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Regolith Weathering, Plastic Deformation and Hydrologic Evolution in a Volcanic Landscape

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Abstract Text:
Landscape level observations of streams on the island of Hawai'i indicate that runoff ratios are essentially zero on the young active volcanic surfaces of windward Mauna Loa and Kilauea volcanoes and increase with age on the older Mauna Kea and Kohala surfaces. Recent work on both permanent and ephemeral stream flows shows that the changes in runoff are associated with decreases in saturated hydraulic conductivity (k_h) and aquifer thickness (D) that change with surface age (Perez-Fodich et al. 2024). The processes that control k in soils are plausibly related to weathering but the mechanisms are complex. Chemical weathering causes mass loss and most weathering reactions have negative ΔV so intuitively weathering should increase porosity (f) and likely k_h. Dry bulk density ρ_s of weathered soils initially does decrease with weathering mass losses. However trends in ρ_s reverse with further age, and calculated soil strain becomes negative. A model of poro-plastic deformation where the medium comprises an incompressible soil matrix with a finite yield stress σ_p^s and a void fraction f that is deformable but has zero yield stress (e.g. Gurson 1977) can represent the evolution of soil strain if is a function of weathering mass loss. In this model the overall plastic yield limit is a function of both σ_p^s and f. The constitutive relation between chemical alteration and strength of the residual basaltic soil matrix is not known in detail. We hypothesize that the yield stress of the residual matrix is a function of the loss of network-forming components such as SiO_2, and that the change in yield stress can be described with a power law function of an alteration and mass loss index such as enrichment in an immobile element Nb/Nb_0. The resulting change in soil hydraulic properties diminishes vertical infiltration and promotes lateral flow toward incipient streams. The resulting

incision leads to marked landscape level changes in hydrology and geomorphology, enhanced by incising stream capture of groundwater in shallow aquifers.

Perez-Fodich et al. 2024, EPSL 635:118687; Gurson 1977, Trans ASME 99:1-25

Plain-Language Summary:
Volcanic landscapes begin with high permeability, but with time develop a weathered surface that reduces permeability and diverts increasing amounts of water to stream runoff. On the island of Hawai'i the young volcanoes have no permanent streams; stream incision becomes important the older surfaces (more than about 20,000 years). By treating the weathered surface as a porous-plastic medium we find that weathering can induce compaction of the soil that reduces permeability. The reduction in infiltration and initiation of stream incision fundamentally changes the hydrologic and geomorphic evolution of the landscape. Weathering affects both the chemistry and material properties of the surface and strongly influences landscape development, in ways that can be predicted with reactive transport and mechanical modeling. Geochemical tracers can be used to identify and quantify weathering processes and constrain these models.

Session Selection:
EP007. Bedrock Breakdown: The Role of Weathering in the Evolution and Function of the Critical Zone

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Abstract Title:
Regolith Weathering, Plastic Deformation and Hydrologic Evolution in a Volcanic Landscape

Requested Presentation Type:
Assigned by Committee (oral, poster, or eLightning)

Virtual Participation:
In-person

Recording Permission Given?
Yes

Previously Published?:
Yes

Previously Published Material:
Our work on the evolution of hydraulic conductivity in basaltic catchments in Hawai'i was recently published (EPSL 2024). The substrate deformation modeling has not been previously published.

Comments to Program Committee:
Brantley and colleagues have shown how weathering reactions in granitoids can increase porosity, leading to positive feedback on rates. Our work is an interesting contrast in a different substrate - it does *not* contradict it.

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I decline the opportunity to volunteer as an OSPA reviewer.

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