

The Black Angel Zn-Pb district, West Greenland: Germanium Mineralization and Syn-metamorphic Ore Formation

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The Black Angel district in central West Greenland hosts several Paleoproterozoic marble-hosted Zn-Pb occurrences, including the closed Black Angel mine (11.2 Mt at 12.3% Zn, 4.1% Pb, and 29 ppm Ag). The sphalerite-pyrite-galena dominated massive sulfides in the district are host to briartite, a rare Ge sulfide mineral. The origin of mineralization remains ambiguous, as both Mississippi Valley-type and Kipushi-type deposit models have been suggested. Detailed petrographic studies, electron microprobe, and LA-ICP-MS analyses were applied to breccia-hosted massive sulfide from the South Lakes Glacier prospect to study briartite formation and ore genesis. Graphite thermometry, biotite thermometry, and phengite barometry indicate peak metamorphic conditions of $500^{\circ} \pm 40^{\circ}\text{C}$ and 4.5 ± 1.5 kbar. Macro- and microstructures, such as isoclinally folded marble clasts in the sulfide matrix, poikilitic pyrite, and chalcopyrite trails parallel to S_2 foliation, indicate syn-peak metamorphic and syn-tectonic ore formation during regional D_2 deformation, supported by available Re-Os ages of 1828 Ma. The mineralization was affected by progressive solid-state and dissolution-precipitation sulfide remobilization and is structurally controlled by reactivated D_1 thrusts and D_2 reverse faults and shear zones. Arsenopyrite thermometry ($390^{\circ} \pm 30^{\circ}\text{C}$) indicates that mineralization continued during retrograde cooling. Briartite, occurring as clusters of μm -sized grains as well as anhedral grains of up to 3 mm in diameter, formed by precipitation from Cu-Ge-(Sn)-bearing prograde metamorphic fluids coeval with Ge-bearing chalcopyrite. Whole rock data show Ge grades of 120 ppm and Ga grades of 130 ppm. The widespread occurrence of briartite, the syn-tectonic timing of ore formation, and syn-metamorphic fluid with intermediate sulfidation suggest a Kipushi-type deposit model. The structurally controlled, syn-metamorphic style of Zn-Pb-Ge mineralization highlights structures in metamorphosed carbonate platforms of foreland fold-thrust belts as exploration targets for critical metals.