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Targeting Porphyry Copper Deposits at an Orogenic Belt Scale Using Zircon Trace Element Composition: Impact, Application, and Lessons Learned

Robert G. Lee, Alan J. Wainwright, Fabien Rabayrol, Eoin Cross, Farhad Bouzari, Craig J. Hart
MDRU - University of British Columbia, Vancouver, BC, Canada

Multiple studies have investigated zircon chemical composition to elucidate the temporal and chemical characteristics of magmas. Zircon has high potential as an indicator of magmatic fertility due to preferential inclusion of high field strength elements and rare earth elements such as Ce and Eu, which are used as proxies for the oxidation state of the parent magma. Zircons from magmatic rocks related to porphyry copper deposits typically have elevated Ce and Eu anomalies as well as anomalous trace element concentrations, which indicate increased fertility or the potential that the magma can produce mineralizing fluids. There is debate as to the magmatic physicochemical cause for these anomalies, whether they are related to the oxidation state, water content, or apatite-titanite fractionation. Additionally, the functionality of zircon chemistry as a method to indicate fertility and the direct application to belt-scale mineral exploration may not yet be fully utilized.

Ninety-eight samples collected from the western Tethyan orogenic belt across ~2,500 km from the Balkans to the Lesser Caucasus were selected to test the application of zircon composition as a method for targeting at the belt scale. Samples were collected throughout the belt from barren to copper-gold mineralized porphyry as well as high-sulfidation and intermediate-sulfidation epithermal deposits, including Rosia Montana, Romania; Bor, Serbia, Skouries, Greece; Kişladağ, Copler, and the Artvin district, Turkey, and the Adjara-Trialeti Belt, Georgia in addition to several pre-arc Jurassic to Paleozoic rocks. The composition of these samples includes calc-alkaline to alkaline diorite to monzonite intrusive and andesite to rhyolite extrusive rock types.

Zircons from these samples were analyzed using the LA-ICP-MS method and yielded >2,400 trace element and age analyses. Trace element compositions within individual samples typically show a high degree of variability that can lead to difficulty with interpretation. Using mean values for each of the samples as a first step, however, similar characteristics for mineralized centers in Cretaceous, Paleogene, and Neogene arc rocks are evident. Regardless of age, rock composition and location, the samples that are directly related to mineralization have mean Eu/Eu_N^* values >0.61, Ce/Ce_C^* >1,400, $(Ce/Nd_N)/Y$ >0.03, Yb/Gd_N >35, and Hf/Y >10. Calculated mean zircon temperatures for the mineralized samples tend to be low, from 730° to 650°C. Zircon from the barren Tethyan arc rocks and the older basement rocks generally have mean Eu/Eu_N^* values <0.40, Ce/Ce_C^* <1,000, $(Ce/Nd_N)/Y$ <0.01, Yb/Gd_N <30, and Hf/Y <10. Calculated zircon temperatures and total REE concentration are higher in the barren samples compared to the fertile ones. Mean zircon compositional data show clear differences between barren and mineralized populations. This method provides the first step to potentially identifying mineralized districts, which can be followed up through a more detailed assessment of the zircon composition and petrologic properties.

This project represents one of the most significant regional studies to apply the zircon method to assess the fertility potential of magmatic-hydrothermal porphyry-epithermal mineralized systems across an orogenic belt. Based on three to four samples collected at each site, compositional differences in zircon composition can be used as a fertility indicator.