SEG 2017 Conference

Genesis and Exploration for Skarn Deposits

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Skarn deposits are one of the more abundant ore types in the earth's crust, and form in rocks of almost all ages. Most skarn deposits are zoned, and the general pattern is proximal garnet, distal pyroxene, and minerals like wollastonite, vesuvianite, or massive sulfides/oxides near the marble front. Recognition of distal alteration features such as bleaching, fluid escape structures, and isotopic halos can be critically important in exploration. Because most economic skarn deposits are related to magmatism, details of igneous petrogenesis and tectonic setting form a framework for exploration and classification.

Most large skarn deposits record a transition from early/distal metamorphism resulting in hornfels, reaction skarn, and skarnoid, to later/proximal metasomatism resulting in relatively coarse-grained ore-bearing skarn. Fluid inclusion and isotopic evidence indicates early metasomatism is caused by high-temperature ($\geq$500°C), high-salinity (>50 wt. % total salts) fluids of magmatic origin, which typically are enriched in Si, K, Na, Al, Fe and Mg, and depleted in Ca, ^{18}O, and CO_2 relative to protoliths. Analyses of skarn-hosted inclusion fluids, both liquid and vapor, show high concentrations of K, Ca, Mn, Fe, Cl, Br, Cu, Pb, Zn, and As. With time, skarn metasomatic alteration evolves to lower temperature ($\leq$400°C), generally hydrous, and sulfide-rich assemblages, termed retrograde alteration. Such retrograde alteration usually is accompanied by brecciation and is caused by influx of cooler, lower salinity ($\leq$20 wt. % total salts) fluids that are still magmatic in origin.

For the seven major skarn types (Fe, Au, Cu, Zn, W, Mo, and Sn) a general correlation exists among igneous major- and trace-element composition and skarn type. Plutons associated with Fe and Au skarns contain significantly more MgO and less K_2O or SiO_2, Au and Sn skarn plutons are more reduced, and Cu, Zn, and Mo skarn plutons are more oxidized than average skarn plutons. In terms of geochemical evolution, there is a fairly linear array from relatively primitive calcic Fe skarn plutons through Au, Cu, Zn, to W, Mo, to relatively evolved Sn skarn plutons. Calcic Fe skarn plutons are metaluminous, high in compatible elements such as Ni, V, and Sc, and have Rb/Sr <1. Relative to Fe-skarn plutons, Cu skarn plutons have higher Si, K, Ba, Sr, La, and Fe^{3+}/Fe^{2+}, and contain significantly less Mg, Sc, Ni, Cr, and V. Au skarn plutons are similar to Fe-skarn plutons in their metaluminous nature and their Si, Mg, Cr, and Sc contents and are similar to Cu-skarn plutons in their Ni, V, and Y content. In general, plutons associated with Sn, Mo, and W skarns have a much stronger crustal signature than do plutons associated with other skarn types.

These general patterns and characteristics will be illustrated with major deposits in multiple countries. Recent high metal prices have made many formerly sub-economic deposits economic and the typically high ore grades in skarn deposits continue to make them attractive exploration targets because of the potentially rapid payback of project capitalization costs.