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Thermodynamic and pedogenic differences between desert microsites

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Feedbacks exist between soil properties, climate and ecological productivity. In arid alluvial fan deposits common to the southwestern United States, the strength of these complex feedbacks change slowly over long time frames (e.g., 10s to 100s of millennia) as the climate has become drier and warmer. The feedbacks are also influenced by relatively short-time-frame processes of shrub establishment and subshrub processes that create distinct interspace and sub-canopy microsites. Pedogenic processes in both cases proceed at different rates—slowly in interspaces and rapidly beneath canopies—yet both are subject to similar energy and mass inputs entering the system from above the canopy. In this study, we apply a branch of non-equilibrium (open system) thermodynamics to explain desert pedogenic processes and how the two microsites are tied together. The general concept is that energy and mass flow naturally in directions that minimize gradients, hence maximizing randomness and entropy. We hypothesize that younger soils begin as random bodies, but that energy input from the sun, and mass input from water, dust and vegetation create gradients over time, leading to microsites of pavements and canopies. These features eventually reach metastability and the potential for self-destruction increases (i.e. desert pavements eventually fall apart and erode). We seek to apply these concepts to Mojave Desert soils/ecosystems that have been studied in the field and the laboratory, with the goal of explaining and/or predicting the pathways of pedogenesis in these environments. Of particular interest is how these concepts might be applied in microsite locations influence the two-way coupling of pedologic development and ecosystem functions, and whether we can predict the strength of these feedbacks and processes using knowledge of soil systems today.

The field site is found in the Mojave Natural Preserve, CA, USA, where high spatial resolution infiltrometer measurements were taken along transects radiating from canopies of perennial shrubs into bare interspaces of structured soils. We augmented these measurements with ground-penetrating radar (GPR), laboratory analyses, and (in some cases) soil trenches. The results showed higher saturated conductivity under canopies versus interspaces, regardless of surface age, with the largest differences observed on older, developed soils. Bulk density, soil structure grade, and silt and clay content increased significantly away from the canopy, and organic content decreased toward interspaces. Trends in soil properties, from canopies to interspaces, were found to be predictable to a distance of 1.35 +/- 0.32 times the canopy radius, regardless of the size or genus of the shrub. The microsite environments, which are separated by only 10s of cm, release energy and mass at different rates—the fluxes differ by microsite locations. They exist with different thermodynamic gradients, with larger upward fluxes to support shrubs under canopy microsites and larger downward fluxes in interspaces. Armoured against change in interspaces can explain progressive structural evolution of pedons, a paradoxically reduced water infiltration capacity, and a contraction of canopy volumes and ecosystem production in older soils. We use these gradients to illustrate the importance of microsite location when considering complex feedbacks that result through currently-observed, time-dependent processes of pedogenesis in arid regions of the desert southwest.