Geoderma 314 (2018) 245–261

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Climate, topography, and dust influences on the mineral and geochemical evolution of granitic soils in southern Arizona

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ARTICLE INFO

Editor: M. Vepraskas

ABSTRACT

Mineral weathering transforms rock into soils that supply nutrients to ecosystems, store terrestrial carbon, and provide habitat for organisms. As a result, the mineralogy and geochemistry of soils from contrasting environments are well-studied. The primary objective of this research was to examine how climate, topography, and dust interactively control the mineral and geochemical composition of granitic soils that span an environmental gradient in southern Arizona. Two field sites were selected within the Catalina Critical Zone Observatory that exhibit significant range in precipitation (25 to 85 cm yr^{-1}), temperature (24 to 10 °C), and vegetation composition (desert scrub → mixed conifer). Within each site, two *catena* end member pairs were selected to represent variation in local topography which included divergent, water-shedding summits and convergent, water-gathering footslopes. Soils and parent rock were studied using x-ray diffraction and x-ray fluorescence. Dust samples were collected from ridgetop dust traps at the desert scrub site and examined using x-ray fluorescence. The desert scrub soils showed enrichment in biotite, total feldspar, and Fe + Mg whereas the mixed conifer soils were depleted in feldspars and enriched in Fe + Mg. Depletions of Na, Si, and K + Ca occurred in both the desert and mixed conifer ecosystems, with the convergent soils in the conifer sites exhibiting the greatest degree of elemental loss. We examined dust in the regolith after identifying mineral and elemental enrichments in both ecosystems. Dust fraction estimates ranged from 2 to 21% in desert soils and 9 to 19% for the mixed conifer soils. Our results confirm the interactive role of bioclimate, topography, and dust in driving the geochemical evolution of soils and cycling of nutrients in desert and conifer ecosystems.

1. Introduction

Mineral weathering serves a fundamental role in the critical zone by transforming bedrock to a mantle of weathered rock and soil that delivers nutrients to ecosystems; stores and partitions water; and shapes climate change feedbacks with the global carbon cycle (Berner et al., 1983; White and Brantley, 1995; Dixon et al., 2009). The weathering of silicate minerals, in particular, leads to the retention of atmospherically derived carbon in soils and sediments over geologic timescales (Goudie and Viles, 2012), making the controls on silicate weathering a subject of much study (e.g., Dahlgren et al., 1997; Riebe et al., 2001, 2004; West et al., 2005; Rasmussen et al., 2011). Questions remain on the mechanisms that define climate-weathering relationships across landscapes (Dixon et al., 2012) and how tectonic, topographic, and biologic factors interact as drivers in silicate weathering processes (West et al., 2005). Here, we ask how climate, vegetation, and landscape position drive the weathering of silicate minerals in granitic soils that span desert to mixed conifer ecosystems in southern Arizona. We also assess the role of external dust inputs in soil development across these systems.

The weathering of primary minerals in granitic terrain leads to elemental losses that generally intensify in wetter climates (Whittaker et al., 1968; Dahlgren et al., 1997; Bockheim et al., 2000; Egli et al., 2003; Khomo et al., 2013) and in downslope, water-gathering landscape positions (Nettleton et al., 1968; Hattar et al., 2010; Khomo et al., 2011). Hillslope steepness and landscape stability complicate these climate-landscape relationships that are associated with moisture availability. One such example occurs in the San Gabriel Mountains, California where low-gradient hillslopes (< 25°) exhibited different chemical weathering properties than high-gradient hillslopes (> 25°) in otherwise similar weathering environments (Dixon et al., 2012). Chemical weathering, as quantified by chemical depletion fractions (CDF) and tau values, was greatest in downslope positions of low-gradient hillslopes as would be expected given the conventional *catena* model (Huggett, 1975; Sommer and Schlichting, 1997; Birkeland, 1999). Conversely, in the 20–30° transition to high-gradient hillslopes, chemical depletion decreased downslope; a finding linked to kinetic

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https://doi.org/10.1016/j.geoderma.2017.10.042
Received 29 July 2017; Received in revised form 18 October 2017; Accepted 22 October 2017

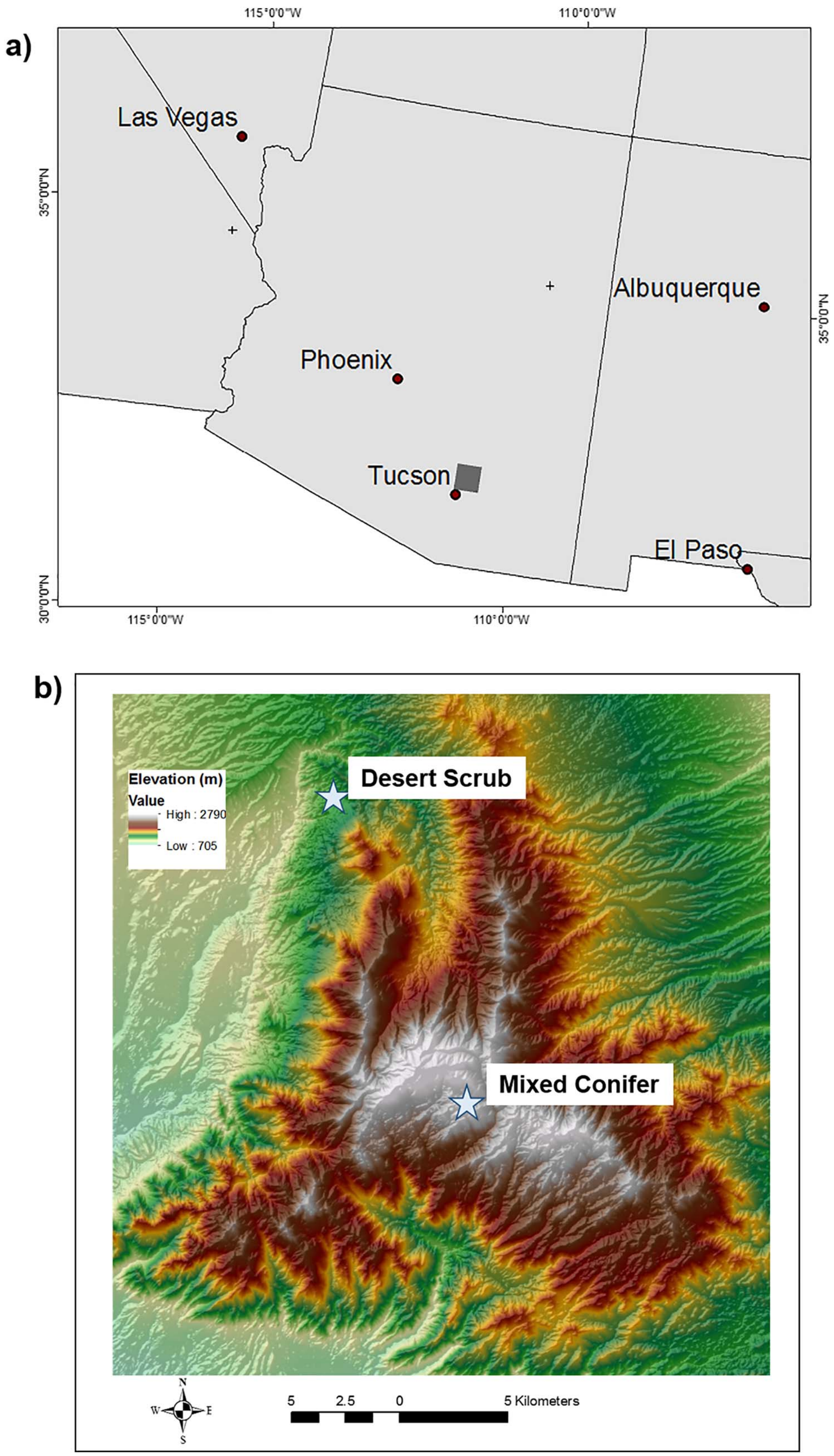

Fig. 1. Site maps for the Catalina Critical Zone Observatory (CZO) including a) an inset map of the CZO located in southern Arizona and b) a digital elevation map showing the desert scrub and mixed conifer field sites.

controls on mineral weathering in tectonically active landscapes that results in greater physical erosion rates, shallow soils, and shorter soil mean residence times compared to low-gradient hillslopes (Dixon et al., 2012). Studies of mineral weathering along hillslopes require consideration of soils with relatively short residence times that integrate estimates of physical erosion rates and the degree of geomorphic stability (Yoo et al., 2007; Dixon et al., 2012). Furthermore, the products of weathering illustrate regional to local site properties,