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Insights into the Genesis and Fingerprinting of a Variscan Polysulfidic Sb mineralization from a combined Sb-Pb-S isotope study of the Wolfsberg Antimony Deposit, Harz Mountains, Central Germany

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The Wolfsberg deposit represents a classical hydrothermal vein system located in the Rhenohercynian Zone of the Harz Mountains (Germany) and is famous for its Sb-rich and polysulfidic mineralization. The mineralization formed from low-salinity fluids during late Variscan tectonism and comprises two major mineralization stages: (1) early Pb–Sb sulfides and (2) later stibnite. The ore bodies occur as quartz-hosted veins containing abundant stibnite and diverse Pb–Sb sulfides with variable Pb/Sb ratios. The diversity of Sb-bearing mineral assemblages provides an excellent opportunity to better understand Sb isotope fractionation during hydrothermal evolution and to fingerprint metal sources.

We applied electron microprobe and femtosecond laser ablation (MC-) ICP-MS for the *in situ* analysis of major and trace elements and Sb, Pb and S isotopes in sulfides. This integrated approach enables spatially resolved characterization of mineral generations and provides new insights into metal sources and ore formation processes. Stibnite is characterized by highly variable As (up to 207 µg/g) and Pb contents (up to 450 µg/g), potentially reflecting differences of the ore formation conditions. $\delta^{34}S$ values of both mineralization stages are around 0 ‰, indicating a dominantly felsic igneous sulfur source. This signature suggests sulfur derivation either by leaching of igneous rocks by external hydrothermal fluids or by degassing and mobilization from silicate melts. However, lead isotope ratios with an U-Pb model age of ~200 Ma do not support a direct magmatic contribution. Instead, they point to significant Pb input from underlying very low-grade metamorphic Palaeozoic sediments.

Antimony isotope data reveal significant variability: the early-sulfide-stage display a wide range of $\delta^{123}Sb$ values (-0.26 to 0.58 ‰) evolving from negative to positive $\delta^{123}Sb$ values that are consistent with a Rayleigh-type fractionation model receiving Sb from a crustal source. The later-stibnite-stage exhibits less Sb isotope variability (0.00 to 0.30 ‰) with constant $\delta^{34}S$ values similarly to the earlier-stage mineralizations, indicating remobilization from previous formed sulfides. Notably, some late-stage mineralization shows low radiogenic $^{206}Pb/^{204}Pb$ (<18.35) and $^{207}Pb/^{204}Pb$ (<15.5) ratios, indicating additional contributions from another local source rocks characterized by lower U/Pb ratios. Collecting, these combined isotopic signatures fingerprint multi-source metal contributions operating within a single hydrothermal system.