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Strontium and uranium isotopes reveal surface water-groundwater interaction as a function of lithology along a mountain stream (Hyalite Canyon, Montana)

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Changing climate and precipitation patterns are projected to transform snowpack storage and late summer stream flows in mountain catchments and across mountain fronts of the interior western United States. Ecosystems, agriculture, and municipalities all depend on the resulting late season flows in rivers traversing intermountain basins. This relationship makes it increasingly important to understand the contribution of groundwater to stream flow (i.e., base flow) in mountain stream-fed watersheds. This connection of soil water and deeper groundwater with stream flow influences water quality and hence the character of alluvial aquifer recharge at mountain fronts; yet tracers of these linkages are not well developed.

As a case study for using geochemical tracers to examine the interaction of ground water with a mountain stream system, Hyalite Creek – a tributary of the Gallatin River in the uppermost Missouri River headwaters - was longitudinally sampled from the headwaters to the mountain front (2100-1700 m elevation) during 2016 and 2017, with a focus on base flow conditions (early February and late August). The Hyalite watershed spans a range of rock types that increase dramatically in age down canyon, from Tertiary volcanic rocks in the headwaters to Cretaceous to Cambrian age sedimentary rocks in mid-reaches and Archean gneiss in the lower reaches. Rock units within the canyon include at least one major water-bearing unit (the Madison formation), and the upper reaches are glaciated.

To elucidate groundwater surface water exchange in this context, we used strontium (Sr) and uranium (U) isotopic compositions as natural tracers of water-rock interaction. Generally, $^{87}Sr/^{86}Sr$ ratios reflect rock sources, while $^{234}U/^{238}U$ activity ratios (UARs) reflect duration of water-rock interaction. Together, UAR and $^{87}Sr/^{86}Sr$ data allow evaluation of transitions in source rock and transport times of waters contributing to stream flow along watersheds with diverse bedrock.

Stream flow under base flow conditions in upper Hyalite Canyon had low $^{87}Sr/^{86}Sr$ values ($\sim$0.7085-0.7089), typical of the volcanic and sedimentary lithologic units it drains, and low UAR values ($\sim$1.5–1.7), consistent with relatively short flow path water (runoff and soil water). In the mid-reaches of Hyalite Creek an increase in UAR up to $\sim$3.0 and a small decline in $^{87}Sr/^{86}Sr$ values indicate deeper groundwater inputs to Hyalite Creek; the initial increase coincides with an outcrop of the Madison limestone formation and associated springs in the stream bank, consistent with the tendency of the Madison formation to host a karst aquifer in the region. In the lower reaches of Hyalite Creek, an increase in $^{87}Sr/^{86}Sr$ values ($\sim$0.7098-0.7120) and decrease in UAR ($\sim$1.7-2.1) suggests greater inputs of water from localized flow through Archean gneiss with high $^{87}Sr/^{86}Sr$ ratios (values of $\sim$0.7350 observed in a groundwater well within the Archean gneiss). Surface water-groundwater interaction implied by these values is quantified using mixing models.