The importance of climate in modulating hillslope weathering environments and landscape evolution in the Mojave Desert

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Introduction and Setting

The Nipton Hills, located on the northwest flank of the New York Mountains in the eastern Mojave Desert, are a series of east-west oriented drainage basins composed of early Proterozoic bedrock (Figure 1). The hills are a relatively low-relief terrain of meta-granitoid, meta-volcanic, and other metamorphic rocks that lie between ~1200-1500 m above sea level, where mean annual precipitation is ~ 196 mm and mean annual temperature is ~ 17.3°C. The region receives significant inputs of warm-season precipitation that sustain perennial grasses on hillslopes where soils have developed within colluvium (McAuliffe, 2016). The prominent east-west axial drainages preferentially create slopes with northerly and southerly aspects. North aspect slopes are curvilinear, mantled by relatively thick soils with Bt and Bk horizons, and have dense, native perennial grass cover (Figure 1C). More xeric southerly aspect slopes expose more bedrock, have thinner, less well-developed soils, and are dominated by desertscrub (Figure 1D). Discontinuous remnants of thicker colluvium, with soils similar to those of the northern aspect slopes, are preserved as isolated remnants on some south-facing slopes (Figure 1E). We investigate how vegetation, dust, and physical weathering of bedrock contributed to the formation of hillslope soils and how climate variations have affected these processes.

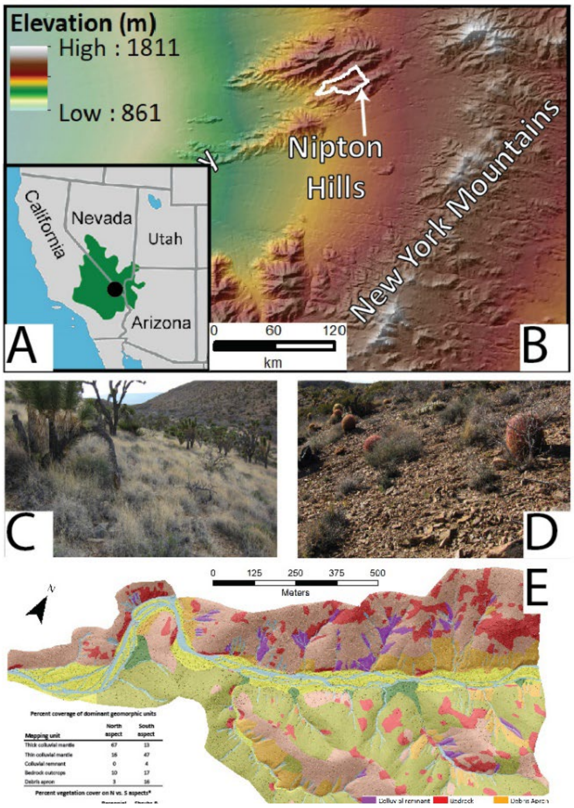

Figure 1. The Nipton Hills (black dot in A) are in the eastern Mojave Desert. East-west axial drainages (B) produce mesic north aspect slopes (C) and xeric south aspect slopes (D). South aspect slopes are dominated by thin soils and frequent bedrock exposures (E). North aspect slopes have more continuous soil cover and fewer bedrock exposures.

Climatic Influences on Slope Soil-Geomorphic Processes

Both topoclimate and millennial-scale climatic changes exert important controls on weathering rates, vegetation cover, soil thickness, and ultimately, landscape evolution. In drylands, hillslope soils and their parent materials are derived from weathering of bedrock combined with eolian inputs of fine sand and silt (McFadden, 2013; Persico et al., 2011). In the Nipton Hills, particle-size distributions of the fine fraction of all slope soils are multimodal, with the highest frequency mode of medium silt to very fine sand (16–125 µm) and a secondary mode of medium to coarse sand (250–1000 µm). Grain morphologies differ between the modes; the coarser grains are more angular and less pitted. Sediment from both sources was deposited on the soil surface and incorporated into

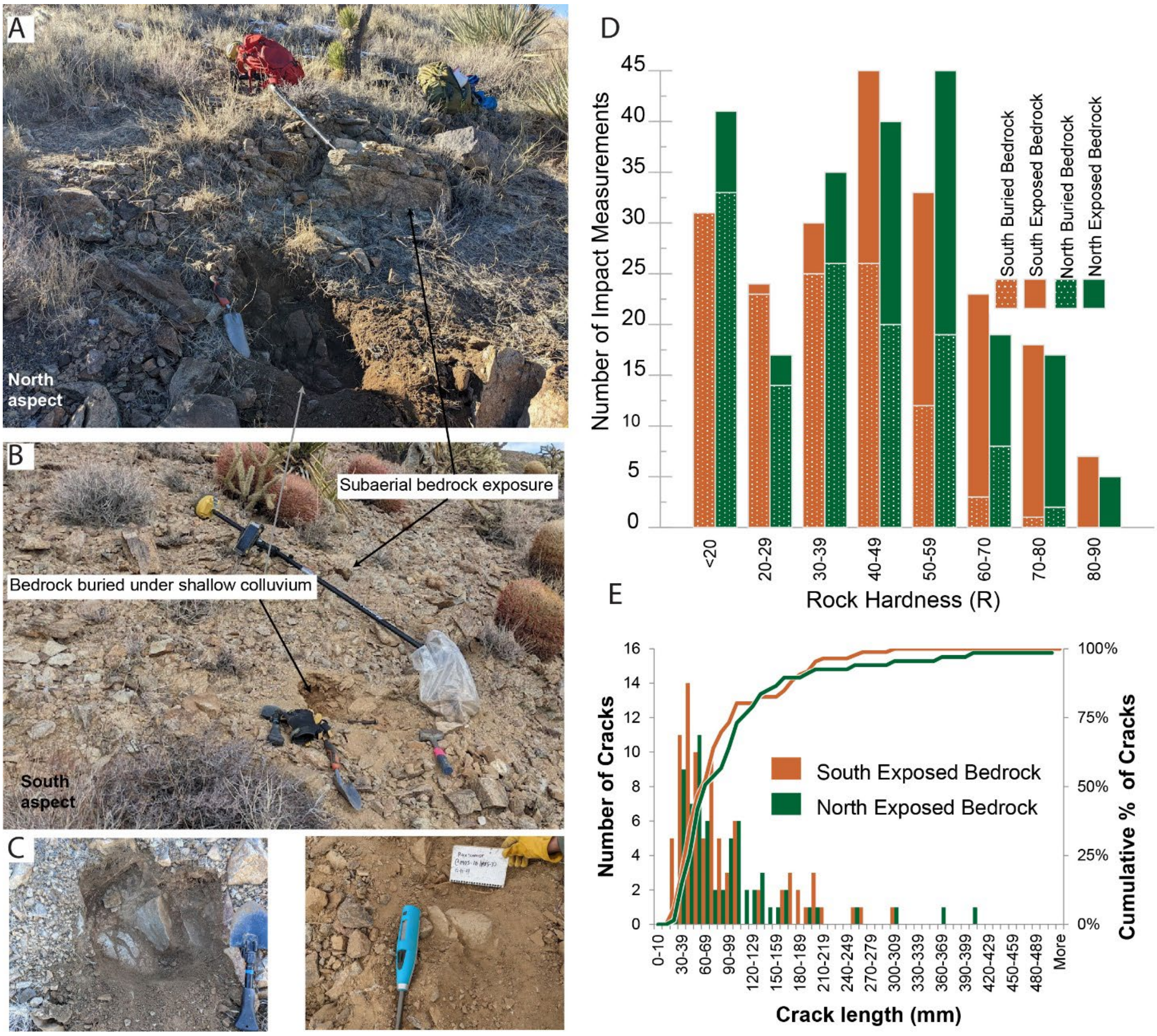

Figure 2. Subaerial bedrock exposures are present on both north (A) and south aspect slopes (B). We estimated bedrock compressive strength using a Rockschmidt Type L rebound test hammer. Buried bedrock (C) is weaker relative to exposed bedrock outcrops (D). We measured crack length and crack widths in two subaerial bedrock exposures of similar size on a north and south aspect slope. Both crack length data sets approximate a power-law distribution and bedrock on northern aspects has more cracks that are longer cracks relative to bedrock exposures southern aspects (E).

colluvium, allowing both processes to be dated with optically stimulated luminescence (OSL). OSL ages indicate a period of increased colluviation and soil development in the late Pleistocene facilitated by dust deposition and increased rates of physical weathering (Persico et al., 2021). Cosmogenic radionuclide (CRN) abundances are lower in bedrock buried by shallow colluvium relative to subaerially exposed bedrock and bedrock compressive strength is less in buried bedrock indicating weaker, more weathered bedrock beneath colluvium (Figure 2). Under the current climate regime, regolith production is minimal, but must have been substantially higher during the late Pleistocene for the colluvial mantles to have formed. Lower Pleistocene temperatures were probably not sufficient to increase physical weathering by frost shattering (Marshall et al., 2021). We conclude that the wetter late Pleistocene climate was conducive to accelerated mechanical weathering by climate-dependent subcritical cracking processes (Eppes and Keanini, 2017). Those processes increased colluviation on slopes with the highest rates of weathering where moisture-driven vapor pressure is highest (Eppes et al., 2020), beneath shallow colluvium. Subaeirally exposed bedrock, where evaporation is higher results in lower rates of weathering and erosion.

Increased colluviation and moisture-related vegetation enhanced incorporation of eolian sediments that generated thick, fine-grained B horizons conducive to maintaining perennial grass cover during the late Pleistocene. Remnants of older colluvium with moderately developed soils on south aspects indicate they were once more extensively mantled by thicker colluvial deposits as well (Figure 3). CRN abundances in bedrock and surface clasts are similar between north slopes and south aspect colluvial remnants suggesting widespread colluviation and soil development during the late Pleistocene. CRN abundances are substantially less in bedrock and clasts on southern aspects slopes with thin colluvium and weak soil development. Lower abundances suggest stripping of older colluvium on south aspects leading to the exposure of fresh bedrock. The number and length of cracks is greater on surface clasts on colluvial remnants relative to surface clasts on stripped surfaces indicating prolonged exposure and more weathering in the older colluvium (Figure 3). The stripped colluvium was deposited in voluminous debris aprons adjact to south aspect slopes (Figure 1E) triggering valley floor aggradation and terrace formation in the middle Holocene (Persico et al., 2021).

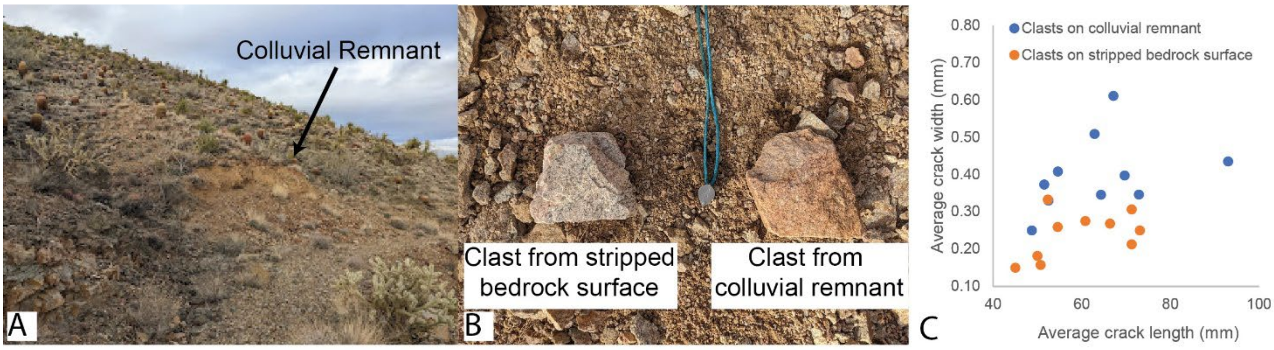

Figure 3. Colluvial remnants (A) are preserved on southerly aspects. Clasts of that mantle remnants have oxidation staining (B) and have more cracks with greater widths relative to clasts that mantle stripped surfaces (C).

The transition to drier conditions in the Holocene diminished vegetation cover on the xeric south aspects, but not until the middle Holocene was that cover reduced below a threshold that led to a major episode of soil erosion and valley floor aggradation. North aspect hillslopes experienced little erosion during the late Pleistocene/Holocene transition or during the Holocene. We attribute variable hillslope geomorphic responses at this eastern Mojave Desert site to slope aspect, the nature and spatial variability of slope soils and the strong role played by grass-dominated vegetation.

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