SEG 100 Conference: Celebrating a Century of Discovery

ST.117

Micron-scale Trace Element Zoning in Carlin-type and Carlin-like Deposits from Nevada and the Yukon Based on Relative Sensitivity Factor Calibration of NanoSIMS Data

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Carlin-type gold deposits (CTGDs), primarily concentrated in north-central Nevada, are the source of some of Earth's largest concentrations of gold. They are characterized by "invisible" (sub-micron) gold hosted within arsenian pyrite overgrowths on precursor barren pyrite grains. The element zoning histories and gold deportment of Carlin ore are not fully understood, partially due to the fine scale of the overgrowths, which can range from nanometers to tens of microns in thickness.

Here we present results from new applications of nanoscale secondary ionizing mass spectrometry (NanoSIMS) to ore-stage sulfide minerals from deposits in Nevada and the Yukon Nadaleen trend. NanoSIMS differs from conventional methods in its ability to detect and quantify chemical variations on the sub-micron scale. We analyzed sulfides on the NanoSIMS using a combination of high-spatial-resolution image analyses and high-precision spot analyses and depth profiles. Due to a lack of sulfide trace element standards for NanoSIMS, concentrations of trace elements were calibrated using their relative sensitivity factors (RSFs). To quantify the RSFs, trace element-rich areas in sulfide grains were measured with both electron probe microanalysis and NanoSIMS to serve as single-point standards. In this study, RSFs for Cu, As, Ag, and Au were determined to be 0.57, 0.03, 4.20, and 0.94, respectively.

High-grade samples from Carlin-type or Carlin-like deposits throughout Nevada (including Turquoise Ridge, Deep Star, and Marigold Red Dot) and Osiris and Conrad in the Yukon Nadaleen trend reveal complex, multi-stage growth patterns in ore pyrite grains with significant variations between deposits. All classic CTGDs from Nevada and the Yukon exhibit the highest concentrations of gold either within the innermost rim zone, adjacent to the precursor pyrite core, or within the outermost rim zone along the edge of the grains. The Carlin-like Red Dot deposit samples show textural and chemical zoning characteristics similar to both magmatically-sourced distal disseminated deposits and classic CTGDs. Red Dot pyrite grains have the same precursor core and ore-stage arsenian pyrite rim pattern as classic CTGDs but contain complex Au and trace element zoning throughout the rims and have higher Ag:Au ratios than typical CTGDs. NanoSIMS $\delta^{34}S$ spot analyses of Red Dot Au-rich rims fall between 3.92 and 7.99‰, which is within the range of $\delta^{34}S$ values for magmatic pyrite in the region.

These micron-scale zoning patterns in both trace elements and sulfur isotopes can reveal clues into changing fluid compositions during hydrothermal ore deposit formation. NanoSIMS methods allow us to see previously impossible levels of detail in ore minerals and can provide better understandings of fluid sources and metal deportment in CTGDs and other deposit types.