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The Copper Kitchen: Observing the Generation of a Cu-Bearing Brine in the Midcontinent Rift System, USA

Simon Jones[1], Tony Prave[2], Tim Raub[2], Jonathan Cloutier[3]
1. First Quantum Minerals, West Perth, WA, Australia, 2. School of Earth and Environmental Sciences, University of St Andrews, St Andrews, United Kingdom, 3. CODES, University of Tasmania, Hobart, TAS, Australia

Redbed sandstones are widely recognized as the principal source of metals in low-temperature sediment-hosted stratiform copper deposits. They form in a variety of depositional settings and commonly contain a large component of detrital feldspar or volcanic lithic fragments. Commencing upon surface exposure and continuing during burial, oxidized pore fluids interact with sediments causing dissolution of labile minerals, and the development of characteristic iron-oxide grain coatings. This oxidation process liberates Cu, Ag, Co and other metals into formation waters. Migration and focused flow of these ‘pregnant’ fluids to a reductant (e.g. shale or hydrocarbon trap) induces copper sulfide precipitation. A less well understood aspect of redbed leaching is the conditions, pathway and rate at which minerals decompose and release their metals. This creates an obvious impediment to evaluating the likelihood that a volume of redbeds has released metals into pore fluids, and thus achieved the first step in a chain of events required to form sediment-hosted stratiform copper mineralization. Here, we present a case study from the 1.1 Ga Midcontinent Rift System, Michigan, USA, of the metal-leaching process responsible for the formation of the White Pine deposit (~250 Mt @ 1.1 % Cu). The Copper Harbor Formation redbed is a sequence of conglomerates and sandstones containing ~50–95% basaltic detrital grains derived from the underlying Portage Lake Volcanics. The depositional setting was a marine-influenced braided fluvial-sabkha environment. Differential exhumation of the Copper Harbor Formation along a 120 km segment the Keweenaw Fault provides a window into diagenesis at depths ranging from ~3-7 km. We demonstrate the onset of metal leaching began in the surface environment with the development of leached weathering rinds and continued during eodiagenesis (~50-100°C, 1-4 km depth) with the partial replacement of rhyolitic and basaltic lithic fragments by beidellite, montmorillonite and interlayered illite-smectite. Dissolution of volcanic grains accelerated rapidly in the telodiagenetic zone (>180°C, 6-7 km depth) with the formation of non-expandable illite-smectite and chlorite-smectite, incipient feldspar dissolution and laumontite precipitation. In addition to liberating ore metals, mineral dissolution and precipitation resulted in a continual exchange of components between mineral phases and pore fluids. Dissolution of evaporites (anhydrite and isolated halite) increased pore fluid salinity, progressive de-watering of interlayered clays contributed water, illitization of smectite consumed Al + K and released Si producing quartz overgrowths, and the combined effects of alkali feldspar dissolution and laumontite precipitation probably created pore fluids with an excess of Mg, Na, and K relative to Ca. We conclude that whilst metals in the White Pine deposit were derived from the Copper Harbor Formation, they were predominantly sourced not from the immediate local, but from a “copper kitchen” some 10s of kms to the north and northeast, at greater depths (>7 km), in a process analogous to petroleum maturation in an “oil kitchen”. Characterizing diagenetic reactions such as those outlined here may provide mineral explorers with a means of evaluating the efficiency of metal leaching in a sedimentary basin; thus helping to mitigate a major risk factor in sediment-hosted stratiform copper exploration.