FORMATION OF CALCITE AND SILICA FROM PERCOLATION IN A HYDROLOGICALLY UNSATURATED SETTING, YUCCA MOUNTAIN, NEVADA

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Geological, mineralogical, chemical, and isotopic evidence from coatings of calcite and silica on open fractures and lithophysal cavities within welded tuffs at Yucca Mountain indicate an origin from meteoric water percolating through a thick (500 to 700 m) unsaturated zone (UZ) rather than from pulses of ascending ground water. Geologic evidence for a UZ setting includes the presence of coatings in only a small percentage of cavities, the restriction of coatings to fracture footwalls and cavity floors, and an absence of mineral high-water marks indicative of water ponding. Systematic mineral sequences (early calcite, followed by chalcedony with minor quartz and fluorite, and finally calcite with intercalated opal forming the bulk of the coatings) indicate progressive changes in UZ conditions through time, rather than repeated saturation by flooding. Percolation under the influence of gravity also results in mineral textures that vary between steeply dipping sites (thinner coatings of blocky calcite) and shallowly dipping sites (thicker coatings of coarse, commonly bladed calcite, with globules and sheets of opal). Micrometer-scale growth banding in both calcite and opal reflects slow average growth rates (scale of mm/m.y.) over millions of years rather than only a few rapidly deposited growth episodes. Isotopic compositions of C, O, Sr, and U from calcite and opal indicate a percolation-modified meteoric water source, and collectively refute a deeper ground-water source. Chemical and isotopic variations in coatings also indicate long-term evolution of water compositions. Although some compositional changes are related to shifts in climate, growth rates in the deeper UZ are buffered from large changes in meteoric input. Coatings most likely formed from films of water flowing down connected fracture pathways. Mineral precipitation is consistent with water vapor and carbon dioxide loss from films at very slow rates. Data collectively indicate that mineral coatings formed in a UZ setting that has been hydrologically stable over million-year time scales.