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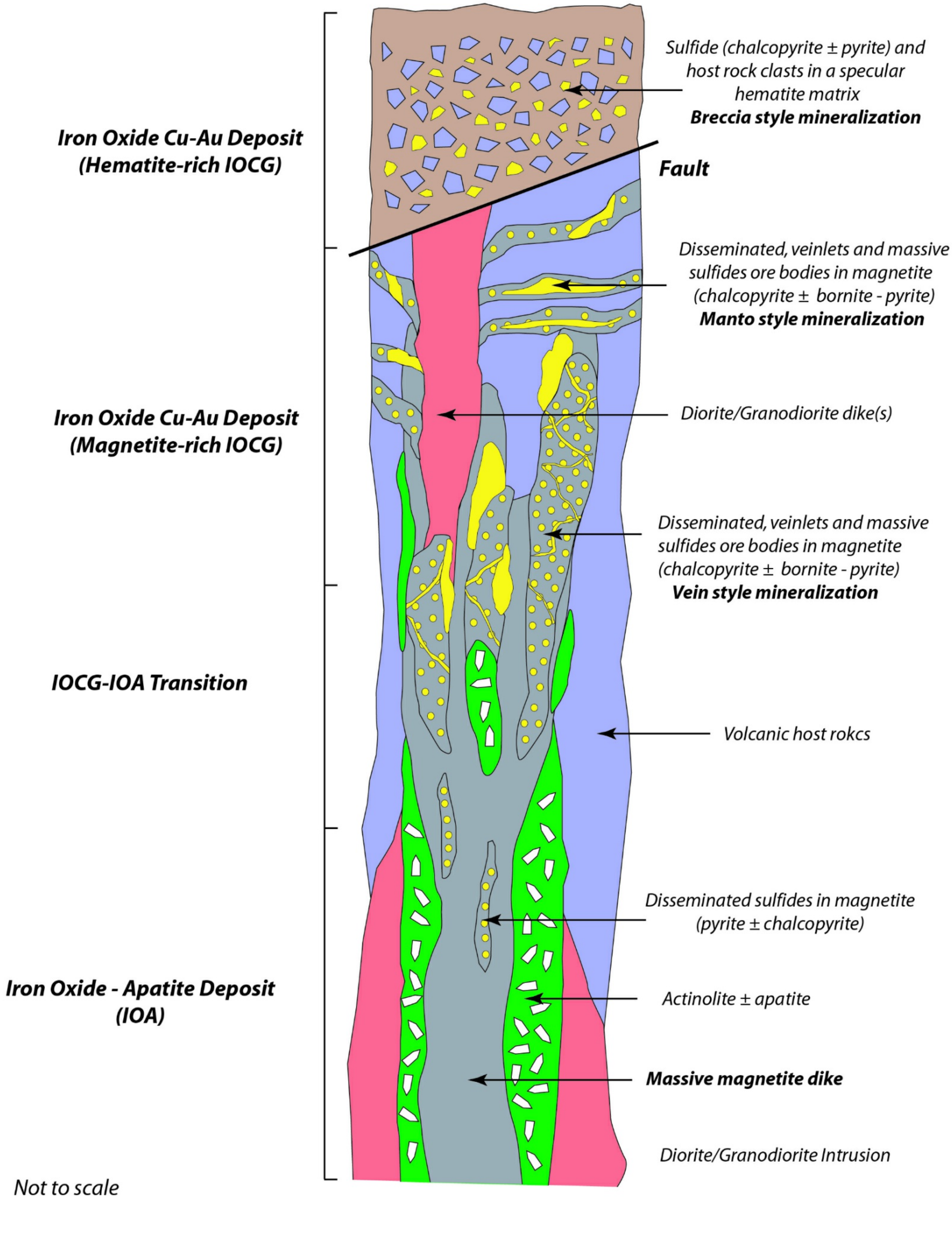
The Formation of Iron Oxide Copper-Gold (IOCG) and Iron Oxide-Apatite (IOA) Deposits: New Insights from Field Studies and Lab Experiments

Adam C. Simon[1], Maria A. Rodriguez-Mustafa[1], Martin Reich[2], Fernando Barra[2], Irene del Real[2], Jose Tomas Orvalle Ortégá[2], John F. Thompson[3], Tristan Childress[1], Nikita L. La Cruz[1], Artur P. Deditius[4], Laura D. Bilenker[5], Ilya Bindeman[6], Daniel R. Blakemore[1], Robert Holder[1]

1. Department of Earth and Environmental Sciences, University of Michigan, Ann Arbor, MI, USA, 2. Department of Geology and Andean Geothermal Center of Excellence (CEGA), FCFM, Universidad de Chile, Santiago, Chile, 3. PetraScience Consultants, Vancouver, BC, Canada, 4. School of Engineering and Information Technology, Murdoch University, Murdoch, WA, Australia, 5. Department of Earth, Ocean, & Atmospheric Sciences, University of British Columbia, Vancouver, BC, Canada, 6. Department of Earth Sciences, University of Oregon, Eugene, OR, USA

Iron oxide copper-gold (IOCG) and Kiruna-type iron oxide-apatite (IOA) deposits are commonly spatially and temporally associated with one another and with coeval magmatism. In many districts, field observations reveal that IOCG mineralization transitions with depth to S-Cu-Au-poor IOA mineralization and/or that IOA mineralization transitions laterally to IOCG mineralization. Several genetic models have been proposed to explain the evolution of IOCG deposits and IOA deposits as separate systems, but no model has successfully explained the geochemical signature of the deposits or the hypothesized genetic continuum between them. Here, we use trace element concentrations in magnetite and pyrite, Fe and O stable isotope abundances of magnetite and hematite, H isotopes of magnetite-hosted fluid inclusions and actinolite, and S in pyrite from IOCG and IOA deposits in Chile and Peru to develop a new genetic model that explains IOCG and IOA deposits as a continuum produced by a combination of igneous and magmatic-hydrothermal processes. The $\delta^{18}O$, $\Delta^{17}O$, $\delta^{56}Fe$, δD, and $\delta^{34}S$ data unequivocally fingerprint a silicate magma as the source of the ore fluid in IOCG and IOA deposits. Magnetite-hosted silicate melt inclusions and aqueous fluid inclusions, along with magnetite trace element compostions, reveal crystallization from silicate melt and magmatic-hydrothermal fluid. The trace element abundances of magnetite and pyrite, and Mg-in-magnetite and Fe# actinolite thermometry, reveal a systematic continuum between IOA and IOCG deposits that is consistent with formation from a cooling magmatic-hydrothermal fluid. The data cannot be explained by existing models. We developed a new genetic model that explains the geochemical data and field observations: 1) magnetite crystallizes as a near-liquidus phase from an intermediate to mafic silicate melt; 2) magnetite microlites serve as nucleation sites for fluid bubbles and promote volatile saturation of the melt; 3) the volatile phase coalesces and encapsulates magnetite microlites to form a magnetite-fluid suspension; 4) the volatile phase scavenges Fe, Cu, Au, S, Cl, P, Si, and other fluid-mobile elements from the melt; 5) the suspension ascends from the host magma during regional extension; 6) as the suspension ascends, originally igneous magnetite microlites grow larger by sourcing Fe and O from the cooling magmatic-hydrothermal fluid, and apatite and gangue minerals (e.g., actinolite) precipitate from the ore fluid; 7) in deep-seated crustal faults, magnetite crystals are deposited to form a IOA deposit due to decompression of the magnetite-fluid suspension; 8) the further ascending fluid transports Fe, Cu, Au, and S to shallower levels or lateral distal zones of the system where hematite, magnetite, and sulfides precipitate to form IOCG deposits. To test this model in the laboratory, we conducted experiments at appropriate PTX conditions to simulate the evolution of intermediate silicate melt during decompression. The experimental results demonstrate that magmatic-hydrothermal fluid bubbles nucleate on magnetite and form magnetite-bubble pairs that bouyantly ascend through the magma during decompression, accumulating in an upper layer that grows during reequilibration. Regional tectonic stress changes promote ascent of the magnetite-fluid suspension along preexisting faults, followed by precipitation of IOA mineralization and then IOCG mineralization as the fluid cools.



Iron Oxide Cu-Au Deposit
(Hematite-rich IOCG)
Sulfide (chalcopyrite ± pyrite) and
host rock clasts in a specular
hematite matrix
Breccia style mineralization
Fault
Disseminated, veinlets and massive
sulfides ore bodies in magnetite
(chalcopyrite ± bornite - pyrite)
Manto style mineralization
Iron Oxide Cu-Au Deposit
(Magnetite-rich IOCG)
Diorite/Granodiorite dike(s)
Disseminated, veinlets and massive
sulfides ore bodies in magnetite
(chalcopyrite ± bornite - pyrite)
Vein style mineralization
IOCG-IOA Transition
Volcanic host rokcs
Disseminated sulfides in magnetite
(pyrite ± chalcopyrite)
Iron Oxide - Apatite Deposit
(IOA)
Actinolite ± apatite
Massive magnetite dike
Diorite/Granodiorite Intrusion
Not to scale