

Spectrum of Volcanogenic Massive Sulfide Deposits in the Penokean Volcanic Belt, Great Lakes Region, USA

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The Paleoproterozoic (ca. 1880 Ma) Penokean volcanic belt extends for over 250 km across northern Wisconsin and western Michigan. The dominantly submarine volcanic rocks comprising the belt were formed in an island arc-related setting at the southern edge of the Superior craton. Despite relatively minor exploration, the majority of which occurred intermittently from 1960 to 1990, approximately 100 million metric tons (Mt) of polymetallic massive sulfide ores have been delineated. Only the supergene enrichment zone of the Flambeau deposit has been exploited. The mined resource accounts for less than 2% of known mineral reserves, which makes the Penokean volcanic belt one of the most accessible, undeveloped, and underexplored volcanic terranes worldwide.

The present study aims to characterize the volcanic setting, deposit characteristics, and alteration signature of significant deposits within the Penokean volcanic belt to provide the first comprehensive metallogenetic model. To accomplish this goal, detailed core logging has been conducted at seven deposits across the belt, namely Back Forty, Bend, Flambeau, Horseshoe, Lynne, Reef, and Ritchie Creek. Representative sampling has been conducted at all deposits for detailed petrographic and geochemical investigation.

Ongoing research has revealed a wide spectrum of volcanic environments and alteration styles across the Penokean volcanic belt. All major deposits occur within felsic-dominated volcanic successions and are hosted by vent-proximal volcanic facies associations. For example, the Back Forty deposit is hosted within a felsic succession (apparent stratigraphic thickness of 1,200 m) comprising coherent rhyolite units and associated volcanic breccias. Felsic volcanism was broadly contemporaneous with the deposition of mass-flow-derived volcanoclastic debris presumably generated by an explosive eruption of a rhyolite source. Mafic-dominated host rock successions are less common in the Penokean volcanic belt and appear to host some of the smaller tonnage deposits, including Horseshoe and Ritchie Creek.

The styles of hydrothermal alteration vary between deposits, with sericite-chlorite-quartz alteration occurring at Back Forty, Bend, and Horseshoe. Acid-style alteration represented by andalusite-biotite-sericite schists has been noted at Flambeau and calc-silicate mineral assemblages are present at Lynne, Ritchie Creek, and Reef. Calc-silicate mineral associations have also been observed at the Pelican River and Spirit deposits, suggesting that the volcanic host rocks were originally interbedded with limestone. Regional metamorphism varies from lower greenschist to amphibolite grade and has obscured relationships in some deposits. Most notable, primary volcanic textures are difficult to recognize at the Reef deposit, which is an unusual disseminated to quartz-sulfide vein confined Au-Cu deposit hosted by strongly deformed and recrystallized rocks. Recognition of significant variations in setting and deposit characteristics across the Penokean volcanic belt likely reflects first-order tectonostratigraphic controls during the development of the Penokean orogeny.