Zircon and Whole-Rock Trace Element Indicators of Magmatic Hydration State and Oxidation State Discriminate Copper Ore-Forming from Barren Arc Magmas

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To meet surging requirements of copper for the green energy revolution, mineable resources subequal to all copper production in history must be found in the next two decades. We show that trace elements in zircon and whole-rock samples that are diagnostic of unusually high-pressure magmatic differentiation and high hydration state and oxidation state of their parent silicate melt are effective for discriminating copper sulphide-ore-productive arc magmas from infertile arc magmas. Tests on our database of 5,777 zircons from 80 igneous complexes, including 2,220 zircons from ore-generative intrusions in 37 major porphyry and high-sulphidation epithermal Cu(-Au-Mo) deposits worldwide, demonstrate that our magmatic copper fertility discriminants perform equally well in intraoceanic arcs, continental margin arcs, and continental collision orogens of Ordovician to Quaternary age. The ratio Ce/√(U × Ti) in zircon is a quantitative indicator of the relative oxygen fugacity of the silicate melt and its sulphur-carrying capacity. The ratio of the europium anomaly to ytterbium in granitoid melts and zircon is an empirically useful indicator of the melt's hydration state and ability to provide chloride-complexed metals to exsolving hydrothermal fluids. Arrays of cognate zircons on (EuN/Eu*)/YbN vs. Ce/√(U × Ti) plots have slopes that vary with pressure-dependent chlorinity of exsolving fluid and its efficacy in scavenging CuCl from the melt. We formulated a composite zircon copper fertility index (ZCFI) that can be applied to each microbeam spot analysis—ZCFI = 104 (EuN/Eu*)/YbN + 5 Ce/√(U × Ti)—and substantially decreases the number of zircon analyses needed for reliable prospectivity assessment, discriminating igneous complexes, arc segments, and time intervals within them that are likely to host magmatic-hydrothermal Cu(-Au-Mo) ore deposits. Our zircon indicators of Cu metallogenic fertility are equally applicable to in situ as well as detrital zircons, thereby making regional or watershed-scale exploration tool cost-competitive with other methods of geochemical exploration.