skarn occurrence in northern Washington, the Buckhorn Mountain deposit (table 4), lies within the southern extension of the Quesnellia terrane into the United States (Silberling and others, 1987). A similar analysis of the terrane distribution for the 106 Fe-Au-skarn occurrences (34 producers) reported by Newberry (1986) reveals 54 occurrences (24 producers) in the Alexander terrane, followed by 26 occurrences (6 producers, including the large Nabesna deposit) in Wrangellia, and 15 occurrences (2 producers) in the Peninsula terrane. Less than 5 occurrences in each are reported for the Tracy Arm, Chulitna, Dillinger, Mystic, and Nixon Fork terranes.

Island-arc volcanic sequences, clastic sediments, and comagmatic calc-alkaline intrusions are common features of the terranes that host the largest proportions of known Au-skarn deposits in British Columbia and in Alaska (Ettliger and Ray, 1989; Monger and Berg, 1987; Jones and others, 1987). In the conterminous United States, the important gold skarn districts of north-central Nevada lie in the Roberts terrane (Silberling and others, 1987), in a geographic position analogous to Quesnellia to the north, just west of ancestral North America proper. However, the

Figure 5. Distribution of Au-skarn districts and geological provinces in the cordillera of western North America. Modified from Monger and others (1972).



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 volcanoclastic-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).