

Fluid-Rock Reactions and Hydrologic Drivers of Iron Cycling in Former Redbed Sandstones

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Iron cycling, often enhanced by microbial activity, is a common process from the land-surface to the bottom of the meters- to kilometers-deep Critical Zone, and one that often leaves manifestations of paleofluid flow in the rock record. Bleaching of redbed sandstones by reduced fluids and precipitation of iron oxide in joints, cements, and concretions with varying geometry in paleo-aquifers (e.g., pipe structures) is a widespread example, particularly in the Colorado Plateau. Questions remain about the fluids involved, hydrologic drivers, and timing of iron bleaching/mineralization events. Here, we hypothesize that topographically-driven reduced hydrocarbon-bearing fluids dissolved hematite in the Navajo Sandstone and mobilized Fe²⁺ downgradient in the regional aquifer. Localized fractures and joints acted as conduits for upward migration of reduced fluids and mixing with shallow oxic meteoric waters, facilitating precipitation of iron oxides. To test our hypothesis, we use a two-dimensional hydrogeochemical model (PFLOTRAN) to compare with field geochemical observations to investigate the mechanisms, timescales, and extent of fluid mixing and fluid-rock reactions in the Navajo Sandstone adjacent to gas fields in the Escalante Anticline.

Model results indicate reduced, CH₄- and CO₂-bearing groundwater can completely dissolve hematite (1% volume fraction), bleaching redbed sandstones, within 600,000 years in relatively high permeability zones. Lower permeability zones can retain hematite for up to 5 Ma. Calcite and illite fully dissolve, quartz precipitates, and K-feldspar and kaolinite decrease but remain present in the bleached sandstone, consistent with XRD results. Mixing of ferrous iron-saturated, reduced deep groundwater, migrating upwards along joints, with more oxic, shallow groundwater can precipitate a comparable amount of goethite, with pipe-like structured oriented downgradient, in the bleached sandstone regional aquifer, as observed in the field, within 2 Ma. These results are consistent with previous (U-Th)/He dating of goethite dominated iron oxides and help constrain hydrologic and geochemical processes responsible for iron cycling and concretion formation.