Zircon Oxybarometry and Hygrometry Discriminate Porphyry-Copper Ore-Forming Magmas from Ordinary, Infertile Arc Magmas: Guides to Exploration Targets

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The ratio (Eu/Eu*)/Yb in zircon increases as hydration state of its parent silicate melt increases (Loucks et al., 2016). The ratio $Ce/\sqrt{(U_i \times Ti)}$ in zircon increases as oxidation state (ΔFMQ) of its parental silicate melt increases (Loucks et al., 2020). U_i is the initial ppm U in zircon, corrected for post-crystallization radioactive decay. Our database of trace-element compositions and U-Pb ages of >8,000 zircons from porphyry-copper ore-forming intrusions in 40 mining districts and from many unmineralized igneous suites at convergent plate margins demonstrate that plots of zircon (Eu/Eu*)/Yb versus $Ce/\sqrt{(U_i \times Ti)}$ are remarkably effective in discriminating zircons in copper-ore-forming granitoid intrusions from zircons in copper-infertile, ordinary magmas of calc-alkalic granitoid compositions. During fluid-undersaturated and plagioclase-undersaturated fractional crystallization of arc magmas at high pressure, the residual melt's (Eu/Eu*)/Yb and $Ce/\sqrt{(U_i \times Ti)}$ rise in tandem. As hydrous granitoid magma ascends through the crust and exsolves hydrothermal fluid in response to decompression, plagioclase crystallizes and the melt's (Eu/Eu*)/Yb ratio decreases. As hydrothermal fluid exsolves, reduced members of Fe, S, C, and H redox couples are preferentially partitioned into exsolving, gravitationally segregating hydrothermal fluid, leaving an increasingly oxidized residual silicate melt. Zircon crystals growing from decompressing, dehydrating melt record the decreasing hydration state of the melt as a typically ~10-fold decrease in (Eu/Eu*)/Yb and simultaneous increase of $Ce/\sqrt{(U_i \times Ti)}$ by a factor of ~3. We introduce a compound hygrometer-oxybarometer indicator of magmatic copper fertility, $10^4 \times (Eu/Eu^*)/Yb_N + 5 \times Ce/\sqrt{(U_i \times Ti)}$ in zircon, which compresses the range of variation to factor of only about 2 within zircon grain populations in individual granitoid plutons, but typically is 2 to 20 times higher in Cu-ore-forming intrusions than in unmineralized, infertile granitoid intrusions. These zircon trace-element discriminants of Cu-fertile arc magmas are applicable to detrital zircons for identification of watersheds containing Cu-prospective igneous complexes upstream from the sediment sampling site.