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The Temporal Evolution of the Candelaria IOCG System, Chile: Insights from U-Pb LA-MC-ICP-MS of Apatite, Magnetite, Titanite, and Ar-Ar of Actinolite

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Iron oxide copper-gold (IOCG) and iron oxide-apatite (IOA) deposits are important sources of copper and iron, respectively, and also host a diverse array of metals critical to modern technology and green energy. Many studies have interpreted the commonly recognized spatial and temporal relationship between IOCG and IOA deposits to indicate that the two deposits types are members of a single mineralizing system. Here, we focus on samples from the Candelaria IOCG deposit, Chile, that reveal a clear transition from magnetite-actinolite-dominated mineralization at depth, to chalcopyrite-dominated mineralization at shallow levels of the system. Textural evidence has been interpreted to suggest that the system evolved upward with time, where early magnetite-actinolite was subsequently overprinted by chalcopyrite-dominant mineralization. This transition makes Candelaria an ideal deposit to study to better understand the hypothesized temporal relationship between IOA and IOCG deposits.

We analyzed samples from a 1,000-meter drill core from the Candelaria deposit using laser ablation-multicollector-inductively coupled plasma-mass spectrometry (LA-MC-ICP-MS) to measure U and Pb isotope abundances of apatite, magnetite, and titanite. The data yield dates of 115.4 ± 0.7 Ma for apatite, 126.3 ± 4.9 Ma for magnetite, and 114.9 ± 1.1 Ma for titanite (2se uncertainties) when calculated by mineral without taking depth into consideration. Age dates for each mineral type were also separately calculated by sample depth in order to determine if there is a difference in age throughout the deposit (Fig. 1). No resolvable difference in age by mineral type was observed when calculated by depth. When dates are calculated together by mineral type without separating by depth, dates for apatite and titanite are consistent with published Re-Os dates for molybdenite of 114.2 ± 0.6 and 115.2 ± 0.6 Ma, which were interpreted to constrain the timing of sulfide mineralization. An Ar-Ar date of 121.2 ± 0.6 Ma for actinolite from one sample falls within the uncertainty of the combined magnetite date. When calculated by mineral type without taking depth into consideration, if the magnetite and actinolite dates represent crystallization ages, the data are consistent with two separate hydrothermal events at Candelaria: the first at 126-121 Ma (actinolite, magnetite) and a second at 115 Ma (apatite, titanite, and main sulfide mineralization). These ages are consistent with published ages of ~122 and ~115 Ma (U-Pb zircon) for the two major early phases of the Copiapo batholith. Because magnetite is not a conventional geochronometer and no external matrix-matched standard yet exists, interpretation of this date is cautioned. However, with appreciable uranium in many of these samples, magnetite U-Pb LA-MC-ICP-MS has exciting potential for geochronology, especially with respect to Fe-rich deposits such as IOCGs and IOAs. The dates calculated in this study will contribute to the overall understanding of the temporal evolution of the Candelaria mine and of IOCGs more broadly.

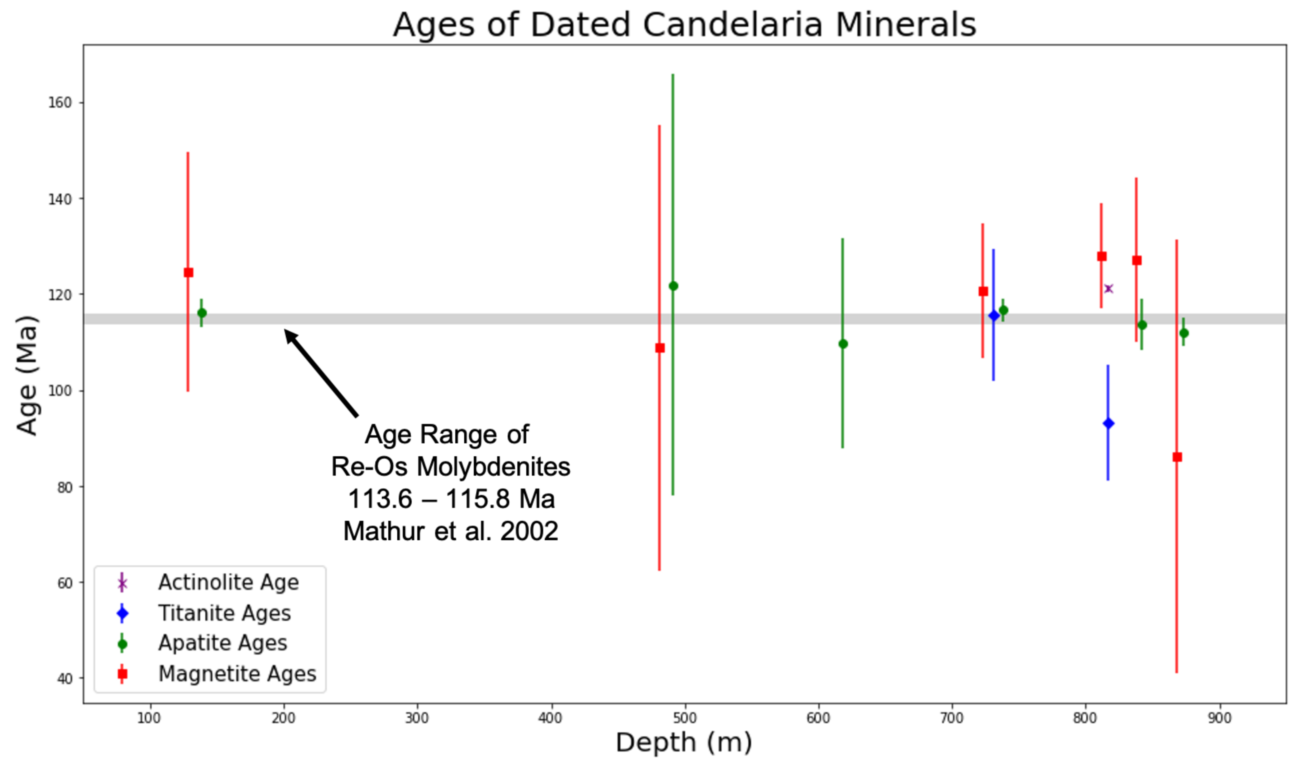

Figure 1. U – Pb ages of apatite, titanite, magnetite and an Ar – Ar date of actinolite, calculated by depth from the Candelaria mine plotted with 2se uncertainties.