Unlocking the Timing of Au-Sb-Hg Mineralization in the Kyrgyz South Tien Shan: Constraints from In-Situ U–Pb Dating of Hydrothermal Calcite

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The Turkestan-Alay segment of the Kyrgyz South Tien Shan is known for hosting many sedimentary rock-hosted low-temperature Au-Sb-Hg ore deposits, e.g., the Khaidarkan and Chauvai. Recent studies have highlighted that these deposits exhibit similar characteristics to Carlin-type gold deposits (CTGDs) in Nevada, USA. Resolving mineralization age and its relationship to geodynamics is essential for understanding the ore genesis. However, this constraint is particularly difficult to achieve for CTGDs, due to the lack of suitable minerals for radiometric dating. Calcite is the most important hydrothermal mineral in CTGDs. Its crystallographic structure can accommodate U and Th in μg/g concentrations. With the advancements of laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), the feasibility of in situ U-Pb dating on calcite has been successfully demonstrated for some hydrothermal gold deposits. Here, three calcite generations, Cal-1, Cal-2, and Cal-3, have been identified based on precipitation mode, mineral associations, and cathodoluminescence (CL) features from the Chauvai and Khaidarkan deposits. Among these, the Cal-2 is characterized by intimate intergrowth with cinnabar containing higher concentrations of Carlin-pathfinder elements (e.g., Au, As, Sb, Tl, and Te), distinct CL zoning, and MREE-enriched composition patterns, indicating that it is clearly associated and coeval with gold mineralization. The LA-ICP-MS dating of Cal-2 yielded U-Pb ages of 231.1 ± 6.2 Ma for Chauvai and 227.5 ± 5.3 Ma for Khaidarkan, representing the timing of Au-Sb-Hg mineralization in the Turkestan-Alay belt. Our new ages suggest that the Au-Sb-Hg deposits in the Turkestan-Alay segment formed in a post-collisional taphrogenic relaxation followed by an intraplate setting. Our case story suggests that hydrothermal calcite could be a robust chronometer for age dating of sedimentary rock-hosted low-temperature gold deposits worldwide.