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Investigating Bedrock Fractures as a Dynamic Hydrologic Reservoir Across a Gradient in Climate and Erosion Rate

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The weathered and fractured bedrock that commonly underlies soils in montane environments can be sufficiently porous and permeable to transiently store and transmit water. There is increasing inferential evidence that this variably saturated weathered bedrock region regulates subsurface biogeochemical processes and the partitioning of precipitation between evapotranspiration and runoff. However, observations of hydrologic dynamics in the bedrock unsaturated zone are sparse, and thus the representation of this region in models of land-surface processes remains poorly constrained. This project seeks to evaluate predictions of how the weathering profile is structured at the hillslope scale by assembling direct observations within four sites underlain by clay-rich bedrock (i.e. shale) across a gradient in climate and erosion rates: the Angelo Coast Range Reserve (ACRR), Sagehorn-Russell Ranch (SRR), Antelope Valley Ranch (AVR), and the LBNL Watershed Function Scientific Focus Area (SFA). To complement existing boreholes at ACRR and SRR, we have now established field monitoring sites in forested shale bedrock at the AVR and SFA sites. The boreholes were outfitted with pressure transducers to monitor groundwater levels and we are currently characterizing mineralogy, geochemistry and pore structure on cores.

With the establishment of new boreholes, we have now documented significant water storage in weathered bedrock using low-field borehole nuclear magnetic resonance (NMR) across all four sites. In the upper 4 m of bedrock, the average water contents at ACRR, AVR, SRR, and SFA are approximately 25%, 16%, 25%, 23% respectively. At the ACRR site, where long-term monitoring via neutron probe surveys and time-domain transmission sensors are available, we have demonstrated that NMR reliably records moisture content and importantly, moisture content dynamics in weathered bedrock. Across all sites, our NMR monitoring has also revealed that a considerable fraction of the water storage occurs in fractures or pores that are significantly larger than the fine-grained bedrock matrix of the parent rock. To identify the proportion of water storage occurring in fractures and large pores, we analyzed the NMR signal by evaluating both the sum of echoes and an inversion of the NMR signal for a distribution of T_2 relaxation times. Both methods reveal that at least 20% of the water storage occurs in fractures and larger pores across all sites. To constrain the interpretation of the in-situ field-scale NMR measurements, we are comparing the NMR response of variably saturated core samples to independent pore-structure information obtained via pycnometry and micro-CT. Preliminary results support the inference that dynamic seasonal water storage is dominantly restricted to the fracture network, which can reach 7% of the total volume. This dynamic range in water content is comparable to that of some soils, underscoring the need to understand how this region of the Earth System is structured, and functions as a hydrologic reservoir.