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Multiple Formation Environments of Advanced Argillic Alteration and Exploration Implications

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Advanced argillic alteration, defined by Hemley as advanced hydrolytic, includes alunite, aluminosilicates (kaolinite, halloysite, dickite, pyrophyllite, andalusite), diaspore, anhydrite, and zunyite and topaz. One or more of these minerals form in five distinctly different acidic ($\text{pH} \leq 1$ to 4-5) geologic environments, most at depths < 500 m (Fig. 1). 1) Vapors that discharge from volcanic vents contain magmatic SO_2 and HCl ; where condensed into local groundwater, hypogene H_2SO_4 and HCl -rich solutions form with a pH of $< 1-1.5$ at $< 250^\circ\text{C}$. Isochemical dissolution of permeable host rock occurs due to the high solubility of Al and Fe hydroxides at $\text{pH} < 2$, aside from a siliceous residue. This residual quartz, commonly vuggy in texture, is barren of metals due to low metal contents in high-temperature, low-pressure volcanic vapor. Alunite, kaolinite, and dickite (\pm pyrophyllite \pm diaspore at higher temperatures) form a halo to the residual quartz. This barren lithocap horizon follows permeable lithologic units near feeder structures and may become mineralized if metal-bearing white mica-stable liquid subsequently ascends to this level. 2) Boiling of geothermal solutions generates vapor with CO_2 and H_2S , and where condensed above the water table in the vadose zone, atmospheric O_2 oxidizes H_2S to sulfuric acid, forming a steam-heated solution of pH 2-3. Kaolinite and alunite horizons form above the water table at $\sim 100^\circ\text{C}$, and amorphous silica derived within the vadose zone replaces the aquifer with opal as the condensate follows the hydraulic gradient. 3) By contrast, where this vapor condenses below the water table, the CO_2 in solution forms carbonic acid (H_2CO_3) with pH of 4-5. This marginal carapace of condensate forms intermediate argillic alteration of clays and Fe carbonates: smectite at shallow depths and interstratified clays to illite \pm chlorite at higher temperature. At sufficiently high H_2CO_3 concentration, kaolinite becomes stable at several 100s m depth, forming illite-kaolinite halos to quartz veins, potentially mistaken as having formed in an advanced argillic environment (e.g., steam-heated sulfate or supergene overprint). 4) The deepest environment, ~ 1 km, is associated with the top of porphyry deposits, where the metal-bearing fluid that forms white-mica alteration continues to ascend and cool, forming pyrophyllite (\pm diaspore \pm dickite) near the base of the residual quartz and advanced argillic lithocap. 5) The final setting is supergene, due to posthydrothermal weathering and oxidation of pyrite, locally creating $\text{pH} < 1$ liquid from high concentrations of H_2SO_4 within the vadose zone, where kaolinite and alunite plus Fe oxyhydroxides form.

Interpretation of the formational environment of alteration, using mineralogy, textures, and morphology, is critical to the effective exploration for epithermal, porphyry, and other hydrothermal ore deposits. For example, hypogene quartz-alunite-kaolinite forms halos to residual quartz lithocaps, which may be mineralized or barren, whereas pyrophyllite-white mica underlies lithocaps but indicates proximity to porphyry deposits. Kaolinite-alunite steam-heated blankets, typically barren, may overlie ore zones. Too often the terms advanced argillic, argillic, etc., are used on maps and sections, thus losing the significance of specific alteration minerals and morphologies, with two or even three different origins of advanced argillic alteration possible in one deposit.

Five formational environments of advanced argillic mineralogy

