Active Groundwater Circulation and Permeability Observations Defined By Interdisciplinary Characterization of Geologic Controls in a Mineralized Headwater Catchment

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BER Program: SBR/Watershed Function SFA

Project: Characterization of groundwater flow and associated geochemical fluxes in mineralized and unmineralized bedrock in the upper East River and adjacent watersheds, Colorado

Project Website: https://minerals.usgs.gov/science/metal-transport-characterization- mineralized-mountain-watershed/index.html

Project Abstract: Geologic controls on groundwater flow, particularly in tectonically and topographically complex mountainous terrain, can be difficult to identify without a detailed understanding of subsurface geologic structure. This structure can influence the magnitude of groundwater flow at different depths within the mountain block, which in turn impacts the distribution and chemistry of groundwater discharge to the near-surface ecosystem.

Characteristic circulation depths and permeability structure in sedimentary-rock mountain blocks are particularly uncertain because the small number of studies that have determined the limits of circulation depth have been performed mainly in crystalline rocks, whereas sedimentary-rock sequences are typically more heterogeneous and anisotropic. We use a combination of geological, geophysical, geochemical, and hydraulic observations over multiple scales, including the detailed characterization of new high-elevation boreholes, to better understand the structure and hydrologic function of mountain bedrock aquifers. Our study focuses on the Redwell Basin in the Upper East River Watershed, CO, a high-elevation headwater catchment underlain by mineralized sedimentary rock. Long-interval depth-dependent packer tests indicate that substantial hydraulic conductivity ($K = 10^{-7}$ to 10^{-6} m/s) exists in the bedrock aquifer, and while permeability generally decreases with depth, some deeper intervals still exhibit relatively high K. In-situ observations from borehole geophysical measurements and drill core indicate the most hydrologically communicative features occur along sub-horizontal bedding plane fractures and at lithologic transitions, suggesting anisotropic permeability is inherited from the sedimentary structure and enhanced in the sub-horizontal direction. However, borehole temperature logs indicate a nearly linear thermal profile below a depth of 20 m with a gradient of 38ºC/km, indicative of low vertical groundwater flow velocities under a primarily conductive heat flow regime ($q < 1$ cm/yr). The chemistry of deeper groundwater (below 20 m) is substantially different from that of shallow groundwater: pH is 7-8 versus 4-5; specific conductance is 400- 600 versus 100-300 µS/cm; and concentrations of multiple constituents (e.g., Ca, Fe) differ by a factor >5. Tritium and He isotope data indicate that the deeper groundwater is dominantly >60 yr old, whereas shallow water is modern with apparent $^{3}H/^{3}He$ ages of 5-15 yr. The deeper water also has high terrigenic He concentrations of 4-8 times solubility, typical for groundwater 100's to 1000's of years old. Available temperature, chemistry, and age data therefore all suggest that, while