Monazite, xenotime and apatite chemistry and textures: Clues to understanding geochronologic discrepancies in the Llallagua tin deposit, Bolivia

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Despite multiple geochronologic studies, there is still a debate around the timing of ore mineralization in of one of world's biggest tin deposits, Sigo XX mine, Llallagua, Bolivia. The deposit is a hydrothermally altered porphyry stock that is part of the orogenic Bolivian tin belt. A well-established inconsistency exists between ages determined from what appear to be primary apatites and monazites from hydrothermal cassiterite veins.

In order to help reconcile this discrepancy and decipher the petrogenetic history of Llallagua, spatially resolved analysis of REEs and trace elements as well as textures of accessory vein monazite, xenotime, and apatite have been studied. Vein and altered host rock assemblages were evaluated using optical microscopy, scanning electron microscopy, electron microprobe analysis, and synchrotron X-ray fluorescence microanalysis, to constrain growth conditions and alteration history.

The results show that apparently unaltered euhedral crystals of all three accessory phases are associated with quartz and the main stage of cassiterite mineralization. Among these the presence of pangenetically coeval xenotime and monazite allows for application of Y+REE based geothermometry suggesting formation at 530°C-350°C. Additionally, distinctive monazite and xenotime (but not apatite) crystals have been found that exhibit textural and chemical evidence of partial to complete replacement.

The presence of micro-porosity and the formation of secondary, reaction induced phases (e.g. xenotime and allanite), which are composed of constituents released from the primary phase, indicate advanced fluid-mediated regenerative dissolution-precipitation. This process resulted in a redistribution of REEs and presumably disturbance of the U/Pb system.

The observed selective hydrothermal alteration of monazite, but not apatite, suggests that after formation of the Llallagua porphyry and initial vein mineralization at ≈ 43My, a later hydrothermal episode presumably reset the monazite and xenotime geochronometers resulting in the observed age discrepancy.