Simulating the Development of Weathering Profiles in Shale Bedrock at the Eel River Critical Zone Observatory

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Abstract: The vadose (unsaturated) zone accommodates seasonally dynamic water storage, supports vegetation and ecosystems and hosts dynamic cycling of solutes, yet quantitative models describing the processes that regulate mass transport and transformation in this dynamic near surface environment are highly simplified relative to that of soils and groundwater. In this study, we investigate the evolution of the vadose zone profile of a hillslope in the Eel River Critical Zone Observatory (ERCZO) in Mendocino County, California through parameterization and constraint of a reactive transport model coupling weathering rates with water residence times in the fractured shale regolith. The ERCZO is selected for this study due to the presence of a well-developed, 5 to 25 meters thick, partially saturated weathered argillaceous bedrock structure. A novel Vadose Monitoring System (VMS) was designed and installed in October 2015 to sample matrix and fracture fluid across the vadose zone at high spatial and temporal resolution. The VMS is composed of two flexible sleeves (referred to as VMS-A and VMS-B) installed through sub-horizontal boreholes, equipped with 10 water sampling ports on each sleeve and 10 gas sampling ports on VMS-B. Hydrogeochemical data obtained from this novel vadose zone sampling system provides unprecedented insight into the transient production of solutes across the vadose zone. Preliminary measurements from the VMS show a dynamic range of cation concentrations throughout the vadose zone profile that are dampened in groundwater and stream chemistry. Leveraging these data, a series of numerical simulations are constructed to describe and predict the evolution of fresh bedrock to weathered bedrock, coupled to fluid and solute transport. The simulations build in structural complexity from a 1-dimensional reactive transport model incorporating a suite of shale weathering reactions, and subsequently expanding to a 2-dimensional model linking dual-domain (high and low permeability zones) using the CrunchTope software[1]. Preliminary geochemical results captured a wide range of solute concentration variations from the VMS, demonstrating that a 2D dual domain simulation is necessary to explain solute generation. Initial conditions are represented by a domain 18 meters in depth composed of fresh argillaceous bedrock and subjected to an upper boundary condition influx of dilute rain water over appropriate timescales to attain the modern weathered regolith profile (i.e. hindcasting). This approach merges a range of processes from regional landscape evolution (tectonic uplift/surface erosion) to local structure (vertical spatial heterogeneity within the vadose zone). Initial conditions are parameterized using bedrock porosity measurements, mineral assemblage, and erosion/uplift rates documented in previous studies. This study addresses a critical challenge in reactive transport modeling to simulate the chemical weathering processes in the subsurface by accounting for dual domain transport and constraints presented by in-situ geochemical data.

References: [1] Steefel etal. 2015 *Computational Geocsciences*